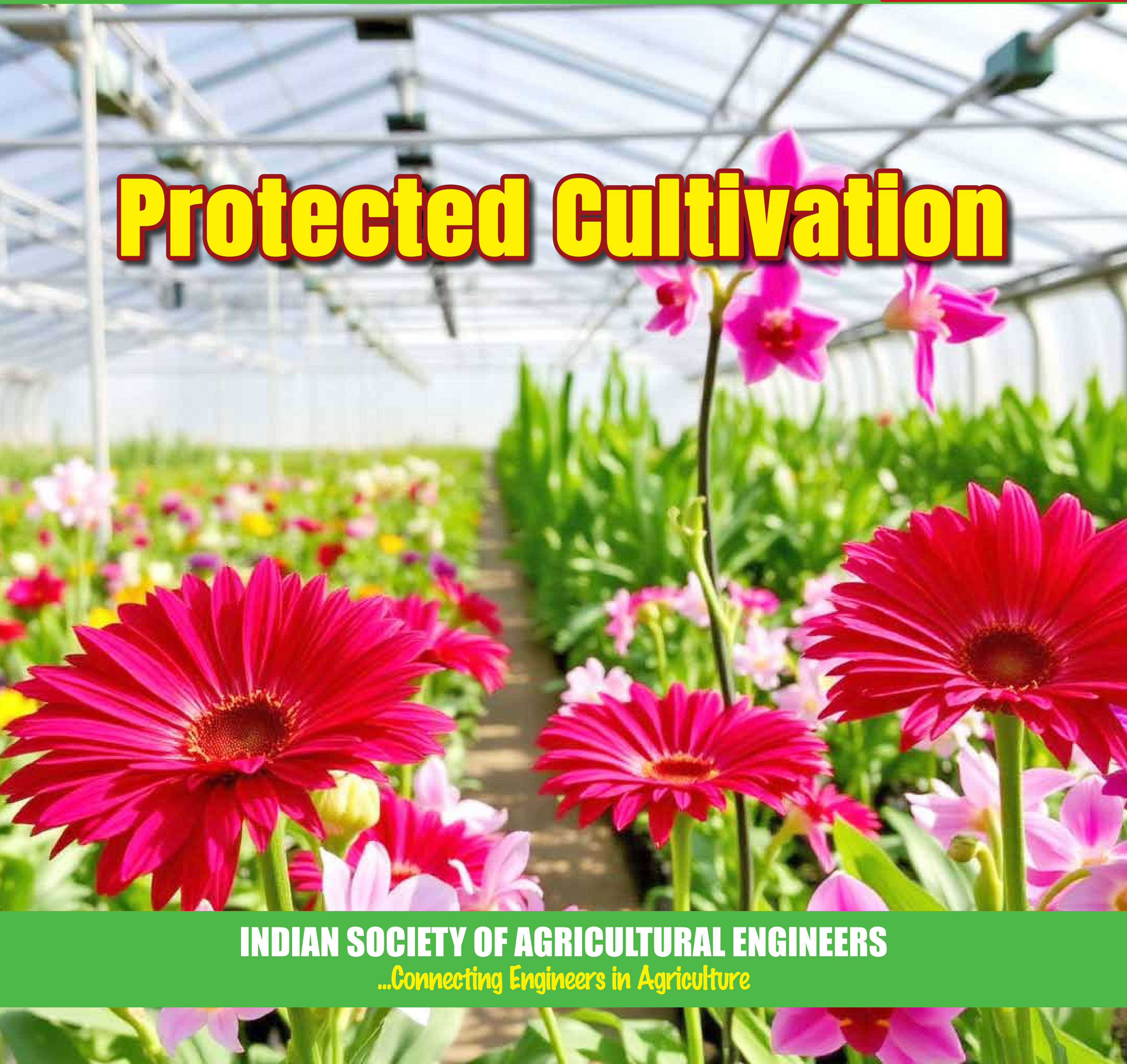
Agricultural Engineering TODAY

ISAE

ISSN (Print): 0970-2962 | ISSN (Online): 2230-7265 | Vol. 50, No. 2 | April - June 2026

www.isae.in



Protected Cultivation

INDIAN SOCIETY OF AGRICULTURAL ENGINEERS

...Connecting Engineers in Agriculture

From the
Editor-in-Chief

Protected Cultivation

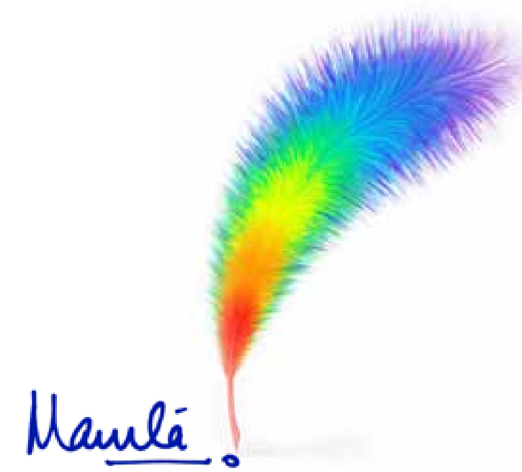
Protected cultivation—growing specific high-value crops in controlled environments like greenhouses, polyhouses, or net houses—is a massive revenue multiplier for modern farming. By shielding crops from unpredictable weather, pests, and diseases, it directly addresses the biggest risks in agriculture, turning farming into a predictable, high-yield business.

The primary boost to farm revenue comes from **exponentially higher productivity**. In a controlled environment, optimized vertical space, precise drip irrigation, and climate management allow farmers to harvest up to 5 to 10 times more yield per square meter compared to traditional open-field farming.

Furthermore, protected cultivation unlocks **off-season production**. Flooding the market with tomatoes or bell peppers during peak harvest season crashes the crop prices. However, raising those same crops during the off-season allows farmers to command premium prices—often 2 to 3 times higher than standard rates.

Revenue is also driven up by **superior crop quality**. Protected environments yield uniform, spotless, and nutrient-dense produce that meets strict grading standards. This premium quality opens doors to high-paying markets, including modern retail chains, organic boutiques, and lucrative export channels that reject standard open-field outputs.

Finally, it optimizes input costs. While the initial setup requires capital, automated systems reduce water consumption by up to 80% and drastically cut down on expensive chemical pesticides. By lowering input costs per ton of produce and maximizing high-value outputs, protected cultivation significantly widens profit margins, transforming small-scale farms into highly profitable, year-round enterprises.



Publication Enquiries

Agricultural Engineering Today is a publication of the Indian Society of Agricultural Engineers
(Tel.: 011-21520143; E-mail: isae1960@gmail.com; Website: www.isae.in)

All communications regarding this publication should be addressed to:

Editor-in-Chief (AET), Indian Society of Agricultural Engineers, G-4, A-Block (GF), National Societies Block, National Agricultural Science Centre (NASC) Complex, Dev Prakash Shastri Marg, Pusa Campus, New Delhi - 110012, India
E-mail: chiefeditoraet@isae.in

The opinions expressed by the authors are not necessarily those of Agricultural Engineering Today or ISAE.

Subscription Details

	Inland	Foreign
Annual subscription	Rs. 3000.00	US$ 550.00
Per copy	Rs. 900.00	US$ 200.00
Additional postage & handling charges		
Full year	Rs. 200.00	US$ 50.00
One copy	Rs. 75.00	US$ 25.00

For payment, cheque/draft including bank charges may be drawn in favour of "Indian Society of Agricultural Engineers" payable at New Delhi and sent to Secretary General, "INDIAN SOCIETY OF AGRICULTURAL ENGINEERS", G-4, A-Block (GF), National Societies Block, National Agricultural Science Centre (NASC) Complex, Dev Prakash Shastri Marg, Pusa Campus, New Delhi - 110012, India

Printed at New United Process, A-26, Naraina Industrial Area, Phase II, New Delhi - 110028, Mob: 9811426024

CONTENT

AGRICULTURAL ENGINEERING TODAY 50 (2)

Protected Cultivation Technologies Status in India vis-à-vis World

Dr. S. N. Jha
President, ISAE & DDG (Agricultural Engineering), ICAR

The history of protected cultivation programme in India is not very long. The Department of Chemicals & Petrochemicals, Ministry of Chemicals and Fertilizers, first considered the promotion and development of use of plastics in agriculture and irrigation for improving agricultural yields, quality of produce and improving input use efficiency in 1977. National Committee on use of Plastics in Agriculture (NCPA) was set up in 1981 to identify areas for use of plastics in agriculture, R&D programmes and to suggest plan for implementation. Plasticulture Development Centres (PDCs) were started in 1985-86. NCPA was transferred to the Ministry of Agriculture and Farmers' Welfare in 1993 and was renamed as National Committee on Plasticulture Applications in Horticulture (NCPAH) and the PDC was renamed as PFDC (Precision Farming Development Centre). ICAR initiated All India Coordinated Research Project (AICRP) on Application of Plastics in Agriculture in 1988 which was later renamed to AICRP on Plastic Engineering in Agricultural Structures and Environment Management (PEASEM) in 2021. The first polyhouse was designed and set up in 1985 at Leh located in

the Union Territory of Ladakh, India. The greenhouse cultivation started in India during VIII plan with total area of 3211 ha. The total area under protected cultivation in 2018 was 2.51 lakh ha. On an average 80% area of protected cultivation is covered under plastic mulching and remaining under greenhouse, tunnel, shade-net and anti-hail net. ICAR AICRP PEASEM has promoted extensive research to provide cultivation strategies, irrigation and fertigation scheduling, indigenized tools and machinery for various unit operations within polyhouse, shade-net house, low-tunnels etc. The benefits of plastic mulching have also been demonstrated.

Protected cultivation in India is not only a concept but has witnessed significant growth, expanding to more than **2.75 million hectares** as of 2023. However, this still represents a meagre percentage of the country's total gross cropped area, starkly contrasting with global leaders like **China**, which manages over **4 million hectares** of controlled environment agriculture. While the global industry moves toward fully automated glasshouses and vertical farming, India's landscape is dominated by low-to-medium-cost structures like **naturally ventilated polyhouses** and **shade net houses**.

CURRENT STATUS: INDIA VS. THE WORLD

The adoption of protected cultivation is a response to the dual challenges of climate change and rising food demand. While the technology is mature in many parts of the world, it still is considered as an emerging sector in India, though here too all relevant technologies and design are available. In addition, most of the people engaged herein consider it as a specialized job of horticulturists, while

https://doi.org/10.52151/aet2026502.1914

Table 1. Status of level of technologies being majorly adopted vis-à-vis global advancement

Feature	Indian Status	Global Advanced Status
Primary Structure	Naturally ventilated polyhouses, shade nets.	Fully automated glasshouses with CO_2 enrichment.
Cooling Systems	Mostly passive (ventilation); some fan-and-pad.	Precision HVAC and liquid cooling systems.
Cultivation Method	Soil-based with drip irrigation; rising hydroponics.	Soilless (Aeroponics/Hydroponics) and Vertical Farming.
Automation	Basic timers for irrigation/fertigation.	AI-driven climate control and robotic harvesting.

major work is of design of structures, environment control and automation etc. It is a highly specialized first engineering job and then cultivation practices.

Current coverage in India is estimated between 50,000 and 70,000 hectares. Distribution of area is primarily concentrated mostly in states like Maharashtra, Karnataka, and Himachal Pradesh. China leads with over 4 million hectares, followed by Japan and European nations like the Netherlands, which uses roughly 10,500 hectares of high-tech glasshouses to become the world's second-largest agricultural exporter. Protected cultivation in India typically increases yields by 3 to 5 times over open-field farming, whereas high-tech systems globally can achieve even higher efficiencies through precise climate control and precision nutrient management. There is a significant difference in the status of technologies being adopted in India and at global level (Table 1).

KEY TECHNOLOGIES IN INDIA

Indian farmers primarily adopt technologies that balance cost with environmental protection. **Polyhouses** mostly made of tubular structures covered with UV-stabilized polyethylene for cultivation of mostly high-value vegetables like **capsicum and cherry tomatoes**, while **Shade Net Houses** are crucial for tropical regions to reduce light intensity and temperature for nurseries and leafy greens. **Plastic Low Tunnel** is an inexpensive solution used in Northern India for off-season vegetable production. **Emerging Technologies** such as **hydroponics** is growing in urban peripherals to serve luxury markets, and **drone technology** is increasingly used for precision spraying in protected environments. High tech fully controlled environment and nutritional management system are also getting momentum.

GOVERNMENT INITIATIVES AND SUPPORT

The Indian government provides substantial financial backing to bridge the gap with global standards.

MIDH & NHB: The Mission for Integrated Development of Horticulture (MIDH) and National Horticulture Board (NHB) offer **50% subsidies** for constructing

Fig. 1. Modern automated greenhouse in India (photo: ICAR-AICRP PEASEM)

greenhouses and polyhouses, while **NHM** (National Horticulture Mission) provides locally additional grants, often capping to some amount per project for commercial units. **Clean Plant Programme is the most recent**: **Rs.1,765.67 crore** initiative aimed at providing virus-free, high-quality planting material, essential for the success of protected cultivations

CHALLENGES AND FUTURE OUTLOOK

Despite the growth, following barriers limit faster expansion of protected cultivation technologies in India to reach global scales:

- **High Initial Cost**: Setting up a basic polyhouse requires significant capital, often exceeding **Rs.1,000 per square meter**.
- **Technical Knowledge**: There is a critical gap in farmer training regarding micro-climate management and pest control inside structures. Trained manpower for constructing high tech and engineering designed structures are also lacking.
- **Lack of standards**: Standard for construction of protected cultivation structures was lacking till now. The bureau of Indian Standards has recently developed the standard and Indian Council of Agricultural Research published a book with region-specific standards. These two should be implemented throughout India.
- **Market Linkages**: While production increases, many farmers lack direct access to high-value retail chains, leading to price volatility.

The future of protected cultivation in India lies in **localized low-cost automation** and the expansion of **vertical farming** in urban areas to ensure food security for a population by 2050.

Transforming Farmers' Income Through Controlled Agriculture: Field Successes and Regional Models

Prof. Ashok Kumar Singh[1] & Dr. Manish Srivastav[2]

[1]Vice Chancellor, Rani Lakshmi Bai Central Agricultural University, Jhansi
[2]Dean, College of Horticulture & Forestry, RLBCAU Jhansi

Indian agriculture is experiencing a gradual but decisive transition towards market centric, high value and technology driven systems. Among these, protected cultivation technologies are emerging as a profitable intervention for enhancing farmers' income. Protected cultivation for growing crops under controlled or partially controlled environmental conditions using structures like greenhouses, polyhouses, glasshouses, shade nets, and low tunnels etc., is gaining momentum and attraction of youth as entrepreneurial activity. These practices offer precise control of growing conditions thereby providing optimal conditions for plant growth. One of the significant advantages of protected cultivation is its potential to increase crop yields substantially. High value vegetables such as tomato, capsicum, cucumber; flowers like rose, gerbera, carnation, and exotic varieties of other horticultural are being cultivated year-round with increased productivity and better produce quality. This not only enhances competitiveness in market but also ensures higher price of produce and income growth for farmers. Off-season production, enables farmers to realise into premium markets, thereby increasing profitability. Another important advantage of protected cultivation is the efficient use of resources. Protected cultivation models ease the adoption of advanced techniques such as drip irrigation and fertigation, resulting into judicious use of inputs such as water and fertilizers. Occurrence of pest and diseases is also remarkably reduced owing to physical barriers and controlled environments, reducing the dependence on chemicals and result in safer and residue-free produce.

An encouraging trend is the integration of renewable energy with protected cultivation structures. Innovative solar greenhouse models developed in India not only enhance crop productivity but also generate electricity for farm uses. This reduces operational costs and improves sustainability. Such models represent the integration of climate smart agriculture and energy efficient farming system. Recent advances in sensor-based monitoring, automation, and precision fertigation are enabling real time crop management, reducing

https://doi.org/10.52151/aet2026502.1915

labour requirement and improving input use efficiency. Emerging technologies such as image-based crop monitoring and AI-driven decision support systems are expected to further improve crop productivity and facilitate precise management of crops under protected conditions.

Beyond theoretical promise, field level success clearly demonstrates transformative potential of protected technologies. Furthermore, government supported programmes have also expanded the impact of protected cultivation technologies. Under MIDH and NABARD supported programmes, farmers receive substantial subsidies often up to 50–80% for protected structures. The economic outcome of protected cultivation is particularly evident in high value crops. For example, farmers growing tomato, capsicum and cucumber in polyhouses often report 2-3 crops per year, compared to single crop under open field conditions. This intensification results into higher annual income per unit area.

In Maharashtra, Karnataka, Himachal Pradesh, and Uttarakhand, clusters of farmers are successfully growing exotic vegetables and cut flowers under protected structures. Majority of these farmers have direct linkages with restaurants, super markets, and export markets, ensuring premium price of produce. It is often reported by growers about income increases upto Rs. 5–8 lakh per acre per year. The impact of protected cultivation technologies becomes even more meaningful in challenging regions experiencing constrains of natural resource which severely limit conventional agriculture. Bundelkhand, spread over parts of Uttar Pradesh and Madhya Pradesh, is characterized by extreme temperatures

(5°C to 48°C), erratic rainfall, and degraded soils with poor fertility and low organic content, making year-round vegetable production tedious under open field conditions. This region has long struggled with agricultural instability and protected cultivation is gradually changing the narrative. Research and field demonstrations at Rani Lakshmi Bai Central Agricultural University, Jhansi highlight that greenhouse and polyhouse cultivation enable off-season production of vegetables, effectively improving availability of vegetables throughout the year and increasing income of growers manifold. A worthy intervention in this region is adoption of vertical farming and soilless protected systems. These systems optimize space utilization and offer a viable way for intensification even on small land holdings in semi-arid ecosystems. University has also established a Hi-tech nursery having capacity to produce millions of improved saplings of high value horticultural crops under protected structures.

Despite successes reported, scaling of protected cultivation technologies remains fragmented. High initial investment, limited expertise, and poor market linkages continue to constrain wider adoption. However, the continuous increase in number of successful farmer-led models indicates that these challenges are manageable with appropriate policy support, capacity building, and institutional coherence. Capacity building and skill development are very critical aspects. Farmers need hands-on training in the design, operation, and maintenance of protected structures, as well as in crop management practices under controlled environments. Agricultural universities and research institutions may play a proactive role in developing region specific models and low-cost models fabricated as per local conditions and requirements. Furthermore, integrating protected cultivation with modern value chains such as cold storage, processing, and market linkages can significantly enhance income opportunities. Agri-startups and digital platforms can also facilitate better price realisation and reduce market intermediaries.

Protected cultivation is not just about technology; it is about giving opportunity to farmers for substantial improvement in their farm income. It reduces uncertainty, ensure continuous income and opens up new economic opportunities. Thus, protected cultivation technologies represent a viable opportunity toward achieving sustainable agricultural intensification and income growth by appropriate institutional support, and farmer-centric capacity building. As India aspires towards the vision of *Viksit Bharat 2047*, scaling up protected cultivation must be recognized as a strategic priority for ensuring economic prosperity of farmers.

Urban Farming To Mitigate Climate Change

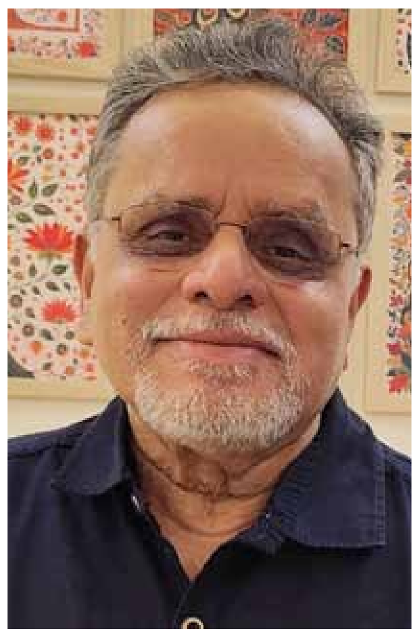
Ajit Srivastava IAS (Retd)
Former Secretary, Government of India

Climate changes and rapid urbanisation are two major Sociological issues engaging attention of present generation all over the world.

Global Climate change, intensified by rapid urbanisation and other social factors have brought about a sharp increase in City temperatures everywhere. The growth in number of cooling devices specially Air Conditioners has had a devastating impact on mean temperatures in cities. It is assessed that in the recent 3-4 decades the average temperatures in cities like New Delhi and Mumbai , Bengaluru have gone up by 4°C. While exploring for the factors responsible it has been found that our cities are contributing to the extent of 70% to total CO_2 emissions.

