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The effect of salinity on water use efficiency of *Balanites aegyptiaca* (L.) Del.

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ABSTRACT

The effects of salinity stress on photosynthesis, transpiration and water use efficiency of *Balanites aegyptiaca* (L.) Del. (Balanitaceae) were measured in potted plants in a greenhouse. Photosynthetic rates were determined on plants watered with NaCl and $CaCl_2$ (1:2) solutions of 0, 12, 24, 36, 60 and 72 dS m^{-1} conductivity. Increasing concentrations of NaCl and $CaCl_2$ in the watering solution decreased the photosynthesis and the transpiration rates and increased the water use efficiency at 24 dS m^{-1}. Increasing $CaCl_2$ at higher salinity levels (36 -72 dS m^{-1}), may cause partial elimination of the NaCl effects on photosynthesis and transpiration rates.

KEYWORDS: *Balanites aegyptiaca,* Balanitaceae, salinity, photosynthesis, transpiration

INTRODUCTION

Balanites aegyptiaca (L.) Del. (Balanitaceae) is a drought-resistant multipurpose tree ideally suited for cultivation in the arid lands of northern tropical Africa, Middle East and India. The wood of *Balanites* is used as fuel, charcoal and timber, its fruits as food and medicine, while its leaves are good as forage (Hall & Walker 1991). Once established, the tree appears to be exceptionally tolerant to disturbance, drought and flooding that makes it a valuable species for stressful conditions (Herlocker *et al.* 1981).

In arid areas salinity often inhibits plant growth, disturbs pigment composition, and inhibits photosynthesis of plants. The effects of salinity depend on salt concentration and ionic composition of the root medium, irradiance, humidity, plant species and stage of plant growth. The decline of photosynthetic rates is generally attributed to stomatal closure under salt stress condition that reduces intercellular CO_2 concentration (Jones 1992; Yang-Jian *et al.* 1995; Panneerselvam *et al.* 1997). Under water stress, salinity inhibits the growth of plant by lowering the water potential in the root medium, and altering plant ionic status due to toxicity (Greenway & Munns 1980). Wild (1988) summarized the main effects of salt damage as: toxic hazard and physiological drought which have a direct effect on osmosis; increase hydraulic resistance of roots and leaves; alter the hormone levels that influence growth rate; damage the photosynthetic mechanisms; affect ion competition, and increase the energy use to maintain the K: Na balance.

Visible outcomes of salinity stress on plants are rather late manifestations of severe stress, which are very difficult to measure. Hence, physiological parameters are most convenient and suitable means to study the response mechanisms of salt tolerance (Tiwari *et al.* 1997).

The objective of this study is to determine physiological responses of *Balanites* seedlings to severe salinity stress in controlled environmental conditions. In the longer term these studies will help to develop a suitable management system for regeneration of natural and cultivated populations of these trees.

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MATERIALS AND METHODS

Balanites seeds collected from Wadi Allaqi during May 1996 were germinated in pots containing one kg of clay and sand (1:1) mixture. Thirty-six seedlings were selected and transferred to a growth chamber with day/night temperature of 30/25° (±1°C) at 16:8 L: D cycle. High-pressure sodium lamps supplied photoperiod irradiance of 1000 wm^{-2} for 16 hours. Salt treatment was carried out by watering six-week-old seedlings (six seedlings for each level of salinity treatment) using different concentrations of $CaCl_2$ and NaCl in water solution at 2:1 ratio. The salts were dissolved in distilled water to obtain watering solutions with different electrical conductivity (12, 24, 36, 60 and 72 dS m^{-1}). Plants watered with distilled water (0 dS m^{-1}) were used as control. The salt content of irrigation water is commonly reported by measuring electrical conductivity (Wild 1988). Francois *et al.* (1984 & 1988) studied the effects of salinity on germination, grain yield and vegetative growth of different plants by adding to the irrigation water different concentrations of NaCl and $CaCl_2$ salts (1:1 by weight) and used the electrical conductivity to measure the salinity of the irrigation water.

