Impact of Salinity Stress on Date Palm (*Phoenix dactylifera* L) – A Review

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1. Introduction

The growth and productivity of palms are primarily affected by salinity stress in the arid regions apart from drought and heat. The world scenario on salinity problems is critical, over 20 percent of the cultivated area and half of the irrigated land in the world is encountering salinity stress of different magnitudes. The importance of date palm culture for its high nutritive, economic and social values is well recognized, especially in arid and semi-arid areas where it plays an important role influencing microclimate in a way that enhances the production of other agricultural crops. Worldwide production, utilization and industrialization of dates are increasing continuously (Botes and Zaid 2002).

Different productivity parameters such as germination of seeds, seedling growth, vigor, reproductive flushing and fruiting are adversely affected reflecting on optimum production and productivity. The basic cause of salinity hazards is enhanced ion toxicity causing impaired sequestering of sodium ions into the vacuoles. The increased ionic concentration of the soil solution decreases the osmotic potential of the soil creating severe water stress derailing the uptake process. This can create imbalance in the absorption process of other minerals. In order to achieve salt-tolerance, the foremost task is either to prevent or alleviate the damage, or to re-establish homeostatic conditions in the new stressful environment (Parida and Das, 2005).

The date palm growth and production in the arid regions is adversely affected by salinity problems apart from other crops like vegetables and fruits (Figures 1 & 2). Date palm is considered as the subsistence crop of the Middle East and North Africa. Despite date palms outstanding agronomic and socio-economic significance, attempts to use date palm biodiversity to screen against salinity tolerance have been limited and therefore of urgent priority. Although potential salt tolerant cultivars are available, there is no systematic approach to characterize such genotypes employing molecular diagnostic techniques. The understanding of the molecular, physiological, biochemical basis and soil factors will be helpful in developing selection strategies for improving salinity tolerance. Therefore pooling the information through the present review on salt responses in relation to various factors is crucial in developing strategies and improving salt tolerant mechanism in date palms. The review article covers the different aspects under the various growth stages of date palm, like seedling, vegetative phase and reproductive phase. The review also focuses on the use of remote sensing technology in date palm responses to salinity.

Plate 1. Deterioration of date palm trees due to high level of salinity.

Plate 2. Date palm field neglected due to the salinity.

The aim of this paper is to pool the various aspects of responses of date palm to salinity tolerance and to review the existing knowledge in relation to biodiversity useful to researchers and developmental agencies, engaged in date palm. The review also facilitates interdisciplinary studies to assess the ecological significance of salt stress in relation to date palm cultivation.

2. Background

Date palm (*Phoenix dactylifera* L) accounts for more than 1500 cultivars around the world (FAO, 2002). In addition to its commercial and nutritional value, the date palm tree has a minimum water demand, tolerates harsh weather, and tolerates high levels of salinity (Diallo, 2005); in fact, it is more salt tolerant than any other fruit crops (FAO, 1982). There are very few trees that can tolerate the desert environment, which is characterized by high temperatures, low soil moistures and high salinity levels. Furr (1975) reported that it is obvious that date palm is more salt tolerant than barley and may be the most salt tolerant of all crop plants since barley known as one of the most salt-tolerant field crops is usually grown in the cool season; in contrast date palms grow faster in hot weather when salinity has the most adverse influence on plants.

On the other hand, increasing of soil salinity is starting to show negative impact on the date palm agro-ecosystem in arid region, especially in the Middle East (Dakheel, 2005). Accurate information about the growth of date palm in saline environment and the variability in salt tolerance among cultivars is largely unknown. A serious attention is needed to maintain the diversity and growth of such plant in the arid regions.

3. Salinity stress and soil response

Salt-affected soil is a worldwide problem; however, it is more common in arid and semi-arid regions because of high evaporation rates and lack of fresh water resources that is required to leach salts. As water evaporates from the soil surface, the salts move upward to the soil surface but stay within or on the soil (Miller & Donahue, 1990). In many irrigated lands, salts occur in the irrigated water leading to accumulation of salts in the soil. The relationship between water and soil salinities and date palm production is illustrated in figure 3.