The huge concrete structures in urban areas absorb tremendous heat during the hot days and act like heating plants when they emit this stored volume of energy in the atmosphere around them. About 5-10% of additional heat around us is deemed to emanate from such sources.

Another major contributory factor is rotting of food items in supply chains which is an unavoidable factor necessitated by virtue of dependence



on long supply chains. In the existing scenario it is a very common occurrence for food items to get destroyed or rot during shipment from one point to another. A conservative estimate would calculate the extent of such loses to 30% of total volume of trade. Impact of this deficiency in supply mechanism is substantially contributing to degradation of climate.

The situation as explained above calls for innovative thinking and a strategic change for mitigating impact of climate change for benefit of urban population.

The strategic solution which is now being visualized is urban farming and **shifting cultivation in the proximity of humans**. To elaborate it may be clarified that the use of rooftops and balconies for plant growth is bound to lead to reduction in temperature of concrete structures by covering up concrete surfaces exposed to heat and would also cover up the issues related to having long food chains which are responsible for part damage which also contributes to degradation of environment.

On the other hand cooling of buildings even by a small percentage would also reduce rate of evaporation from earth and lead to reduction of load on power plants and lesser consumption of coal in big cities as well as reduction in surface temperatures of water bodies This would in long term facilitate a healthier living environment for humans and other species everywhere.

It is for this scenario that the concept of **Urban Farming** comes handy. Cultivation can be made in flowerpots, on empty areas around us including empty spaces in Office Buildings, Metro Stations and Exhibition Grounds and household terraces depending on availability of land for one cropping cycle. Small is beautiful. Contributions from such

https://doi.org/10.52151/aet2026502.1916

micro projects can add up to cover up the losses arising from deficiencies of systems which have proliferated in the urban areas.

An added bonus which shall accrue on promoting of the locally produced food items from neighbourhood is saving of transport mileages and consequent pollution, refrigeration and fuel cost. There shall be saving on storage expenses too.

Another major benefit of Urban Farming is that it keeps the soil healthy. If the soil around us is healthy it has the potential to trap Carbon Dioxide and save the environment from degradation. Reduction in level of Carbon Dioxide around us will have miraculous benefits for promoting health of small children and senior citizens as well as other healthy individuals.As the roof gardens absorb rain water the risk of flooding in neighbourhood is mitigated.

The Global Water Monitor 2025 reveals rising water risks as climate change intensifies rainfall, droughts, and global hydrological extremes. The report states that 2025 was the third hottest year on record, characterised by significant hydrological extremes. The global water cycle has shown increasing variability, with rapid transitions between very wet and very dry conditions. The regions that previously experienced minimal water risks are now facing heightened exposure to floods, drought and extreme heat.

The next issue that may crop up is as to how to proceed with this concept. Some State Govts are contemplating subsidies too. As a beginner any gardening lover can start with a small collection of pots and grow bags.System can be improved as the

garden expands.Waste plastic bottles may come handy for smaller plants. Further as your cultivation is free from pesticide you are contributing towards a healthy environment. As a common man or ordinary citizens we may have the pleasure of admiring our plants every morning besides tending to plants -an activity which shall have health benefits for all humans.

Terrace or Rooftop farming has ease of management. It is not dependant on animal power or a tractor (not even a bullock Cart). One does not need a security team for maintaining a watch round the clock. It also does not require the duty of running around the markets for procurement of inputs and sale of products.However the impact when calculated in cumulative terms is big.

Today As rapid urbanisation is taking place all around it is essential that Governments and Local Bodies take note of the avenues which are opened by Urban farming and the benefits which are expected to accrue to the urban communities by implementation of concept of urban farming . The benefits of urban farming must be given due importance and properly publicised.

Scientific studies. made in several parts of the world have shown that the combination of extreme temperatures and humidity increases health risks. Our future cities must integrate risk and climate considerations into urban planning to build resilience, safety, and sustainability by promoting and facilitating Terrace farming wherever and to whatever extent feasible. Water Management, definitely, has a very important role in climate mitigation. Improved waste water treatment can help reduce CO_2 emissions and supply renewable energy in the form of biogas.

How Much Protected is Protected Cultivation in India

Suresh K. Malhotra
Vice Chancellor, Maharana Pratap Horticultural University, Karnal
Former Agriculture and Horticulture Commissioner
Ministry of Agriculture & Farmers Welfare

Protected cultivation is one of the key technological solutions for sustainable agriculture production under the current scenario of climate change, resource scarcity, and increasing demand for high-quality produce. It enables the regulation of environmental parameters such as temperature, humidity, and light, and facilitating year-round and off-season production of high value crops with superior yield and quality compared to open-field systems. The scope of protected cultivation is expanding rapidly due to its ability to enhance productivity per unit area, improve resource-use efficiency, and reduce climatic risks, which aligns with FAO's emphasis on climate-resilient agricultural systems. Because of the necessity to produce crops in a regulated environment as a result of changing climatic patterns, the idea of protected farming is becoming more and more popular. The growing horticulture trade exacerbates this trend. By employing artificial techniques to get around climate obstacles, protected farming enables the production of crops outside of their typical growing seasons. The growth of this practice has been fueled by the steady demand for several commodities throughout the year. Also, protected cultivation offers immense potential for addressing food security and livelihood improvement for small and marginal farmers through higher returns from limited land. Major crops include vegetables such as tomato, capsicum, cucumber, leafy greens, broccoli, and exotic vegetables, fruits such as strawberry, melon, and blueberry; and floriculture crops including rose, gerbera, carnation, and lilium.

WORLD SCENARIO

The 19th century saw the introduction of greenhouse horticulture to both Europe and the United States. China and Japan currently lead the world in protected farming, however other important nations including the Netherlands, Israel, Egypt, Spain, and Canada also heavily engage in protected agriculture. Usually constructed of glass or plastic, a greenhouse is a framed or inflated structure intended to create a controlled climate for the best possible crop development. Protected

https://doi.org/10.52151/aet2026502.1917

cultivation has expanded rapidly worldwide in recent decades, with the global greenhouse area estimated at approximately 1.3 million hectares, spanning more than 119 countries. Earlier estimates, which include low-technology structures such as plastic tunnels and net houses, suggest that the total protected cultivation area may reach 5–5.6 million hectares globally. The global greenhouse market was valued at approximately USD 33 billion in 2024 and is projected to grow to nearly USD 70 billion by 2033, reflecting the increasing adoption of controlled environment agriculture. These trends clearly indicate that protected cultivation has evolved from a niche practice into a major strategy for agricultural intensification and high-value crop production.

Regionally, Asia dominates the global protected cultivation scenario, with China alone accounting for nearly 60% of the world's greenhouse area, making it the largest contributor globally. Other countries such as Japan and South Korea also play significant roles in the adoption of protected cultivation technologies. Overall, Asia is estimated to hold 70% to 90% of the global protected cultivation infrastructure. In contrast, Europe particularly countries such as the Netherlands, Spain, and Italy is characterized by highly advanced, technology-intensive greenhouse systems with precise climate control, especially in the Mediterranean region where protected cultivation is widely used for high-value vegetable and fruit production. The Americas, led by the United States and Mexico, have developed strong commercial greenhouse industries, particularly for vegetable production, with increasing emphasis on peri-urban agriculture. Meanwhile, Africa and the Middle East are witnessing rapid expansion of protected cultivation, primarily driven by water scarcity and food security concerns. In terms of global food production, protected cultivation plays a disproportionately large role despite its relatively limited land area. Intensive protected systems are estimated to contribute up to 60% of fresh vegetable production in certain regions, particularly under high-input conditions. Protected cultivation is dominated by vegetable crops, followed by ornamentals, fruits, and emerging specialty crops, with increasing adoption driven by the need for higher productivity, improved quality, and climate resilience. The major crops grown under protected cultivation include tomato, cucumber, capsicum, and lettuce, which benefit from controlled environmental conditions, higher productivity, and year-round cultivation.

INDIAN SCENARIO

Protected agriculture is quickly gaining attraction in India thanks to the growing retail sector. High-value, low-volume crops are frequently grown in greenhouses, which have also been shown to work well for a wide range of vegetables, short-duration fruits, and flowers. Ornamental plants including roses, gerberas, chrysanthemums, cacti, anthuriums, and orchids are grown in greenhouses, along with crops like strawberries, capsicum, baby corn, tomatoes, and cucumbers. High-quality yields are encouraged by the regulated environment, which shields the crops from wind and rain. Greenhouses improve quality, increase yield, hasten crop development, and frequently lessen the effects of pests and insects. However, a major obstacle to the broad application of greenhouse technology is still the expensive cost of building. Protected cultivation in India has emerged as a significant technological intervention for enhancing horticultural productivity under changing climatic conditions. The approach should be used more widely because it can boost yields by up to 300%. With an estimated 3 lakh hectares under protected cultivation, India ranks seventh in the world. Of this, 70–80% are under permanent structures (glass houses, greenhouses, polyhouses, shed nets, etc.), and 20–30% are under low tunnels, mulching, flow check, anti-hail nets, and anti-bird nets. Under the Mission for Integrated Development of Horticulture (MIDH), the government encourages protected cultivation; the top four states with the greatest coverage are Tamil Nadu, Gujarat, Karnataka, and Maharashtra. The technology, introduced in the early 1990s, has expanded steadily due to government initiatives such as the National Horticulture Mission, which brought approximately 2.15 lakh hectares under protected cultivation between 2005–06 and 2017–18. Despite this growth, India's share remains relatively small compared to global leaders; estimates indicate that protected cultivation contributes only about 1% of global greenhouse area, highlighting its early-stage adoption. FAO-based global analyses suggest that the worldwide protected cultivation area exceeds 600,000 ha of high-tech horticultural systems, with China alone contributing nearly 45%, whereas India's area remains comparatively limited. Various protected structures such as greenhouse, high-tech polyhouse (fan & pad based systems), naturally ventilated polyhouse, insect proof net-house, shade net-house, walk-in tunnel, poly net-house, low plastic tunnel, hydroponic and aeroponics are prevalent in India. Considering the needs and objectives the different suiting protected structures are used in different agroclimatic conditions. In terms of cropping pattern, protected cultivation in India is predominantly horticulture-oriented, focusing on high-value crops. Major vegetable crops include tomato, capsicum (bell pepper), cucumber, and cucurbits, while fruit crops such as strawberry and melons are also grown under controlled environments. In addition, floriculture crops like rose, gerbera, carnation, and chrysanthemum constitute an important segment due to export potential. Yield advantages under protected conditions are substantial; mostly significantly higher than open-field cultivation. Regionally, adoption is concentrated in states such as Maharashtra, Karnataka, Gujarat, Andhra Pradesh, and Himachal Pradesh, driven by subsidies, market access, and peri-urban demand. Maharashtra alone accounts for about 7.4% of the national protected cultivation area. Economically, protected cultivation is highly profitable despite high initial investment, with crops like capsicum and rose showing higher net returns compared to open cultivation, which explains increasing farmer interest. However, the Indian scenario is still constrained by several factors, including high initial cost of structures, lack of region-specific designs, inadequate technical knowledge, and weak market linkages, which limit widespread adoption. Nevertheless, recent trends reported that protected cultivation is contributing to increased productivity in the horticulture sector and is expected to expand further with technological and policy support.

ESTABLISHMENT OF INTERNET OF PLANTS (IOP) ON A PILOT SCALE AT MHU, KARNAL

Haryana, a predominantly agrarian state, has long been recognized for its high productivity in wheat and rice, contributing substantially to the central pool of food grains. However, with the country having largely achieved self-sufficiency in staple grain production, the focus has gradually shifted toward nutritional security through agricultural diversification, particularly in horticulture. Recognizing this need and demonstrating forward-looking vision, the Government of Haryana established Maharana Pratap Horticultural University (MHU), Karnal in 2016 as a dedicated institution for advancing horticultural education, research, and extension. The university aims to serve as a centre of excellence in horticulture and allied sectors, contributing to food and ecological security, enhanced farm income, and sustainable livelihoods.

In this context, the concept of Smart Horticulture emerges as a transformative approach that integrates advanced technologies to improve efficiency, precision, and sustainability in horticultural production systems. The proposed establishment of an Internet of Plants (IoP) at a pilot scale at MHU, Karnal, is a strategic initiative to operationalize this concept. The IoP system will act as a centralized Smart Horticulture hub where plant-based data, environmental parameters, and real-time monitoring tools are integrated using sensors, automation, and data analytics. This science-driven approach will enable precise decision-making, optimize resource utilization such as water and nutrients, and enhance crop productivity and quality.

Under the leadership of the author, the pilot establishment of IoP at MHU, Karnal, in collaboration with Kochi University, Japan, will also facilitate international knowledge exchange and technological advancement. This initiative is expected to play a crucial role in the production of high-value vegetable crops, efficient resource management, and overall enhancement of horticultural productivity. Ultimately, the project will strengthen the capacity of farmers and researchers, paving the way for a more sustainable, profitable, and technologically advanced horticulture sector in Haryana.

CONCLUSION

The technology enables precision agriculture practices, including hydroponics, aeroponics, and vertical farming, which can significantly increase productivity while minimizing water and nutrient use. Furthermore, the integration of automation, artificial intelligence, and climate-smart technologies is expected to transform protected cultivation into a highly efficient and knowledge-driven production system in the near future. Economically, protected cultivation is highly promising due to its ability to produce off-season crops that fetch premium market prices, generate employment, and support export-oriented horticulture, particularly in floriculture and exotic vegetables. This system contributes to reduced pesticide use, improved water-use efficiency, and sustainable intensification, making it a cornerstone of future agricultural development.

Agricultural Engineering Today | 50 (2)

Perspectives, Future Challenges and Strategic Options in Protected Cultivation in India

Prof. Balraj Singh

President, Society of Horticultural Research & Development
Former Vice Chancellor, SKNAU Jobner

Protected cultivation has emerged as one of the most promising technologies for enhancing productivity, quality, profitability, and resource-use efficiency in horticultural crops. Over the last few decades, it has proven to be an effective technological intervention for managing both biotic and abiotic stresses that commonly limit crop production under open-field conditions. By creating a controlled or partially controlled microclimate around crops, protected cultivation enables higher yields, better quality produce, offseason production, efficient utilization of water and nutrients, and improved protection against adverse environmental conditions.

Globally, the adoption of protected cultivation technologies has expanded rapidly, particularly in countries surrounding the Mediterranean region and in China. Various forms of protected cultivation such as mulching, plastic low tunnels, walk-in tunnels, insect-proof net houses, shade net houses, naturally ventilated greenhouses, and climate-controlled greenhouses are now widely used for cultivation of vegetables, flowers, fruits, and nursery crops. Among all countries, China has emerged as the global leader in protected cultivation, with nearly 3.5 million hectares under different forms of protected horticulture. More than 95% of this area is devoted to commercial vegetable cultivation and hybrid seed production.

India has also witnessed considerable growth in protected cultivation during the last two decades. Presently, more than 160,000 hectares are under various forms of protected structures, largely promoted through government schemes such as the Mission for Integrated Development of Horticulture (MIDH), National Horticulture Mission (NHM), National Horticulture Board (NHB), Rashtriya Krishi Vikas Yojana (RKVY), and state horticulture missions. However, unlike China, where protected cultivation evolved through strong research–industry–farmer integration, the Indian experience has been mixed because many technologies were initially adopted without sufficient adaptation to diverse agro-climatic conditions.

India is characterized by highly variable climatic conditions ranging from arid and semi-arid regions to humid tropical and temperate ecosystems. Consequently, protected structures designed for European

https://doi.org/10.52151/aet2026502.1918

climatic conditions often failed to perform efficiently under Indian environments, particularly in the hot plains of northern and western India. In contrast, relatively milder regions such as Bengaluru, Pune, and parts of Himachal Pradesh and Uttarakhand achieved better success due to more suitable climatic conditions. Over time, research conducted by institutions such as the Indian Agricultural Research Institute, ICAR institutes, and State Agricultural Universities has clearly demonstrated that region-specific protected structures and crop production modules are essential for achieving sustainability and profitability.

Protected cultivation has enormous potential in India not only for increasing productivity but also for generating rural employment, promoting agri-entrepreneurship, and strengthening nutritional and economic security. The technology offers significant opportunities for educated rural youth, women entrepreneurs, Farmer Producer Organizations (FPOs), and peri-urban farming systems. Under the emerging framework of organized retail, export-oriented horticulture, and increasing consumer demand for safe and high-quality produce, protected cultivation can substantially enhance farmers' income through production of offseason vegetables, cut flowers, high-value nursery crops, and hybrid seeds.

High-value crops such as coloured capsicum, parthenocarpic cucumber, cherry tomato, tomato, lettuce, exotic leafy vegetables, gerbera, carnation, chrysanthemum, and roses have shown tremendous potential under protected conditions. Similarly, insect-proof net houses and low-cost structures are becoming increasingly important for raising healthy seedlings, hybrid seed production, and cultivation of virus-sensitive crops. Protected cultivation also facilitates higher water-use efficiency through drip irrigation and fertigation, reduces indiscriminate pesticide application, and supports Good Agricultural Practices (GAP) and residue-free production systems.

Despite these advantages, several challenges continue to limit the large-scale adoption and sustainability of protected cultivation technologies in India.

MAJOR CHALLENGES IN PROTECTED CULTIVATION IN INDIA

1. Lack of Region-Specific Protected Structure Designs

One of the major limitations is the non-availability of scientifically validated region-specific designs suitable for different agro-climatic zones. Structures developed for temperate climates often fail under extreme Indian conditions such as high temperatures, strong winds, heavy rains, and dust storms.

2. Poor Quality Fabrication

The fabrication of protected structures has increasingly become commercially driven, often compromising structural quality. Use of substandard galvanized pipes, cladding materials, and poor engineering practices significantly reduces the life and effectiveness of structures.

3. Shortage of Skilled Human Resources

India faces a serious shortage of trained professionals for design, installation, maintenance, and crop management under protected cultivation systems. Large-scale skill development initiatives are still lacking.

4. Limited Availability of Suitable Crop Varieties

Most varieties currently available are imported hybrids with high seed costs. There is insufficient development of public-sector varieties specifically bred for protected cultivation conditions.

5. Weak Marketing and Value Chain Integration

Many growers adopt protected cultivation without proper market assessment, resulting in oversupply and poor price realization. Lack of organized marketing, cold chain infrastructure, and processing facilities further aggravates the problem.

6. Increasing Soil-Borne Diseases

Continuous cultivation under protected environments has led to serious issues related to Fusarium wilt, root-knot nematodes, salinity, and soil fatigue.

7. Non-Availability of Disease-Free Planting Material

The absence of certified disease-free and virus-free planting material remains a major bottleneck in vegetables, flowers, and fruit crops.

8. Energy and Water Constraints

Reliable electricity and quality irrigation water are critical for successful protected cultivation. In many regions, inadequate infrastructure limits sustainability.

STRATEGIC OPTIONS AND FUTURE DIRECTIONS FOR INDIA

The future of protected cultivation in India is highly promising if implemented with scientific planning, regional customization, and market integration. The following strategic interventions can accelerate sustainable adoption:

PROMOTION OF LOW-COST AND CLIMATE-RESPONSIVE STRUCTURES

Instead of promoting expensive imported greenhouse models, emphasis should be placed on low-cost naturally ventilated structures, insect-proof net houses, shade net houses, and walk-in tunnels suitable for Indian conditions.

CLUSTER-BASED DEVELOPMENT APPROACH

Protected cultivation should be promoted in cluster mode, especially in peri-urban regions near major consumption centres. Such clusters should be integrated with input hubs, cold chains, grading facilities, and market linkages.

STRENGTHENING NURSERY AND SEEDLING INDUSTRY

Commercial plug-tray nurseries and protected nurseries for production of healthy seedlings can emerge as major agri-enterprises. Disease-free planting material production must become a national priority.

PROTECTED CULTIVATION FOR HYBRID SEED PRODUCTION

India has immense potential to become a global hub for hybrid vegetable seed production under protected structures because of favorable climatic diversity and comparatively lower production costs.

SKILL DEVELOPMENT AND ENTREPRENEURSHIP

Large-scale capacity-building programmes should be launched for rural youth in two domains:

- Design, fabrication, and maintenance of protected structures
- Crop production and agribusiness management under protected systems

The Chinese model of skill-oriented protected horticulture development may provide useful lessons for India.

INTEGRATION WITH SOLAR ENERGY AND RAINWATER HARVESTING

Solar-powered irrigation and climate management systems should be integrated with protected cultivation units. Similarly, all protected cultivation clusters should be linked with rainwater harvesting infrastructure.

