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Impact of salinity stress on citrus production and its alleviation strategies

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Abstract
Salinity stress poses a significant threat to citrus cultivation, impacting overall plant growth, yield, and fruit quality. High salt concentrations in the soil or irrigation water disrupt the osmotic balance, leading to water deficit and ion toxicity. Consequently, citrus crops experience reduced yields and compromised economic viability. Understanding the impact of salinity stress on citrus production is crucial for developing effective management strategies. This review provides an overview of salinity stress in citrus, its impact on yield, current management strategies, the role of resistant or tolerant rootstocks, and potential areas of future research. Salinity stress negatively affects citrus yield through multiple mechanisms. Osmotic stress reduces water availability to plants, impairing cell expansion, photosynthesis, and nutrient uptake. Ion toxicity disrupts cellular functions, causing nutrient imbalances and metabolic disorders. These physiological disruptions ultimately lead to decreased fruit set, smaller fruit size, lower sugar content, and reduced overall yield. To manage salinity stress in citrus, the use of resistant or tolerant rootstocks has proven effective. Rootstocks such as Cleopatra mandarin, Troyer citrange, and Swingle citrumelo possess inherent tolerance to salinity and can mitigate the adverse effects on scion varieties. Selecting appropriate rootstocks based on their salinity tolerance levels and compatibility with desired scion varieties is crucial for successful salinity management. In conclusion, salinity stress poses a significant challenge to citrus production, impacting yield and quality. The adoption of resistant or tolerant rootstocks, coupled with the continued research on the molecular and genetic basis of salinity tolerance, holds promise for developing effective strategies to manage salinity stress in citrus crops and ensure sustainable citrus production in the future.

Keywords: *Citrus sp.*, salinity, rootstock, tolerance, Volkameriana lemon, Cleopatra mandarin, *Poncirus trifoliata*

Introduction

The salt-affected area in India is estimated about 6.73 M ha (ICAR-CSSRI, Karnal database). Citrus cultivation plays a crucial role in India's agricultural sector, contributing significantly to the country's economy. However, the increasing problem of salinity in citrus-growing regions has emerged as a significant challenge for Indian citrus farmers. Salinity refers to the accumulation of salts in the soil, leading to adverse effects on plant growth, development, and productivity. The detrimental impact of salinity on citrus trees has resulted in reduced yields and compromised fruit quality, necessitating a closer examination of this issue. The citrus plants are acclimatized to adverse salinity conditions by modifying the morphological and biochemical traits. Rodrigues *et al*. (2018) [18] stated that citrus plants exposed to salt stress developed smaller and thicker leaves, which help reduce water loss through transpiration and minimize salt accumulation in leaf tissues.

In another study, Wu *et al*. (2019) [45] reported that citrus rootstocks subjected to salinity stress exhibited increased root length, root surface area, and root hair density. These adaptations enhance the root system's ability to absorb water and nutrients, compensating for the limited availability of resources in saline soils.

Increased accumulation of Na^+ and Cl^- in the soil root zone reduces the concentration of available Ca_2^+, K^+, Mg_2^+, NO_3^-, and H_2PO4^- resulting in the reactive oxygen species (superoxide radicals, hydrogen peroxide, hydroxyls, etc.) generation causes damage to plant cells (Khoshbakht *et al*., 2014; Barbosa *et al*., 2017; Pathania and Singh, 2021) [17, 6, 31]. This injury leads to a reduction in the photosynthetic rate, stomatal conductance, relative growth rate, membrane stability, and lower antioxidants accumulation thereby overall decreasing the yield and productivity of citrus.