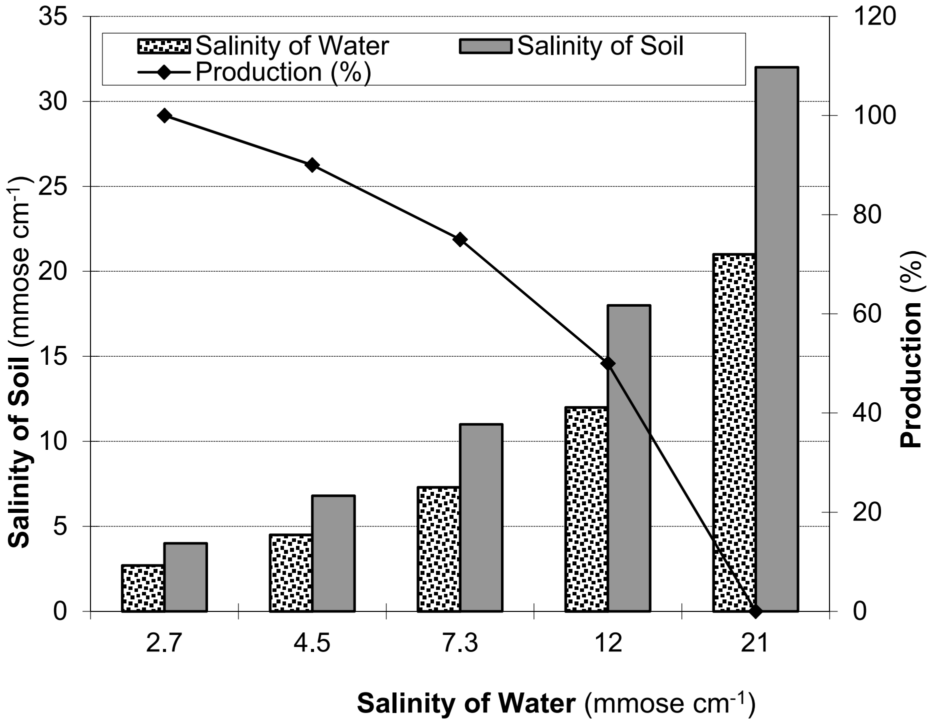

Fig. 3. Relationship between salinity of irrigated water, salinity of soil and production of date palm trees (Zaid and Liebenberg 2005).

Plant development will be affected when the soil has high levels of soluble salts, and the salt may become concentrated enough to be toxic to plants. Presence of salts on the soil is usually associated with osmotic and ionic negative effects, which will then lower the biological activity. Furthermore, salts have significant effect on fertility of the soil as well as its physical, chemical and biological characteristics (Srour et. al, 2010).

The approximation of global salt-affected area is 1 billion hectares, which correspond to about 7% of the earth's continental extent or about 20 times the size of a country such as France. About 77 million hectares have been salinized as a result of human activities, with 58% of these concentrated in irrigated lands. Generally speaking, over 40% of irrigated lands in the world are subject to different degrees of salinity (Dakheel, 2005). As a consequence of increasing population pressure, more arid land will be put into agricultural production in future, which means more salinization danger associated with irrigations.

Soil is a complex system involving interaction between cations on the soil solution with other cations on the soil particles exchange site. The role of the cations on the soil solution is highly dependent on the pH and the negative charge of soil colloids. The common inorganic solutes present in the soil solutions are Na^+, Mg^{2+}, Ca^{2+}, K^+ , Cl^-, SO_4^{2-}, HCO_3^-, NO_3^- and CO_3^{2-}, in addition to boron, selenium, molybdenum, and arsenic that may found in small amounts. Plants will show signs of injury and yield reduction when soluble salts exceed certain level of concentrations (Essington, 2003).

