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Saurabh
Ph.D. Scholar,
Department of Vegetable Science, Indira Gandhi Krishi Vishwavidyalaya, Krishak Nagar, Raipur, Chhattisgarh, India

Tarun Kumar
Ph.D. Scholar,
Department of Floriculture and Landscape Architecture, Indira Gandhi Krishi Vishwavidyalaya, Krishak Nagar, Raipur, Chhattisgarh, India

Mrinal Kumar
Department of Vegetable Science, Indira Gandhi Krishi Vishwavidyalaya, Krishak Nagar, Raipur, Chhattisgarh, India

Corresponding Author:
Saurabh
Ph.D. Scholar,
Department of Vegetable Science, Indira Gandhi Krishi Vishwavidyalaya, Krishak Nagar, Raipur, Chhattisgarh, India

Vegetable production under challenging conditions-abiotic stress: A review

Saurabh, Tarun Kumar and Mrinal Kumar

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Abstract
Around the world, people are already feeling the effects of a changing climate, and predictions show that droughts and periods of extremely high temperatures will happen more frequently. The production and yield of vegetable crops are being affected by these abiotic stressors. In turn, this poses difficulties for food distribution networks and has an effect on water supplies for agriculture and drinking. Plants are subjected to harsh environmental challenges in a changing climate, including high and low temperatures, drought, flood, salt, wind, sun radiation, and nutritional deficiencies. Additionally, it is anticipated that increased CO_2 levels will change the protein composition and nutrient profile of food crops. Due to their high-water requirements, sensitivity to fluctuating temperatures, and dependence on saline soils, vegetable crops might be particularly vulnerable to abiotic pressures. To stop additional production losses and create agricultural plants that are more resilient to abiotic stress, it is essential to improve current cultivars and breed new ones with enhanced abiotic stress tolerance features.

Keywords: Abiotic stress, climate, production, tolerance, environment

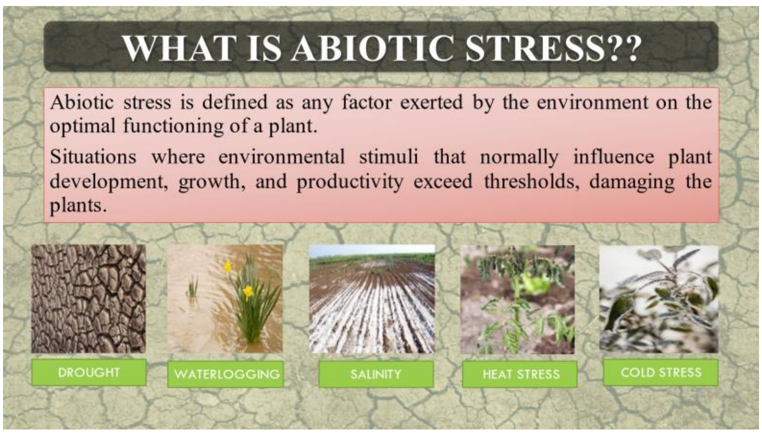
Introduction

Vegetables are nutritionally rich, often referred as 'Protective Food'. It refers to the fresh, edible portion of herbaceous plant part consumed in either raw or cooked form (Ward, 2016) [25]. Vegetable are the best resources for overcoming deficiencies and provide smallholder farmers with much higher income and more jobs per hectare than staple crops.

Vegetable is severely affected different biotic and abiotic stresses under field conditions. The interaction between these stresses and their impact on plants growth, quality and yield (Pandey *et al*., 2015) [26]. Weeds account for 45% of the pest's impact on yield, compared to 30% of insects, 20% of diseases, and 5% of other pests (iari.res.in).

In today's climate change scenarios, crops are exposed to abiotic stress episodes as drought, salt, high temperatures, flooding, and nutritional deficits more frequently. Crop output is limited by these pressures. Our understanding of how crops respond to these stresses and the underlying causes of varietal differences in tolerance has significantly improved in recent years as a result of discoveries in physiology, molecular biology, and genetics.

So, work on various innovative research techniques for better vegetable production under challenging condition are much required.



A. Drought stress: Heat and drought frequently coexist, which encourages evapotranspiration, affects photosynthetic kinetics, heightens moisture stress, and eventually lowers agricultural output (Mir *et al.*, 2012) [27]. According to (Linsley *et al*. 1959) [28], a drought is defined as a prolonged period without considerable rainfall.
“Drought can be defined as an extended period of deficient rainfall relative to the statistical mean for a region.”

