Drought and Salinity in Citriculture

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Among the various abiotic stresses, drought is the major factor limiting crop productivity worldwide. Citrus has been recognized as a fruit tree crop group of great importance to the global agricultural sector since there are 140 citrus-producing countries worldwide. The majority of citrus-producing areas are subjected to dry and hot summer weather, limited availability of water resources with parallel low-quality irrigation water due to increased salinity regimes. Citrus trees are generally classified as "salt-intolerant" with high water needs, especially during summer. Water scarcity negatively affects plant growth and impairs cell metabolism, affecting the overall tree growth and the quality of produced fruit. Key factors that overall attempt to sustain and withstand the negative effect of salinity and drought stress are the extensive use of rootstocks in citriculture as well as the appropriate agronomical and irrigation practices applied.

Keywords: abiotic stresses ; citrus water needs ; irrigation practices ; sustainability of citriculture

1. Introduction

Citrus has been recognized as a group of fruit tree crops of great importance for the global agricultural sector. The majority of the cultivated areas of citrus are located in the subtropical region, in the so-called citrus belt, defined by the 40° north–south latitudes, where the temperature rarely drops below severe freezing temperatures [1]. The majority of the citrus-producing areas are subjected to dry and hot summer weather, limited availability of water resources with parallel low-quality irrigation water due to increased salinity regimes. These factors negatively affect citrus tree productivity and fruit quality. Furthermore, the negative effect of climate change in citrus-producing areas should not be neglected since it augments the detrimental effect of salinity and drought stress [2].

Climate change, combined with the resulting desertification and overexploitation of water resources, due to overpopulation and intensification of agriculture, will be a challenge for the survival, growth, and sufficient yield of agricultural commodities [3]. Especially in citrus crops, water scarcity negatively affects plant growth and impairs cell metabolism, affecting the overall tree growth and produced fruit quality. Drought stress is also affecting the post-harvest handling of citrus fruit since it reduces significantly the reed thickness, rendering the fruit more prone to damage during handling and transportation [4].

Salinity and drought stress demonstrate similar physiological disorders to plants when they occur. Under the effect of salinity and drought stress, interlinked molecular responses are activated in order to provide an acclimation effect to the plant and initiate signaling cascades so as to facilitate the alleviation of the occurred stress syndromes [5]. There are several molecular interactions between salinity and drought stress that are impossible to separate in the field. Additionally, overall plant responses to simultaneous stress factors are complex and can be different in terms of response to each individual stress factor, depending also upon the duration and intensity of each stress syndrome [2].

Citrus are generally classified as "salt-intolerant" crops since irrigation with salinized water immediately arrests tree growth and negatively affects fruit quality, more than in many other crops [6]. Citrus at cellular and organism level can cope with salt and water deficit via the implementation of stress avoidance and stress tolerance mechanisms that block ion accumulation and tissue dehydration or maintain the integrity of cell structures and functionality of crucial biomolecules [7].

A key factor to the overall attempt to sustain and withstand the negative effect of salinity and drought stress is the extensive use of rootstocks in citriculture. Extensive work has been conducted upon citrus trees showing that rootstocks are a key component to the ability of the tree to withstand water scarcity since they modulate the physiological performance of the tree via variations in plant hydraulic conductance, leaf water potential, and stomatal conductivity [8][9].

Several reports indicate that citrus growers worldwide encounter several cultivational problems due to drought and salinity stress, which cause the decline in citrus yield and fruit quality. Thus, it is of paramount importance to provide the necessary means and insight that would guide farmers into the implementation of novel agricultural practices that would increase their income and minimize the negative impact of salt and water stress. Towards this goal, several traditional breeding programs are active and have produced several improved varieties of citrus plants [10]. The deleterious effect of water-related abiotic stresses such as salinity and drought stress can be minimized via the precise and sophisticated agricultural practices that take into account the actual tree needs and the availability of natural resources. The scope of the current review is to harness useful scientific data that could be utilized and guide the successful implementation of agronomic practices that improve citrus tolerance against stress factors.

2. Agricultural and Irrigation Practices That Cope with Salinity and Drought in Citrus

Figure 1 depicts specific agricultural practices in citriculture that could significantly alleviate the negative effects either from salinity or from drought stress. All these practices are analyzed in the following parts of this section. Citrus trees' need for water depends on tree age, tree size, citrus species, climate, and soil type. As a general guide, research studies suggest that mature citrus (orange) trees need about 4000–5000 m^3 of water per hectare and year [11]. Water use for grapefruit and lemon trees is about 20% higher than that of oranges, while water use for mandarins is about 10% less. Additionally, regarding the appropriate irrigation frequency, this depends on the season and soil type and ranges from 7 to 25 interval days [4][12]. There are three main irrigation systems used in citriculture: micro-sprinkler and sprinkler irrigation, which give good results mainly on sandy soils, and drip irrigation, one of the best techniques from a technical point of view, due to water economy. The irrigation schedule should start according to the soil moisture, which can be determined by soil samples with an auger or soil moisture sensors/tensiometers. The installation of tensiometers following the irrigation line in the middle point between two emitters (0.20 m from the emitter, 1 m from the trunk) is recommended for mature citrus trees. In the case of a micro-sprinkler, the installation of tensiometers at a distance of 0.5 m from the mini sprinkler or 1 m from the sprinkler is recommended [13]. Citrus has a relatively shallow root system. Thus, it is important to apply irrigation at the effective root zone, minimizing the deep percolation of water. For citrus, the effective root zone is usually up to 30 cm soil depth (depending on the soil type). At that depth, there is a minimum threshold of critical matric potential, which needs to be maintained. Typical thresholds are 20 kPa for sandy soils and 100 kPa for clayey soils [11][14].