Salt-affected soils are classified into three classes, saline, sodic, saline-sodic soils. They differ based on their chemistry, morphology, and pH. The United States Salinity Laboratory classified salt-affected soils into three classes based on the basis of two criteria, the total soluble salt content and the exchangeable sodium percentage (ESP) or sodium adsorption ratio (SAR).

1. Saline Soils: these soils have a saturated paste electrical conductivity (EC_e) of 4 dS m^{-1} or more and SAR of <12 (ESP <15%). The pH of these soils, which were formerly referred to as white alkali soils, is less than 8.5. Because of a high salt content, these soils reduce water uptake by plants, and increase ion toxicity to the plant tissues. Furthermore, ion imbalances may occur in some soils.
2. Sodic Soils: these soils have an EC_e of less than 4 dS m^{-1}, and SAR of 12 or more (ESP ≥ 15%), and their pH exceeds 8.5. Exchangeable sodium percentage of 15 means that Na^+ occupies more than 15 % of the soil's cation exchange capacity. Formerly, these soils were called black alkali because of dispersed black organic matter coatings on peds and the soil surface. The most important problems for these soils are poor structure due to breakdown of structural units, ion toxicity (mainly Na^+ and Cl^-), and ion imbalances, especially deficiencies in Ca^{+2}, Mg^{+2}, and K^+.
3. Saline-Sodic Soils: these soils have EC_e ≥ 4 dS m^{-1}, SAR ≥ 12, and their pH is less than 8.5. They have similar problems to saline soils, especially reduced water uptake due to high soil osmotic potential.

4. Plant responses to salinity stress

When plant exposed to low-moderate salinity, it may metabolize normally and does not show symptoms of injury. However, more energy is required to maintain normal metabolism demand (Gale and Zeroni, 1985), which may cause reduction in growth and yield (Subbarao and Johansen, 2010). In most crops, lose of production can be significant even before the appearance of foliar injury (Francois and Maas, 2010).

In general, salinity can reduce plant growth through osmotic effects, toxicity of ions, nutrient uptake imbalance, or a combination of these factors (Karim and Dakheel, 2006; Maathuis, 2006). Dynamics observed in juvenile plant water uptake and tree growth observed in of juvenile date palms (*Phoenix dactylifera* L., cv. Medjool) for salinity and boron occurring independently and together were summarized by decreased water uptake but not ion accumulation for NaCl and CaCl salts and by boron that was accumulated in leaves and subsequently was associated with reduced tree size. It is suggested that while mechanisms for plant response to salinity are dominated by lowered soil water potential (osmotic stress); boron becomes toxic as it accumulates to a threshold level in plant tissue (Trippler et. al, 2007).

4.1 Morphological responses

The excess of salinity in the soil water can cause significant morphological changes in the plant growth responses. Morphological parameters like plant height, leaf production, and collar girth of different varieties, in the vegetative phase of growth subjected to high salinity irrigation showed differential responses. There is a threshold level of salinity that each palm can tolerate under the progression of salinity (Kurup et. al, 2009). Effects of salinisation of soil on emergence, growth, and physiological attributes of seedlings of the date palm showed negative relationship between percentage seed germination and salt concentration when a mixture of chlorides and sulfates of Na, K, Ca, and Mg maintained at 4.3, 6.0, 8.2, 10.5, 12.8, and 14.6 dS m^{-1}. Seedlings did not emerge when soil salinity exceeded 12.8 dS m^{-1}. Seedlings survived and grew up to a soil salinity of 12.8 dS m^{-1} and evidently this species is salt tolerant at the seedling stage as well (Ramoliya and Pandey, 2003). Furr and Ream (1968) studied the effect of salts ranging between 520 to 24,000 ppm on growth and salt uptake of 'Deglet Noor' and 'Medjool' varieties of date palm. The result of their study was that the average growth rate of leaves was depressed as the salinity increased and that the decline in the growth was more related to salinity of irrigation water than to salt content of the plants. Khudairi (1958) evaluated seed germination of 'Zahedi' cultivar grown in three NaCl solutions (0.5, 1.0, and 2.0%). He found that NaCl suppressed seed germinations during the early stages and the maximum germination did not exceed 50%. He also evaluated seeds of the same cultivar on several NaCl concentrations ranging between 0.1% and 2.5%. He observed that NaCl concentration below 0.8% did not affect seed germination, while the germination sustained in solutions up to 2%.