In the present experiment the net photosynthetic and transpiration rates were measured in salt treated plants by using an infra-red gas analyser (LI-COR 6400) at 0, 20, 40, 60, 100, 150, 200, 350, 500, 700, 1000, 1500 and 2000 μmols $m^{-2}s^{-1}$ Photosynthetically active radiation (PAR) levels that allows rapid and direct gas analysis and gas exchange characteristics of leaves (Pearcy *et al.* 1989; Parkinson *et al.* 1990). Photosynthetically active radiation corresponds to visible light but represent only the small part of it falling between 400 - 700nm (Pearcy *et al.* 1989). A cold lamp, LED type 670 nm was used to supply artificial light. Transpiration and photosynthesis rate measurements were carried out under an ambient air temperature of 30 ± 1°C, 40 % air humidity and 400 PPM μmol mol^{-1} CO_2. Water use efficiency (WUE) is the ratio of net assimilation to water transpired, and its unit expressed in molar units, μmol CO_2/ mmol H_2O (Jones 1992). Water use efficiency (WUE) of *Balanites* under different salinity rates was calculated by applying the equation: WUE = uptake CO_2 μmol /lost H_2O mmol (ADC Ltd. 1992).

Statistical analysis was carried out using Minitab programme (two-way analysis of variance) to estimate the significance in changes in photosynthesis, transpiration and water use efficiency which could be attributed to salinity treatment and PAR, and one-way analysis of variance was used to estimate the significance in changes of photosynthesis, transpiration and water use efficiency at different salinity levels between 500 and 2000 μmols m^{-2} s^{-1} (PAR).

RESULTS AND DISCUSSION

Photosynthesis rate of *Balanities* at different level of salinity (0, 12, 24, 36, 60 and 72 dS m^{-1}) are shown on figure 1 (a – f), respectively. Plants that were treated with distilled water (0 dS m^{-1}) at zero μmols m^{-2} s^{-1} PAR, showed negative photosynthetic rate of -0.412 μmol CO_2 m^{-2} s^{-1} (Fig. 1a). This is probably due to the dark reaction and the absence of Photosynthetically active radiation (PAR), an essential factor for photosynthesis to take place. This cannot be photorespiration, which is the efflux of CO_2 stimulated by light, since there was no PAR. Photosynthesis rate reaches zero μmol CO_2 m^{-2} s^{-1} at a PAR between 0 to 20 μmols m^{-2} s^{-1}, which is known as the compensation point at low PAR (Fitter *et al.* 1993). At this point, assimilation rate is equal to respiration rate and as a result no net growth occurs. Photosynthesis rate increased sharply from 1.82 to 4.831 μmol CO_2 m^{-2} s^{-1} at low PAR (20 - 350 μmols m^{-2} s^{-1}). At higher PAR (500-2000 μmols m^{-2} s^{-1}) the rate of photosynthesis was directly proportional to PAR ranging from 5.695 to 7.119 μmol CO_2 m^{-2} s^{-1}.

For plants watered with 12 dS m^{-1} solution (Fig. 1b), the photosynthesis rate stabilized at lower PAR (150 μmols m^{-2} s^{-1}) than plants watered with 0 dS m^{-1} solution. The photosynthesis rate at higher PAR (200-2000 μmols m^{-2} s^{-1}) is less and stabilised at almost half the value (3.298 - 4.122 μmol CO_2 m^{-2} s^{-1}) of plants watered with distilled water. Furthermore, increasing the salt concentration of the watering solution to 24 dS m^{-1} caused a considerable decrease in net photosynthetic rate even at high PAR (Fig. 1c). This may be due to the inhibitory influence of Na on chlorophyll and hence on the plant growth. Khavari-Nejad & Chapazadeth (1998) reported similar inhibitory effects of salinity on photosynthesis of various plants.