MECHANIZATION AND AUTOMATION

Promotion of raised bed makers, mulch laying machines, tunnel-making equipment, fertigation systems, and automation tools can improve efficiency and reduce labour dependency.

STRENGTHENING RESEARCH AND POLICY SUPPORT FOR EFFECTIVE & ECONOMICALLY SUSTAINABLE SYSTEM

- Region-specific crop production protocols
- Indigenous region-specific greenhouse designs
- Public-sector Varieties or Hybrids development for Protected conditions
- Seed production of Public-sector developed varieties suitable for Protected conditions
- Soil health management technologies
- Biological control of biotic stresses & pollination management under protected Conditions
- Integrated pest and disease management systems only limited to some problems
- Artificial intelligence and sensor-based climate management

Government support should gradually shift from merely subsidizing structures to supporting complete production systems, market integration, and entrepreneurship development.

CONCLUSION

Protected cultivation is no longer merely an alternative production technology; it is becoming an essential component of climate-resilient and high-value horticulture in India. In the context of shrinking landholdings, water scarcity, climate variability, rising consumer demand for safe food, and increasing opportunities in organized retail and exports, protected cultivation offers a transformative pathway for sustainable horticultural intensification.

However, the long-term success of the technology depends on scientific region-specific interventions, strong research–extension–industry linkages, quality infrastructure, market-driven production planning, and large-scale skill development. The future growth of protected cultivation in India should focus not only on increasing the number of structures but also on developing economically viable, technically sound, environmentally sustainable, and farmer-centric production systems.

If implemented strategically, protected cultivation can significantly contribute to doubling farmers' income, generating rural employment, strengthening nutritional security, and positioning India as a global leader in high-value horticultural production and hybrid seed systems.

Protected Cultivation Techniques for Enhancing Income

C. R. Mehta[1] and Yogesh A. Rajwade[2]
[1]Director, [2]Scientist, ICAR - Central Institute of Agricultural Engineering, Bhopal

INTRODUCTION

Over 70% of Indian agriculture is rainfed and dominated by small and marginal farmers, who are highly vulnerable to the vagaries of climate. Climate change affects the agricultural ecosystem by eroding topsoil, altering the hydrological cycle, disrupting flora and fauna, and modifying cropping cycles and yields. Given these constraints, traditional openfield agriculture is increasingly unable to meet the dual mandates of national foodnutritional security and farmer economic prosperity. To achieve the required production targets, technologies such as precision agriculture, regenerative agriculture, vertical farming, soilless cultivation, and intensified and diversified cropping systems are essential.

As of 2023, only about 50,000–60,000 hectares out of 28 million hectares under horticulture are under protected cultivation, representing roughly 0.2% of horticultural production. This indicates substantial scope to expand protected cultivation to enhance sustainable food and nutritional security with improved inputuse efficiency. Climateresilient and technologydriven agricultural practices must be adopted to maximize yield and economic returns per unit of input cost. In this context, protected cultivation has emerged as a transformative and highly viable strategic intervention.

Protected cultivation encompasses a range of protective structures such as low tunnels, walkin tunnels, shade nets, climatecontrolled greenhouses, and modern vertical farming systems that provide full or partial control over the growing environment. By creating a physical barrier between the plant canopy and the external climate, these structures buffer crops against adverse weather fluctuations, including temperature extremes, strong winds, intense ultraviolet radiation, and unseasonal rainfall. The closed nature of these systems also reduces pest infestations and vectorborne viral diseases, thereby lowering dependence on agro-chemicals and supporting safer, highquality food production. Protective covers such as shade nets and polyfilms filter light intensity and diffusion inside the structures, significantly enhancing photosynthetic activity and maintaining optimal light levels (30,000–50,000 lux) on plant leaves.

https://doi.org/10.52151/aet2026502.1919

Agricultural Engineering Today | 50 (2)

These structures can be integrated with precision agriculture technologies, enabling site and plantspecific input management. The controlled environment is particularly suited to advanced microirrigation and automated fertigation systems. Through drip irrigation networks, water and watersoluble fertilizers including calculated NPK combinations are delivered directly to the active root zone at optimal concentrations and frequencies. This minimizes nutrient leaching, reduces ground water extraction, and improves nutrientuse efficiency. Studies indicate fertilizer and water savings of 20–40% in openfield cultivation and 25–50% under protected cultivation.

The economic potential of adopting protected cultivation in India is substantial. Agronomically, it overcomes the traditional constraints of seasonality, enabling yearround production of high value, short duration crops, exotic greens, and floricultural products. By aligning crop harvests with periods of low market supply and higher prices, farmers can realize significantly higher incomes. The controlled environment also reduces physical blemishes and size variability caused by weather and pests, resulting in produce with superior quality, uniformity, and extended shelf life. This improved quality helps farmers meet the standards of organized retail chains, supermarkets, and export markets, thereby enhancing gross income. Although agronomic and gross returns are markedly higher, protected cultivation is capitalintensive, with significant upfront costs for structures and recurring operational expenses for climate control, fertilizers, and system maintenance. This requires rigorous financial appraisal before scaling. Moreover, successful operation depends on specialized farmer skills, necessitating targeted training in intensive crop scheduling, micro-climate management, and advanced postharvest handling. A few examples of economics of different types of protected cultivation techniques are given below.

Coloured capsicum cultivation inside a forced ventilated polyhouse

FORCE VENTILATED POLYHOUSE CULTIVATION

A force ventilated polyhouse is a GI structure covered with polyfilm and has provision of exhaust fans and cellulose pads for regulating temperature and foggers for humidity. These are climate smart structures which can be integrated with sensors and automation for micro-climate control enabling year round cultivation of high value crops.

The procurement and installation cost of a forcedventilated polyhouse over a 500 m² area for a farmer is approximately Rs.9,00,000 (Rs.1,800/M²). With a structure lifespan of 10 years, the annual depreciation cost amounts to Rs.90,000. For a tomato–colored capsicum cropping system, recurring annual costs for labour, seedlings, fertilizers, electricity, and other inputs are estimated at about Rs.2,10,000. Assuming yields of 10 tonnes of tomato and 6 tonnes of colored capsicum per 500 m², and market prices of Rs.20 per kg for tomato and Rs.60 per kg for colored capsicum, the total annual revenue is Rs.6,00,000. Under state and central government schemes, farmers can avail subsidies of up to 50% for polyhouse construction and microirrigation systems. After accounting for depreciation and recurring costs, the farmer can earn approximately Rs.3,00,000 per year from roundtheyear cultivation in a small 500 m² poly-house, with a benefitcost (B:C) ratio in the range of 1.5–2.0.

CABLE AND POST SHADE NET CULTIVATION

A cable and post shade net consist of GI columns connected by high tensile wire grid covered by insect proof net/shade net and is primarily used for extreme summer climate. It is a cheaper

Cucumber cultivation inside a cable and post shade net

alternative to polyhouses which provides protection from sun and wind and partially from rainfall. It is easy to install and maintain as compared to force ventilated poly-houses.

A farmer opts for a cableandpost shade net structure over a 500 m² area, with a material and construction cost of Rs.2,50,000 (Rs.500 per square meter). Assuming a lifespan of 5 years, the annual depreciation cost is Rs.50,000. With a cropping pattern of growing cucumber twice and leafy vegetables during the summer season, the annual operational cost is approximately Rs.1,30,000. Assuming yields of 9 kg per square meter for cucumber and 3 kg per square meter for leafy greens, and market prices of Rs.20 per kg for cucumber and Rs.40 per kg for leafy greens, the total annual revenue is approximately Rs.2,40,000. Under state and central government schemes, farmers can avail subsidies of up to 50% for shadenet structures, microirrigation systems, and related components. After accounting for depreciation, operational costs, and the applicable subsidy, the farmer can earn approximately Rs.90,000 per year from roundtheyear cultivation under the shadenet structure.

HYDROPONICS CULTIVATION

Hydroponics is a soilless cultivation technique in which nutrient solution is directly supplied to roots of plants which are often supported by media like coco-peat, saw dust, clay balls etc. This technique can reduce water consumption upto 90% as compared to traditional farming and provides control over root environment (EC and pH), multiple vertical stacking and accelerated growth.

A farmer adopts a soilless cultivation technique i.e. hydroponics in a small polyhouse or structure of 100 m². A total of 15 setups, each with a threelayer configuration of 1 m × 2.5 m and accommodating 150 plants, can be installed and operated satisfactorily for crops such as leafy vegetables and strawberry. A cropping pattern of strawberry (October–February) and leafy vegetables for the rest of the year requires an approximate capital investment of Rs.1,00,000 in setups and an annual operational cost of Rs. 50,000. With a setup lifespan of 5 years, the annual depreciation cost is Rs.20,000. A wellmonitored and maintained system can yield 10–15 straw berries per plant, with an average

fruit weight of 10 g. Leafy vegetables can be harvested at about 100–150 g per plant. At a market price of Rs.50 per 200 g for strawberries and Rs.50 per kg for leafy vegetables during the summer season, the system can generate a total revenue of approximately Rs.55,000–60,000 from strawberry and Rs.10,000–15,000 from leafy vegetable production.

Strawberry cultivation under hydroponics cultivation

GOVERNMENT OF INDIA INITIATIVES AND WAY FORWARD

To enhance the adoption of protected cultivation techniques, the Government of India has put in place a robust policy framework. Financial interventions led by the National Horticulture Board (NHB) and the Mission for Integrated Development of Horticulture (MIDH) provide substantial capital subsidies to offset the high initial infrastructure costs associated with protected cultivation. In addition, subsidies for microirrigation systems can be availed under the Per Drop More Crop (PDMC) scheme, implemented through the Rashtriya Krishi Vikas Yojana (RKVY). Despite these targeted measures, widespread adoption among Indian farmers remains limited due to complex costbenefit dynamics and perceived investment risks.

To maximize the area under protected cultivation by 2050, the agricultural framework must shift towards smartagronomic ecosystems powered by advanced sensor and AI enabled technologies. Future engineering efforts should prioritize the development of AI and IoT integrated fertigation controllers that use sensorbased canopy data and realtime soil moisture mapping to enable dynamic microdosing and thereby maximize nutrientuse efficiency. Moreover, the revisions to MIDH cost norms in future may subsidize these technologydriven ecosystems by updating precision farming guidelines to support financially the inclusion of automated fertigation units, closedloop IoT climate controllers, and automated polyhouse operations as standard components of hightech protected cultivation systems.

The Farmer Feeds yet he gets only one-third on Every Rupee

Shantanu Pendsey
Former CGM, State Bank of India

The most fundamental inequity in India's economic architecture is hiding in plain sight. The farmer, who battles uncertain weather, tends the living soil, and delivers food to 1.4 billion people-frequently retains less than one-third of every rupee that food earns in the retail market. In many perishable supply chains, the bulk of the value flows instead to intermediaries, traders, processors, transporters, and retailers, leaving the primary producer with minimal margins.

THE STRUCTURAL CONTRADICTION

Agriculture employs **45–50% of India's workforce** yet contributes only **15–18% of GDP.** Services, employing just 31–33%, contributes **54–56% of Gross Value Added.** *This is not merely an economic gap it is a systemic imbalance.*

The salaried class receives dearness allowance, annual increments, and credit products engineered around their income cycles. ***The farmer? He absorbs every rupee of input cost inflation, alone, season after season.*** A bold corrective of historic proportions is long overdue.

WHY FARMERS REALLY FAIL

Farmers do not fail primarily because of drought. They fail because of **structurally uneconomic land holdings**; the absence of **collectivisation**; working capital that is scarce, expensive, mistimed; and little advisory ecosystem to help them graduate from ***Producers to Processors.***

A farmer is a living, capital-intensive enterprise operating under high uncertainty yet one that receives none of the institutional respect or adequate financial architecture it truly deserves.

THE VICIOUS CYCLE AND ITS SILENT VICTIMS

Intensive and unbalanced use of chemical fertilizers, irrigation, and crop protection inputs, degraded soil, nutrient-deficient crops — all downstream of a broken credit chain. The phosphorus, nitrogen, and micronutrients that once sustained Indian agriculture are vanishing from our soils. The organic produce urban India pays a premium for is frequently grown in land too depleted to deliver real nutrition. **NFHS-5** confirms the fallout: iron deficiency, Vitamin D collapse, zinc depletion are not random crises they are consequences of decades of structural under-investment in the farmer as an economic enterprise.

"We reap exactly what we allow our farmers to sow."

BRIDGING THE LAST MILE: FROM SCHEMES TO FARMER

India's policy ambition for agriculture is genuine and substantial — the KCC revision, PM-KISAN, Bharat Vistaar, AgriStack, AIF, and PMFBY represent an unprecedented and growing commitment. The opportunity now lies in **convergence**: bringing these together so they amplify one another and reach the farmer as a single unified, intelligible offer.

https://doi.org/10.52151/aet2026502.1920

Well-intentioned programmes spanning the Ministry of Agriculture, MoFPI, NHB, APEDA, and NABARD often reach farmers as disconnected fragments each with its own channel, and enrolment process. The farmer, navigating limited awareness, low literacy, and group-dependent decision-making, needs one convergent touchpoint.

Bharat Vistaar — India's emerging rural digital backbone — can be that bridge, delivering AgriStack benefits, soil data, credit access, market signals, and scheme information in local languages to every farmer's mobile.

Financial literacy must accompany every intervention. When debt relief is provided through waivers or restructuring it must be paired with structured counselling so farmers rebuild credit eligibility and transition into productive capital, not back into the debt trap.

PMFBY: COMPLETING THE PROMISE

Pradhan Mantri Fasal Bima Yojana is among the most ambitious crop insurance programmes in the world. Its potential is immense — and largely unrealised. Awareness at the farm level remains thin; many enrolled farmers do not understand their coverage or how to file a claim. A **two-stage settlement design** would multiply its impact: an immediate, modest credit directly to the farmer's account within days of a notified crop loss — so he does not approach a moneylender for sustenance or re-sowing — followed by full, audited claim settlement within thirty days. *Timely insurance is transformative insurance.* Insurance that arrives after the farmer has already borrowed shifts only the source of his debt, not its burden.

A REVAMPED AGRICULTURE ARCHITECTURE

India needs structural reimagination across twelve dimensions:

Adequate, timely credit — Inflation-indexed, need-based; KCC delivered via digital underwriting, SHG-linked channels, and co-lending models.

Bharat Vistaar + AgriStack — Rural digital backbone delivering soil data, scheme benefits, market signals, and credit access in local languages to every farmer's mobile.

PMFBY reform — Two-stage payouts: immediate partial credit at loss notification; full audited settlement within 30 days.

Debt-trap exit literacy — Structured counselling post-waiver so farmers rebuild formal credit access and do not re-enter usurious cycles.

Climate resilience — Drought-tolerant varieties, micro-irrigation, carbon-smart soil management mainstreamed, not piloted.

Collectivisation at scale — FPOs built on the NRLM model — a dedicated national body with ring-fenced funding and professional management.

De-politicised cooperatives — Professionalisation and autonomous governance transforms cooperatives into genuine farmer-service institutions.

Technology-led efficiency — India-specific precision tools, flexible machinery leasing, soil health monitoring to lift output without proportional cost increases.

Reimagined farm education — Universities shifting to farmer life-cycle outcomes: literacy, market linkages, value addition, climate adaptation.

Warehousing and market linkages — Micro cold storages near farm-gates with long-term off-take agreements eliminate harvest-time distress sales.

Value chain participation — Farm-gate processing units using AIF and convergent schemes shift meaningful income back to the producer.

Farmer recognition — A national framework — agriculture's answer to the Padma awards — restoring the dignity and pride that farming deserves.

India cannot credibly aspire to a **five-trillion-dollar economy** while its most essential workforce earns **Rs.27 a day** net of costs. A peak built on negligible purchasing power for half the population is ***structurally hollow.***

Agricultural reform is **national nutrition policy, public health strategy, soil restoration imperative,** and **rural economic justice** — all at once.

The farmer who feeds 1.4 billion people deserves to be treated as the most essential live enterprise in this nation. This is not corrective justice. This is the need of the hour.

The views expressed in this article are solely those of the author(s) and do not necessarily reflect the official policy or position of Agricultural Engineering Today or any of its editors / office bearers.

Protected Cultivation Technologies: Engineering Predictable Farm Income in a Changing Climate

Dr. Praveen Singh
The Khetibadiwala, Gurugram, Haryana | thekhetibadiwala@pprii.com

Indian agriculture is undergoing a structural transition from subsistence to market-oriented production. However, this shift is challenged by shrinking landholdings, rising input costs, and increasing climate variability. With over 85% of farmers classified as small and marginal, improving income per unit area has become more critical than increasing overall production.

Simultaneously, consumer demand particularly in urban India is shifting toward safe, residue-free, and high-quality produce, exposing inefficiencies in the existing supply chain. Fresh vegetables often travel 800–2000 km before consumption, leading to 15–30% post-harvest losses and nutritional degradation. This mismatch highlights the need to move from climate-dependent to climate-managed agriculture, and from yield-focused to income-oriented systems.

Conventional open-field farming faces multiple structural constraints. Climate variability remains the most significant. In regions such as Delhi NCR, temperature fluctuations from 4°C in winter to 45°C in summer adversely affect crop yield and quality. Extreme weather events frequently result in crop losses.

Resource inefficiency further aggravates the issue. Traditional vegetable cultivation consumes approximately 3,000–5,000 liters of water per kg, while fertilizer use efficiency remains below 40%, leading to economic loss and environmental degradation.

Income instability is another critical concern. Farmers typically earn Rs.2–4 lakh per acre annually, with returns dependent on fluctuating market prices. Additionally, post-harvest quality deterioration reduces value; leafy greens can lose up to 50% of *Vitamin C* within 48 hours, limiting premium realization.

These factors create a system characterized by high effort, low efficiency, and unpredictable income, underscoring the need for technological intervention.

https://doi.org/10.52151/aet2026502.1921

Protected Cultivation Technologies (PCT) offer a robust solution by enabling farmers to create a controlled microclimate around crops. Structures such as polyhouses, shade net houses, fan-and-pad greenhouses, and indoor vertical farms allow precise regulation of temperature, humidity, light, irrigation, and nutrient delivery, transforming farming into a

The technical benefits are significant. Crop productivity under protected systems is typically 3–6 times higher per unit area, while hydroponic systems reduce water consumption by 80–95%. Controlled environments also enable two to three additional crop cycles annually, particularly for high-value crops.

From an economic standpoint, the gains are substantial. While conventional farming yields Rs.2–4 lakh per acre annually, polyhouse cultivation can generate Rs.10–25 lakh, and hydroponic systems can reach Rs.30–50 lakh, depending on crop selection and market access. Off-season production further enhances profitability, often fetching 2–3 times higher prices.

Polyhouse cultivation is widely adopted for crops such as capsicum and cucumber, achieving yields up to 80–120 tons per acre annually. Hydroponic systems are particularly suitable for leafy greens and herbs, ensuring uniform quality and faster growth cycles. Indoor vertical farming, using multi-layer racks and LED lighting, offers complete climate independence and higher space utilization, making it suitable for urban and peri-urban production.

Protected cultivation also improves nutritional quality and supply chain efficiency. Hyperlocal production within a 25 km radius ensures faster farm-to-

plate delivery, preserving up to 40–50% more nutrients. Precision fertigation systems enhance nutrient use efficiency by 30–40%, reducing input costs and environmental impact.

From a business perspective, these systems typically offer a payback period of 2–4 years, supported by government subsidies of up to 50% under schemes such as MIDH. Integration with renewable energy systems, including solar and agrivoltaics, further reduces operational costs and enhances sustainability.

Protected cultivation represents a paradigm shift in agriculture. It enables a transition from uncertainty to predictability, from volume to value, and from traditional practices to technology-driven production systems. For farmers, it offers higher productivity, improved quality, and stable income across seasons.

India currently has approximately 70,000 hectares under protected cultivation, with the potential to exceed 2 lakh hectares by 2030. This expansion will be driven by both climate necessity and economic viability.

In conclusion, protected cultivation is not merely an alternative farming method but a strategic pathway for income enhancement and sustainable agriculture. As climate variability intensifies, the ability to control growing conditions will define the future of farming. The farmer of tomorrow will evolve into a system manager, optimizing climate, resources, and technology to deliver consistent and profitable outcomes.

Beyond the Open Field: Growing Income Through Protected Cultivation

Chetan Dedhia
Managing Partner, CVD SOLUTIONS & JJOVERSEAS, Mumbai

Over the last three decades of my practical experience in hi-tech farming, I have seen one lesson repeat itself: open-field farming leaves too much to chance. A good season can reward you, but unseasonal rain, heatwaves, or pest attacks can undo months of work. That is why more farmers are turning to protected cultivation as a practical way to reduce risk and improve returns.