Aljuburi (1992) studied the growth of four cultivars of date palms, 'Lulu,' 'Khalas,' 'Boman,' and 'Barhee,' using four salinity concentrations (0, 0.6, 1.2, and 1.8%). He found that the cultivar 'Lulu' was more affected by salinity compared to the other cultivars. The research done by Hewitt (1963) tested the effect of different salts and salt concentrations on the germination of 'Deglet Noor' seeds using various combinations of NaCl, calcium chloride ($CaCl_2$), sodium sulfate (Na_2SO_4), NaCl + $CaCl_2$, and NaCl + Na_2SO_4 with salt's concentrations from 10,000 to more than 30,000 ppm. He indicated that the growth of 'Deglet Noor' decreased slightly at 10,000 ppm, decreased drastically at 20,000 ppm, and was prevented at 30,000 ppm except for three seedlings in NaCl + Na_2SO_4 34,000 ppm treatment.

The behavior of mature date palm was studied by Furr and Armstrong (1962). They examined the growth of 'Halawy' and 'Medjool' 17-year-old cultivars using salinities ranging between 2,500–15,300 ppm. They found little or no effect on growth rate of leaves, yield, size or quality of fruit, or on chloride content of the leaf pinnae.

Response of tissue culture plantlets of date palm Khalas variety to marginal saline water irrigation at varied frequencies with and without the use of mulch influenced the growth factors considerably (Al-Wali et. al, 2011).

4.2 Physiological and biochemical basis of salt stress

The physiological basis of salt tolerance in date palm was found as a strict control on Na^+ and Cl^- concentration in leaves and keeping up the K^+ content (Alrasbi et. al, 2010). It can be recommended that date palm plants of certain varieties can be irrigated with saline water during vegetative growth. Youssef and Awad (2008) conducted a study to enhance photosynthetic gas exchange in date palm seedlings under salinity stress (subjected to seawater treatments at 1-, 15-, and 30- mS cm^{-1}) using a 5-Aminolevulinic Acid-based fertilizer. They found that date palm seedlings accumulated significant amounts of Na+ in the foliage with increasing salinity, about a threefold increase in the accumulated Na+ between the control and 30 mS cm^{-1} salinity treatment. Electrolyte leakage indicated a significant reduction in membrane integrity as salinity increased. A strong linear correlation was observed between the chlorophyll (chl) a/b ratio and assimilation rate throughout salinity treatments. Salinity did not induce any change in the carboxylation efficiency of the rubisco enzyme (Vc,max), or in the rate of electrons supplied by the electron transport system for ribulose 1,5-bisphosphate (RuBP) regeneration.

The physiological basis of salt tolerance in date palm was found to be based on Na and Cl concentration in leaves and keeping up the K content. Therefore it can be recommended that date palm (seedlings of varieties 'Khalas', 'Khunaizy' and 'Abunarinjah') can be irrigated with saline water during vegetative growth. However, a significant decline in growth is expected when the EC of irrigation water exceeds 9 dS m^{-1} that may reach up to 50% with water EC 18 dS m^{-1} (in sandy soil with very good drainage). (Alrasbi et. al, 2010).

4.3 Molecular basis of salt stress mechanism

The metabolic adjustments to salt stress at the cellular level are the main focus to molecular characterization and identification of a large number of genes induced by salt.