Furthermore, in the biochemical study, Perez-Clemente *et al*. (2017) [21]. found that citrus rootstocks enhanced the activity of antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD) in response to salinity. These enzymes play a crucial role in scavenging reactive oxygen species (ROS) and minimizing oxidative damage caused by salt stress. One potential strategy to address the citrus salinity problem is the selection and utilization of appropriate rootstocks that exhibit enhanced tolerance to salt stress. Rootstocks play a vital role in citrus cultivation as they influence the tree's overall vigor, growth, nutrient uptake, and tolerance to environmental stresses. Traditionally, citrus growers in India have relied on rootstocks like Rough lemon and Trifoliate orange. However, these rootstocks have limited tolerance to salinity and are susceptible to the adverse effects of high salt concentrations in the soil. In this review, we delve into the citrus salinity problem in India, explore the change in the adaptation of rootstocks to salinity, and examine the resulting consequences of reduced yield and fruit quality.

Salinity mechanism in citrus

The mechanisms of salinity tolerance in citrus involve various physiological, biochemical, and morphological changes at the cellular and molecular levels. Here are some key aspects and references to studies exploring these mechanisms:

Morphological Changes

Root Architecture: Salinity stress alters the root system architecture in citrus plants. It often leads to the development of longer and deeper roots to explore larger soil volumes and access relatively fewer saline regions. (Koyama *et al*., 2001)[19].

Physiological Changes

Osmotic Adjustment: Citrus plants respond to salinity by accumulating compatible solutes such as proline, glycine betaine, and sugars to maintain osmotic balance. This helps prevent water loss and maintain turgor pressure (Munns and Tester, 2008) [27].

Ion Homeostasis: Citrus plants regulate ion uptake, transport, and compartmentalization to minimize the toxic effects of excessive salt accumulation. This involves mechanisms such as ion exclusion from roots, selective ion uptake, and ion compartmentalization in vacuoles. (Zhu, 2003; Maathuis, 2006).

Biochemical Changes

Antioxidant Defense System: Salinity induces the production of reactive oxygen species (ROS), leading to oxidative stress. Citrus plants enhance their antioxidant defense system by increasing the activity of enzymes such as superoxide dismutase (SOD), catalase (CAT), peroxidase (POD), and ascorbate peroxidase (APX). (Mittler, 2002; Asada, 2006)

Phytohormone Regulation: Salinity stress affects the balance of phytohormones, including abscisic acid (ABA), cytokinins, and ethylene. ABA plays a crucial role in regulating stomatal closure, reducing transpiration, and promoting stress tolerance. (Munns and Tester, 2008; Deinlein, *et al*., 2014) [27, 8].

Molecular studies: Song, *et al*. (2023) [40] reported the decreased ROS accumulation greatly in autotetraploid citrus rootstock (*Citrus junos* Sieb. ex. Tanaka) was due to the activation of the chitin pathway under salt-induced stress. However, the responsible differentially expressed genes were confirmed through transcriptome analysis by comparing the roots of both autotetraploid and diploid progenitors.

Suitable citrus rootstocks for salinity tolerance

1. **Cleopatra mandarin (*Citrus reshni*):** Cleopatra mandarin is one of the most used rootstocks in areas with salinity issues. It has good tolerance to salinity and can be used for various citrus varieties.
2. **Troyer citrange (*Citrus sinensis* × *Poncirus trifoliata*):** Troyer citrange is another widely used rootstock known for its high tolerance to salinity. It performs well under moderate to high salinity conditions and is compatible with many citrus varieties.
3. **Swingle citrumelo (*Citrus paradisi* × *Poncirus trifoliata*):** Swingle citrumelo is a hybrid rootstock that exhibits good tolerance to salinity. It is commonly used for grapefruit and can help manage salinity stress effectively.
4. **Carrizo citrange (*Citrus sinensis* × *Poncirus trifoliata*):** Carrizo citrange is a widely used rootstock that offers good tolerance to salinity. It is commonly used for sweet oranges and can thrive in moderately saline soils.
5. **Volkamer lemon (*Citrus volkameriana*):** Volkamer lemon rootstock exhibits moderate tolerance to salinity. It is often used in areas with slightly saline soils and can be compatible with various citrus varieties.
6. **Sour orange (*Citrus aurantium*):** Sour orange is one of the most salt-tolerant rootstocks in the wider geographical regions of India (Sajid, *et al*., 2021) [35].
7. **Attani (*Citrus rugulosa*):** Attani rootstock is more tolerant to saline soils due to its high rate of photosynthesis, lower leaf scorching, higher membrane stability index, and lower ROS accumulation (Kalal, *et al*., 2019) [14].
8. **Rangpur lime (*Citrus limonia*):** It is a more salinity-tolerant rootstock than others. It could limit the movement of Cl ions from the root to the shoot, exclude Cl, and tolerate significant amounts of Cl buildup in the leaves.
9. **Eremocitrus:** One of the true citrus genera known for its tolerance against salinity stress.