For farmers moving toward a more planned, high-value model, protected cultivation can improve consistency, crop quality, and market timing instead of leaving income entirely to seasonal price swings.

WHY MORE FARMERS ARE MOVING UNDER PROTECTION

In India, where landholdings are shrinking and weather is becoming less predictable, open-field cultivation is harder to manage profitably. Protected cultivation gives farmers more control over rain, heat, insects, and crop quality by making growing conditions less dependent on outside uncertainty.

When temperature, humidity, irrigation, and crop protection are

managed better, both yield and quality usually improve. In high-value crops, the biggest advantage is often not just more production, but more consistent production.

CHOOSING THE RIGHT PROTECTED CULTIVATION SYSTEM

Protected cultivation is not one technology. The right structure depends on crop, climate, budget, management capacity, and market plan. The best choice is the one that fits your purpose—not simply the most advanced one.

1. Shade Net Houses

For many growers, a shade net house is a sensible starting point. It is relatively affordable and helps where crops suffer from harsh sunlight, heat stress, or certain flying pests.

- **Income Impact:** Lower capital cost and quicker returns, especially for crops that fetch better prices outside their normal season.

2. Naturally Ventilated Polyhouses (NVPH)

Naturally ventilated polyhouses are widely used in India because they offer more protection than a net house while remaining practical for many commercial growers. For crops such as cucumber, coloured capsicum, and most commercially grown flowers, they can improve scheduling and market timing.

- **Income Impact:** Better timing can help growers reach the market when open-field supply is lower and prices are stronger.

3. Climate-Controlled Greenhouses

Climate-controlled greenhouses suit crops with enough value to justify higher investment. They allow tighter environmental control and can

https://doi.org/10.52151/aet2026502.1922

support high-quality production, but they also require strong management and technical oversight.

- **Income Impact:** Higher-quality output can support supply to modern retail, hospitality, and premium institutional buyers.

4. Hydroponics and Precision Automation

When combined with protected structures, hydroponics, fertigation, and precision irrigation can improve water use efficiency, reduce soil-borne disease problems, and make production more predictable. These systems work best where both economics and management skills are strong.

- **Income Impact:** Better space use, lower disease pressure, and more predictable production can improve earnings per square metre.

5. Protected Orchards

Fruit growers also benefit from anti-hail nets, shade nets, and rain shelters, especially in regions facing frequent weather extremes. In many orchards, these structures are becoming an important risk-management tool rather than an optional extra. They help protect fruit from direct damage, reduce issues such as sunburn and surface cracking in some crops, and improve the chances of harvesting produce that meets market expectations for appearance, uniformity, and saleable quality.

- **Income Impact:** Protective nets reduce damage from hail, heat, birds, and bats, helping growers maintain fruit quality and reduce sudden crop losses.

HOW PROTECTED CULTIVATION IMPROVES FARM INCOME

The income advantage usually comes from three things working together:

better timing, better quality, and lower production risk.

- **Off-season advantage:** Protected cultivation helps time harvests for periods when supply is lower and prices are better.
- **Quality premium:** Better-looking, more uniform produce can attract stronger prices from urban and organised buyers.
- **Risk mitigation:** Structures reduce losses from weather shocks and help stabilise annual cash flow.

PRACTICAL ADVICE BEFORE YOU INVEST

Government support can reduce the burden of initial investment, but subsidies should be treated as support—not as the main reason to build a project. A protected structure should make business sense even before subsidy is counted.

My strongest advice is simple: learn first, invest second. Understand the technology, operating costs, labour needs, crop cycle, pest risks, and market before you commit. Many projects fail not because the structure was wrong, but because planning was weak.

Marketing must be planned early. Protected cultivation often produces a more uniform and more perishable crop, so depending only on the local *mandi* may not be enough. If possible, line up buyers in advance and match production to real demand.

LOOKING AHEAD

Hi-tech farming asks growers to think beyond production alone. It also requires discipline in cost, quality, timing, and sales. Protected cultivation can be a strong tool, but it works only when backed by skill, planning, and patience.

For farmers willing to learn and build market linkages before expanding, protected cultivation can make farming more stable, more resilient, and more rewarding than relying entirely on the open field.

In the next print/online issue of KJ, I will share ***'CD's 10 Commandments for Protected Cultivation'*** - a practical checklist for anyone planning to enter this space.

Protected Cultivation Technologies for Profitable Farming

Aman K Sharma
Landscape Irrigation Expert, JLL

For many farmers today, the challenge is no longer limited to increasing production. The real concern is producing quality crops consistently despite unpredictable weather, rising cultivation costs, and shrinking land resources. In this changing agricultural scenario, protected cultivation technologies are emerging as a practical solution for improving productivity, reducing climatic risk, and generating better income from farming.

Protected cultivation refers to growing crops under structures that provide a controlled or partially controlled environment. Depending on the crop and local climatic conditions, farmers use polyhouses, shade-net houses, insect-proof net houses, low tunnels, and naturally ventilated structures. These systems help protect crops from excessive heat, heavy rainfall, strong winds, frost, and pest infestation while creating favourable growing conditions for better crop performance.

A few years ago, protected cultivation was mainly associated with large commercial farms and floriculture projects. However, the situation is gradually changing across India. Farmers in many states are now adopting protected structures for vegetables, nurseries, flowers, and high-value horticultural crops. In several areas, even small farmers are exploring low-cost shade-net houses for raising healthy nursery plants and cultivating off-season vegetables.

One of the key reasons behind the growing popularity of protected cultivation is the opportunity for off-season production. Under open-field conditions, vegetable cultivation often becomes difficult during periods of extreme weather. Protected structures allow farmers to continue production during such periods and supply the market when prices are relatively high. Crops like coloured capsicum, cucumber, tomato, lettuce, and exotic leafy vegetables are increasingly being cultivated under protected conditions because of their strong market demand and better economic returns.

Climate uncertainty has become a serious challenge in agriculture. Untimely rainfall, hailstorms, prolonged heat, and sudden temperature variation frequently affect crop productivity. Farmers investing an entire season in a crop often face losses due to a few days of unfavourable weather. Protected cultivation helps reduce this uncertainty to a considerable extent by creating a more stable microclimate around the crop. The overall impact is visible not only in higher yield but also in improved crop quality and consistency.

Efficient water management is another major advantage of protected cultivation systems. Most modern protected structures are integrated with drip irrigation and fertigation systems, which is allowing precise application of water and nutrients directly near the root zone. This improves nutrient-use

https://doi.org/10.52151/aet2026502.1923

efficiency and minimizes wastage of both water and fertilizers. In water-stressed regions, many farmers now recognize that protected cultivation is not only about increasing production, but also about producing more with limited water resources.

From an irrigation management perspective, protected cultivation offers better control over soil moisture conditions compared to open-field farming. Since evaporation losses are lower and irrigation can be scheduled accurately, crops remain under less moisture stress. This creates favourable conditions for healthier root development and uniform crop growth. Proper irrigation scheduling inside protected structures also plays a significant role in preventing disease incidence associated with overwatering and humidity imbalance.

In many protected cultivation projects, drip irrigation and fertigation systems have demonstrated substantial savings in water and fertilizer use compared to conventional farming methods. Depending on crop type and management practices, we consistently see around 40–60% water savings compared to open-field cultivation with well-managed systems. Better nutrient management and controlled environmental conditions also contribute to higher productivity and improved crop quality. Farmers cultivating high-value vegetables under protected conditions frequently achieve better income per unit area than traditional open-field cultivation.

Another important benefit is improved produce quality. Crops grown under protected conditions generally show better size, colour, uniformity, and shelf life. Such produce often attracts premium buyers including supermarkets, hotels, and organized retail chains. In urban markets especially, consumers are increasingly willing to pay more for visually appealing and good-quality fresh produce.

Protected structures also help reduce pest pressure to some extent. Insect-proof net houses act as a physical barrier against many harmful insects and vectors. As a result, dependence on chemical pesticides can be reduced when compared with conventional cultivation practices. Reduced pest incidence inside protected structures also helps lower pesticide application, resulting in cleaner produce and reduced crop protection expenses. This supports safer production systems and encourages more sustainable agricultural practices.

The adoption of protected cultivation is creating new possibilities for rural youth and progressive farmers interested in high-value agriculture. Since higher returns can be achieved from comparatively smaller land areas, the concept is becoming attractive for farmers looking to diversify beyond traditional crops. In peri-urban regions especially protected cultivation is supporting market-oriented farming linked with direct vegetable supply chains and nursery businesses.

Government support through various horticulture and micro-irrigation schemes has also encouraged farmers to adopt protected cultivation technologies. Subsidies for polyhouses, shade-net houses, and drip irrigation systems have improved accessibility for many farmers. At the same time, technical guidance from agricultural universities, horticulture departments, and industry professionals is critical to turning technical potential into field result.

Despite its advantages, protected cultivation is not free from challenges. Scientific management is extremely important for achieving consistent results. Improper ventilation, poor fertigation practices, low-quality planting material, and lack of market planning can cut profitability. Farmers require practical training and technical understanding before investing in protected structures.

As agriculture moves toward precision-based farming systems, the importance of protected cultivation is expected to grow further. Integration of automation, smart irrigation, climate sensors, and fertigation technologies will continue improving efficiency and crop performance under controlled environments. The long-term success of Indian horticulture will depend not only on increasing production, but also on improving quality, water-use efficiency, and climate resilience.

Protected cultivation is gradually becoming more than just a modern farming practice. For many growers, it is now a practical way to achieve stable production, better market prices, and efficient use of water and inputs. As Indian agriculture continues moving toward precision and quality-driven farming, protected cultivation is likely to play an increasingly important role in strengthening farmers income and improving long-term sustainability in the horticulture sector.

Promoting Protected Cultivation in India

Dr Pitam Chandra

Former Director, ICAR-CIAE, Bhopal

BACKGROUND

Mitigation of climate change and safeguarding future food production centred on health and sustainability require the agriculture sector to step up its transition to more resource-efficient and climate-friendly technologies. Reasons for seeking better agriculture include (1) rapidly increasing world population, (2) urbanization, (3) aging population, (4) economic growth, (5) agricultural investments, (6) economic inequality, (7) greater competition for natural resources, (8) climate change, (9) trans-boundary pests and diseases, and (10) plateauing of agricultural productivity for many crops. A more fundamental approach to food production in tune with contemporary innovations occurring in other domains of science and technology is required. One such innovation is Protected Cultivation that has the potential to overcome the majority of shortcomings of traditional agriculture.

PROTECTED CULTIVATION

Crops in open fields are subjected to a large number of biotic and abiotic stresses leading to their partial or complete failure. Protected cultivation came into existence with a view to provide economically justifiable protection against the important stresses. Protective cultivation technologies generally include Anti-Hail / Anti-Bird Nets, Cloche, Mulching, Row cover/ low tunnel, Floating row cover, Shade/ Net house, Micro-irrigation, Hydroponics, Aeroponics, Aquaponics, Aeroponics, Zeoponics, Greenhouse, Plant factory, and Agri-cube. Protected cultivation is an intensive technology in terms of capital, energy, and technology.

Protected cultivation allows the raising of plants anytime, anywhere on or under land/ water, and in space. Crop productivity is possible to be maximized per unit area, per unit time, per unit input, and per unit volume. The crop output has high-quality and is free from all kinds of contaminants.

The most advanced type of protected cultivation, plant factory (indoor plant production) systems, backed up by the concerted efforts of industry, government and academia, is now gaining momentum in the forms of urban agriculture and vertical farms.

ENGINEERING CONCERNS

Protected cultivation today relates to sustainability, resource efficiency, and automation through the incorporation of optimized design of structures, energy conservation, use of renewable energy sources, smart micro-climate control, and machines for crop operations including robots and autonomous ground and arial vehicles.

Simple structures are adequate under mild climates. However, greenhouses for harsher climates need to be designed not only for strength but also for energy conservation. Preceding three decades have witnessed significant advancements in the management of climate control, production technologies, and strategies to improve resource use efficiency in greenhouses.

https://doi.org/10.52151/aet2026502.1924

Greenhouse climate control is practised for extension of growing season, increasing the yield, and enhancing the produce quality with maximized resource use efficiency. Recent engineering developments in greenhouse technology relate to structural design; covering materials; climate control strategies, hybrid lighting, robotics, AI, rainwater retention pond, energy conservation, renewable energy applications, combined heat and power systems, suspended hydroponics, hyperspectral imaging.

For colder regions, hybrid lighting in greenhouses combines high-pressure sodium (HPS) lamps and light-emitting diodes (LEDs) to balance energy efficiency with beneficial heat generation. LEDs provide better light spectrums and lower operational costs.

Non-electric greenhouse cooling relies on passive techniques to manage temperatures, primarily focusing on ventilation, shading, evaporative cooling, and earth-tube heat exchangers. Key methods may include installing automatic solar-powered roof vents, applying 50-70% external shade cloth, painting roofs with reflective whitewash, using water barrels for thermal mass, and maximizing natural airflow through lower side vents.

A digital twin is a virtual construct, representing the structure, context, and behaviour of a physical system.

A digital twin is born out of using advanced sensor technology, IoT, and AI. The digital twin keeps on getting updated with data from its physical twin and, thus, it is dynamic and changing. The digital twin helps to monitor the physical system in real time, make predictions, and take management decisions.

Greenhouses with no carbon footprint achieve net-zero emissions by generating 100% of their energy on-site via renewable sources like solar, geothermal, or waste heat, coupled with high-efficiency design. Key features include passive solar design, superior insulation, thermal mass (water barrels, sand batteries, rock-beds), and energy-efficient lighting (LED/optical films).

PROTECTED CULTIVATION IN INDIAN CONTEXT

Protected cultivation is a futuristic form of agriculture capable of offsetting the threats of climate change and shortages of land and natural resources. India began to develop and harness the benefits of protected cultivation in late 1980s. This technology could be used to engage Gen Z youth in the development of next-generation agriculture. Protected cultivation systems fit very well in modern value chains that aim at increasing number of quality-conscious urban consumers.

Estimated global protected cultivation area today is 5.6 M ha with about 83% area in China. Protected vegetable cultivation in China has expanded to a total area of 4.0 M ha. Total area under all forms of protective cultivation in India today is only about 0.125 M ha. Our country needs to target at least one million ha under protected cultivation in the next decade to create millionaire farmers and 10 million jobs, besides ensuring the availability of high-quality horticultural produce for domestic and export markets.

Adoption of protected cultivation technologies throughout the country would require R&D efforts to provide solutions to emerging field problems. There is so far no dedicated institution in the country to lead the protected cultivation programme. Therefore, establishment of an institute on protected cultivation technology (say, National Institute on Protected Cultivation Technologies) is essential to support the protected cultivation programme in India.

Good Agricultural Practices (GAP) in Protected Cultivation

Anand Zambre
Assistant Vice President (AVP), Reliance Industries Ltd

Protected cultivation or Greenhouse technology is becoming increasingly popular among the farmers in India to grow vegetables, flowers and exotics. As we all know, the cultivation of Agriculture/horticulture crops in open cultivation is dependent on various climatic factors like rain, heavy winds, temperature, humidity, light intensity etc and based on these climatic factors, the farmers get good production sometimes and entire crops is a waste sometimes in bad weather conditions. Thus, cropping in open cultivation is a risky business and efforts were made by various scientists all over the world to find out some suitable measures at least to maintain and cultivate rare high value crops. It was concluded that protected cultivation is the best option to cultivate horticulture crops with the best quality and higher yields of the produce irrespective of outside weather conditions. It is possible to create and maintain desired climate conditions inside protected structures like greenhouses that are required for better growth of crops.

Greenhouse cultivation on commercial basis started in India 35 years ago in 1990-91. Today greenhouse cultivation is very common in India almost in every state and farmers are increasingly showing interest in greenhouse cultivation. At present, more than

30,000 greenhouses exist in India cultivating roses, gerbera, carnations, anthuriums, orchids and vegetables like capsicums, tomatoes, cucumbers, exotic vegetables etc. However, farmers/growers need to study and adopt Good Agriculture Practices in protected cultivation to make it a more successful and profitable business. In India, there is always debate whether greenhouse technology is successful in India or not. Success of any technology depends upon how we adopt it. It is observed that the farmers adopting good agriculture practices are highly successful in protected cultivation, achieving good profits and expanding area under protected cultivation.

For farmers who are beginners in protected cultivation or who want to start protected cultivation, it is very important to understand what good practices are to adopt for successful business. Adopting Good Agriculture Practices (GAP) assures the following advantages.

1. Good agriculture practices always help farmers to achieve better production in terms of quality and yield of produce.
2. It reduces the cost of production by reducing input costs.
3. Enhance quality production and productivity per unit area resulting in achieving higher profits.
4. Record keeping, analyzing and evaluation help with taking proper decisions in critical situations.
5. Following GAP with certification help in exports of produce and creating brand in domestic and export markets.

Protected cultivation involves various operations/activities right from selection of proper site for greenhouse erection up to marketing of the produce. In each of the activities, certain good practices need to be studied and followed to achieve profits/success.

A. SELECTION OF SITE FOR GREENHOUSE CONSTRUCTION

Site selection is one of the most important activities as if it is wrong, the entire project may fail. The following are some criteria to consider

https://doi.org/10.52151/aet2026502.1925

Wrong selection of site

for selection of the right site.

- Levelled land with good soil (Soil EC & ph)
- The site should be slightly higher elevated than the surrounding land.
- Availability of Irrigation water (Water EC & ph)
- Availability of electricity/backup
- Pollution free site
- Availability of communication facilities, connectivity of good roads.
- Avoid land below high-tension cables
- Shadow free
- Sufficient land should be available considering future expansion

B. CROP/VARIETY SELECTION

Following criteria/good practices should be adopted for crop/variety selection.

- Based on market demand, location and suitable climate high value crops to be selected
- Flowers/vegetables/fruits/nursery
- Planting material – Healthy, pest/disease resistant. Portrays seedlings should be encouraged to avoid mortality
- Seedling – 35 to 40 days old, 16 to 20 cm height with minimum 4 to 6 leaves
- Should have good rooting system

Various crops like flowers and vegetables under protected cultivation

- Other characteristics like fruit color, shape, vigor, production etc

C. SELECTION OF GREENHOUSE/AREA/ORIENTATION

Based on crops, location and climate conditions, following criteria/good practice need to be adopted while selecting greenhouse type, area and direction of greenhouse.

- Functional, easy to operate, allows for planting variety of crops
- Design should be as per agroclimatic zones with facility of water harvesting
- Strong enough to withstand extreme climatic conditions (wind, snow, hail, rain)

- Strong enough to support the load of internal service systems and plant foliage
- Minimum shading with maximum longevity
- Easy service, maintain, cover & recover with cladding materials
- Provision of appliances to regulate climatic factors inside the greenhouse
- Economics

D. SOIL/MEDIA PREPARATION, FYM & BASAL DOSE APPLICATION

The following criteria/good practices should be adopted.

- The soil should have a pH of 5.5 to 6.5 and EC of 0.5 to 0.7 Ms/cm

Media preparation and Fumigation

Mixing of FYM and Bed preparation

- The pH of the irrigation water should be 5.5 to 7.0 and an EC between 0.1 to 0.3 ms/cm.
- Soil should be mixed with optimum quantity of well decomposed FYM
- If required, enough rice husk should be added in soil.
- Soil fumigation/sterilization with available permeable fumigants (with proper and safe procedure of application)
- Wash the soil and bed preparation as per standards
- Basal dose application of fertilizers and mixing of topsoil

E. SELECTION OF MICRO IRRIGATION SYSTEM

Based on crop and variety, following criteria/good practice to be adopted while selecting Micro Irrigation system for water and nutrients distribution.

- Proper design of Drip irrigation system to optimize uses of water and nutrient application based on crop water and fertilizer requirement.
- Design the system with proper required specifications of components like dripper discharge, spacing, pressure, filtering capacity etc
- Select an appropriate type of fertigation system viz Ventury, fertilizer tank, dosing pump, A-B-C tank system
- Calculate water requirements, watering period, time of application
- Regular checks and maintenance of Drip/fogger system
- Fogging/misting system for reducing temperature and increasing relative humidity in the protected structures

F. WATER AND NUTRIENT MANAGEMENT

To achieve maximum production and better quality of produce, water and fertilizer management and distribution is very critical and important. The following practices need to be adopted.