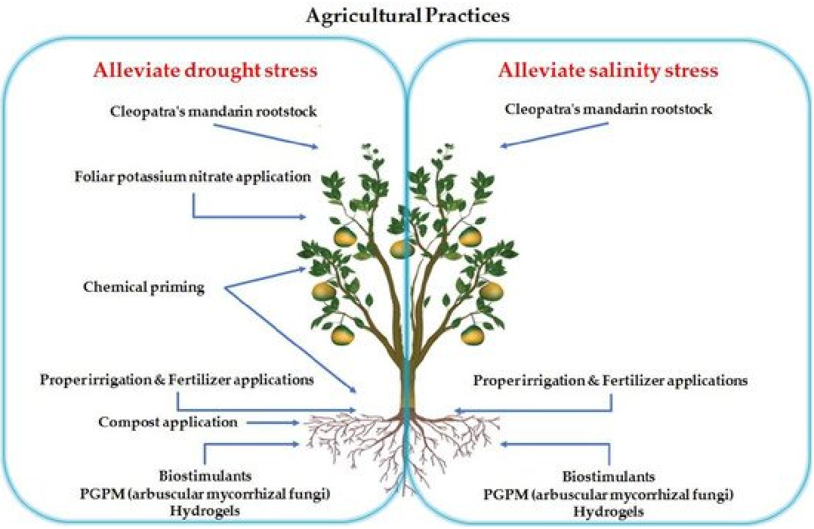

Figure 1. A mechanism diagram of agricultural measures to alleviate citrus drought and salinity.

Citrus is moderately resistant of salty water, but salts can accumulate in the soil or on the foliage and can cause root dieback or leaf loss. Salinity will always be more of a problem on poorly drained clay or silt soils than on permeable sandy or gravelly soils. In the case that citrus trees are irrigated by drip or micro-sprinkler method, which is the most common one, care should be taken so that water will not contact the leaves, since salt may burn citrus foliage. Salts may also plug emitter orifices. Frequent or shallow irrigations will lead to salt accumulation on the soil surface (in the form of a white crust), and accumulation in the root zone. Salt may be moved from the root zone through the process of leaching. To leach salty soil, apply large amounts of water to the soil once or twice a year [15].

In citrus, the choice of the rootstock plays a crucial role in the water relations of the tree with the soil and determines its overall response to abiotic stresses [16][17][18]. The genetic characteristics of the rootstock determine the robustness of the scion and its survival under water stress [19]. Studies have shown that orange trees, of cv. Lane Late, grafted on Cleopatra's mandarin rootstock demonstrated in their foliage higher water use efficiency (WUE) and osmotic adjustment and kept this parameter at high levels under drought conditions, compared to plants crafted upon Carrizo citrange hybrid rootstock [20][21].

Different relieving methods have been assessed to increase yield under salt stress and water deficit conditions. First, wise control of irrigation and fertilizer applications is considered essential to tackle this problem in a commercial orchard. Other horticultural practices such as the use of orange varieties as interstocks, the use of hydrogels, shading, treatments with persistent analogs of phytohormone abscisic acid (ABA), and polyamines [22] improved citrus performance under drought and/or salt stress conditions, as well. Various practices have dealt with the effect of increasing calcium or nitrates in the nutritional solution as well as treatments in order to relieve salt stress. In the presence of an adequate concentration of calcium (Ca^{2+}), plants exclude Na^+ more efficiently and avoid their accumulation in cells [23]. It has been repeatedly shown that nitrate and other nitrogen-derived compounds such as urea or ammonium have had positive effects on the growth response of citrus [24]. Moreover, nitrate seems to have two separate effects that can improve the performance of citrus seedlings under saline conditions. First, it has been observed that nitrate supplementation stimulated photosynthesis and growth as well as reduced leaf abscission. Second, the nitrogen-induced increase in leaf biomass has resulted in chloride dilution, the critical factor for salt damage [25]. In addition, foliar potassium nitrate application can improve the endurance of citrus seedlings to drought conditions [22].

Using compost is one of the best ways to conserve irrigation water by retaining soil moisture within the root zone. Apply two to four inches of compost under the plant canopy. Compost can consist of pine needles, leaves, bark, wood chips, straw, or any other organic materials. The compost should not directly contact the trunk and should be expanded as the plant grows. A good cover of compost will help to control weeds under the tree canopy, as well as reduce water evaporation. Trees that are enhanced with compost can be irrigated less frequently than those that are not. Composting can also lower soil temperature, thus allowing for better root growth, and will eventually decompose and add significant organic matter to the soil [26][27].