Salt tolerance is a multigenic trait and a number of genes categorized into different functional groups are responsible for encoding salt-stress proteins (Parida and Das, 2005).

In order to identify salinity tolerant date palms, evaluation of four varieties was conducted using fourteen random primers to detect the DNA polymorphism. Randomly amplified polymorphic DNA (RAPD) technique was employed to characterize these varieties. Primer OPD-02 distinguished Bugal white, which proved to be salinity tolerant, with a DNA fragment of about 1200 bp (Kurup et. al, 2009). Sedra et. al, (1998) used RAPD marker system as a tool for the identification of date palm cultivars and examined 43 cultivars from Morocco. RAPD markers showed considerable difficulties when characterizing cultivars, and these difficulties include mainly low polymorphisms, irreproducibility and lack of evident organization. Microsatellite markers have been applied to assess the genetic relationships of 45 date palm cultivars for salinity tolerance collected from Sudan and Morocco (Elshibli and Korpelainen, 2008).

Somaclonal variations in tissue culture-derived date palm plants using isoenzyme analysis and activities of peroxidase (PER), polyphenol oxidase (POD) and glutamate oxaloacetate (GOT) and randomly amplified polymorphic DNA (RAPD) fingerprints were analyzed for salinity. The frequency of somaclonal variations was found to be age dependent. Similar isoenzyme patterns for PER and GOT were detected in all analyzed plants (Saker et. al, 1999).

5. Remote sensing techniques

The internal status of plants grown in saline environment is not clearly observable particularly when dealing with halophytes such as date palm. Response of halophytes to salinity needs longer time to be measurable using usual experimental methods. Satellite and digital imagery play a considerable function in remote sensing, offering great information about the area studied. It has the ability to observe vegetation changes at different periods, which assists in the study of vegetation change quickly and precisely (Alhammadi & Glenn, 2008; Howari, 2003; Jackson, 1986). Several attempts were carried out using various satellite sensors to study the date palm responses to salinity (Harris 2001; Alhammadi & Glenn 2008).

One of the recognized techniques of satellite imaging is to map the vegetation through change detection. This technique is commonly used to observe vegetation changes at different time periods, providing quick and precise information of the plants condition. Since plant is a dynamic component, any vegetation change occur can be detected using a comparison of several images from different periods.

The technique simply depends on the implementation of vegetation indices (VI) obtained from multispectral imagery, such as Soil Adjusted Vegetation Index (SAVI) and Normalized Difference Vegetation Index (NDVI). Vegetation indices combine the low reflectance in the visible region of the electromagnetic spectrum (red) with the high reflectance in the near infrared band (NIR). When a correlation between VI and the vegetation biomass is found, any decline in the plant pigment or condition can be detected by the difference of the index images (Tucker 1979).

It has been recognized that in the saline environment, the plant excludes the salts from the cytoplasm accumulating them outside the cells. Therefore, water moves from the cell to outside to accommodate the ion changes causing dehydration of the cell (Volmar et al., 1998). The NIR reflectance of the electromagnetic spectrum is highly affected by the cellular structure of the leaves, while the short wave infrared region is highly affected by the water content in the leaves (Gausman et al. 1978; Gausman 1985; Tucker 1980). In healthy active vegetation, chlorophyll is a strong absorber in the red region, while the cellular structure is a strong reflector in the NIR region. On the other hand, unhealthy vegetation has a lower photosynthetic activity causing increase reflectance in the red region and decrease reflectance in the NIR region (Weiss et al. 2001). Based on these findings, several studies were able to correlate spectral characteristics and vegetation health (Alhammadi and Glenn 2008; Peñuelas et al. 1997; Wiegand et al. 1992).