Agricultural drought: A prolonged dry period that affects crops' ability to grow and their yield. When the amount of moisture in the soil is insufficient to meet the needs of growing crops, it results in drought, which has an effect on agriculture. This happens when there is a sustained shortage of moisture input from irrigation or rainfall. Since the soil moisture deficit depends on both the rate of input and the rate of loss, it is impossible to define a period of time without rain as an agricultural drought.

Effects of drought stress on crops

- Reduced seed germination and seedling development
- Poor vegetative growth
- Severely impaired reproductive growth
- decreased plant height and leaf area
- Significantly reduction in leaf weight
- Reduced photosynthesis
- Diminished stomatal conductance
- Markedly decreased total dry matter

How to grow vegetables under drought condition

1. Crop and variety selection: Crops like dolichos bean, cowpea, cluster bean, lima bean, chilli, onion, drumstick and tomato were found to be suitable for rain-fed cultivation. Legume vegetables are among those that can be suggested for backup crop planning in the event of late monsoon rains. It is important to choose varieties with strong root systems and the ability to recover after stress has subsided.

Grow drought tolerant/resistant cultivars

Crops	Genotype/Variety	Reference
Tomato	Arka Vikas, Arka Meghali, Paiyur-1, RF- 4A	Singh, 2010 [21]
	S. pimpinellifoloium, S. chilense, S. pennellii, S. cerasiforme, S. cheesmanii	Rai *et al*., 2011 [29]
Brinjal	SM- 1, SM- 19, SM- 30, Violette Round, Supreme, PKM-1, Kashi Sandesh, Kashi Taru	Selvakumar (2014) [30]
	S. microcarpon, S. gilo, S. integrifolium	
Chilli	Arka Lohit, IIHR – Sel.-132 Singh (2010) Samrudhi, Kashi Anmol *C. chinense, C. baccatum*	Singh, 2010 [21]
Potato	Kufri Sheetman, Kufri Sindhuri, Alpha, Bintje *S. acaule, S. demissum, S. stenotonum, S.curtilobum, S. xjuzepczukii*	Arvin and Donnelly (2008) [31]
Okra	*A. caillei, A. rugosus, A. tuberosus*	
Onion	Arka Kalyan, MST -42,46, Agrifound Dark Red *Allium fstulosum, A. munzii*	Singh, 2010 [21]
French bean	*Phaseolus acutifolius*	Kavar *et al*., (2011) [32]
Clusterbean	RGC-936, RGC-1003, RGC-1017, RGC-1066, Thar Bhadavi	Rai and Yadav (2005) [33]
Cucumber	INGR-98018 (AHC-13)	Rai and Yadav (2005) [33]
Bottle gourd	Thar Samridhi, Kashi Ganga	Rai and Yadav (2005) [33]
Ash gourd	Kashi Dhawal	Rai and Yadav (2005) [33]
Water melon	*Citrullus colocynthis* (L.)	Dane and Liu (2007) [34]
Winter Squash	*Cucurbita maxima*	Dane and Liu (2007) [34]
Cassava	Shree Sahya Co-3, Co-4	Dane and Liu (2007) [34]
Sweet potato	Sree Bhadra, Sree Nandhini, VLS6, IGSP - 10,14	Selvakumar (2014) [30]
Colocasia	White Goriya, Haloo Kesoo	Hazra and Som (1999) **[35]**
Elephant Foot Yam	NDA-5, Gajendra	Hazra and Som (1999) **[35]**

Source: Modified from Kumar *et al*., (2012) [36], Maheswari *et al*., (2015) [37] and Solankey *et al*., (2015) [38]

2. Grow short duration and small canopy crops: Early flowering and seed production: In response to drought stress, some plants adopt a survival strategy by accelerating their reproductive processes. They allocate resources towards flowering and seed production earlier than usual, ensuring the propagation of the species. This early reproductive effort reduces the overall vegetative growth, resulting in shorter durations and smaller canopies.

3. Use of Antitranspirants: They are substances or compounds that lessen the size and quantity of stomata, hence lowering water loss from plant leaves. The plant loses over 99% of the water it takes in through transpiration. Antiranspirants are any natural substances applied to the surfaces of transpiring plants to lessen water loss.

