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Commercial vegetable production

under protected structures in saline environments: A promising strategy for livelihood security

R. L. Meena*, B. L. Meena, Priyanka Chandra, S. K. Sanwal and Bhaskar Narjary

ICAR-Central Soil Salinity Research Institute, Karnal, Haryana 132 001

Salinity and water scarcity are major constraints in arid and semi-arid regions of India, where a large share of groundwater is saline. Protected cultivation through polyhouses, shade nets and tunnels provides a viable option for vegetable production under such environments. These structures improve microclimate, enhance water and nutrient use efficiency and enable the safe utilization of saline water. Crops like tomato, capsicum and chilli perform well under drip fertigation and raised-bed systems in polyhouses. Technologies such as grafting, mulching, soilless media and saline water blending reduce salt stress and improve yield and quality. With higher profitability, employment generation and government support, protected cultivation offers a promising strategy for livelihood and nutritional security.

Key words: Climate resilience, Livelihood security, Polyhouse, Protected cultivation, Saline water irrigation, Vegetable production

IN India's arid and semi-arid regions, the problem of water scarcity is particularly acute. States like Rajasthan, Gujarat, Haryana, southwestern Punjab, and northwestern Uttar Pradesh frequently face erratic and low rainfall coupled with poor-quality groundwater. Surveys report that 32–84% of the groundwater in these regions is saline or alkaline, severely affecting sustainable crop production. However, studies suggest that saline water with EC levels up to 11 dS/m can be used successfully for certain crops when appropriate irrigation methods are adopted. Among these, drip irrigation under protected cultivation has shown considerable promise by allowing precise water application, minimizing salt stress, and protecting crop foliage. India's diverse climate ranging from freezing winters to scorching summer sposes additional challenges to open-field vegetable cultivation. Despite being the world's second-largest vegetable producer, India faces low per capita availability due to traditional practices, low yields, and susceptibility to climatic stress. To meet rising demand and ensure nutritional security, expanding vegetable production through improved varieties and scientific farming methods is essential. Protected cultivation systems such as polyhouses, shade nets, low tunnels, and plastic mulches offer a sustainable solution. These structures create favourable growing conditions, reduce water use, enable off-season production, and support the safe use of saline water, ultimately improving crop quality and profitability.

Vegetables are vital for human nutrition and farmer livelihoods. Their commercial value has grown rapidly, outpacing cereals in recent decades. In 2014–15, vegetables were grown on just 2.8% of India's cropped area, yielding 169.47 million tonnes from 9.52 million hectares. States like Haryana produced 5.5 lakh tonnes from 373.17 thousand hectares, showing considerable potential for growth (National Horticulture Board 2015). Given the twin challenges of water scarcity and climate variability, there is an urgent need to promote sustainable and innovative farming approaches. Efficient saline water use and expansion of protected vegetable cultivation can play a key role in securing food supplies, enhancing incomes, and sustaining agriculture under changing environmental conditions.

Understanding salinity and its effects on crop

Salinity refers to the accumulation of soluble salts in soil and water, mainly sodium (Na^+), chloride (Cl^-), and sulfates (SO_4^{2-}). These salts inhibit seed germination, disrupt nutrient uptake, reduce photosynthesis, and affect plant water relations. In vegetables, this leads to lower yields, poor-quality fruits, and in some cases, complete crop failure. Among vegetables, tomato exhibits moderate tolerance to salinity, while crops like cucumber and okra are more sensitive. Managing salinity requires site-specific interventions, particularly when using saline water with electrical conductivity (EC) above 2 dS/m. Additionally, prolonged exposure to high salinity reduces microbial activity in soil, negatively influencing nutrient mineralization. This leads to nutrient deficiencies and imbalances in plants. Secondary stresses, such as oxidative stress from reactive oxygen species (ROS), also accumulate, further impairing plant metabolism and growth.

Soil salinity can be classified as natural (primary) or induced (secondary), with secondary salinity often resulting from human interventions like improper irrigation practices and lack of drainage. Identifying the type of salinity and implementing appropriate agronomic and engineering solutions is essential for long-term management.

Protected cultivation: An overview

Protected cultivation or controlled-environment agriculture (CEA) uses structures such as greenhouses and polyhouses to shield crops from external stresses. These systems facilitate: Better temperature and humidity control, reduced pest and disease pressure, efficient water and nutrient use, and Enhanced crop quality and yield. CEA practices are particularly suited to India's agro-climatic zones, enabling year-round vegetable production even under extreme temperatures or degraded soils. These systems also enhance resource use efficiency critical in water-scarce, salinity-affected areas.