- Irrigation along with nutrition should be done in the morning preferably before 9 am.
- Application of water to be based on water requirement calculations and measured quantity of water to be applied through drip to the root zone of the crop.
- Frequent monitoring of drippers while irrigation
- Soil analysis, water analysis, leaf analysis in suggested period
- Application of WSF based on analysis/crop stage and requirement
- Stress management
- Regular maintenance of micro irrigation system

G. CULTURAL PRACTICES, USE OF PROPER TOOLS

Timely cultural practices for proper growing of crops and selection of right tools for cultural practices is very important and following practices should be adopted.

- Different crops need different cultural practices for optimum growth
- As per selected crop, Cultural practices need to be adopted.
- For roses – Pinching, disbudding, bending, removal of wild shoots, removal of blind shoots, development of ground shoots and plant structure, Thinning
- Removal of old and/or infected leaves, removal of weeds
- Development of Two leader/ Four leader structures for raising capsicum crops
- Support system nylon/GI wire for raising crops
- Sickling/raking of soil on top

Drip Irrigation system for Soil/soilless Cultivation & components

H. INTEGRATED PEST MANAGEMENT

Understanding probable pest attack, different pests and their infestation/ damage to the crops, probable control measures is a must for farmers and hence following practices need to be adopted and followed.

- Use resistant varieties of crops.
- Use Pest & disease-free planting material
- Quarantine incoming plant material
- Practice good sanitation techniques
- Monitor crop on daily basis
- Scouting (Identification of pest and diseases.)
- Monitor and suppress insect population
- Modify the environment
- Avoid plant stress
- Use pheromone traps, light traps, sticky cards etc
- Keep unauthorized traffic to minimum

I. HARVESTING AND POST-HARVEST MANAGEMENT

From market point of view, harvesting of produce and post-harvest management adds value to the produce and thus following good practices to be adopted and followed during harvesting and post-harvest.

- Right stage of harvesting
- Optimum color development, shape and size
- Right time of harvesting
- Selection of proper flowers, fruits for harvesting
- Right kind of tools for harvesting
- Preservatives added in containers/ buckets
- Avoid damaged flowers/fruits during harvesting

Bunching and packing as per market requirement

Post-Harvest care of the produce

Proper care of harvested produce is required to keep produce fresh till it reaches to market and consumer. The following are some criteria/practices to adopt.

- Keep the harvested flowers/fruits in a cool place for a few hours
- Precooling chamber
- Cold storage
- Grading according to length of stems, weight and size of fruits
- Sorting according to bud/disc size, color and shape
- Bunching/arrangement of fruits
- Packaging as per standards domestic/international
- Packed Boxes in cold storage before transport

J. TRANSPORT TO MARKETING DESTINATION

Different types of modes are available for transport of produce to market. The following practices should be learnt and adopted for safe handling of produce till it reaches to market.

- If possible, use cold vans for far distance domestic markets/ international markets and follow cold chain
- For smaller distances, cold chains are not required.
- During transport, care of boxes must be taken to avoid damage.
- Keep refrigerator on while in transit/stops in between etc
- Maintain temperature, humidity and light intensity in vans during transport as per standards

K. RECORD KEEPING

Keeping record of all the activities performed at our farm is most essential generally not done by most of the growers. Now a days farmers are more cautious about the produce quality, markets, consumer preference etc and record keeping and the use of the same is done by many progressive farmers. It helps the farmers to make right decisions in problematic situations.

- Record temperature every 2 hours from 8 am to 6 pm daily.
- Record relative humidity every 2 hours from 8 am to 6 pm daily.
- Record minimum and maximum temperatures of the day.
- Record light intensity for every 2 hours from 8 am to 6 pm daily.
- Record EC and ph of soil/media once a week.
- Record EC and ph of water once a week.
- Record EC and ph of drip water once a week and compare with standard.
- Maintain daily records of workers and what work they complete.
- Mark numbers to each bay/beds/ greenhouse for easy understanding of worker movements.
- Maintain a register for regular checks in the irrigation system like daily checks, weekly checks, monthly checks etc
- Maintain a record of maintenance of irrigation systems on a daily, weekly, monthly basis.
- Record timing of foggers/misters running and temperature &

Media preparation and Fumigation

humidity before and after fogging for understanding reduction in temperature and increase in humidity as per requirement.

- Record of soil analysis, water analysis, daily fertilizer/nutrients applied in A, B, C tanks (greenhouse/ crop wise)
- Record of cultural practices done in greenhouses (time required, labor required, tools used, cleaning/ washing of tools etc)
- Scouting/monitoring of crops daily (crop, bed no, bay no, greenhouse no, date)
- Identification of pest disease if any (bed no, bay no, crop, greenhouse no, stage of infection etc)
- Spot application to suppress the pest/disease to avoid spreading (name of chemical/ingredient, concentration, water used, time of application, method of application etc)
- Record result of spot applications (no result, partially killed, completely killed, side effect if any like scorching/burning etc)
- Record of sprays applied in full greenhouse (crop, pest disease name and stage, chemical/biopesticide used, concentration used, total amount of water, time and date of spray, result of spray, method of application)
- Record of TEST sprays on new chemicals introduced for 1st time
- Record of harvest (crop, no of stems/quantity in Kgs etc bay no, greenhouse no, date and time of harvest)
- Record of packaged flowers/fruits (quality and quantity parameters)
- Record of temperatures/humidity/ light in precooling & cold chambers)
- Record of rejected materials (reason for rejection, quantity, source greenhouse no, discard of rejected materials)
- Record of meetings discussions/ suggestions to reduce rejections and improve quality & quantity of standard produce that can be sold on higher rates – Production manager, greenhouse managers/ supervisors etc

Agricultural Engineering Today | 50 (2)

Protected Horticulture in India: Technical Advancements and Nutritional Security Pathways

T. Janakiram[1], Pavan Kumar P[2] and Amulya S. Patil[3]

[1]Emeritus Professor, College of Horticulture, UHS Campus
[2]Assistant Professor, Department of Floriculture and Landscaping College of Horticulture, UHS Campus
[3]PG Scholar, Department of Floriculture and Landscaping, College of Horticulture, UHS Campus

Protected cultivation is an advanced agricultural practice that enables crop production under controlled environmental conditions, thereby enhancing quality, productivity, and overall profitability. Various protected cultivation technologies viz., poly-houses, shade-houses, hydroponics, and drip fertigation systems and their role in improving farmers income. Many evidences suggest that the protected cultivation can increase yield by 2-5 times and significantly improve income through off-season as well as superior quality production. Government support and technological advancements further enhance its potential as a sustainable agricultural or horticultural strategy. protected cultivation could bring the prosperity to horticultural crop growers in India and ensure nutritional security.

INTRODUCTION

The farmers have experienced that conventional farming is unpredictable and high risk due to variable weather, high cost of production and unstable market. It is high time for farmers to think for alternate technology for assured and maximum productivity and profitability. Hence there is an option to change from the conventional farming to advanced farming such as protected cultivation. The protected cultivation refers to the practice of cultivating crops in controlled environments that safeguard them from extreme weather, pests, and diseases. These structures create an optimal microclimate, regulating temperature, humidity, and light exposure, leading to higher yields and better-quality produce. Farmers in India are increasingly adopting protected farming techniques to overcome challenges like unpredictable monsoons, soil degradation, Pest and disease infestations, and market fluctuations. It is particularly beneficial for small and marginal farmers aiming to maximize returns from limited land resources.

Status of protected cultivation: There are more than 65 countries now in the world where cultivation of crops is undertaken on a commercial scale under cover, and it is continuously growing at a fast rate internationally with an estimated 623,000 ha of greenhouses

https://doi.org/10.52151/aet2026502.1926

spread over all the continents. Israel is one country which has taken big advantage of this technology by producing quality fruits, vegetables, flowers, etc. in water deficit area. In India, protected cultivation technology for commercial production is hardly three decades old. Approximately 1.25 lakh ha area is under 'protected cultivation' in India, which includes greenhouses (permanent structures) and other temporary protected structures. The exportable quality produce of vegetables and flowers are produced under protected condition and their productivity is very high due to real time monitoring of inputs and plant health. Most commonly grown crops under protected conditions are cucumber, capsicum and tomato, in addition blueberry and strawberry are emerging crops under this system.

TYPES OF PROTECTED CULTIVATION STRUCTURES

Polyhouse (Greenhouse)

Polyhouses are structures covered with transparent polyethylene sheets that allow partial or full environmental control. Two types of polyhouses are designed in Indian condition, one is called naturally ventilated polyhouse and the other is called force ventilated (fan-pad) polyhouse. Naturally ventilated polyhouses are used mainly in temperate and moderate climate conditions while force ventilated (fan-pad) polyhouses are suitable for tropical, sub-tropical and arid zone farming systems. Polyhouse is main structure of protected -cum-covered cultivation groups. It is made by GI pipe and covered by ultra-violet (UV) stabilized plastic sheet with a service life of 3-4 years. These sheets are generally available in 7 and 9 meter widths with 200 micron thickness. The polyhouse structures provide 4-5 time higher yields with export quality produce, high water and fertilizer use efficiency and round the year production facility in any part of the country. Polyhouses enable off-season production, improve crop quality, and increase yield significantly. However, they require high initial investment and technical expertise. They are widely used for cultivating high-valued vegetables and flowers like Tomatoes, Bell peppers, Cucumber, Roses, Chrysanthemums, Carnations, Anthuriums, Gerbera etc.

Shade Net House

Shade net houses are covered with synthetic nets that reduce solar radiation and temperature. These structures are cost-effective and suitable for nursery raising of crops and leafy vegetables. Shade nets generally use two colour nets (green and black) in horticulture-based farming systems. Both colour hade nets are available in 30, 50, 75 and 90% capacity of shading protection.

This structure enhances 25-35% more yield as compared to traditional methods during peak summer season. Suitable crops identified for shade net houses from economic viability include horticulture nurseries, leafy vegetables, summer tomato and capsicum. Because these systems are mainly used to grow off-season cultivation of crops, their produce fetches much higher prices in the market, hence providing good economic returns to growers, thereby improving livelihood and nutritional security to the farming. Although environmental control is limited, they offer protection from excessive heat and reduce water loss.

Low Tunnels and Walk-in Tunnels

Low tunnels are temporary structures made using plastic sheets supported by hoops. They are primarily used for early crop production. Plastic low tunnels are often used to promote the growth of plants during the period of winter season. Low tunnels are supported above the plants by using hoops of GI wire and a clear or transparent plastic of 20-30 micron is covered/stretched over the hoops and the sides are secured by placing in soil. The farmers can grow different varieties of summer squash (round-fruited, long-fruited), which is an emerging crop along with cultivation of netted muskmelon varieties. These structures are economical and help farmers access markets earlier, leading to better prices.

Insect-Proof Net Houses

These structures prevent pest entry while, allowing ventilation, making them suitable for organic farming systems. These structures make use of insect proof screens of different intensities of perforations, ranging from 25 mesh to 60 mesh. IPP nets of 40 or higher mesh are effective means to control entry of most flying insects and save crop from diseases. Crops suitable for these structures include tomato, cherry tomato, cucumber, bitter gourd, musk melon, summer squash, papaya, meadow and high density orcharding of mango, guava and pomegranate and strawberry etc.

KEY TECHNOLOGIES IN PROTECTED CULTIVATION

Drip Irrigation and Fertigation

Drip irrigation delivers water directly to plant roots, while fertigation supplies nutrients through irrigation systems. This combination improves water and nutrient use efficiency. This is one of the major tools of precision farming which effectively increase water and nutrient use efficiency thus

contributing significantly in water scare areas, increasing production and overall livelihood upliftment through horticulture-based crops. Many of the studies also proved that the water savings of up to 50% and yield increases of 20-40%.

Hydroponics

Hydroponics (soil-less cultivation) a method of growing the plants in (a water based, nutrient rich solution), water containing fertilizers. Plants are grown with or without the use of an artificial media (sand, gravel, vermiculite, rock wool, perlite, peat moss coir, sawdust etc.). It offers high productivity and efficient land use. It is particularly suitable for urban agriculture and high-value crops such as lettuce and herbs.

Benefits:

- Saves up to 90% water compared to soil farming
- Increases plant growth rate and yield
- Ideal for urban and rooftop farming

Various crops grown under hydroponic system:

- **Vegetables:** Tomato, Lettuce, Spinach, Celery, Swiss chard, Cucumber, Muskmelon, Brinjal, Beet, Winged bean, Capsicum, Cabbage, Cauliflower, Radish, Coriander etc.
- **Flowers:** Gerbera, Rose, Orchids, Anthurium, Marigold, Carnation, Chrysanthemum, etc.
- **Fruits:** Strawberry, Raspberry etc.

Sky Farming

Sky farming or vertical farming is the practice of growing crops in vertically stacked layers. It often incorporates controlled environment agriculture, which aims to optimize plant growth, growth, and soilless farming techniques such as hydroponics, aquaponics, and aeroponics.

Climate Control Systems

Climate control systems in protected cultivation are technologies used to maintain optimal environmental conditions for plant growth by regulating temperature, humidity, light, carbon dioxide, and irrigation. These systems include heating and cooling methods such as ventilation, exhaust fans, evaporative cooling, fogging, and shading, along with automated irrigation and fertigation systems controlled through sensors and smart controllers. Proper climate control improves crop yield, quality, water-use efficiency, and year-round production while, reducing pest and disease incidence. Depending on the level of technology, systems may range from simple naturally ventilated structures to fully automated smart greenhouses using IoT and AI-based monitoring. Protected cultivation with climate control is widely used for crops like tomato, capsicum, cucumber, flowers, and other high-value crops, especially in regions with variable climatic conditions.

ECONOMIC IMPACT AND INCOME GROWTH

- **Higher Productivity:** Yields increase by 2-5 times compared to open-field farming
- **Off-Season Production:** Farmers can produce crops when market supply is low.
- **Improved Quality:** Uniform produce fetches premium prices.
- **Resource Efficiency:** Reduced water and fertilizer use lowers costs.

GOVERNMENT SUPPORT AND POLICIES

Presently, various state Govts extend financial support in the form of subsidies to the growers upto 1 acre of structure costing approximately Rs. 35-40 lakhs of which about 50% of the cost is borne by Central Govt. with sizable and additional subsidies from State Govts which include the cost of structure, drip irrigation and fertigation system and seed/planting material etc. The Smart Precision Horticulture Programme under the Mission for Integrated Development of Horticulture (MIDH) has allocated Rs. 60.0 billion to cover 15,000 acres and benefit 60,000 farmers between 2024 to 2029.

CONCLUSION

Protected cultivation technologies offer a sustainable and profitable approach to modern agriculture. By enabling controlled environment farming, they ensure higher productivity, better quality produce, and year-round cultivation. Although initial investment and technical requirements pose challenges, government support and proper market linkages can make protected cultivation highly viable. Strategic adoption of these technologies can significantly enhance farmers' income and contribute to agricultural sustainability. Protected cultivation is expected to expand with advancements in automation, precision agriculture, and IoT-based monitoring systems. Integration of digital technologies can enhance efficiency, reduce labor dependency, and improve decision-making. Further, there is a need to convert 10% of the greenhouses into hydroponics/aeroponics with a controlled environment, which can save approximately 15-20% fertilizer and water requirements. To attain the sustainable food system by 2047, our target may be to cut nutrient losses by 50% and reduce fertilizer use by at least 20% by using the protected cultivation.

The Reality of Polyhouse Adoption in India: Overcoming Capital and Skill Barriers

Neha Oswal
Director, Harvel Irrigations

India has roughly twenty-five thousand hectares under polyhouses, greenhouses, shade nets and low tunnels. Vegetable and flower cultivation in this country covers more than sixteen million hectares. Less than one per cent. That single number is both the promise and the problem of protected cultivation in India.

For a country where most farmers work less than two hectares, where the monsoon is harder to predict every year, and where prices punish the careful planner more than the lucky one, protected cultivation should be one of the most powerful answers we have. It often is. But adoption has been uneven, and the reasons are worth understanding.

WHAT IT ACTUALLY IS

Protected cultivation simply means growing crops inside a structure that controls the conditions. A basic polyhouse costs around Rs.800 to Rs.1,200 per square metre. A fully climate-controlled greenhouse will run several multiples of that. The aim, across the range, is the same. Keep the plant in a predictable environment so that it grows faster, more uniformly, and with fewer losses.

THE INCOME DRIVERS

Three things change when you move from the open field to a structure. Yields go up. A capsicum grower in Nashik who used to harvest 8 to 10 tonnes per acre in the open field can routinely get 35 to 40 tonnes under a polyhouse. The same is true for tomato, cucumber, coloured peppers and most cut flowers. The harvest window also stretches, which helps cash flow.

Quality goes up. The produce is uniform, less bruised, and more attractive on the shelf. Organised retail, exporters and modern restaurant chains pay a premium for that uniformity. Add residue-free credentials and proper IPM records, and you are in a different conversation with the buyer altogether.

You can grow off-season. This is often where the real income comes from. A tomato that sells for Rs.15 a kilo in February can fetch Rs.40 in July if you can produce it. A strawberry farmer near Mahabaleshwar who extends his crop into May is selling into an empty market.

Water and pesticide use both come down. Drip and fertigation, which go hand in hand with protected cultivation, cut water consumption by 40 to 60% compared to flood irrigation. In states where groundwater is being mined faster than it recharges, that is not a side benefit. Insect-proof nets combined with proper IPM bring the pesticide bill down by 60 to 80 per cent.

WHY ADOPTION IS STILL SLOW

The reasons are familiar to anyone who has spent time in this sector.

Capital is the first one. A 1,000 square metre polyhouse with drip and fertigation costs Rs.10 to Rs.14 lakh on the ground. MIDH offers a 50 per cent subsidy, and 65 per cent

https://doi.org/10.52151/aet2026502.1927

in the North-East and the hilly states, but the paperwork is heavy and the approval cycle slow. Many farmers who would have benefited never get to the application.

Skill is the second. A polyhouse is not a field. Temperature has to be monitored, fertigation scheduled, pests scouted every week, and crop rotation planned six months ahead. A farmer who walks into a polyhouse without training will struggle in the first crop and often gives up before the second.

Market linkage is the third, and probably the most important. Premium produce is only premium if someone pays for it. Too many polyhouses have been built without anyone asking who will buy the output in the off-month, the rainy week, the festival glut. FPOs, contract farming and direct-to-consumer platforms are filling that gap, but the picture is still patchy.

WHAT NEEDS TO CHANGE

My honest view is that we have done enough with subsidies. The next phase will not be solved by writing bigger cheques. What is needed instead is an ecosystem. Clusters that share grading, packing and cold chain. Agronomists embedded in those clusters. Good planting material. Reliable inputs. Above all, assured markets with predictable prices. Where these have come together, the results show. The strawberry belt around Mahabaleshwar, the rose cluster of Hosur, and the capsicum farms around Pune were not built by subsidy alone. They are the product of patient, unrushed work over many years.

The other piece is manufacturing. If polyhouse components, plastic film, GI structures and fertigation kits were made at scale within India, capital costs would come down by at least a fifth. Make in India and the PLI framework have a clear application here that we have not yet exploited.

WHAT COMES NEXT

The next ten years will look very different. IoT sensors that read temperature, humidity, EC and pH now sell for a few thousand rupees each. Smartphone apps identify pests from a photograph. Within five to seven years, the kind of precision that exists today only in large export greenhouses will be within reach of a one-acre farmer near her own village.

Protected cultivation is not magic. Used with care, it can lift a small farmer's income two or three times in a handful of crop cycles. Used carelessly, it puts her into debt. The economics are sound and the buyers are there. What still has to happen is the slow work of building the system around the structure. We have built thousands of polyhouses already. The real work now is to make sure each one earns what it can.

Controlled Environment Agriculture: Unlocking Emerging Opportunities in Herbal and Export Crops

Dr Dharmendra Rai

Country Director – Association for Vertical Farming e.V. (Germany)

India's agriculture sector is at a critical juncture, facing multiple challenges such as climate variability, shrinking landholdings, rising input costs, and inconsistent market prices. Traditional open-field farming continues to expose crops to unpredictable weather conditions, pest attacks, and fluctuating yields, which directly impact farmers' income. According to estimates, nearly 55–60% of Indian agriculture remains dependent on monsoons, making it highly vulnerable to climate uncertainties. In this evolving scenario, protected cultivation technologies are emerging as a reliable and scalable solution to enhance productivity, improve quality, and ensure sustainable income growth.

Protected cultivation refers to the practice of growing crops under controlled or semi-controlled environmental conditions using structures such as greenhouses, polyhouses, and shade net houses. These systems enable farmers to create a favorable microclimate by regulating

temperature, humidity, light intensity, and irrigation. Over time, protected cultivation has expanded beyond basic structures to include advanced techniques such as hydroponics, vertical farming, and fully controlled indoor farming systems, allowing precise control over crop growth.