There are of four types

Materials causing stomatal closure

- Herbicides like 2, 4 – D, Phosphon D and Atrazine
- Fungicides like **Phenyl Mercuric Acetate (PMA)**
- Metabolic inhibitors like hydroxy sulfonates, potassium metabisulphite e
- Growth hormones like ABA, Ethrel, TIBA, succinic acid, ascorbic acid and Cycocel (CCC)

Reflectant types: Spray Kaoline @ 3% during moisture stress, China Clay, Calcium bicarbonate, Lime water

Thin forming chemicals: Hexadecanol, Cetyl alcohol, Methanol, Paclobutrazol 5. Brassinolide

Polyethylene materials forming thick films: Mobileaf, Folicot, Waxol

4. Adopt mulching techniques: Covering of upper most layer of soils by organic or inorganic means.

- **Soil moisture conservation:** Mulching helps to reduce evaporation by acting as a protective layer over the soil surface. It slows down the rate at which water evaporates from the soil, thus helping to conserve soil moisture. This is particularly important during drought conditions when water resources are limited.
- **Weed suppression:** By suppressing weed growth, mulching helps to conserve soil moisture for the desired plants.
- **Temperature regulation:** Mulching can help regulate soil temperature, keeping it cooler during hot periods and reducing evaporation.
- **Erosion control:** Mulch acts as a protective layer, reducing soil erosion by shielding the soil from direct contact with the elements.
- **Organic matter and nutrient retention:** Organic mulches, such as compost or straw, break down over time, adding organic matter to the soil. This improves soil structure, enhances water retention capacity, and promotes nutrient availability for plants.

5. Water harvesting techniques aim to capture and store water from various sources, such as rainfall runoff or surface runoff, and make it available for later use. This helps to maximize water resources and ensures a more sustainable water supply during drought periods.

6. Adopt drip irrigation technique: Drip irrigation minimizes water loss due to evaporation and runoff, which lowers the danger of pest - disease infestation and weed growth. It also provides water straight to the root zone of plants.
By putting seeds into a regulated state of pre-germinative metabolism, the process known as seed priming increases germination rates and germination vigour**.** (Paparella *et al*., 2015). Seed priming or hardening done with KH_2PO_4 @1%.

7. Applying fertilizers: Applying split dose of nitrogenous and phosphatic fertilizers. Foliar spray with DAP @ 2%+KCL @ 1% during critical stages of crops. Spraying of $ZnSO_4$ @ 0.5%+$FeSO_4$ @ 0.5% + Boric acid @ 0.3%.

8. Spraying plant hormones i.e., NAA @ 20 ppm or Cytokinin @ 10 ppm or Brassinosteroids @ 1.5% or Salicylic acid @ 100 ppm or CCC @ 500 ppm.

9. Wind break and barrier cropping: Windbreaks are rows of trees, shrubs, or tall plants that are strategically planted to create a barrier against strong winds. In drought conditions, strong winds can accelerate evaporation, leading to further moisture loss from the soil. Windbreaks help to reduce the impact of wind on crops by creating a sheltered microclimate, reducing water loss through evaporation.

10. Use protray grown seedlings: Seedlings that have been pre-grown in protrays have well-developed root systems, which increases their chances of survival in drought conditions. These seedlings have stronger root structures, allowing them to access water from deeper soil layers where moisture may still be available. Proper hardening done in protray nursery seedlings before transplanting of crops to protect the initial field temperature.

- Changing season and time of planting of vegetables
- Adopt organic farming and crop rotation

B. Heat stress: Due to direct exposure of temperature results above and below threshold level of temperature create heat stress. Plants may endure high temperatures on a daily or seasonal basis. Additionally, there is mounting evidence that long-term climate changes are causing average temperatures to rise, the geographic area in which high temperatures consistently limit crop output to grow, and the frequency and intensity of extreme temperature occurrences to rise.

Temperature differences in warm season and cool season vegetable crops:

Parameter	**Cool Season** **Cole crop, bulb & root crops**	**Warm Season Tomato, pepper, squash and melons**
Germination	5 °C to 26 °C 23 °C optimum	10 °C to 38 °C 23 °C optimum
Growth	Daytime 5 °C minimum 18 °C – 23 °C preferred	Daytime 15 °C minimum 28 °C optimum
	Night time Greater than 0 °C for tender transplants down to mid-20 °C for established plants	Night time 0 °C-10 °C chilling injury
Flowering	Temperature extremes lead to bolting and buttoning.	Daytime: Greater than 35 °C by 10 a.m., blossoms abortion Night time: Below 12 °C, non-viable pollen (use blossom set hormones-kinetin).
Soil	Use organic mulch to cool soil. Since seeds germinate best in warm soils, use transplants for spring planting, and direct seeding for mid-summer plantings.	Use black plastic mulch to warm soil, increasing yields and earliness of crop