It is important to note that while these rootstocks show some level of tolerance to salinity, they may not be completely immune to its effects. The suitability of a particular rootstock may also depend on the specific salinity levels, local soil conditions, and climate factors in each region.

Effect of salinity on growth and Physio-chemical traits of citrus rootstocks and its hybrids

Salinity causes negative effects on plant growth by inducing osmotically induced water stress, specific ion toxicity due to high concentrations of sodium and chloride, nutrient ion imbalance due to high levels of Na^+ and Cl^-, reducing the uptake of K^+, NO^-, $PO4^{3-}$etc, and increased production of reactive oxygen species which damage the macromolecules (Greenway and Munns, 1980) [11]. Ruiz *et al*. (1997) [34]

evaluated the four citrus rootstocks (sour orange, Cleopatra mandarin, Carrizo citrange, and *C. macrophylla*) in nutrient solutions containing 0, 10, 20, 40, or 80 mM NaCl for 20, 40, or 60 days. They concluded that the concentrations of Cl^- and Na^+ increased in plants treated with < 40 mM NaCl until day 20, and then remained constant for the remainder of the study, whereas the concentrations of Cl^- and Na^+ in plants treated with 80 mM NaCl increased slightly between the days 20 and 60. Salinity reduced K^+ concentrations in the roots of all rootstocks and in leaves of the sour orange, Cleopatra mandarin, and Carrizo citrange rootstocks, whereas K^+ concentrations increased in leaves and roots of *C. macrophylla* rootstocks. In addition to this, the concentrations of Ca^{2+} and Mg^{2+} were reduced by salinity in all the rootstocks, except *C. macrophylla.*

Suppression of plant growth because of salt stress largely depends on the severity of the stress. A sudden reduction in the growth of leaves and stem due to mild osmotic stress takes place, whereas roots may continue to grow and elongate (Hsiao and Xu, 2000). Salt absorbed by the plant does not inhibit directly the growth of the new leaves; however, over a period, salt absorbed by the plant is gradually transported from older leaves into the transpiring leaves resulting in the death of leaves due to higher accumulation of Na^+ and Cl^- contents. Subsequently rapid accumulation of salt in the cytoplasm (Munns, 2005) [26]. Gradually chlorosis and necrosis are expressed by the plant due to reduced uptake of K^+, and suppress the enzyme activity and toxicity of Na^+ and Cl^-, resulting in symptoms almost similar to those of K^+ deficiency (Karimi *et al*., 2005) [15]. As per Larkindale and Knight (2002) [20], calcium has an important role in stress protection by stabilizing membranes and reducing oxidative damage. The production of reactive oxygen species (ROS) can be up-regulated by allowing the *Arabidopsis* plants to salt stress resulting in an increase in the level of H_2O_2 (hydrogen peroxide), O^-_2 (superoxide), $^1O_2$ (singlet oxygen) and OH^- (hydroxyl radical). Higher accumulation of ROS leads to phytotoxic reactions such as lipid peroxidation, protein degradation, and DNA mutation (McCord, 2000, Wang *et al.*, 2003; Vinocur and Altman, 2005; Pitzschke *et al*., 2006) [24, 44, 43, 32].