A key driver behind the success of protected cultivation is the integration of modern technologies. Drip irrigation and fertigation systems can reduce water usage by 90% while improving nutrient efficiency. Climate control mechanisms help maintain ideal growing conditions, leading to yield improvements of 2 to 5 times per square meter, depending on the crop. The use of high-quality planting material further enhances productivity and reduces crop losses. Additionally, innovations such as LED grow lights and automation systems allow year-round production, even in regions where climatic conditions are not naturally favorable.

The impact of these technologies on farmers' income is substantial. Protected cultivation enables significantly higher yield per square meter compared to traditional farming methods. High-value crops such as strawberries, capsicum, and leafy greens perform exceptionally well under controlled environments, often generating 3–4 times higher income per unit area. The quality of produce is also superior, with uniform size, better color, and minimal pesticide residue, which helps farmers secure premium pricing—sometimes 20–40% higher

https://doi.org/10.52151/aet2026502.1928

than open-field produce in organized markets.

Another important advantage is the ability to produce crops throughout the year, allowing farmers to target off-season markets where prices are significantly higher. Reduced dependency on pesticides lowers input costs by an estimated 70 to 80%, while also aligning with the increasing demand for safe, residue-free food. Based on practical experience in controlled environment agriculture, particularly in crops like strawberries, it has been observed that such systems significantly reduce crop losses caused by pests, diseases, and adverse weather conditions, resulting in more predictable and stable income streams.

An emerging and highly promising segment within this domain is the cultivation of medicinal and aromatic plants. India has a strong opportunity not only to cater to domestic demand but also to tap into the rapidly growing international market for plant-based pharmaceuticals, nutraceuticals, and wellness products. The global herbal medicine market is estimated to exceed USD 400 billion by 2030, indicating significant export potential for Indian growers. Protected cultivation can play a crucial role in ensuring year-round production of high-quality, standardized medicinal crops that meet stringent export requirements.

The Ministry of AYUSH has been instrumental in promoting this sector by supporting farmers and facilitating structured development through State Medicinal Plant Boards. Notably, initiatives in Western India and by the Karnataka State Medicinal Plants Authority have introduced organized trading platforms, including auction-based systems that bring together buyers and sellers. These platforms are improving transparency, enabling better price discovery, and encouraging farmer participation, indicating that this segment holds strong potential to become a major income-generating avenue for the agricultural sector.

Despite its many advantages, protected cultivation does come with certain challenges. The initial investment required for infrastructure and technology can range from Rs.800 to Rs.2,500 per square meter, depending on the level of automation and control. Additionally, effective management of these systems requires technical knowledge and regular monitoring. Market linkages also play a critical role in ensuring that farmers can realize the full value of their produce.

To overcome these challenges, a collaborative approach is essential. Government support in the form of subsidies—often covering 40–60% of project costs under various schemes—can significantly reduce the burden of capital investment. Training and capacity-building programs are necessary to equip farmers with the required skills and knowledge. Public-private partnerships can further strengthen the ecosystem by providing integrated solutions, including technology access, infrastructure development, and assured market linkages.

Looking ahead, protected cultivation is poised to become a cornerstone of modern agriculture in India. With increasing urbanization and rising demand for high-quality fresh produce, there is significant potential for urban and peri-urban farming models. Advanced systems such as vertical farming and modular growing units can be integrated into smart cities, commercial establishments, and residential complexes, bringing production closer to consumption while ensuring efficiency and sustainability.

In conclusion, protected cultivation technologies represent a transformative opportunity for Indian agriculture. By enabling higher productivity, superior quality, and year-round production, these systems can significantly enhance farmers' income and reduce risks associated with traditional farming. When combined with emerging opportunities such as medicinal plant cultivation and export-oriented production, protected cultivation can play a vital role in building a resilient, profitable, and future-ready agricultural sector in India.

Dharmendra Rai is actively involved in promoting controlled environment agriculture and vertical farming systems in India. He works closely with industry stakeholders, farmers, and organizations to develop sustainable, high-yield farming solutions, with a focus on strawberries, high-value horticultural crops, and medicinal, herbal, and aromatic plants. He represents India as Country Director for the Association for Vertical Farming, a registered non-profit organization based in Germany, and is also associated with Growpipes AB, Sweden.

Kharif 2026: A Risk-Management Imperative for Indian Agribusiness

Dr Shailendra Singh
COO – Agro, Zydex Group, Vadodara

Three structural forces are converging on Indian agriculture in Kharif 2026: a high-probability El Niño event, a geopolitically fractured fertiliser supply chain, and soil systems degraded by decades of chemical-intensive farming. For agribusiness leaders, this is not a weather story. It is a supply-side risk event with direct implications for input demand, channel strategy, and farm-level yield outcomes across the country's highest-revenue Kharif crops.

THE CLIMATE RISK IS PRICED IN — THE AGRONOMIC RESPONSE IS NOT

NOAA's Climate Prediction Center places El Niño emergence probability at 61–62% for May–July 2026, with persistence through November–January 2026/27 at 72–80%. IMD and Skymet projections point to a familiar El Niño signature: adequate June–July monsoon onset, followed by a spatially uneven and deficient August–September the reproductive window for cotton, soybean, groundnut, paddy, and sugarcane. Compounding this, heat wave frequency is forecast to increase through late Kharif, delivering thermal stress precisely

when crop physiology is least tolerant of it.

The climate signal has been absorbed by policy planners and commodity traders. What has not been adequately priced is the agronomic vulnerability of crops grown in soil systems that have lost the biological capacity to buffer against it. That gap is where the real business risk and the real market opportunity sits.

SOIL HEALTH AS A BALANCE SHEET ITEM

Green water precipitation stored within the soil profile and accessed by crop root systems supplies over 60% of India's rain-fed Kharif area. Its availability is not a function of rainfall alone; it is a function of soil water-holding capacity (WHC) and infiltration rate, both of which have deteriorated materially. Intensive chemical farming has compacted topsoils and depleted organic carbon across major Kharif geographies, reducing WHC by an estimated 15–25% below agronomic benchmarks. The result: crops that cannot access subsoil moisture reserves during the August–September dry windows that El Niño reliably delivers.

Restoring this capacity is not a long-cycle proposition. Biodegradable polymer-based biological platforms notably the Zytonic technology simultaneously improve soil porosity and WHC while establishing mycorrhizal and bacterial consortia in the rhizosphere. The agronomic outcome is larger and denser root systems that penetrate deep into the soil profile, accessing moisture that surface-rooted crops on compacted ground cannot reach. In yield-risk terms, the difference between a crop

https://doi.org/10.52151/aet2026502.1929

that survives a 10–15 day dry spell and one that does not is determined at basal application stage, weeks before the stress event occurs.

THE FERTILISER SUPPLY CHAIN: TWO SEPARATE PROBLEMS REQUIRING TWO SEPARATE RESPONSES

The Hormuz disruption of February 2026 has bifurcated India's fertiliser challenge along subsidy lines, and the two tracks demand distinct strategic responses.

On subsidised inputs, the exposure is availability. India enters Kharif 2026 with urea opening stocks of 5.5 million tonnes against a seasonal requirement of 18–19.4 million tonnes. The Strait of Hormuz closure severed over 50% of import flows and cut LNG feedstock supply, driving a 30% domestic output shortfall in March 2026 alone. Import bid prices moved from US$400–450/tonne in January to approximately US$950/tonne by April. The government has held retail prices and absorbed the fiscal shock the fertiliser subsidy bill has crossed Rs.2 trillion but the distribution consequence is peak-window supply unpredictability at the district level. Dealers and channel partners who plan on fixed replenishment calendars will face stockouts.

On non-subsidised specialty inputs, the exposure is margin. DAP prices have moved from US$625 to US$865/tonne. Ammonia and sulphur key raw materials for complex fertilisers have crossed US$900/tonne. Water-soluble NPKs, micronutrients, and specialty formulations, none of which carry subsidy support, have absorbed 20–30% landed cost increases with full farm-gate pass-through. For distributors and input companies

operating in this segment, the margin calculus has shifted.

NITROGEN USE EFFICIENCY (NUE): THE EFFICIENCY LEVER THAT CHANGES THE ECONOMICS

India's Nitrogen Use Efficiency the proportion of applied nitrogen recovered by the crop stands at approximately 35%, against a Green Revolution-era baseline of 48% and a current North American benchmark of 53%. The consequence: 65% of applied nitrogen is lost through volatilisation, leaching, and denitrification. In a normal cost environment, this is an agronomic inefficiency. In a supply-constrained, price-inflated environment, it is a direct P&L exposure for every participant in the input value chain.

The biological pathway to NUE improvement nitrogen-fixing bacteria, phosphate solubilisers, zinc and potash mobilisers deployed via advanced carrier platforms reduces the synthetic input load required for equivalent nutritional outcomes. Polymer-based slow-release urea coating is an emerging technology that addresses this from the inorganic side, synchronising nutrient release to crop uptake demand and substantially reducing loss pathways. It represents the next frontier in input efficiency, with commercial deployment on the horizon.

CROP PHYSIOLOGY UNDER THERMAL STRESS: THE STANDING CROP RISK WINDOW

El Niño's late-season heat events drive a specific and predictable physiological cascade in standing crops: stomatal closure, photosynthesis suppression, pollination impairment, and accelerated flower and fruit abscission. The commercial consequence yield loss concentrated in the highest-value reproductive stages is disproportionate to the duration of the stress event. A 10-day heat wave at flowering can reduce yield by 15–25% in unprotected crops.

Zytonic Suraksha addresses this through hygroscopic chemistry that harvests atmospheric moisture (dew) and forms a leaf-surface micro-film, moderating canopy temperature and sustaining stomatal function under compromised internal water status. The mechanism is protective, not remedial: efficacy depends on deployment before abscission is triggered, at V3–V4 onset, square/flower initiation, and boll/pod set or immediately on a 7–10 day dry spell forecast. Field performance data across cotton, soybean, paddy, and groundnut consistently demonstrates suppressed heat-induced shedding.

This is not a yield recovery tool; it is a yield protection tool the distinction matters for how it is perceived by farmers.

PEST PRESSURE: THE COMPOUNDING RISK THAT FOLLOWS STRESS

Heat-stressed, moisture-depleted crops present elevated susceptibility to sucking pests and caterpillar infestations — a correlation well-documented in El Niño years. Zytonic Neem (2–3 ml/litre), applied as a tank-mix with Zytonic Suraksha, delivers ovicidal and oviposition-deterrent activity while remaining safe for beneficial insect populations. Adding Zytonic Bio-booster (1 ml/litre) to any spray in this window enhances growth performance a meaningful efficiency gain when application windows are narrow. At 40–50 DAS, deployment of the Zytonic Bio-pesticide Foliar Kit — *Bacillus subtilis, Beauveria bassiana, Verticillium lecanii*, and Zytonic Neem provides preventive biological protection at the reproductive stage, when crop vulnerability and pest exploitation risk peak simultaneously.

THE FOUR-STAGE DEPLOYMENT FRAMEWORK

A structured four-stage programme aligns biological and nutritional inputs to the precise agronomic risk windows of a 2026 El Niño season:

Stage 1 — Pre-sowing (basal): Deploy Zytonic Mini Kit (Zytonic M + Zytonic NPK + Zytonic Zinc) to rebuild soil architecture and WHC while establishing rhizosphere biology. Supplement with Zytonic PROM+ where DAP supply is constrained replacing up to 50% of DAP requirement. Apply Zytonic Bio-pesticide Soil Kit (*Trichoderma harzianum* + *Metarhizium anisopliae* + *Paecilomyces lilacinus* + Zytonic Neem) for pre-emptive root zone protection against soil-borne pathogens, root grubs, and nematodes.

Stage 2 — Fertiliser NUE programme: Deploy Zytonic K (Potash Mobilising Bacteria on Zytonic platform) for continuous season-long potash mobilisation replacing the 7–10 day availability window of chemical MOP with sustained biological release. Align all split-dose applications to forecast moisture windows rather than fixed calendar dates to maximise nutrient-uptake synchrony.

Stage 3 — Stress response and pest management (standing crop): At any 7–10 day dry spell, heat event, or visual stress onset, apply Zytonic Suraksha + Zytonic Neem tank-mix with Zytonic Bio-booster. Suraksha protects photosynthesis and prevents abscission; Neem suppresses the pest build-up that invariably follows crop stress; Bio-booster helps in improving crop growth and performance.

Stage 4 — Mid-season biological protection (40–50 DAS): Apply Zytonic Bio-pesticide Foliar Kit for preventive management of caterpillar, sucking pest, and fungal disease pressure at the reproductive stage — the highest-risk window in an El Niño season.

Kharif 2026 presents a well-defined risk matrix: climate, supply, cost, and soil health converging simultaneously. The farmers that will outperform are those that move early on biological soil investment, build channel readiness for biological fertiliser substitution, and equip their crops with the precision stress-management protocols that the season will demand. The science is validated. The application window is now.

Protected Cultivation Technologies: A Pathway to Enhanced Farm Income and Resilient Horticulture

Dr. Natarajan Seenivasan
Professor (Horticulture), Sri Konda Laxman Telangana Horticultural University, Mulugu, Siddipet, Telangana

In the face of climate variability, shrinking land resources, and increasing demand for high-quality produce, protected cultivation has emerged as a transformative approach in modern horticulture. By enabling controlled growing conditions, these technologies help farmers improve productivity, ensure quality, and achieve higher income. Protected cultivation not only reduces risk but also allows year-round and off-season production, making it a key driver of sustainable agricultural growth.

Protected cultivation refers to the practice of growing crops under structures that provide partial or complete control over environmental conditions. These include greenhouses, polyhouses, shade net houses, low-cost poly tunnels and insect-proof net houses. By regulating temperature, humidity, light, and ventilation, these systems create an optimal microclimate for crop growth, resulting in improved yield, quality, and resource-use efficiency.

Greenhouse cultivation represents the most advanced form of protected agriculture. Equipped with systems such as ventilation, cooling pads, foggers, and automated sensors, greenhouses allow precise control of environmental parameters. This enables the cultivation of high-value crops such as capsicum, cherry tomato, cucumber, gerbera, carnation, and roses. Under greenhouse conditions, productivity can increase two to five times compared to open-field cultivation, while ensuring uniform and export-quality produce.

Polyhouses, often considered a cost-effective alternative to high-tech greenhouses, are widely adopted in India. Constructed using galvanized iron frames and polyethylene sheets, polyhouses provide a controlled environment at a relatively lower cost. Naturally ventilated polyhouses are particularly suitable for tropical climates, as they rely on passive airflow, reducing energy requirements. These structures

https://doi.org/10.52151/aet2026502.1930

Chrysanthemums under Protected Structure

have enabled small and medium farmers to diversify into high-value horticulture with improved returns.

For small and marginal farmers, even polyhouses may involve significant investment. In such cases, low-cost poly tunnels offer a practical and affordable solution. These simple structures, made from bamboo, PVC, or metal hoops covered with polyethylene sheets, create a localized microclimate that protects crops from cold, wind, and light rainfall.

Low tunnels are especially effective for early and off-season cultivation, allowing farmers to bring produce to market ahead of time and benefit from higher prices. Crops such as cucurbits, leafy vegetables, and strawberries respond well to this system. In addition to improving germination and early growth, poly tunnels provide partial protection from pests and mechanical damage.

Economically, these structures require minimal investment and can be easily assembled and reused, making them ideal for resource-poor farmers. When combined with drip irrigation and mulching, they enhance water-use efficiency and yield. Although they offer limited control compared to advanced systems, low-cost poly tunnels play an important role in climate-resilient agriculture and serve as an entry point for adopting protected cultivation technologies.

Shade net houses and insect-proof net houses provide partial environmental control and are particularly useful for nursery raising, leafy vegetables, and floriculture crops. By reducing solar radiation and preventing insect entry, these structures improve plant health and reduce dependence on chemical pesticides. The use of colored shade nets can further influence plant growth and development.

A key strength of protected cultivation lies in its integration with precision farming technologies. Drip irrigation and fertigation systems enable the efficient application of water and nutrients directly to the root zone, reducing wastage and improving nutrient uptake. Water savings of up to 50–70% can be achieved, along with better crop growth and uniformity. Automation of these systems further enhances efficiency and reduces labor requirements.

Soilless cultivation methods, including hydroponics and cocopeat-based systems, are increasingly being adopted within

Capsicum under shadenet house with Bamboo structure

Ornamental Foliage Plants under Shadenet house

protected environments. Hydroponics allows crops to grow in nutrient solutions without soil, significantly reducing water use and eliminating soil-borne diseases. Cocopeat, derived from coconut husk, serves as an excellent growing medium due to its high water retention and aeration capacity. These methods ensure higher productivity and are particularly suitable for high-value crops.

Mulching is another important component that supports protected cultivation. The use of plastic or organic mulch helps conserve soil moisture, regulate temperature, suppress weeds, and improve soil conditions. When combined with raised bed planting, mulching enhances root development and overall crop performance.

The economic benefits of protected cultivation are substantial. One of the major advantages is off-season production, which allows farmers to sell their produce at premium prices. The superior quality of produce, characterized by uniform size, color, and longer shelf life, enhances market value and export potential. Additionally, reduced crop losses due to weather and pests contribute to income stability.

Protected cultivation also promotes safer and more sustainable farming practices. The use of physical barriers reduces pest incidence, thereby lowering the need for chemical pesticides. This creates opportunities for residue-free and organic production, catering to the growing demand for safe food. Moreover, the efficient use of water and nutrients contributes to environmental sustainability.

From a socio-economic perspective, protected cultivation generates employment opportunities in areas such as nursery management, greenhouse operations, and post-harvest handling. It also attracts youth towards agriculture by presenting it as a technology-driven and profitable enterprise.

Despite its advantages, several challenges limit widespread adoption. High initial investment, limited access to credit, and the need for technical knowledge can act as barriers. Maintenance of structures, pest management within enclosed systems, and market fluctuations also pose challenges. Therefore, strengthening market linkages, cold chain infrastructure, and price support mechanisms is essential.

Government initiatives and institutional support have played a vital role in promoting protected cultivation in India. Subsidies, training programs, and extension services have encouraged farmers to adopt these technologies. Agricultural universities and research institutions continue to develop location-specific solutions and provide technical guidance to farmers.

Looking ahead, the integration of advanced technologies such as sensors, automation, and data-driven decision-making is expected to further enhance the efficiency of protected cultivation systems. Smart farming approaches will enable precise monitoring and management of crops, reducing costs and improving productivity.

In conclusion, protected cultivation technologies offer a comprehensive solution to the challenges of modern agriculture. From advanced greenhouses to low-cost poly tunnels, these systems provide scalable options for farmers with varying resource levels. By improving productivity, ensuring quality, and enabling market advantages, protected cultivation significantly enhances farm income. With continued support, innovation, and awareness, it has the potential to transform horticulture into a resilient and profitable sector.

Protected Cultivation Technologies for Income Growth

Vikas Thakare[1] and Nirutti Shinde[2]
[1]Founder and [2]MD, Mauli Organic

Agriculture is the backbone of the Indian economy, providing livelihood to millions of farmers. However, traditional farming methods are increasingly facing challenges such as climate change, irregular rainfall, pest attacks, declining soil fertility, and fluctuating market prices. To overcome these problems and ensure better income for farmers, protected cultivation technologies are emerging as a modern and profitable solution. Protected cultivation refers to the practice of growing crops under controlled environmental conditions using structures such as greenhouses, polyhouses, shade nets, low tunnels, and mulching systems. These technologies help farmers produce high-quality crops throughout the year with higher productivity and reduced risk.

Protected cultivation creates a favorable microclimate for crops by controlling temperature, humidity, light, and irrigation. It protects crops from adverse weather conditions such as heavy rain, strong winds, excessive heat, frost, and pests. As a result, farmers can cultivate vegetables, flowers, fruits, and nursery plants more efficiently and profitably. Crops grown under protected conditions generally yield better quality produce with improved appearance, taste, and shelf life, which fetches higher prices in the market.

One of the most popular forms of protected cultivation is the polyhouse. A polyhouse is a framed structure covered with transparent polythene sheets that allow sunlight to enter while maintaining optimum temperature and humidity inside. Polyhouses are widely used for cultivating tomatoes, capsicum, cucumber, strawberry, gerbera, carnation, and other high-value crops. Since environmental conditions are controlled, crops can be grown during off-seasons when market demand and prices are high. This significantly increases farmers' income compared to open-field cultivation.