Effects of heat stress on plants

- Inability to establish seedlings
- Drying of leaf margins and searing impact on leaves
- Reduced plant growth
- Pollen development is affected
- Alteration in photosynthesis
- Total biomass is reduced
- Spikelet sterility
- Grain and fruit development and quality is affected

How to grow vegetables under heat stress condition

Grow heat tolerant/resistant cultivars:

Vegetables	Genotypes tolerant to heat
Tomato	Pusa Hybrid-1, Pusa Sadabahar, Pusa Hybrid-8, Arka Meghali, Arka Vikas, Punjab Barkha Bahar-1, Punjab Barkha Bahar-2, Punjab Tropic, Marjano, P-4, Analanche, Chiko-III, Ment, Pusa Hybrid-1, Pusa Sadabahar, Sun leaper, Solar Fires, Heat Master and Equinox, EC – advance lines
	S. pimpinellifolium, S. pennellii, S. habrochaites, S. chmielewskii, S. cheesmaniae
Brinjal	Kashi Sandesh
Chilli	IIHR Sel.-3,5
Potato	Kufri Surya
Okra	Kashi Pragati, Kashi Kranti
Cauliflower	Sabour Agrim, Pusa Meghna, IIHR 316-1, IIHR-371-1
Broccoli	Abrams
Bottle gourd	Thar Samridhi, Pusa Santushti
Cucumber	Pusa Barkha
Garden pea	Matar Ageta-6, Azad Pea G 10, IIHR-1, IIHR-8
Frenchbean	IIHR-19-1
Cluster bean	RGC-197, RGC-936
Cowpea	Kashi Kancha, Kashi Nidhi
Onion	NP53, Raseedpura local
Radish	Pusa Chetki
Carrot	Pusa Kesar, Pusa Vrishti
Snap bean	PV 857, Annihilator, Dominator, Usambara
Lettuce	Forlina, Salanova, Green Butter, Salanova, Red Butter, Skyphos, Starfghter; Dov, Arroyo.

Source: Modifed from Hazra and Som (1999) [35], Spaldon *et al*., (2015), Selvakumar (2014) [30], Maheswari *et al*., (2015) [37] and Solankey *et al*., (2015) [38]

Classification of vegetable crops according to their adaptation to field temperature

Cool-season vegetable crops		Warm-season vegetable crops	
Hardy (Can withstand moderate frosts)	**Half-hardy** (Can withstand light frosts)	**Tender** (sensitive to frost and low temperatures)	**Very Tender** (Very sensitive to low temperatures)
Asparagus, Garlic, Radish, Broad Bean, Horseradish, Rhubarb, Broccoli, Kohlrabi, Spinach, Brussels Sprouts, Turnip, Cabbage, Parsley, Chive and Garden Pea	Beetroot, Chinese Cabbage, Potato, Carrot, Globe Artichoke, Swiss Chard, Cauliflower, Lettuce, Celery & Parsnip	New Zealand Spinach, Sweet Corn, Tomato & Green Bean.	Chilli, Okra, Sweet Pepper, Cucumber, Pumpkin, Sweet Potato, Eggplant, Squash, Vegetable Marrow, Lima Bean, Sweet Melon &Watermelon

- Plants must be grown under conditions of shadow.
- Overhead irrigation to avoid sunburn: The major method to reduce high temperature or heat stress is by overhead watering (sprinkling or misting) for improved water supply, reduction of tissue temperature and lessening of water vapour pressure deficit.
- To promote alpha-amylase production for seed germination, gibberellic acid is used.
- BAP (6-benzylamino-purine) lessens lipid peroxidation and leaf senescence.
- Salicylic acid increases the capacity for thermotolerance.
- Glycine betaine decreased ion leakage.
- Ethylene application improves seed germination.
- Under high and low temperature stress circumstances, the application of PCPA (parachlorophenoxy acetic acid) (tomatotone) sprayed at 30 ppm improved fruit set in tomato.
- During the summer, spraying Ethrel at 200 ppm 2-3 days before to transplanting enhances the roots system of tomato transplants.
- The use of shade fabric in hot locations to lower radiant heat and overall ingress.
- The use of windbreaks and agricultural barriers.
- Using organic mulches to lower surface radiation and maintain wetness to increase the reflection and dissipation of radiative heat.

