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A review on salinity adaptation mechanism and characteristics of *Populus euphratica*, a boon for arid ecosystems

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ABSTRACT

Salinity is a worldwide problem, occurring in all climatic regions. *Populus euphratica* is a diverse riparian species, which survives in saline environments, and have numerous adaptation capacities to combat salinity stress. In this review, we collected available research information about the effect of salinity on its physiology, morphology, anatomy with relation to hydraulic traits. The information showed that *P. euphratica* can progressively tolerate high salinity stress by changing its stomatal aperture, activities of antioxidant, xylem anatomy and hydraulic conductivity. It can be a good option for afforestation and reclamation of salinized lands, which may be an option for increasing the production of feed stocks for non-food goods, and positive impact on climate.

Contents

1. Introduction

Currently around 6% of the world's land area are salt affected [1,2], and increasing due to improper irrigation regimes or use of saline water. *Populus euphratica* is a phreatophytic tree, able to grow in saline environments, and more adaptable in saline soil [3–5]. It is unique

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woody tree for afforestation in arid, semi-arid and in barren lands, where it acts as a sand stabilizer [6]. Poplar forests are dominant species of the desert ecosystem, expanding afforestation in saline areas or with saline ground water. It may be an option for increasing the production of feed stocks for domestic use [7].

The high salinity responds to modification in wood anatomy such as changes in tracheary elemental density, lumen area and alterations in cell wall, morphology i.e. stomatal density, shape, and size, plant growth, hormones synthesis and also on activities of anti-oxidative enzymes. Among various poplar species, *Populus alba* and *P. euphratica* are found to with-stand moderate to high salinity [3,5] and best characterized for salt tolerance till date [8,9]. Researches on molecular basis of salt resistance in plants have been mainly focused on herbaceous plants [10] and rarely studied in woody plants [7]. The main targets of salt effects are on vegetative growth, anatomical changes, flowering, fruit development, and seed germination, accompanied by metabolic dysfunctions, decreased photosynthetic rates, protein and nucleic acid metabolism and enzymatic activity. The review deals with the effects of salinity on possible modifications in *P. euphratica*. This information may helpful to assessing its capacity to adapt high saline environments.

2. Origin, distribution and characteristics of *P. euphratica*

The genus *Populus* L. is a member of the Salicaceae family and dominant tree species in arid areas (annual precipitation 50 to 250 mm), distributed in many climatic zone and adapted to diverse conditions, resulting in a rich source of variation in tree morphology, anatomy, physiology and respond to abiotic and biotic stress [11]. The Euphrates poplar was described by Olivier in 1801 and named after the Euphrates River, where the large populations of *P. euphratica* were existed [12,13]. The distribution of *P. euphratica* is spread from Morocco in the west over North Africa, West and South Asia to Central Asia as far as Mongolia [14]. It is also found in the India, Pakistan, Kazakhstan, Mongolia, Iran and China as well.

The Tarim River and the Heihe River are two most important and largest inland rivers in Western China. Their basin area is known as green corridor covered with lush riparian forests. World's 54% area of *P. euphratica* vegetation is spread in this basin [15], and mainly distributed on river-banks or areas with deep water tables [16,17]. *P. euphratica* is a medium size deciduous and anemophilous tree. There are big variation in plant height, 6 M in Spain, 10 M in Turkey & India, 15 M in China & Pakistan; most of them shaped like sparse shrubs, bark light grayish-brown, lower part stripe cracked, sprouting branch slender and round smooth or with villi, bud elliptical smooth brownish and about 7 M long. The male catkin grows about two or three, towards the end of the flowering period, up to 7 cm in length. The purple red anthers give to the inflorescence a reddish appearance. Female catkins are 2–5 cm long, and grow up to 10 cm in length during ripening period [18]. Similar results were obtained by Shiji et al. (1996), the length of catkin varied 3–6 cm [19]. Whereas, Soleimani et al. (2014) suggested that, catkin length is genetically variable [20].