At salt concentrations of 36 dS m^{-1} and above (60 and 72 dS m^{-1}) the photosynthesis rate was increased considerably, compared with its values at the lower salt concentration of 24 dS m^{-1}. It is interesting to note that at high salinity of 72 dS m^{-1} (Fig.1f), the shape of the curve was similar to that without salts (Fig.1a) and the photosynthesis rate was related significantly to PAR.

The salt treatment at low concentrations of salts changed the photosynthetic light-response curve (Fig. 1b and c) by increasing the initial slope (quantum yield) and decreasing photosynthetic capacity at high photosynthetic photon flux density of PAR (Fig. b to f). As a result, the quantum use efficiency decreased, attributed to the declining stimulation and mesophyll conductance (Xu *et al.* 1994). At high salt concentrations (Fig 1 d, c and f) the photosynthetic capacity increased in accordance with PAR as it did at control (Fig. 1a)

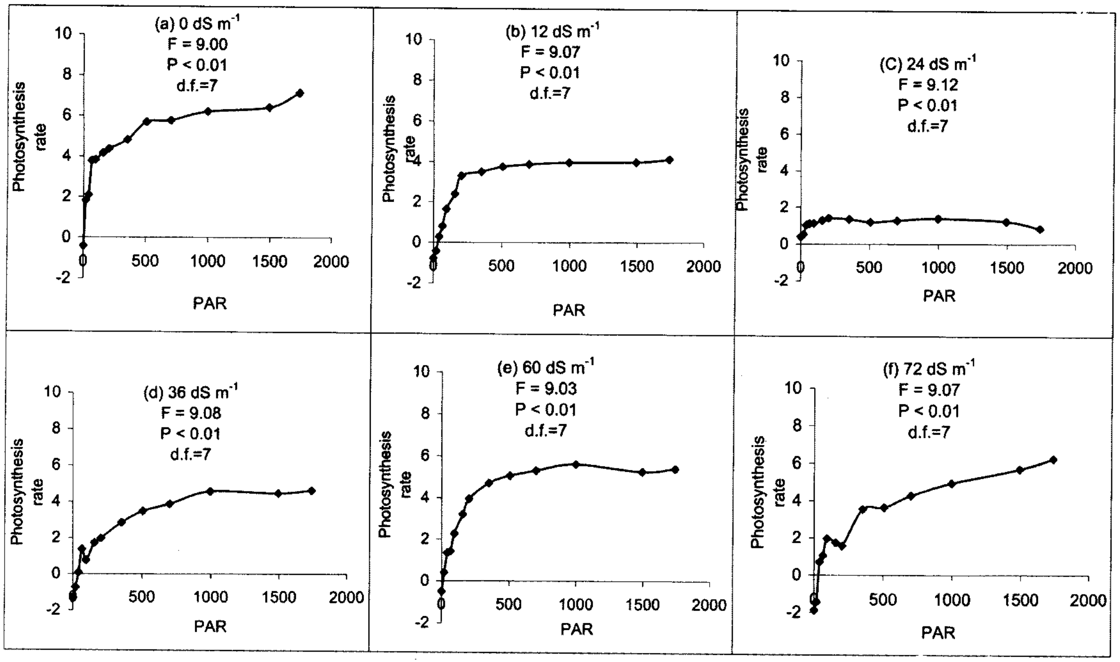

Fig. 1: Photosynthesis rate (μmol CO_2 m^{-2} s^{-1}) of *Balanites aegyptiaca* seedlings in relation to Photosynthetically active radiation PAR (μmols m^{-2} s^{-1}) at (a) 0 dS m^{-1}; (b) 12 dS m^{-1}; (c) 24 dS m^{-1}; (d) 36 dS m^{-1}; (e) 60 dS m^{-1} and (f) 72 dS m^{-1}. (Two-way analysis of variance: Photosynthesis rate to PAR: F=23.66; P = 0.000; D.F.=77. Photosynthesis rate to salinity: F=19.29; P= 0.000)