Types of structures

- ***Greenhouses:*** Fully controlled environments for high-end production with temperature, humidity, and CO_2 regulation.
- ***Polyhouses:*** Semi-controlled and cost-effective structures ideal for smallholders using locally available materials.
- ***Shade net houses:*** Simple and economical, reducing light intensity and preventing heat stress. Ideal for nursery production.
- ***Low tunnels:*** Temporary mini-structures that protect seedlings and early-stage crops from salinity and temperature extremes.
- ***Walk-in tunnels:*** Intermediate structures offering partial climate control with lower cost than full greenhouses.

Each structure type has unique advantages, and selection depends on crop type, location, economic feasibility, and farmer experience.

Suitable vegetable crops for saline protected cultivation

Many vegetables exhibit differential tolerance to salinity. Those with moderate tolerance, short duration, and high value are preferred under protected cultivation in saline condition. Other crops like spinach, lettuce, broccoli, coriander, and fenugreek also show promise under regulated environments with optimal nutrient and water management.

Table 1. Salinity tolerance limits (ECiw) of selected vegetable crops and recommended adaptation strategies for cultivation under saline irrigation conditions

Crop	Salinity tolerance (ECiw)	Adaptation strategies
Tomato	Up to 10 dS/m	Grafting, drip irrigation
Capsicum	Up to 6 dS/m	Mulching, soilless media
Green Chilli	Up to 6 dS/m	Raised beds, saline water blending
Eggplant	Up to 3.5 dS/m	Salt-tolerant rootstocks
Okra, Cucumber	Up to 2.5 dS/m	Shade net, frequent leaching
Leafy Greens	Up to 2.0 dS/m	Soilless cultivation, misting systems

Pest and disease management

Protected cultivation environments often create favourable conditions for the rapid build-up of pests and diseases, primarily due to high humidity levels. Effective management requires an integrated approach. Integrated Pest Management (IPM) combines cultural, biological, and chemical control methods to ensure

Drip-irrigated tomato seedlings planted in raised beds inside a naturally ventilated polyhouse

Performance of capsicum and tomato under 10 dS/m saline water irrigation

Performance of chilli under 10 dS/m saline water irrigation

sustainable crop protection. The use of bioagents such as *Trichoderma*, *Pseudomonas*, and neem-based biopesticides helps in reducing the dependence on synthetic chemicals. Preventive measures like insect-proof netting and yellow sticky traps are useful in controlling insect vectors. Maintaining proper sanitation and practicing crop rotation help minimize the carryover of pathogens between crop cycles. Additionally, advanced monitoring tools including pheromone traps, thermal foggers, and decision-support system said in early detection and timely intervention, thereby reducing crop losses and enhancing productivity.

Table 2. Key challenges in protected cultivation under saline environments and corresponding mitigation strategies

Challenge	Solution
High capital cost	Government subsidies; FPO or SHG-based ownership
Salinity build-up	Drainage, gypsum use, rotation with salt-tolerant crops
Skill gap	Training by ICAR/KVKs, demo units, mobile apps
Pest/disease outbreak	IPM practices, regular monitoring
Climate stress	Thermally insulated covers, side vents, misting
Market access	Linking with FPOs, digital platforms, cooperative models
Input availability	Localized production of seedlings, nutrient kits

Techniques for salinity management in protected cultivation

To maximize vegetable performance under saline conditions, specific practices and technologies are adopted in protected cultivation systems. These reduce salt accumulation in the root zone and improve crop resilience.

- ***Soilless media:*** Substrates like cocopeat, perlite, and vermiculite offer excellent drainage and aeration, which dilute salt effects and promote root health.
- ***Leaching salts through controlled irrigation:*** Excess salts can be leached below the root zone by applying controlled volumes of low-salinity water through drip irrigation or during off-season flushing. Periodic leaching maintains the root zone EC within acceptable limits.
- ***Use of grafted plants for improved salt resistance:*** Grafting salt-sensitive scions onto salt-tolerant rootstocks improves the plant's physiological tolerance to salinity. Grafted tomatoes and melons exhibit improved water uptake, nutrient absorption, and reduced sodium translocation to shoots. This technique is gaining popularity in saline-prone regions under protected farming.
- ***Salt-tolerant cultivars and hybrids:*** Selecting salt-tolerant vegetable varieties or hybrids is the most sustainable long-term approach. Examples include

salt-tolerant cultivars of tomato (e.g. 'PusaRohini'), chilli (e.g. 'Pusa Sadabahar'), and brinjal (e.g., 'Arka Neelkanth'). Protected environments further buffer these cultivars from abiotic stress, enhancing yields.