Moreover, chemical priming has been suggested as a promising method in the field of plant stress physiology and crop stress management. Plants are apparently capable of causing stress “memory” or “stress imprinting” following a first stress exposure, which leads to adjustment to later biotic or abiotic stress. Through priming (also known as hardening), plants are able to trigger responses to a range of stresses, providing low-cost protection in relatively high-stress/pressure conditions [28]. Reactive oxygen species (ROS) in the form of hydrogen peroxide (H_2O_2) and reactive nitrogen species (RNS) in the form of nitric oxide ($NO^{\bullet}$) induce priming toward salinity and drought in citrus plants [11]. These chemical agents, also including sodium nitroprusside, sodium hydrosulfide, melatonin, and polyamines, can potentially result in enhanced resistance in the field against multiple abiotic stresses [29][30][31].

Furthermore, the use of biostimulants has become a common agricultural practice by many farmers. The use of these compounds provides protective effects against abiotic stress factors and contributes positively to overall plant growth [32]. These alleviating effects are exerted via the orchestrated activity of plant hormones, proline, sugars, amino acids, etc. whose production is stimulated by the applied biostimulant [33]. The recent scientific data highlight that the usage of biostimulants facilitates citrus root development or regulates the osmoregulatory mechanisms in plant cells [34]. Orange trees (*Citrus sinensis* L.), when spayed with commercial extract of *Ascophyllum nodosum,* exerted improved water relations and better water use efficiency (WUE) when irrigated with 50% restitution of evapotranspired water [35]. The use of biostimulants is considered an agricultural practice that could contribute positively to the alleviation of drought stress and increase WUE in citrus crops, especially in drought-prone regions where citrus trees are agronomically important but water resources are limited due to urban use and climate change [32].

A novel and promising agricultural practice is the use of compounds enriched with plant-growth-promoting microbes (PGPM). The extended use of chemical fertilizers and pesticides has caused a severe decline in soil quality, hence there is an urgent need to establish and implement agricultural techniques that will sustain agricultural production. Towards this goal, several novel products have been released that engulf the technology of the application of plant-growth-promoting microbes (PGPM) along with mycorrhizal fungi in the root system of the plant, enhancing plant growth and plant protection against abiotic stress conditions [36]. Specifically, it has been reported that Arbuscular Mycorrhizal induced water deficit tolerance of roots of Trifoliate orange by regulating polyamine homeostasis [37], whereas in another study, drought stress conditions stimulated H^+-ATPase activity and PtAHA2 gene expression, resulting in nutrient uptake, increased root growth, and lower soil pH microenvironment [38].

Apart from the above, the hydrogel polymer compound seems to be particularly effective to be used as a soil conditioner in citriculture, increasing crop tolerance and growth in drought conditions. Abobatta and Khalifa [39] highlight that medium or high dose of hydrogel composite (1000 to 1500 g/tree) enhances total yield, fruit weight, and fruit quality (fruit content of total soluble solids and total sugars). This may be due to the crucial role of applied longtime hydrogels in increasing water availability and nutrients for citrus trees. Additionally, research studies indicate that hydrogels may minimize the adverse effects of salinity by reducing the levels of salt ions in citrus tissues [40][41]. Specifically, hydrogel composite releases water and nutrient to the trees when the soil surrounding the root zone starts to dry up. Hydrogel materials cause a reduction in irrigation amount as well as intervals by 50%. In addition, it has been proved that hydrogels can increase soil's water-holding capacity up to four times, ensuring safe soil moisture levels as well as nutrients under drought conditions. There are three forms of hydrogel composites containing natural polymers (polysaccharide derivatives), semisynthetic polymers (cellulosic primitive derivatives), and synthetic polymers. Synthetic polymers indicate higher stability under different environmental conditions than shown by natural ones [42]. **Table 1** highlights in a strict matter all the above-mentioned practices and their role to alleviate salinity and water stress in citrus

Table 1. Summarizing the main agricultural practices to alleviate drought/salinity stress.

Agricultural Practice	Alleviate Drought Stress	Alleviate Salinity Stress	Reference
Proper irrigation (amount and frequency) based on tree age, tree species, climate, soil type, and/or saline irrigation	**P**	**P**	[4][12]
Appropriate fertilizer applications (calcium or nitrates in the nutritional solution)	**P**	**P**	[23]
Foliar potassium nitrate application	**P**	**NP**	[22]
Use of Cleopatra's mandarin rootstock and hybrids—orange varieties as interstocks	**P**	**P**	[16][21][18]
Compost application	**P**	**NP**	[26][27]
Chemical priming (use of sodium nitroprusside, sodium hydrosulfide, melatonin, and polyamines)	**P**	**NP**	[29][30][31]
The use of biostimulants	**P**	**P**	[34][35]
Use of plant-growth-promoting microbes (arbuscular mycorrhizal fungi)	**P**	**P**	[38][40]
The use of hydrogels	**P**	**P**	[42]

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