The response curves of transpiration rates of *Balanites* at different level of salinity are shown on figure 2 (a-f). In the control, without salts added (0 dS m^{-1}), transpiration rates increased slowly at low PAR (0-350 μmols m^{-2} s^{-1}), with a sharp increase at higher PAR (500-2000 μmols m^{-2} s^{-1}) (Fig. 2a) that could be due to stomatal response to light. Maximum stomatal aperture is usually achieved with irradiance greater than about a quarter of full summer sun or about 400 mmols m^{-2}

s^{-1} PAR (Jones 1992). At salinity levels of 12 dS m^{-1}, 24 dS m^{-1} and 36 dS m^{-1} (Fig.2 b, c and d, respectively) there was almost no response of transpiration rate to the PAR. A sharp decrease in transpiration was observed at 24 dS m^{-1}. Similar results of decreasing transpiration under salinity stress were observed in experiments with the desert plant, *Tamarix aphylla*, over a full range of PAR (Hagemeyer & Wasiel 1989). These authors suggested that this was due to a decrease in water uptake by the roots. With increasing salinity to 60 dS m^{-1} and 72 dS m^{-1} the transpiration rate increased accordingly, and also showed a significant positive response to PAR (Fig. 2e and f).

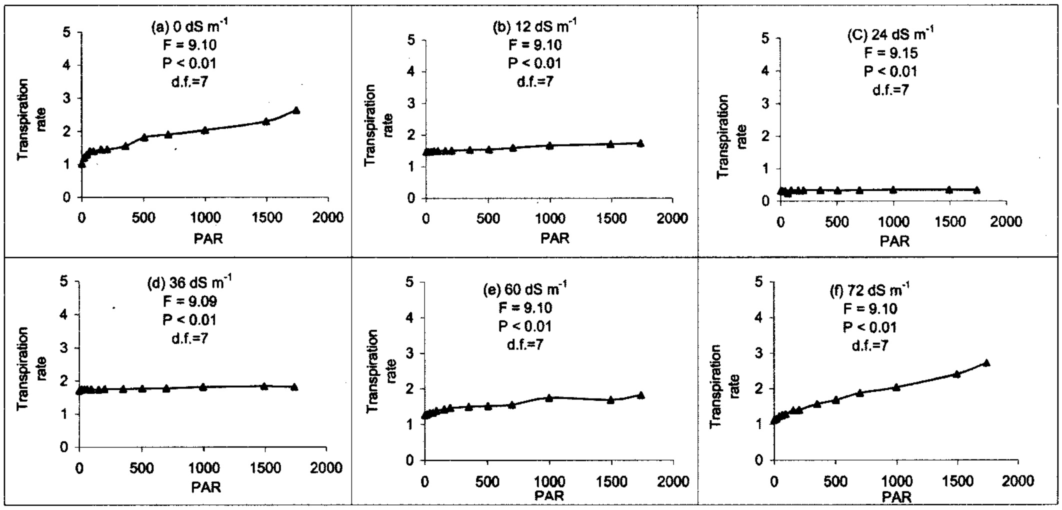

Fig. 2: Transpiration rate (mmols H_2O m^{-2} s^{-1}) of *Balanites aegyptiaca* seedlings in relation to Photosynthetically active radiation PAR (µmols m^{-2} s^{-1}) at (a) 0 dS m^{-1}; (b) 12 dS m^{-1}; (c) 24 dS m^{-1}; (d) 36 dS m^{-1}; (e) 60 dS m^{-1} and (f) 72 dS m^{-1}. (Two-way analysis of variance: Transpiration rate to PAR: F=5.75; P = 0.000; D.F.=77. Transpiration rate to salinity: F=79.18; P= 0.000)

Water use efficiency (WUE) of *Balanites* seedlings at different level of salinity (0, 12, 24, 36, 60 and 72 dS m^{-1}) are shown in figure 3 a-f. In the control without salts, (Fig. 3a), WUE increased sharply at low PAR and reached a maximum of 3.120 µmol CO_2/mmol H_2O at 350 µmols m^{-2} s^{-1}. A slight decrease of WUE was seen at higher PAR from 500 to 2000 µmols m^{-2} s^{-1}.