However, date palm tree was not intensively studied with remote sensing due to the special characteristics of canopy structure and the variations of the tree spacing (Harris 2001, Alhammdi and Glenn 2008, Alhammadi 2010). Alhammadi and Glenn (2008) used two types of satellite sensors, Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) to study the health of date palm trees grown in salt-affected environment. They implemented change detection technique from two dates 1987 and 2000 using SAVI, which work more with areas of low vegetation cover. They found that a serious decrease in date palm trees health was associated with increased salinity levels. Although, the official census data show a general increase in agriculture lands, the condition and the production of date palm decreased. They recommended using high resolution sensors for future studies due to the canopy structure of the palm trees and extent of background soil. In another study, Alhammadi (2010) investigated the ability of using high resolution satellite sensor (QuickBird) with pixel size of 60 cm to evaluate growth rate of eighteen cultivars of date palm trees grown in three salinity levels (5, 10, 15 dS m^{-1}) during years 2003 and 2008. The results showed that QuickBird sensor was able to detect significant variations in the growth of date palm cultivars at the three salinity levels in year 2008. Furthermore, date palm trees health were highest in year 2003 and started to decrease by time. Further investigations are needed to develop a consistent correlation between the date palm growth parameters on the ground and vegetation indices of satellite images.

6. Conclusion

Date palm growth and development with regard to salinity tolerance and use of remote sensing diagnostic tools are discussed in the review paper. The paper provides information on two major aspects classified as salinity stress in relation to soil and plant response with emphasis morphological, physiological, biochemical, and molecular basis of salt tolerance in date palm in seedling, vegetative and reproductive phases. In general, salinity can reduce plant growth through osmotic effects, toxicity of ions, nutrient uptake imbalance, or a combination of these factors. Results of studies indicated that there are differences in salt tolerance between date palm cultivars, which appear to be related to the salt exclusion mechanisms by the root parts (Greenway and Munns 1980), resulting in reduced Na^+ translocation to the shoots. Khnaizi, Lulu, Nabtat Safi, and Razez cultivars showed greatest growth parameters and Na:K ratios that indicates higher sodium discriminations from plant parts than other cultivars. Efforts should be made to compare the relative sensitivity of various cultivars to salt, uptake and transport of NaCl and their interactions with nutrients. In addition, it is required to identify differences in salinity tolerance between date palm cultivars, and thus start new breeding programs to improve salinity tolerance. In order to bring arid and semiarid regions into production, future researches should focus on using halophytes as an alternative crop and seawater for irrigation. Remote sensing as a tool to detect salinity stress should be effectively applied in future date palm development programs.

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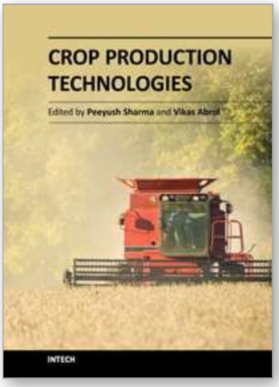

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Crop production depends on the successful implementation of the soil, water, and nutrient management technologies. Food production by the year 2020 needs to be increased by 50 percent more than the present levels to satisfy the needs of around 8 billion people. Much of the increase would have to come from intensification of agricultural production. Importance of wise usage of water, nutrient management, and tillage in the agricultural sector for sustaining agricultural growth and slowing down environmental degradation calls for urgent attention of researchers, planners, and policy makers. Crop models enable researchers to promptly speculate on the long-term consequences of changes in agricultural practices. In addition, cropping systems, under different conditions, are making it possible to identify the adaptations required to respond to changes. This book adopts an interdisciplinary approach and contributes to this new vision. Leading authors analyze topics related to crop production technologies. The efforts have been made to keep the language as simple as possible, keeping in mind the readers of different language origins. The emphasis has been on general descriptions and principles of each topic, technical details, original research work, and modeling aspects. However, the comprehensive journal references in each area should enable the reader to pursue further studies of special interest. The subject has been presented through fifteen chapters to clearly specify different topics for convenience of the readers.

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