Greenhouses are another important protected cultivation technology. These structures use glass or plastic materials to create a controlled environment suitable for crop growth. Advanced greenhouses may include automated irrigation systems, cooling fans, foggers, and climate control devices. Though greenhouse farming requires higher initial investment, it offers excellent returns through increased productivity and superior quality produce. Commercial flower cultivation under greenhouses has become highly profitable in many parts of India.

Shade net houses are also gaining popularity among farmers. These structures are covered with shade nets that reduce sunlight intensity and protect crops from excessive heat and insect attacks. Shade nets are especially useful for growing leafy vegetables, medicinal plants, ornamental flowers, and nursery plants. Compared to greenhouses, shade net houses are less expensive and easier to maintain, making them suitable for small and medium farmers.

Another important component of protected cultivation is drip irrigation and fertigation. Drip irrigation supplies water directly to the root zone of plants in controlled quantities, reducing water wastage and improving water-use efficiency. Fertigation involves supplying fertilizers through irrigation water, ensuring better nutrient absorption by plants. These technologies not only increase crop yield but also reduce labor costs and fertilizer losses. In water-scarce regions, drip irrigation plays a major role in sustainable agriculture and income enhancement.

Mulching is another effective practice used in protected cultivation. In this method, the soil surface around plants is covered with plastic sheets or organic materials. Mulching conserves soil moisture, suppresses weed growth, maintains soil temperature, and improves crop quality. Plastic mulching is commonly used in vegetable cultivation and has shown remarkable benefits in increasing productivity and reducing input costs.

Protected cultivation technologies contribute significantly to income growth by enabling year-round cultivation and higher crop productivity. Farmers can produce crops even during unfavorable seasons and sell them at premium prices. Since crops are protected from pests and diseases, the use of pesticides is reduced, leading to healthier produce and lower production costs. Higher quality products also open opportunities for export and supply to supermarkets, hotels, and food processing industries.

In India, government agencies are promoting protected cultivation through various subsidy schemes and training programs. The National Horticulture Mission (NHM), Mission for Integrated Development of Horticulture (MIDH), and state horticulture departments provide financial assistance for constructing polyhouses, greenhouses, and drip irrigation systems. Farmers are encouraged to adopt modern technologies to improve productivity and double their income. Agricultural universities and Krishi Vigyan Kendras (KVKs) also conduct training programs to educate farmers about protected cultivation practices.

Despite its many advantages, protected cultivation also faces certain challenges. High initial investment, lack of technical knowledge, maintenance costs, and limited access to quality planting material are some of the common problems faced by farmers. Small farmers may find it difficult to invest in greenhouse structures without financial support. Therefore, proper training, access to credit facilities, and technical guidance are essential for successful adoption of these technologies.

The future of protected cultivation in India is very promising. With increasing demand for high-quality vegetables, fruits, and flowers, protected farming offers a sustainable path for enhancing agricultural productivity and farmer income. Climate change and shrinking agricultural land further highlight the importance of controlled environment agriculture. By adopting protected cultivation technologies, farmers can reduce risks, improve resource efficiency, and achieve better economic stability.

In conclusion, protected cultivation technologies represent a modern approach to profitable and sustainable agriculture. Polyhouses, greenhouses, shade nets, drip irrigation, fertigation, and mulching are helping farmers increase production, improve quality, and earn higher incomes. These technologies not only ensure better crop protection but also support efficient use of water, fertilizers, and other resources. With proper government support, training, and awareness, protected cultivation can transform Indian agriculture and improve the livelihoods of farmers across the country.

https://doi.org/10.52151/aet2026502.1931

Protected Cultivation as a Climate Change Mitigation Strategy for Sustainable Agriculture in Jharkhand, India

Dr Ajai Singh

Professor, Department of Civil Engineering, Central University of Jharkhand, Ranchi, India,
Email: ajai.singh@cuj.ac.in

The technologies associated with protected agriculture focus on designing and implementing controlled environments which ensures regulation of microclimate factors such as temperature, relative humidity, light, and carbon dioxide levels. Examples of controlled environments are greenhouses/polyhouses, shade net houses, and low tunnels, each being suitable for particular crops under specific environmental conditions. For instance, a greenhouse is designed to cover a specific area using UV stabilized polyethylene or polycarbonate sheets which may be naturally ventilated or have climate-controlled conditions through fan and pad systems. It is largely used for high value crops such as offseason vegetables and flowers. The greenhouses can also be provided with CO_2 generators for enriching the atmosphere to stimulate photosynthesis. Efficient soil moisture management is ensured by adoption of drip irrigation and fertigation systems which enable watering the roots efficiently. The construction of such structures includes galvanized iron or aluminum structures coupled

with tough cladding material that can withstand wind force and provide appropriate drainage and orientation. In spite of the high costs involved in the process and subsequent maintenance requirements, protected cultivation results in higher productivity and water efficiency along with the ensuring year round cultivation.

Coverage and adoption of protected cultivation in India is still limited but is growing steadily due to implementation of scheme such as Mission for Integrated Development of Horticulture. The total area under protected cultivation, as of 2026, amounts to around 5.6 million ha. China leads in this field with more than 90% share in the world production of vegetables through protected cultivation. In India, the total acreage covered under protected cultivation including that under polyhouses, greenhouses, shade-net houses, and plastic tunnels is estimated to be about 2.5-2.75 lakh ha, which is highly insignificant in terms of total cultivated area in the country as well as against other nations such as China, which exceeds 2 million ha. Thus, it may be stated that the practice of protected cultivation in India is still at a nascent stage accounting for less than 2% of the total horticultural area despite its rapid growth owing to incentives, modern technologies, and demand for high-value crops. However, the scenario regarding the adoption of protected cultivation in the state of Jharkhand stands out as being at a primitive and limited level. The main objective of using greenhouses in Jharkhand is the promotion of protected agriculture

https://doi.org/10.52151/aet2026502.1932

with an aim to increase productivity from agricultural products such as carnations, gerbera, roses, marigolds, and other exotic vegetables like tomato and capsicum. There are around 1.8 million ha of cultivated land in the state with low irrigation levels and largely rain-fed agricultural practices, there lies great potential in terms of adopting protected cultivation in Jharkhand. Currently, adoption of protected cultivation is largely found in peri-urban areas such as Ranchi, where farmers have started using polyhouses as well as shade net technology for vegetables and floriculture with technical training and subsidies provided by state governments.

The technique of protected cultivation is one of the pragmatic approaches to overcome the difficulties associated with climate change, especially in a state like Jharkhand, where agriculture is predominantly dependent on rainwater, climatic variability is rising, and irrigation facilities are still inadequate. Erratic rains and extended dry periods are some of the most significant threats posed by climate change in Jharkhand. The systems of protected cultivation, such as polyhouses and shade-net houses, make efficient use of water resources via drip irrigation and fertigation techniques, thus minimizing water usage without affecting plant development even in water-deficient situations. Protected cultivation structures help shield plants from temperature fluctuations caused by climate change by creating a stable microclimate environment through ventilation, shading, and evaporative cooling processes.

Protected cultivation provides strong quantitative evidence in addressing climate change challenges, particularly in Jharkhand where agriculture is predominantly rainfed and highly vulnerable to climatic variability. One of the most critical advantages of protected cultivation is water-use efficiency, as drip irrigation and fertigation systems can reduce water consumption by 40–70% and improve nutrient-use efficiency by 25–40%, which is highly relevant for Jharkhand where irrigation coverage is less than 10% of the net sown area. In terms of productivity, protected cultivation can increase yields by 2 to 5 times compared to open-field conditions; for instance, capsicum yields can rise from 20–30 tonnes/ha in open fields to about 80–120 tonnes/ha under polyhouse conditions. These systems reduce crop losses caused by extreme weather events such as heavy rainfall, hailstorms, and strong winds, with damage reduction ranging from 60 to 90%, while also lowering pest incidence by 30–50%. Water productivity also improves by 2–3 times, and cropping intensity increases from a single seasonal crop to 2–3 crops per year, enhancing overall land-use efficiency. Economically, farmers can achieve 3–5 times higher net returns, supported further by government subsidies of 40–60% under schemes such as MIDH. The protected cultivation enhances resource efficiency, stabilizes yields, reduces climate risks, and improves farmer income, making it a highly effective strategy for climate-resilient agriculture in Jharkhand and similar other states.

In the context of uncertain climates, protected cultivation converts threat into sustainability and scarcity into abundance. The future of farming is in controlled systems, where technological advancements enable the farmer to triumph over climatic difficulties and sustain productivity.

Protected Cultivation Technologies for Sustained Income

Maninder Singh
Founder & CEO, CEF Group

India feeds over a billion people. Yet every year, farmers struggle with weather volatility, pest pressure, and market unpredictability that erases months of hard work in days. Much of this loss is preventable. The answer isn't a magic seed or a government scheme. It's a shift in how we grow from open-field dependence to structures that give farmers a fighting chance against nature's worst days.

Protected cultivation- growing crops under polyhouses, net houses, shade nets, and low tunnels has been around for decades. What's changed is the economics. Technology costs have dropped. Drip irrigation and fertigation systems are more accessible than ever. And the data from farms across Maharashtra, Punjab, Himachal Pradesh, and Karnataka is unambiguous: farmers who shift to protected structures see yield improvements of 40 to 300 percent, depending on the crop, and a dramatic reduction in input losses.

WHAT 'PROTECTED CULTIVATION' ACTUALLY MEANS ON THE GROUND

This term gets used loosely. Protected cultivation is not one technology, it's a spectrum. At the simpler end, a shade

net over a tomato crop in Rajasthan can cut heat stress losses by 30 percent at a cost a small farmer can justify. At the more sophisticated end, a climate-controlled polyhouse growing capsicum or exotic floriculture for export markets can transform a landholding's economics entirely.

The key technologies worth understanding are: walk-in tunnels and low tunnels for seasonal vegetables; naturally ventilated polyhouses (NVPHs) for year-round cultivation of tomatoes, capsicum, cucumber, and gerbera; net houses for nursery development and insect exclusion; and fog or mist cooling systems for hot climate regions. Each has a different cost-benefit profile,the right choice depends on the crop, climate zone, water availability, and market access.

THE INCOME EQUATION: WHAT THE NUMBERS TELL US

The income differential between open-field and protected cultivation is consistently striking. A farmer growing tomatoes in an open field in North India typically gets two to three harvests annually, with losses from pest, disease, and rain frequently exceeding 25 to 35 percent of yield. The same farmer with a naturally ventilated polyhouse on even half a hectare can achieve near year-round production, with losses under 10 percent and a price premium from consistent, off-season supply.

Net income per hectare under open cultivation typically ranges from Rs.2 to 4 lakhs annually. Under protected structures, this figure regularly crosses Rs.8 to 15 lakhs per hectare for similar crops and significantly more for floriculture. The capital cost of a NVPH ranges from Rs.15 to 35 lakhs per hectare, but with subsidy support under the National Horticulture Mission, farmer contribution can be reduced substantially. Payback

https://doi.org/10.52151/aet2026502.1933

periods of three to five years are commonly achieved.

POLYHOUSE DESIGN AND CROP MATCHING: GETTING IT RIGHT

One of the most common mistakes is poor crop-structure matching. A high-humidity crop like cucumber in a poorly ventilated polyhouse in a hot, humid region will underperform not because the technology fails, but because the design wasn't right for the environment. Agronomic planning before construction is essential.

UV-stabilised polyethylene films with anti-drip, anti-fog, and diffused light properties improve light distribution and reduce disease from condensation. Insect-proof netting at 40 to 50 mesh excludes whitefly and thrips, significantly cutting pesticide dependency. Combined with drip-based fertigation that delivers nutrients directly to the root zone, these structures create growing conditions that open fields simply cannot replicate.

WHAT NEEDS TO CHANGE FOR WIDER ADOPTION

The technology works. The economics justify adoption. So what is slowing us down? Three things.

First, affordable credit. Subsidy schemes exist but disbursement is slow and documentation requirements are prohibitive for farmers without formal land records or banking history.

Second, last-mile technical support. A polyhouse requires ongoing management humidity control, pruning, integrated pest management, fertigation scheduling. Farmers who invest without support underperform and blame the technology, not the management gap.

Third, market linkage must be pre-arranged, not post-production. Without an aggregator, cold chain, or institutional buyer in place before harvest, even a quality crop can end in distress sale. Protected cultivation must be planned as part of an end-to-end value chain.

THE OPPORTUNITY IN FRONT OF US

Climate variability is no longer a future risk, it is a present reality farmers deal with every season. Greenhouses and polyhouses are not luxury infrastructure for large commercial farms. Designed and supported correctly, they are practical tools for income stabilisation that small and medium farmers across India can access and benefit from.

The agricultural engineering community has a central role: innovate on structure cost and durability, develop climate-appropriate designs for India's diverse agro-ecological zones, and build the service networks that make adoption sustainable beyond the first season. Government must streamline the subsidy pipeline. And practitioners must document and share what actually works, so the next farmer makes decisions based on evidence, not a brochure.

Protected cultivation is not a silver bullet. But it is one of the most reliable tools we have to shift Indian agriculture from subsistence risk to sustainable income. That's worth building seriously.

Engineering and Technologies for Protected Cultivation: Pathway to Blueberry Cultivation in India

Pawan Kumar
Chief General Manager, Patanjali Organic Research Institute

BLUEBERRIES UNDER COVER: HOW PRECISION CULTIVATION IS REWRITING INDIA'S HORTICULTURE STORY

Blueberries have become one of the fastest-growing fruit crops globally, with production crossing 2 million tonnes. Countries like China, the United States, and Peru dominate, with Peru leading exports through highly efficient production systems. Yields in advanced regions range between 10–20 tonnes per hectare, supported by improved varieties and organised supply chains. Rising global demand, driven by the fruit's strong health appeal, has made blueberries a year-round, high-value commodity.

In India, blueberries remain a nascent but rapidly evolving crop. Cultivation is expanding across Maharashtra, Karnataka, Himachal Pradesh, and Uttarakhand, largely under protected and soilless systems. Domestic production is estimated at 2,000–3,000 tonnes annually, far below demand. Imports exceed 20,000 tonnes each year, primarily from Peru, Chile and the United States, making India a strongly import-dependent market.

1. **Agricultural Transition:** India's agricultural transition is quietly but decisively moving away from a singular focus on volume. The new direction is shaped by precision, quality and value. Among the crops symbolising this shift, blueberries stand out, not just for their premium market appeal, but for the way they are pushing farmers and agri-entrepreneurs to rethink how crops are grown. At the centre of this transformation lies protected cultivation, where engineering meets biology to create controlled, high-performance growing systems.
2. **Crop Sensitivity:** Blueberries are not a conventional Indian crop. They demand specific conditions eg acidic soil, controlled moisture, mild temperatures and protection from excessive rainfall. In open field conditions, these requirements are difficult to meet consistently. Protected cultivation, however, changes the equation. By creating a microclimate around the plant, it allows growers to manage variables that were once left to chance.
3. **Structural Systems:** Structures such as polyhouses and polytunnels form the physical backbone of this system. Built using metal frames and UV stabilised plastic films, they trap solar radiation and maintain a stable internal environment. This does not merely shield the crops from extreme weather, it actively shapes the conditions in which plants grow. Ventilation systems, insect-proof nets and fogging units ensure that temperature, humidity & airflow remain within optimal ranges. For a crop as sensitive as blueberry, such stability is essential.
4. **Root Zone Engineering:** Equally important is what happens below the plant. Traditional soil often becomes a limiting factor in blueberry cultivation due to its pH and structure. The solution has come in the form of substrate-based systems. Instead of relying on native soil, plants are grown in engineered media such as cocopeat, perlite or peat moss. These substrates allow precise control over root conditions especially pH and nutrient availability while ensuring excellent drainage and aeration. The result is uniform root development and healthier plants.
5. **Container Innovation:** Containers such as grow bags and air pots further enhance this system. They prevent root circling and improve oxygen availability, both of which directly influence plant vigour and productivity. In many ways, the root zone becomes a designed environment, much like the structure above it.
6. **Water & Nutrient Precision:** Water and nutrient management represent another critical layer of precision. Drip irrigation systems deliver water directly to the root zone in measured quantities, reducing wastage and ensuring consistency. When combined with fertigation where soluble nutrients are supplied through irrigation lines, this system becomes highly responsive. Growers can adjust nutrient composition in real time, aligning it with the plant's growth stage. This level of control has a visible impact on fruit quality, influencing size, sweetness, firmness and shelf life.
7. **Weed Management:** Weed management, often overlooked, also benefits from simple yet effective engineering solutions. Weed mats and plastic mulches suppress unwanted growth without the need for chemical herbicides. At the same time, they help retain soil moisture and regulate temperature, contributing to overall crop health. For high-value crops like blueberries, where cleanliness and uniformity matter, these small interventions make a significant difference.
8. **Data-Driven Farming:** What truly distinguishes modern protected cultivation, however, is its growing reliance on data. Sensors placed within the growing environment continuously monitor temperature, humidity, light intensity and root-zone parameters such as moisture, electrical conductivity and pH. This information feeds into digital dashboards, allowing growers to track conditions in real time. Instead of reacting to problems after they occur, decisions can be made proactively.
9. **Emerging Technologies:** Emerging technologies are taking this a step further. Automated irrigation systems, integrated with sensor data, can adjust water delivery without manual intervention. Early-stage tools using artificial intelligence are beginning to detect signs of plant stress, nutrient deficiencies or disease before they become visible to the human eye. While still evolving, these tools point towards a future where cultivation is increasingly guided by predictive insights rather than experience alone.
10. **Expanding Geography:** The success of blueberries in such systems illustrates the broader potential of protected cultivation in India. Once considered limited to temperate regions, blueberries are now being grown across diverse agro-climatic zones, thanks to the availability of low-chill and zero-chill varieties. Combined with controlled environments, these varieties are expanding the geographical scope of the crop.

CHALLENGES & CONSTRAINTS

Yet, the path forward is not without challenges. The initial investment required for structures, irrigation systems and monitoring equipment can be substantial. Technical knowledge remains a barrier, particularly for first-generation adopters. Access to quality planting material and reliable inputs is still uneven. Without adequate training and support, the risk of failure can discourage potential growers.

WAY FORWARD

Addressing these constraints requires a coordinated approach. Capacity building must move beyond one-time training sessions to continuous, field-level support. Financing mechanisms need to be more accessible and aligned with the realities of neo-entrepreneurs. Local manufacturing of equipment can help reduce costs, while digital advisory platforms can bridge knowledge gaps in real time.

CONCLUSION

Despite these hurdles, the direction is clear. Protected cultivation is not just a technology it represents a shift in mindset. Blueberries, with their demanding nature and high returns, are simply the most visible expression of this shift. In the coming years, the lessons learned from blueberry cultivation are likely to influence a wider range of crops, shaping a more resilient and value-driven future for Indian horticulture.

https://doi.org/10.52151/aet2026502.1934

Agricultural Engineering Today | 50 (2)

Protected Cultivation: Growing the Future of Urban Food

Dr. Veenita Kumari
Deputy Director (Gender Studies), MANAGE Hyderabad

Cities are expanding faster than ever before. Towering buildings, shrinking open spaces, and rising populations are redefining how we live and how we eat. As the distance between farms and urban consumers continues to grow, so does the challenge of ensuring access to fresh, nutritious food. In this evolving landscape, a quiet revolution is taking root:- 'protected cultivation'.

Blending innovation with sustainability, protected cultivation is transforming urban spaces into productive green hubs. From rooftop gardens to high-tech vertical farms, cities are reimagining agriculture not as something distant and rural, but as an integral part of urban life.

FARMING WITHIN THE CITY

Urban agriculture is no longer a niche concept. It is rapidly becoming a necessity. Traditionally, cities have depended on rural areas for their food supply, relying on long and complex supply chains. While effective in scale, this system often compromises freshness, increases transportation costs, and contributes significantly to carbon emissions.

Urban agriculture makes this possible by bringing food production closer

to where it is consumed. Rooftops, balconies, and even unused urban plots are being converted into thriving growing spaces. The result is not just fresher produce, but also a reduced environmental footprint and stronger local food systems.

Beyond the environmental benefits, urban farming is also building communities. Shared gardens and rooftop farms are fostering collaboration, encouraging healthier lifestyles, and giving people a deeper connection to the food they consume.