Tozlu *et al*. (2000) [41] evaluated *C. grandis* L. (Osb.), *P. trifoliata* (L.) Raf. and their F 1 against salt stress under 0, 40, and 80 mM NaCl concentrations for 5 months and observed the decreased mean growth and dry weights of nearly all tissues of the plant under salinized environment as compared to the control condition. Under 40 mM NaCl treatment, there was an exception of increased fine root mass and dry weight (30%) in *P. trifoliata* as compared to control plants. Leaf tissues of *P. trifoliata* and root tissues of *C. grandis* proved to be highly sensitive to salinity. In order to minimize the salt accumulation, *P. trifoliata* and *C. grandis* tended to increase the root dry mass production and leaf mass respectively, thus F1 plants showed tolerance to salinity. In another study, Tozlu *et al*. (2000) [41] recommended the use of 40 to 60 mM NaCl concentration for testing the *P. trifoliata* and their progeny. They found it to be the best genetic source for improving citrus salinity tolerance because of its increase in *P. trifoliata* fine root production even under saline conditions.

Lopez-Climent *et al*. (2008) [21] tested 5 different citrus genotypes in order to understand their physiological response under salinized conditions, and observed that even in a salinized environment, the consistent photosynthetic performances were shown by the new genotype Forner-Alcaide #5 as compared to the sudden decrease of net assimilation rate, stomatal conductance, the performance of PSII and photosynthetic efficiency in Cleopatra mandarin. The greater reduction in NAR (Net Assimilation Rate) was found in citrumelo, Carrizo, and C35 citrange due to a higher accumulation of Cl^- in the leaves. A salinity experiment was carried out using two citrus rootstocks for a comparative study between Cleopatra mandarin, which is known to be a relatively salt tolerant rootstock and contains higher Na^+ in leaf and root tissues whereas Troyer citrange considered as salt sensitive it contains higher Cl^- in leaf. They concluded that more proline was accumulated in the leaves of salt-sensitive Troyer citrange seedlings as compared to that of salt-tolerant Cleopatra mandarin. And, the N and P content of leaves and root tissue were decreased due to salinity treatments (Anjum, 2008) [2].

Patel *et al*. (2011) [30] conducted the salinity experiment using 5 citrus rootstocks in order to study the effect of NaCl (0, 50, 100 mM) applied through irrigation water under a pot for a period of 6 months, and observed the decrease in plant height and increase in defoliation and the activity of superoxide dismutase (SOD) and peroxidase (POD) in the salt susceptible rootstocks *viz.*, Troyer citrange and Billikhichlli at the higher level of saline treatments. Salt-tolerant rootstocks such as Attani-2, sour orange, and RLC-6 showed higher leaf proline accumulation. They concluded that for the evaluation of citrus rootstocks against the NaCl-induced stress, proline accumulation, and leaf abscission may be the reliable indicator of tolerance. Forner-Giner *et al*. (2011) [9] successfully studied new citrus hybrid rootstocks such as Forner-Alcaide no.5 (FA-5) and Forner-Alcaide no.13 (FA-13) against salinity stress under a greenhouse saline environment at 0, 20, 40 and 60 mM NaCl concentration through irrigation water for 2 months. They observed a greater decrease in relative growth of scion cultivar while grafted on *P. trifoliata* due to reduced uptake of nutrients in comparison to FA-13, FA-5, and Cleopatra mandarin rootstocks. The uptake of the nutrients by the citrus plants was inversely correlated to the accumulation of saline ions.

The tolerance capacity of nine months old citrus rootstocks such as Rubidoux (*P. trifoliata*), Rangpur lime (*C. limonia*) and Carrizo citrange (*C. sinensis* x *C. trifoliata*) and Sanchton citrumelo (*C. trifoliata* x *C. paradisi*) was assessed by subjecting them to different concentrations of NaCl (0, 30, 60, or 90 mM) under greenhouse condition (Balal *et al*., 2012) [5]. They observed the higher antioxidants enzyme activity and lower transportation of Na^+ and Cl^- content from root to shoot and shoot to leaves in salt tolerant rootstocks *viz*., Rangpur lime and Rubidoux, whereas salt susceptible rootstocks like Carrizo citrange and Sanchton citrumelo behaved vice versa. An increasing salinity also reduced the RWC of all rootstocks. Under saline conditions, cell elongation rate and turgidity decrease, and the cell wall become thicker and rigid due to a decrease in water potential and higher absorption of Na^+ and Cl^- ions (Fricke and Peters, 2002). High salt concentrations led to the generation of more ROS in sensitive rootstocks, which are detoxified by up-regulating their antioxidant enzyme activities (Patel *et al*., 2011) [30].