- ***Mulching to reduce evaporation and surface salt accumulation:*** Mulching with plastic films or organic materials (e.g. straw, compost) minimizes soil evaporation, thereby reducing upward salt movement. Helps maintain stable soil temperature and moisture. Reduces weed pressure and promotes beneficial microbial activity in the root zone.

Water management in protected cultivation

Efficient water management is essential for successful crop production under protected cultivation, especially in saline environments. Drip irrigation delivers water directly to the root zone, minimizing evaporation losses and ensuring efficient use. Fertigation, which combines irrigation with fertilizers, allows for precise nutrient application while maintaining salt balance in the root zone. Rainwater harvesting systems are useful for collecting and storing quality water, helping to dilute salts and reduce long-term salinity buildup. Blending saline water with fresh water ensures that the electrical conductivity (EC) of irrigation water stays within crop-specific safe limits. Subsurface drainage systems aid in leaching accumulated salts and maintaining overall soil health. Additionally, automated irrigation systems equipped with soil moisture sensors help regulate water flow accurately, ensuring crops receive the right amount of water at the right time.

Nutrient managementin protected cultivation

Proper nutrient management is critical for maintaining soil fertility and crop productivity under protected and saline conditions. Balanced application of macronutrients (NPK) and micronutrients, tailored to the specific crop and growth stage, ensures optimal plant development. In sodic soils, gypsum (calcium sulfate) is applied to replace sodium ions and improve soil structure. Foliar sprays of micronutrients like iron (Fe), zinc (Zn), and manganese (Mn) help correct deficiencies often caused by high soil pH. Regular monitoring of parameters such as EC, sodium adsorption ratio (SAR), and *p*H is essential to prevent salt accumulation and nutrient toxicity. The use of organic fertilizers and microbial inoculants further enhances nutrient availability, improves soil health, and increases crop resilience to environmental stress.

Economic feasibility and farmer benefits

Protected cultivation offers substantial returns, especially when market demand and quality premiums are considered. Polyhouse production ensures round-the-year employment and income, especially for women and youth. Surplus production may be marketed directly or through FPOs. Additional benefits include:

- Promotion of women entrepreneurship through nursery and value-addition units

Table 3. Yield and gross returns of selected vegetable crops under protected cultivation in an area of 300 m^2

Vegetable Crop	Yield (q/300m^2)	Gross Returns (₹)
Tomato	31.75	1,98,099
Capsicum	12.89	1,38,052
Green Chilli	10.78	1,15,525

- Total Production Cost: ₹2,15,623
- Net Present Value (NPV): ₹6,25,711
- Benefit-Cost Ratio (BCR): 1.41
- Payback Period: 2 years

- Climate resilience through protected structures against extreme weather
- Higher employment due to labour-intensive nature of precision farming

Policy support and future prospects

The Government of India has taken several initiatives to promote protected cultivation, recognizing its potential to enhance productivity, improve resource use efficiency, and ensure year-round vegetable supply. Key schemes such as Mission for Integrated Development of Horticulture (MIDH), Rashtriya Krishi Vikas Yojana (RKVY), National Horticulture Board (NHB), and National Mission for Sustainable Agriculture (NMSA) provide strong policy backing. Farmers can benefit from various forms of assistance including capital subsidies of up to 75%, credit-linked back-ended subsidies, and technical guidance through ICAR institutes. Moreover, protected cultivation is now recognized under priority sector lending through the Agri-Infrastructure Fund, encouraging investment in climate-resilient technologies. Looking ahead, future prospects for protected cultivation are promising with the integration of digital tools for precision fertigation, adoption of solar-powered irrigation systems, and the development of carbon credit models that reward climate-smart practices. Technologies like blockchain can enhance traceability and help farmers achieve premium prices, while e-commerce platforms offer new avenues for direct-to-consumer vegetable sales, strengthening market linkages and farmer profitability.

SUMMARY

Protected cultivation under saline environments offers a viable pathway for sustainable vegetable production. It helps utilize degraded lands and brackish water efficiently, generating high income from small holdings. With suitable policy, institutional, and technical support, it can transform rural economies by ensuring food, income, and nutritional security in salt-affected areas. Farmers must be empowered through capacity-building, public-private partnerships, and inclusive market linkages. Scaling these systems across India's saline zones could play a pivotal role in achieving rural prosperity and climate-resilient agriculture.

*Corresponding author email: rlmeena69@gmail.com