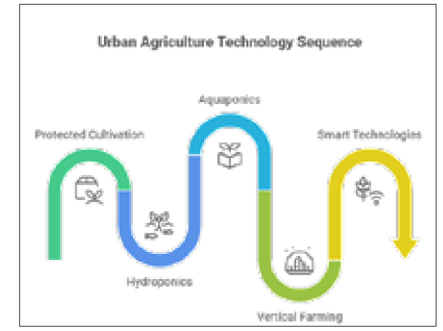
THE TECHNOLOGY BEHIND THE TRANSFORMATION

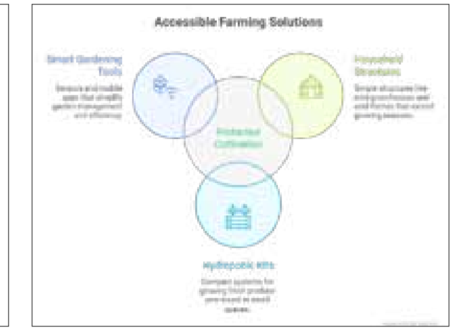
At the heart of this movement lies protected cultivation a method that allows crops to grow in controlled environments where temperature, light, humidity, and nutrients are carefully managed. This approach shields plants from unpredictable weather and pests, ensuring consistent quality and higher productivity.

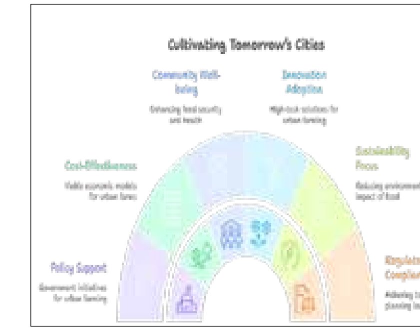
Among the most exciting innovations is hydroponics, a method of growing plants without soil. Instead, crops are nourished through nutrient-rich water solutions, enabling faster growth and significantly reduced water usage. In fact, hydroponic systems can use a fraction of the water required in traditional farming.

Aquaponics takes this a step further by combining fish farming with plant cultivation. In this closed-loop system,

https://doi.org/10.52151/aet2026502.1935







fish waste provides natural nutrients for plants, while plants help purify the water. It is a striking example of how nature and technology can work together efficiently.

Then there is vertical farming perhaps the most futuristic expression of urban agriculture. By growing crops in stacked layers within controlled indoor environments, vertical farms make optimal use of limited space. Equipped with LED lighting and automated systems, these farms can operate year-round, independent of seasons or climate conditions.

Smart technologies are further enhancing these systems. Sensors and digital tools now allow farmers even beginners to monitor plant health and environmental conditions in real time. With precise control over inputs, waste is minimized and productivity maximized.

BRINGING FARMING HOME

One of the most compelling aspects of protected cultivation is its accessibility. It is not limited to large-scale commercial operations; it can be adopted at the household level with ease.

Simple structures such as mini-greenhouses, cold frames, and protective tunnels can create ideal growing conditions even in small spaces. These setups help extend the growing season and protect plants from harsh weather.

For urban residents interested in modern techniques, compact hydroponic kits offer an excellent entry point. These systems are designed for balconies, terraces, and even indoor use, making it possible to grow fresh herbs, leafy greens, and vegetables throughout the year.

The integration of smart gardening tools has made home cultivation even more convenient. With sensors tracking moisture, temperature, and light, and mobile applications offering real-time insights, managing a home garden has never been easier or more efficient.

A SUSTAINABLE AND RESILIENT FUTURE

Protected cultivation is not just about growing more food it is about growing smarter. By optimizing resource use, it significantly reduces water consumption and limits the need for chemical inputs. Controlled environments also lower the risk of pest infestations, leading to safer and healthier produce.

From an economic perspective, urban agriculture opens new avenues for entrepreneurship. Small-scale growers can supply fresh produce to local markets, restaurants, and communities, creating income opportunities while strengthening local economies.

Perhaps most importantly, protected cultivation enhances resilience. In a world facing climate uncertainties and supply chain disruptions, local food production provides a reliable buffer. It empowers cities to become more self-sufficient and less vulnerable to external shocks.

CULTIVATING TOMORROW'S CITIES

As urban landscapes continue to evolve, the integration of agriculture into city life is becoming increasingly essential. Protected cultivation offers a practical and forward-thinking solution one that aligns with the goals of sustainability, food security, and community well-being.

Whether it is a high-tech vertical farm or a modest balcony garden, every effort contributes to a greener, healthier urban environment. The future of food is not just in distant fields it is growing all around us, in the heart of our cities.

Protected Cultivation Technologies for Higher Revenue in Modern Agriculture

Vibhor Agarwal
Founder & CEO, VA Agro Farm & Nursery & Hortiprise

Agriculture today is no longer just about production—it is about profitability per unit area. With shrinking land holdings and increasing input costs, farmers need systems that generate higher returns from the same piece of land. In this context, protected cultivation technologies are emerging as one of the most reliable ways to increase farm income.

Protected cultivation involves growing crops under controlled structures such as polyhouses, greenhouses, and shade nets. These systems allow farmers to regulate environmental conditions and produce high-value crops more efficiently and consistently.

From practical experience working with farmers at VA Agro Farm & Nursery, it is clear that protected cultivation becomes truly impactful when it is used with a revenue-first approach, not just as a production technology.

1. CROP SELECTION: THE FIRST STEP TOWARDS HIGHER REVENUE

The biggest mistake many farmers make is growing low-value crops inside high-cost structures. Protected cultivation is most profitable when used for high-value crops such as:

- Colored capsicum
- English cucumber
- Cherry tomato
- Exotic leafy greens

These crops have strong demand in urban markets, hotels, and modern retail chains, ensuring better price realization.

Choosing the right crop based on market demand, not tradition, is the foundation of higher revenue.

2. OFF-SEASON PRODUCTION = PREMIUM PRICING

One of the strongest advantages of protected cultivation is the ability to grow crops during off-season periods.

When supply in the open market is low, prices automatically increase. Farmers using polyhouses can supply produce when others cannot, leading to 20–50% higher market prices.

https://doi.org/10.52151/aet2026502.1936

For example, off-season capsicum or cucumber can generate significantly higher returns compared to peak-season open-field produce.

3. YIELD MAXIMIZATION THROUGH CONTROLLED ENVIRONMENT

Protected structures create an ideal microclimate, allowing crops to grow faster and healthier. This directly impacts revenue through:

- Higher yield per plant
- Multiple harvest cycles
- Reduced crop failure

In crops like capsicum, yield can reach 8–10 kg per plant, which is several times higher than open-field production. More output from the same area means direct increase in income.

4. PRECISION INPUT MANAGEMENT (LOWER COST, HIGHER OUTPUT)

Technologies like drip irrigation and fertigation play a major role in improving profitability.

Instead of applying fertilizers randomly, nutrients are delivered in precise quantities directly to the root zone. This leads to:

- Better nutrient use efficiency
- Reduced fertilizer wastage
- Improved crop quality

Lower input cost combined with higher output significantly improves net profit margins.

5. QUALITY SEEDLINGS: A SMALL INVESTMENT, BIG RETURNS

One of the most underestimated factors in protected cultivation is the use of professional, high-quality seedlings.

Weak or non-uniform seedlings reduce productivity and affect overall crop performance. On the other hand, strong, disease-free seedlings ensure:

- Better plant survival
- Uniform growth
- Higher yield consistency

At VA Agro Farm & Nursery, we have observed that farmers using protray seedlings raised under controlled conditions achieve noticeably better results compared to traditional nursery plants.

In a high-investment system like a polyhouse, starting with the right planting material is critical for maximizing returns.

6. MARKET LINKAGE: TURNING PRODUCTION INTO REVENUE

Higher production does not automatically guarantee higher income. The real profit comes from selling at the right place and price.

Farmers adopting protected cultivation should focus on:

- Direct supply to retailers and supermarkets
- Tie-ups with hotels and restaurants
- Local premium vegetable markets
- Contract farming or bulk buyers

Better market linkage ensures that the high-quality produce grown under protected conditions is sold at a **premium price**, not at average mandi rates.

7. HYDROPONICS AND HIGH-DENSITY SYSTEMS

For farmers looking to maximize revenue from limited space, advanced systems like hydroponics and vertical farming offer strong potential.

These systems allow:

- Higher plant density
- Faster crop cycles
- Premium product quality

Crops like lettuce, basil, and microgreens can generate continuous income streams, especially when linked to urban consumers.

CHALLENGES TO CONSIDER

While protected cultivation offers strong income potential, it requires:

- Initial investment
- Technical knowledge
- Proper planning and management

Without the right approach, returns may not meet expectations. However, with training and correct crop planning, these challenges can be managed effectively.

CONCLUSION

Protected cultivation technologies are not just about increasing production—they are about maximizing revenue per square meter.

When combined with:

- High-value crop selection
- Off-season production
- Efficient input management
- Quality seedlings from reliable nurseries like VA Agro Farm & Nursery
- Strong market linkage

these systems can transform farming into a high-income enterprise.

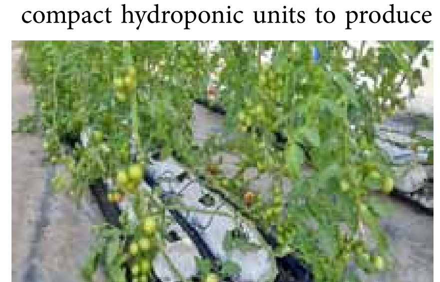
The future of Indian agriculture lies in adopting such smart, income-oriented technologies, where every decision is guided by profitability rather than tradition.

Engineering and Technologies for protected Cultivation

Dr Nilesh Biwalkar
Professor, Department of Soil and Water Engineering
Punjab Agricultural University, Ludhiana-141004

Agriculture today is changing at a pace we have never seen before. Farmers are facing uncertain weather, smaller land holdings, and growing expectations from consumers who want fresh, clean, and high-quality produce throughout the year. These challenges have pushed both farmers and scientists to look beyond traditional methods and adopt smarter, more reliable ways of growing crops. One such approach that is steadily gaining attention is protected cultivation. With the support of modern engineering and innovative technologies, farmers can now grow crops inside specially designed structures like greenhouses, polyhouses, shade nets, and net houses. These structures are not just shelters for plants, they act as carefully managed growing spaces that help farmers use resources wisely, produce crops even in the off-season, support urban farming, and save precious water and nutrients while improving overall farm efficiency.

One of the major challenges facing agriculture today is the problem of low land holding, especially in countries like India where farms are often fragmented into small plots. Traditional farming methods sometimes struggle to provide adequate income from such limited areas. Protected cultivation offers a practical solution by increasing productivity per unit area. Through well designed polyhouses and greenhouses, farmers can grow more crops in less space. Engineering design ensures that every square meter of land is used effectively. Vertical growing systems, trellising methods, and optimized spacing techniques allow farmers to maximize production even on small plots. This makes protected cultivation particularly valuable for small and marginal farmers who seek higher returns from limited land. Engineering innovations have made it possible to build lightweight greenhouse structures on rooftops, terraces, and vacant urban spaces. These structures use automated irrigation systems, artificial lighting when needed, and compact hydroponic units to produce



https://doi.org/10.52151/aet2026502.1937

vegetables close to consumers. Urban agriculture reduces transportation costs, minimizes post-harvest losses, and ensures the availability of fresh produce in cities. It also encourages community participation and promotes awareness about sustainable food production.

The production of high quality produce is one of the strongest advantages of protected cultivation. In open field farming, crops are exposed to pests, diseases, dust, and unpredictable weather conditions. However, in protected structures, environmental factors such as temperature, humidity, and light can be carefully controlled using engineering solutions. Technologies such as cooling pads, exhaust fans, foggers, and shading systems maintain the ideal climate for plant growth. Insect-proof nets prevent the entry of pests, reducing the need for chemical pesticides. As a result, fruits, vegetables, and flowers produced under protected cultivation are cleaner, more uniform, and more attractive in appearance, making them highly suitable for premium markets. Protected cultivation also plays a crucial role in off-season crop production, enabling farmers to grow crops when they are normally unavailable in the market. For example, vegetables such as tomatoes, capsicum, cucumbers, and leafy greens can be produced during extreme weather conditions that would otherwise damage crops in open fields. Engineering technologies such as heating systems, thermal screens, and controlled ventilation allow farmers to maintain suitable temperatures throughout the year. By producing crops during off-season periods, farmers can take advantage of higher market prices and increase their profitability.

Another exciting advancement within

protected cultivation is hydroponic vegetable production, a soil-less farming method that relies on nutrient-rich water solutions. Hydroponic systems are carefully engineered using channels, pumps, reservoirs, and filtration units that circulate nutrients directly to plant roots. Systems such as Nutrient Film Technique (NFT) and Ebb and Flow Technique allow vegetables like lettuce, spinach, cucumbers, and tomatoes to grow rapidly and consistently. Hydroponics is especially beneficial in areas where soil quality is poor or land availability is limited. It also supports vertical farming, making it ideal for urban agriculture and small-scale farming systems.

A key strength of protected cultivation lies in its ability to support water and nutrient conservation, which is increasingly important in regions facing water scarcity. Engineering innovations such as drip irrigation and fertigation systems deliver water and nutrients directly to the root zone of plants. This targeted application reduces wastage, evaporation losses, and nutrient runoff. Soil moisture sensors and automated controllers help regulate irrigation schedules, ensuring that plants receive only the required amount of water. In addition, rainwater harvesting systems can be integrated into protected structures to store and reuse water during dry periods. These technologies make farming more efficient and environmentally sustainable.

Automation and digital monitoring systems further enhance the performance of protected cultivation. Sensors measure environmental parameters such as temperature, humidity, and nutrient levels, while automated controllers adjust irrigation, ventilation, and lighting systems accordingly. Such smart technologies bring precision and reliability to farming operations. Despite the many advantages, adopting protected cultivation requires knowledge, training, and initial investment. However, with growing awareness, government support programs, and advancements in technology, these systems are becoming more affordable and accessible to farmers of different scales. Training programs and demonstration units help farmers understand the operation and maintenance of these structures, ensuring long-term success.

By addressing the challenges of low land holding, enabling urban agriculture, producing high-quality and off-season crops, supporting seed potato multiplication, promoting hydroponic vegetable production, and conserving water and nutrients, protected cultivation represents a forward looking approach to farming. As agriculture continues to face pressures from population growth and climate change, these engineered solutions offer a promising path toward food security, higher farmer incomes, and responsible resource management.

Smart Farming and Agritech Education: Teaching Students to Bridge Traditional Farming with Modern Innovation

Dr. Kannan. V
Dy. Dean, School of Agriculture, Mohan Babu University

Agriculture has been the backbone of many human civilization and economies across centuries. Until 19th century farmers practised traditional farming techniques to produce crops with limited resources. Across the world during mid-19th century's scientist and farmers participated in the green revolution to increase the crop productivity to meet out the growing population by using new short duration varieties and excess application of fertilizers, which in turn increases the yield but increased application of pesticides and fertilizers degraded the cultivable land and cause more environmental pollutions. Adoption of traditional farming practices and green revolution techniques increased the input cost like labours, seeds, pesticides and fertilizers.

However the rapid growth of global population, shrinking land resources, climate unpredictability, soil degradation, and the increasing need for sustainable food production have placed enormous pressure on traditional farming practices. Agriculture stands at a critical crossroads as a global population

grows exponentially and climate pressures intensify, the sector must radically enhance its productivity and sustainability.

Smart farming refers to the application of advanced technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), deep learning and machine learning, image processing, sensors, robotics, drones, big data analytics, and precision agriculture tools to improve the efficiency, productivity, and sustainability of farming operations. These technologies are used to enhance the crop productivity by providing deeper insights into soil health, weather patterns, crop water requirement, pest and disease behaviour, and resource management.

For example, earlier farmers relied on experience to determine the irrigation schedule now can use soil moisture sensors and automated drip/sprinkler irrigation systems to deliver water precisely based on the crop needs and its growth cycle. This advanced technology not only increases yields but also conserves valuable resources reduces environmental impact. like human's agriculture practices and techniques also evolved parallelly, In this evolving landscape, smart farming and agri education have emerged as transformative forces. By integrating age-old wisdom with modern technology, educational institutions are now preparing students to become the next generation of innovators capable of revolutionizing agriculture.

Recognizing the need of the technological interventions needed in the smart farming, the Indian Council of Agricultural Research (ICAR)

https://doi.org/10.52151/aet2026502.1938

Agricultural Engineering Today | 50 (2)

has also updated its agricultural curriculum to equip the students receive the knowledge and skill sets to cater the needs of future smart farming. NAHEP is the major initiative taken by the ICAR (National Agricultural Higher Education Project) with world bank funding to modernize the Indian Agricultural Education. Through NAHEP it developed the Climate Smart Agriculture and Water Management (CAAST-CSAWM) at Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, they provide training to faculty and students on Drone technology, IoT-based sensor technology, Geo-informatics and data analysis.

Students learn to use digital tools, analyze field data, program automated systems, and apply scientific reasoning to solve farm-level challenges. By combining theoretical knowledge with hands-on training, these educational programs ensure that students not only understand how to operate technological tools but also appreciate the cultural and ecological importance of traditional practices. Students trained in smart farming can serve as intermediaries, helping local farmers understand and apply modern solutions without disrupting cultural or ecological practices. When young agricultural graduates work closely with rural communities, they become catalysts for change, promoting sustainability, profitability, and resilience.

State and central governments along with many agricultural universities now encourages innovation hubs and and agribusiness incubation centres at their campus they regularly conduct start up competitions where young minds can experiment, conduct trials, and develop prototypes that can later be commercialized for farmer benefit. These centres supports the selected teams through continuous mentorships and funding through government and angel investors.

Additionally, the integration of smart farming in education creates a wide range of entrepreneurial opportunities. Students can develop start-ups focused on smart and precision farming equipment, mobile-based advisory services, climate-smart innovations, agribots, or supply-chain optimization platforms. This not only addresses real-world agricultural challenges but also contributes to rural employment and economic growth.

In conclusion, India is transforming its agricultural educational system with the aim of producing a new generation of young professionals who are able to lead the sustainable and productive smart agriculture sector. This is achieved through sustained efforts aimed at making technology more affordable and ensuring that small-scale farmers are also able to access agricultural innovations.

Protective Cultivation and Market Linkage

Sandeep Bhatia
Director, Green Staple

SUSTAINABILITY VS THE BOTTOM LINE IN COMMERCIAL HORTICULTURE

The shift toward efficient greenhouse systems is accelerating. Water recycling, nutrient recovery and lower-carbon production are increasingly being engineered into modern facilities. In many cases, these are no longer optional features, but part of the baseline design for new developments. However, these systems come with a cost. Higher capital expenditure, increased technical complexity, and tighter operational requirements all raise a fundamental commercial question:

WHERE DOES SUSTAINABILITY CREATE REAL VALUE?

The answer is often straightforward - At the point of sale. In most retail markets, price remains the dominant factor. Consumers may express a preference for sustainable, residue free produce, but this does not consistently translate into a measurable premium. Yet focusing only on retail pricing misses the wider shift taking place. Value is increasingly being recognized elsewhere in the chain:

- In long-term off take agreements where consistency and traceability are critical
- In retailer procurement standards that prioritise resource efficiency and supply

security
- In export markets where compliance is becoming more stringent
- In regulatory environments that are steadily tightening

In these contexts, sustainability is not simply a differentiator. It is becoming a condition of participation. This reframes the question. The issue is no longer whether sustainability commands a premium at the shelf. It is whether a production system can meet the requirements of the markets it intends to serve reliably, consistently, and at scale.

Protective Cultivation systems, efficient water use, and integrated resource management are not just environmental considerations. They are directly linked to operational resilience, input stability, and long-term cost control.

The commercial outcome, therefore, is not always visible in the price of a single product. It is reflected in:
- Access to markets
- Stability of supply
- Predictability of production
- The ability to operate under increasing regulatory and resource constraints.

Sustainability, in this context, is not a premium feature. It is a performance requirement.

The real question is:
Which parts of the value chain are willing to pay for it, and which are not?

https://doi.org/10.52151/aet2026502.1939

pnb

#JustOneApp

PRADHAN MANTRI KISAN URJA SURAKSHA EVAM UTTHAN MAHABHIYAN (PM KUSUM) SCHEME

Promoting Solar Energy in Agriculture

- Decentralised Ground/Stilt Mounted grid connected Solar Power Plant setup
- Installation of Stand alone solar pumps
- Solarisation of grid connected agri pumps including feeder level solarisation
- Interest subvention benefits and credit guarantee coverage under AIF
- CFA/SFA to the tune of 30% & above
- Minimal Margin & Collateral Requirement
- Attractive ROI

Follow us: www.pnb.bank.in | Toll Free No: 1800-1800 & 1800-2021 | Give a missed call 1800 180 8888

पंजाब नैशनल बैंक
...भरोसे का प्रतीक !

punjab national bank
...the name you can BANK upon !