Of the 12 citrus genotypes evaluated for salinity tolerance, Poncire Commun citron and Marumi kumquat were the most sensitive species, while mandarins, pummelo, and Australian sour orange proved to be the most tolerant species. Among the genotypes, Engedi Pummelo presented a specific trait for salt tolerance that had not been previously reported. Taken together, the results suggested that low leaf chloride content can be used as an indicator of salt stress tolerance in citrus genotypes. The exploitation of this indicator will enable the improved evaluation of citrus genetic resources and should lead to the identification of new sources of tolerance for rootstock breeding (Hussain *et al.*, 2012) [12]. Swingle citrumelo rootstocks had been reported to withstand salt stress by the restricted accumulation of sodium (Na^+) in its root zone resulting in a lower concentration of Na^+ in leaves as compared to higher content of Na^+ in leaves of Rough lemon. These events occurred in plants due to the build of higher Na^+ in the vacuoles of root tissue and the restriction of cell walls for Na^+ accumulation (Gonzalez *et al.*, 2012) [10].

A salinity stress experiment was conducted using one-year-old potted three indigenous citrus rootstocks (Jatti khatti, Attani-1, and Attani-2) under the effect of NaCl (0, 25, or 50 mM). At 50 mM NaCl treatment, Jatti khatti showed a greater membrane injury index (MII) as compared to Attani-2 and Attani-1. A greater increase in RWC and leaf-proline content was observed in the Attani-1 followed by Attani-2 and Jatti Khatti under 50 mM NaCl treatment. The activity of SOD was increased in all rootstocks with an increase in the salt concentration, whereas the activities of CAT and POD were decreased in all the rootstocks at higher salt levels. Attani-1 had the greater salt tolerance capacity followed by Attani-2 and Jatti Khatti (Singh *et al.*, 2014) [39].

Five months old nine citrus rootstocks (Sour Orange, Bakraii, Cleopatra Mandarin, Rangpur lime, Rough lemon, Macrophylla, Swingle citrumelo, citrange, and Trifoliate orange) were evaluated in order to study the effect of NaCl (0, 25, 50, and 75 mM) under field condition for 60 days, wherein the lowest leaf damage was observed in Cleopatra plants, while it was highest in trifoliate orange at all salinity level. The highest ion leakage was observed at 75 mM NaCl in the trifoliate orange and was lowest in the sour orange and Cleopatra rootstocks. In addition to this, the highest leaf-proline was found at 75 mM NaCl in Rangpur lime while it was lowest in the Bakraii, citrange, and trifoliate orange. During the present study, Swingle citrumelo, citrange, and trifoliate orange were the most salt susceptible rootstocks. The low-to-moderate tolerance to salinity was found in the rough lemon and Macrophylla, while it was moderate-to-high in the Rangpur lime and Bakraii rootstocks (Khoshbakht *et al.*, 2014) [17]. The high salt susceptibility of citrus is substantiated by the fact that fruit yield decreases by about 13% for every 1 dSm^{-1} increase in salinity above 1.43 dSm^{-1}, which has been reported as the threshold value of soil saturation paste salinity for *Citrus* spp. The salinity-induced changes in growth, physiological and biochemical parameters manifested as toxic accumulations of Na^+ and Cl^+ ions, impaired water relations, osmotic stress, and poor photosynthetic efficiency account for poor plant performance in salt-affected soils (Murkute *et al.*, 2005) [28].