C. Cold stress: Both the chilling effect, which causes physiological and developmental problems, and freezing, which either directly damages cells or results in cellular dehydration, are ways that low temperatures can harm plants. Many low-temperature injury symptoms were described by Lyons (1973) [39]. As high as 20 °C can cause damage to several physiological processes, such as rice flowering, which are very sensitive to low temperatures. Wilting, bleaching from photo-oxidation of pigments, waterlogging of the intercellular spaces, browning, and ultimately necrosis of the leaves and plant death are common indications of low-temperature harm to the leaves.

Effects of cold stress on plants

- Leaves include wilting
- Bleaching due to photo-oxidation of pigments
- Waterlogging of the intercellular spaces
- Browning, and eventually leaf necrosis and plant death

How to grow vegetables under cold stress condition

- Ammonium molybdate 0.15% foliar spray lessens the impact of low temperature stress.

- Using GA_3 and proline as a pre-soaking therapy improves seed germination.
- Paclobutrazol application boosts the activity of scavenging enzymes.
- Application of Uniconzole (50 ppm) decreases electrolyte loss.
- Cryo-protectants are also utilized to lessen the effects of stress.
- ABA contributes to the development of cold tolerance.
- Low temperature management, through grafting
- Because the rootstock can absorb water and nutrients more effectively at low temperatures, cucumber grafted onto figleaf gourd (*Cucurbita ficifolia*) is an ideal rootstock even in cold climates. In a recent experiment, it was determined that grafting a cucumber scion onto a squash rootstock (*Cucurbita moschata* Duch) would allow the plant to survive low or subpar temperatures better than a self-grafted cucumber.
- Grafting low temperature tolerant rootstocks, such as interspecific hybrids between *Cucurbita maxima* X *C. moschata*.

D. Salinity stress: Salinity is characterised as the existence of high concentrations of soluble salts that interfere with or impair plant growth. A saturated soil paste extract's pH, exchangeable sodium percentage (ESP), or sodium adsorption ratio (SAR), and electrical conductivity (ECe) are used to measure it. Therefore, saturated soil paste extracts with ECe > 4 dSm1, ESP 15%, and pH 8.5 are considered to be saline soils. Saline soils have a mixture of salts of9 Chloride, Sulfate, Sodium, Magnesium and Calcium ions with sodium chloride often dominant. There are two main sources of salinity:

1. **Primary or natural sources:** resulting from mineral weathering and soil development/derivation from source rocks that are salty.
2. **Secondary salinization:** a result of human activities like irrigation, logging, overgrazing, or intensive agriculture.

Effects of salt stress on plants

- Osmotic effect, also known as the water deficiency effect, slows down a plant's ability to absorb water. This is salinity's osmotic, or water-deficit, effect.
- Salts infiltrate the transpiration stream and eventually harm the cells in the transpiring leaves, slowing growth further. This is known as the salt specific impact or Ion Excess impact.
- Alkaline soil-grown plants frequently have a distinctive yellow hue on their new growth.
- Veins continue to be green, but the spaces between them start to turn yellow. The leaves may become nearly white in cases of severe shortage.
- High salt concentrations c9an result in leaf burn, prevent the uptake of water, and obstruct the uptake of some vital nutrients (such as calcium).
- Na^+ and Cl^- buildup is hazardous to cells because it affects the way that enzymes function.

How to grow vegetables under salinity stress condition: Grow salinity tolerance crops

Soluble salt test values and relative salt tolerance of vegetable crops

Non tolerant 0-2 mm hos/cm	Slightly tolerant 3-4 mm hos/cm	Moderately tolerant 5-7 mm hos/cm	High tolerant 8-16 mm hos/cm
Carrot, Frenchbean, Onion, Radish	Cabbage, Lettuce, Peppers, Potato, Sweetcorn	Beetroot, Cucumber, Muskmelon, Squashes, Tomato, Spinach	Asparagus, Swisschard

- Seed hardening with NaCl @ 10 ml/kg of seed.
- Applying split dose of nitrogenous and potassic fertilizers. Foliar spray with DAP @ 2%+KCL @ 1%.
- Spraying plant hormones i.e., NAA @ 40 ppm or Brassinosteroids @ 1.5% or Salicylic acid @ 100 ppm or CCC @ 100 ppm.
- Application of gypsum @ 50%.
- Incorporation of Dhaincha crop (*Sesbania bispinosa*) to reduce salinity on soil.
- Maintain ratio of K:Na by application of potash & Ca.
- Exogenous application ABA reduce leaf abscission and apply ethylene decrease the Cl ion in leaves.
- Application of ascorbic acid+$ZnSO_4$ increase plant height and biomass.
- Combine application of ascorbic acid+gibberellic acid increases xanthophyll content in fruits.