An optimal condition for germination is bright sunlight, temperature between 25 and 30 °C, water saturated soil and salt below than 0.2%. Such conditions are increased germination rate more than 80% [21]. The seedling is devoted mainly for the root system and forms prominent tap roots that allow the plant to keep contact to the ground water [22]. Wiehle et al. (2009) measured an average shoot length of 8.1 cm whereas, an average root length of 41.7 cm in one year old seedling [23]. The longest tap root found in one year old seedlings were measured a solid 119 cm. When plant reaches an age of 10–15 years, they started to propagate clonally via root suckers, produced on horizontally running lateral roots, close to the soil surface up to 40 M away from the parental tree. Poplar requires 4–5 years to become sexually mature [24]. Root suckers also triggered by exposure or damaging of the root system [23]. Since generative regeneration is not possible in established stands, vegetative reproduction becomes the only means of rejuvenation and expansion, after the first phase of colonization [17]. The distance root suckers have ability to form chains of root suckers [23]. The spatial arrangement and size of old clones is further illustrated the importance of clonal growth in forming adjoining forests [25].

A waxy cuticle and sunken stomatal aperture are the most prominent concessions to the harsh climatic conditions. These obligate phreatophytes require constant access to the ground water table. Even short term disconnection from their water supply leads to degradation and execution of whole stands [17]. Poplars are found in a great variety of forest ecosystems, from boreal to sub-tropical, and from mountains to riparian. In some environments such as boreal forests and in large river valleys, they form large stands, while in other situations they are found as small stands or groups of trees. The Poplar species and their hybrids vary greatly in their adaptability to climate, although all are nutrient demanding and perform best with an abundant and continuous supply of moisture. *P. euphratica* have characteristics to adopt high salinity, long term soil flooding [26] and severe drought conditions [27].

3. Mechanism of salt tolerance

Plants develop several biochemicals, physiological, anatomical and molecular mechanisms to deal with salinity stress [28]. The mechanism of salt tolerance is to minimize the salt taken up by roots, and distribute it in tissue and cellular organs for avoid toxic concentration in the cytosol of leaves, which transpire about 50 times more water than they retain. Most of the plants exclude approximately 98% of soluble salts in the soil, allowing only 2% to be transported in the xylem to shoots. In general, salt tolerant plants express two different types of responses: (a) mechanisms that minimize the entry of the salts into the plant and (b) mechanisms that partition salts at the tissue and cellular level to avoid toxicity in cytoplasm [29].

Plant adaptations to salinity involves a wide range of mechanisms that generally involve the control of uptake of Na, Cl, and their distribution within the plant [28,30]. Effect of salinity is expressed in the two phase e.g. osmotic effect and salt specific effect [7]. The first phase of salinity is effect on plant growth, which occurs immediately after exposure of NaCl. This response is due to the osmotic changes outside the root causing imbalance in cell water relations (osmotic effect). The osmotic effect initially reduces the ability of the plant to absorb water. The other effect of salinity is much slower, taking days, weeks or months and resulted accumulation of salt in leaves, leading to the salt toxicity in the plant, primarily in the older leaves (i.e. salt-specific effect), caused death of leaves and reduced total photosynthetic leaf area [31].

The capability of *P. euphratica* to tolerate high salt concentrations has been described as a root-born processes such as limited ion loading into the xylem [32,33] and high capacity to exclude NaCl ions at the root level [34]. In mild saline condition, *P. euphratica* showed three key mechanisms of salt tolerance. The primary mechanism had a strong control over NaCl ions. Secondly, the trees allocated large proportions of NaCl into the leaves, which served as a salt elimination mechanism. Thirdly, the tree tolerate high foliar Na^+ concentrations through a combination of osmotic adjustment using sucrose and probable sequestering of Na^+ in the apoplast [35]. Moreover, there can be large differences in salt tolerance capacity of plants at the juvenile and maturity stage.

Salinity can directly affect nutrient uptake, such as Na^+ reducing K^+ uptake or by Cl^- reducing NO^{-3} uptake, and also cause a combination of complex interactions that affect plant metabolism, susceptibility to injury or internal nutrient requirements. Therefore, high concentrations of Na^+ and Cl^- ions in the soil may depress nutrient ion activities and create critical ratios of Na^+/Ca^{2+}, Na^+/K^+, Ca^{2+}/Mg^{2+} and Cl^-/NO^{3-} ions. As a result, the plant becomes susceptible to osmotic and specific-ion injury as well as to nutritional disorders which may reduce growth [36]. Potassium is the most abundant cation in higher plants, and essential for various physiological processes, and plays an important role in stomatal movements and maintaining cation anion ratio. It is also essential for osmo-regulation, cell-expansion, stomatal movements and enzyme