In plants watered with 12 dS m^{-1} solution (Fig. 3b), the WUE showed a similar response to PAR, but its value was lower in comparison with plants watered without salts. At 24 dS m^{-1} the WUE increased considerably in comparison with all treatments applied, both above and below this level of salinity. The curve (Fig. 3c) also indicates a considerable decrease of WUE at high PAR. Liang & Maruyama (1995) observed that under drought stress, physiological parameters (leaf conductance, photosynthesis and transpiration) of *Alnus firma* plant decreased the leaf water-use efficiency increased. Here, the potential transpiration probably affected the plant sooner than potential photosynthesis, and hence their ratio (CO_2 uptake/ H_2O lost) increased. On the other hand, in a greenhouse pot experiment with *Medicago sativa* cv. *gilboa* conducted by Khan *et al.* (1994), increasing salinity (0-100 mM NaCl) caused a decrease in the photosynthetic rate, stomatal conductance, water use efficiency and leaf area, while transpiration rate was least affected. This showed that the physiological response of different species to water stress and salinity varies considerably.

With increasing salinity levels (36 dS m^{-1}, 60 dS m^{-1} and 72 dS m^{-1}) the water use efficiency at high PAR level was similar to those at low salinity. However, at high salt stresses the shape of the curves in Fig. 3 (d, e and f) showed the slow increase of WUE at low PAR.

If the curves of water use efficiency of *Balanites* seedlings at control (0 dS m^{-1}) and high salt concentrations (60 dS m^{-1}) were compared, a small difference could be observed in both curves, especially high PAR, in spite of statistical analyses of variance which indicate significant differences in water use efficiency to both PAR and salinity treatment ($P<0.001$).

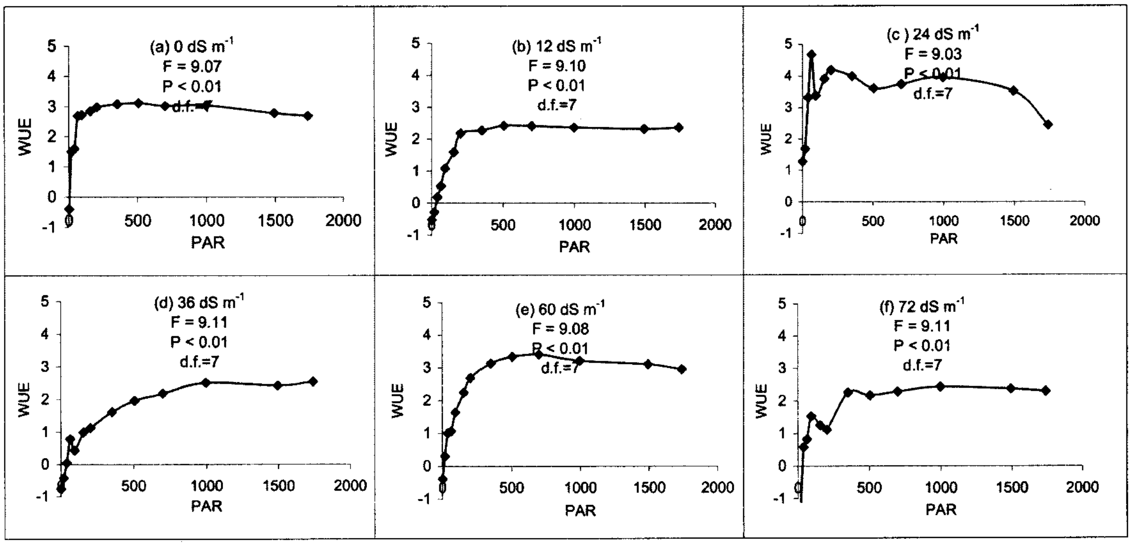

Fig. 3: Water use efficiency WUE (µmol CO_2 /mmols H_2O) of *Balanites aegyptiaca* seedlings in relation to Photosynthetically active radiation PAR (µmols m^{-2} s^{-1}) at (a) 0 dS m^{-1}; (b) 12 dS m^{-1}; (c) 24 dS m^{-1}; (d) 36 dS m^{-1}; (e) 60 dS m^{-1} and (f) 72 dS m^{-1}. (Two-way analysis of variance: Transpiration rate to PAR: F=5.75; P = 0.000; D.F.=77. Transpiration rate to salinity: F=79.18; P= 0.000)