Iqbal *et al.* (2015) [13] evaluated the one-year-old four citrus rootstocks (Rangpur lime, Rough lemon, Volkameriana lemon, and Trifoliate orange) against NaCl-induced stress (0, 75, 100, and 150 mM concentrations) for 25 days under greenhouse conditions. The concentrations of K^+ and Ca^{+2} decreased in all the rootstocks with increased salt concentration, but Rangpur lime showed a better uptake of K^+ even at 100 mM NaCl treatment. The lower leaf Cl^- accumulation was found in the Rangpur lime and rough lemon, whereas it was higher in Trifoliate Orange and Volkameriana lemon than others. They concluded that Rangpur lime proved to be a better performer even at high salt concentrations, whereas Trifoliate orange was found highly sensitive to higher concentrations of salt stress. A study conducted on screening of 5 citrus rootstocks against NaCl-induced salinity exhibited increased proline accumulation and decreased RWC in plant tissues at the higher levels of salinity treatments. The reduction in K content in leaves was accompanied by the increased Na^+ and Cl^- contents in leaves. Among 5 rootstocks, Cleopatra mandarin, and Shaker were found to have higher RWC and proline levels than other rootstocks listed (Shafieizargar *et al.*, 2015) [36].

NaCl treatment results in burning symptoms on leaves. Tuzcu 891 sour orange, Swingle citrumelo, and Volkameriana have been reported to express lighter leaf burning than Rubidoux trifoliate and 34 12 N Citremon (Yesiloglu *et al.*, 2015) [46]. The 'Olinda' Valencia scion reduces rootstock tolerance to salinity, however, trees grafted to the C22 and C146 rootstocks showed more salinity tolerance than those grafted on sour orange rootstock, emphasizing that both rootstock and scion should be considered while selecting the commercial planting under saline conditions (Simpson *et al.*, 2015) [38]. In a study conducted by Barbosa *et al.* (2017) [6] to evaluate the eight citrus rootstock genotypes ['Santa Cruz Rangupur' lime (LCRSTC); common 'Sunki' mandarin (TSKC) x 'Swingle' citrumelo (CTSW) – 028; TSKC x CTSW – 033; TSKC x CTSW – 041; 'Volkamer' lemon (LVK) x 'Rangpur' lime (LCR) – 038; 'Florida Sunki' mandarin (TSKFL); TSKC and 'Florida' rough lemon (LRF)] with five salinity levels of irrigation water (0.8, 1.6, 2.4, 3.2 and 4.0 dS m^{-1}), Santa Cruz Rangpur' lime, TSKC x CTSW – 041, LVK x LCR – 038 and 'Florida' rough lemon exhibited the moderate tolerance to salt stress during the first 30 days of exposure to the stress. The genotypes TSKC x CTSW-033 and common 'Sunki' mandarin proved to be the most sensitive to salinity.

Table 1: Different citrus rootstocks govern salinity tolerance with specific traits.

Sl. No.	Citrus rootstocks	Traits	References
1	Trifoliate orange and its hybrids Swingle citrumelo & Carrizo citrange	Excluded Na at the lowest salt level	Zekri and Parsons, 1992 [47]
	Cleopatra mandarin	Excluded Cl at the lowest salt level	
2	Pummelo×Troyer Citrange hybrids P×T-86, P×T-98 and P×T-102	Displayed low scorching of leaves. Expressed the low level of lipid peroxidation and Cl- accumulation in leaves when hybrids exposed at 100 mM NaCl treatment.	Kalal *et al.*, 2019 [14]
3	Rangpur lime and Rubidoux	Enhanced levels of antioxidant activities, increasing concentrations of osmoprotectants, and limiting leaf levels of Na and Cl contents in the rootstocks.	Shahid, *et al.*, 2019 [37]
4	Cleopatra mandarin and pomelo rootstocks	These rootstocks displayed maximum accumulation of proline, less Na and Cl against varied concentrations of saline irrigation.	Alam, *et al.*, 2020 [1]