Low soil pH or acidity and its management: Acidic soils can cause a range of symptoms in plants, including toxicity to aluminium (Al), hydrogen (H), and/or manganese (Mn), as well as calcium (Ca) and ma9gnesium (Mg) nutritional shortages. Vegetable crops are more vulnerable to bacterial wilts when the pH is low. Liming is basically part of management.

Grow acid tolerance crops *i.e.*

Less tolerant	Moderately tolerant	Tolerant
Onion, okra, cabbage, cauliflower, chinese cabbage, muskmelon	Tomato, brinjal, chilli, carrot, radish, squashes	potato, sweetpotato, rhubarb, watermelon

Grafting Technology for abiotic stress management

- By employing this strategy, abiotic stress conditions including salinity drought, low temperature, water logging, uptake of water and nutrients, etc. can be overcome.

A plant's roots serve as its first line of defense against abiotic stress

- A special technique for modifying plants to withstand environmental stresses is by grafting elite cultivars onto chosen vigorous rootstocks (Lee and Oda, 2003). This

method increases the likelihood that the plant will survive stressful conditions if the soil in which it is growing is healthy and biologically diverse.
- This ecologically friendly method is frequently used to lower crop losses in abiotically stressed solanaceous and cucurbitaceous vegetables.

E. Flooding: Flooding is an environmental disturbance that significantly reduces crop output and growth. The main cause of flooding in tropical and subtropical areas is excessive rainfall, which is frequent, especially in soils with poor drainage. 10% of the world's land surface is affected by waterlogging, which is one of the biggest obstacles to the growth of agricultural crops. Depending on the crop species, soil type, and length of the stress, the yield loss caused by water logging might range from 15% to 80%.

All of the pores in the soil or soilless mixture are filled with water when it is waterlogged, which virtually eliminates the oxygen supply. In order to maintain their activities for nutrition and water intake, plant roots need oxygen for respiration.

Effects of flooding stress on plants
- Decay and death of leaves
- Wilting
- Abscission
- Epinasty
- Lenticels formation
- Nutrient deficiency & Toxicity:

How to grow vegetables under flooding stress condition
- Drainage should be improved because, in most cases, as long as water drains within 24 hours, the influence on plant health is low.
- Provide adequate drainage facilities for remove excess water around root system.
- Foliar spray with DAP @ 2%+KCL @ 1%.
- Spraying plant hormones i.e., NAA @ 40 ppm or Brassinosteroids @ 1.5% for improve photosynthesis. Salicylic acid @ 100 ppm or CCC @ 100 ppm for increasing stem reserve utilization in submerged condition.
- Spraying $ZnSO_4$ at 0.5%, $FeSO_4$ at 0.5%, and Boric acid at 0.3% onto the leaves.
- Balanced uses of fertilizer.
- Made Ridges and furrows and Raised beds for growing of vegetables.
- After significant rainfall and flooding, soils with a high clay content may become compacted and develop a surface crust. Additionally, a fine clay crust or coating is left behind by flood waters on top of the soil, preventing aeration—the infiltration of oxygen—into the soil.
- Aerate the soil and increase its oxygen content as quickly as possible by cultivating between vegetable rows.
- Foliar fertilizer sprays should be applied for a crop's speedy recovery.

Concluding remarks
The average global temperature climbed by 0.85 °C between 1885 and 2022, and it is expected to rise by 1.6–5.8 °C by the end of the twenty-first century. India loses 1.5% of its GDP annually as a result of climate change. (StatisticsTimes.com). 9While high temperatures have a negative impact, elevated CO_2 has favourable effects on productivity of various vegetables that range from 24-51%. The crop needs 50% more water for every 10 °C increase in temperature. creation of perennial vegetables and climate-resilient cultivars. Different strategies to counteract the effects of difficult conditions include encouraging conservation and the adoption of appropriate agronomic practises, grafting, urban agriculture, and organic farming.

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