Our results showed that *Balanites aegyptiaca* seedlings are sensitive to salts at low salinity levels applied in this experiment. However it should be mentioned that lowest salinity level used (12 dS m^{-1}) is already considered to be saline irrigation water. Saline water at 24 dSm^{-1} is harmed for the growth of seedlings by decreasing both photosynthesis and transpiration rate. Because the transpiration rate declined more rapidly than photosynthesis, it led to an increase of water use efficiency. Furthermore increasing the concentration of salt showed positive effects on CO_2 uptake and increased the transpiration rate of seedlings, hence the water use efficiency increased accordingly. It is important to note that the higher PAR values (above 500) characteristic of hot arid climates had little effect on water use efficiency of *Balanites* seedlings at high salinity levels.

The mechanism of adaptation of these plants to high salinity was not the purpose of the present study. However, we have some suggestions regarding the water solutions. Use of a 2/1 ratio of Ca^{++} /Na^{+} for the watering solution resulted in an exponential increase of Ca^{++} at higher levels of salt concentration. Most probably the increasing calcium altered or reduced the influence of sodium hazard. As reported by many authors, the application of calcium reduces the sodium effects and results in increased plant growth (LaHaye & Epstein1971; Hanson 1984; Cramer *et al.* 1985, 1986, 1987; Kent & Lauchli 1985; Kurth *et al.* 1986; Khavari-Nejad 1988). Panneerselvam *et al.* (1997) reported that NaCl salinity increased respiration rate, further accelerated in the presence of $CaCl_2$. The importance of Ca^{2+} in maintaining membrane integrity against leakage from roots was also demonstrated in the root-pathogen interaction (Spiegel *et al.* 1987). Tolerance of *Balanites* to sodium concentration of 3840 ppm was reported by Firmin (1971).

The calculated, the water uses efficiency of *Balanites* seedlings is high at low salinity stress mainly because of very low transpiration rates attributed to sodium hazard. However, high salinity had little effect on the water use efficiency of *Balanites* seedlings, allowing this plant to be placed in the group of saline tolerant plants.

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الملخص العربى

تاثير الإجهاد الملحي على كفاءة استخدام الماء فى نبات الهجليج

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فى هذا البحث تم دراسة تأثير تركيزات مختلفة من الملحية على كل من معدلات البناء الضوئى والنتح وكفاءة استخدام الماء فى نبات الهجليج. كما تم قياس تلك التأثيرات على بادرات مزروعة فى أصص وداخل صوبة زراعية رويت بمحاليل ملحية (خليط من كلوريد الصوديوم وكلوريد الكالسيوم) ذات قيم توصيلية كهربية مختلفة (٠، ١٢، ٢٤، ٣٦، ٦٠، ٧٢ ديسيمنز/م). وقد أثبتت التجارب أن التركيزات المتزايدة لملحى كلوريد الصوديوم وكلوريد الكالسيوم بنسبة ١:٢ فى مياه الرى قد قللت كلا من معدلات البناء الضوئى والنتح وزادت من كفاءة استخدام الماء عند درجات ملحية (١٢، ٢٤ ديسيمنز/م). ومن التجارب تأكد أن الزيادة من ملح كلوريد الكالسيوم عند المستويات الملحية العالية (٣٦، ٧٢ ديسيمنز/م) سببت الغاءاً جزئياً لتأثير ملح كلوريد الصوديوم على كل من معدلات البناء الضوئى والنتح.