5	Sour orange	In comparison to 'Troyer' citrange and Citrus volckamariana, Sour orange rootstock showed the largest number of leaves plant-1, stem thickness, chlorophyll content, leaf area, fresh and dry shoot weight, root weight, survival %, fewest toxicity symptoms, and maximum proline accumulation. When grown under saline conditions, the rootstock Sour orange was found to be tolerant, whilst 'Troyer' citrus was found to be extremely sensitive.	Sajid, *et al.*, 2021 [35]
6	Diploid Kinnow mandarin grafted on tetraploid Volkamer lemon	Showed salinity tolerance by a maximum increase in antioxidative enzymes (SOD, CAT, POD, APx, GR) and osmolytes (PRO, GB) in leaves and roots at 75 and 150 mM	Khalid, *et al.*, 2022 [16]
7	Sour orange, Trifoliate orange, and Carrizo citrange	Sour orange was found to have the lowest decline in plant height (13.36%), leaf area (31.19%), and root length (8.13%). Trifoliate orange had the lowest decrease in fresh weight of the plant (6.82%) and root (4.42%). Trifoliate orange was shown to have the highest levels of catalase activity. SOD and peroxidase activities were found to be highest in Carrizo citrange and sour orange.	Arıkan, 2022 [3]
8	Volkamer lemon and Sour orange	In comparison to sour orange, Volkamer had higher seedling height, stem diameter, and root components (length, fresh weight, and dried weight). Volkamer lemon showed higher levels of N, Na+, K+, and P compared to sour orange, which had higher leaf Cl, Ca, and Mg+2. As a result, the Volkamer rootstock is more tolerant to salt stress than sour orange.	Othman, *et al.*, 2023 [29]

Salinity Management in citrus

Salinity management is a crucial aspect of citrus crop cultivation in India, particularly in regions with saline soils or water. Salinity stress can significantly impact citrus trees' growth, yield, and overall productivity. To effectively manage salinity in citrus crops in India, the following key points should be considered:

Selection of Suitable Rootstocks: Using resistant rootstocks is an essential strategy to mitigate the effects of salinity. Rootstocks like Cleopatra mandarin, Sour orange, Attani, Rangpur lime, Troyer citrange, Swingle citrumelo, Carrizo citrange, and Volkamer lemon have demonstrated tolerance to salinity and can be considered for citrus cultivation in saline areas.

Site Selection and Water Management: Careful site selection is crucial to avoid areas with high salinity levels. Proper water management practices, such as efficient irrigation systems, drainage systems, and the use of good-quality water, can help minimize the buildup of salts in the soil.

Soil Amendments and Amendments: Applying soil amendments, such as gypsum, can aid in leaching excess salts from the root zone. Additionally, organic matter incorporation and balanced fertilization can improve soil structure and nutrient uptake efficiency, enhancing the overall resilience of citrus trees to salinity stress.

Monitoring and Testing: Regular monitoring of soil and water salinity levels is important to detect changes and take timely corrective measures. Conducting soil and water tests, along with observing plant responses, can provide valuable insights into the salinity status and enable informed management decisions.

Local Expert Consultation: Seeking guidance from local agricultural experts, horticulture departments, or research institutions specializing in citrus cultivation is highly recommended. They can provide region-specific recommendations, updated information on suitable rootstocks, and effective salinity management practices tailored to the specific challenges faced in India.

By implementing appropriate salinity management strategies, citrus farmers in India can minimize the detrimental effects of salinity stress on their crops and improve citrus tree health, productivity, and profitability.

Conclusion

The citrus yield and productivity can be optimized under salt-prone regions by utilizing various salinity-tolerant rootstocks. Hybridization, mutation, polyploids, and other genetic engineering tools offer further opportunities for developing rootstocks with enhanced salt tolerance. By crossing different citrus species and selecting desirable traits, breeders can create new rootstock varieties that exhibit improved adaptability to salinity. This breeding approach allows for the incorporation of genetic diversity and the identification of unique combinations of traits that contribute to salt tolerance. By combining the above management approaches and strategies, citrus growers can reduce salinity impacts, enhance crop productivity, and ensure sustainable citrus cultivation in saline environments. Continued collaboration between researchers, breeders, and growers will be vital in developing effective solutions and implementing best practices for salinity management in citrus.

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