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Original research

Water Use Efficiency of Acacia seyal (Del.) in extreme arid environment prevails in South-Western Desert, Egypt

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Abstract:

The present investigation involves the studies of water use efficiency of *Acacia seyal* (Del.) seedlings under extreme arid conditions. Experiments were performed in a hyper arid environment to study the effects of drought stress using different water regimes at 12%, 9%, 6%, 4% and 2%. Calculated instantaneous water use efficiency was measured under full Photosynthetic Active Radiation range (0-2500μmols^{-1}m^{-2}). *Acacia seyal* showed maximum photosynthesis rate at 9% soil moisture content, and at high Photosynthetic Active Radiation levels. Maximum transpiration rate recorded at 9% soil moisture content at highest Photosynthetic Active Radiation. The maximum instantaneous water use efficiency was noticed at 4% soil moisture content at high Photosynthetic Active Radiation level. *Acacia seyal* maximized photosynthesis rate and minimized transpiration rate, giving maximum instantaneous water use efficiency at the high Photosynthetic Active Radiation and low soil moisture content levels.

Keywords: Drought stress, photosynthetic Active Radiation, photosynthesis, transpiration rate, water use, Riverian plant.

Abbreviations: *Pn*: photosynthesis rate, *E*: transpiration, *WUE*: instantaneous water use efficiency, *PAR*: photosynthetic active radiation and *SMC*: soil moisture content.

INTRODUCTION

Drought stress is the most prevailing environmental factor restricting plant production (Bray, 1997) and there are continuous changes in climate which arising in severe drought conditions (Dai, 2012; Basu *et al.*, 2016). The effect of drought stress is recognized as a decline in photosynthesis and growth at all plant regimes, and it is concerned with changes in carbon and nitrogen metabolism (Cornic and Massacci, 1996; Mwanamwenge *et al.*, 1999; Yordanov *et al.*, 2003). The reduction of drought stress related to stomatal closure in response to low soil water content, which leads to the minimized of intake of CO_2 (Chaves, 1991; Cornic, 2000; Flexas *et al.*, 2004; Ahmad *et al.*, 2011). Plants in arid environments have developed physiological mechanisms to resist drought stress (Kozlowski and Pallardy, 2002; Elfeel and Alnamo, 2011).

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Acacia seyal exists in the Nile region including the Delta, Valley and Faiyum; Nile banks and Islands (Boulos, 1999). Woods of *Acacia seyal* used as a fumigant, leaves and bark used for treating gastric ulcers, gum is extracted from the plant therapeutic significance against rheumatism, and pods are useful in feeding in livestock (Boulos, 1983). *Acacia seyal* considered as threatened due different man activities such as cutting trees for fuel wood and drought fluctuations (ElBahaa, 2012; Marshall *et al.*, 2012; New, 1984; Sinclair *et al.*, 2008).

The aim of the current research was to reveal the physiological mechanisms of *Acacia seal* to resist the combination of drought stress and high irradiance during seedling establishment which in turn help in the restoring and cultivation of endangered endemic species.

MATERIALS AND METHODS

Seed collection from Desert Garden, Aswan University Campus, Aswan, Egypt in May 2015, seed dormancy of impermeable seed coat of *Acacia seyal* was breaked through a pre-germination treatment by immersing seeds in concentrated sulphuric acid (95%) for 10 minutes to weaken seed coat (Danthu *et al.*, 1992; Ndour, 1997; Zetta *et al.*, 2017) then washed with tap water. Seeds were sown directly into plastic pots of 30 cm in diameter and 20 cm deep with four 1.5 mm-holes at the bottom. Soil used in experiment was clay: sand (1:2) (Taher *et al.*, 2006). The experiment was carried out for 16 weeks old of *Acacia seyal* (Del.) under a different *SMC* from 12% (3% above field capacity) to 2% (almost dry) to impose soil water depletion. The soil moisture content in pots is measured by Model 5910A Soil moisture Meter (KIMBLE Glass, Inc.) (Sheded and Radwan, 2008). Measurements of the photosynthesis and transpiration rate were performed by using infrared gas analyzer (IRGA, CI-340) handheld photosynthesis system (CID Bio-Science, Inc.) and measured in *PAR* range (0-2500μmols^{-1}m^{-2}) by module CI-301LA. Six homogenous seedlings were selected and marked for the measurements of gas exchange along different levels of *SMC*. *WUE* was determined using the following formula: Instantaneous Water Use Efficiency = the current net CO_2 assimilation rate (*Pn*)/ the current transpiration Rate (*E*) (Silva *et al.*, 2013).

Two-way ANOVA compares means in groups of two different factors (*SMC* and *PAR*). Each variation term again has an associated number of degrees of freedom (DF) Total: N-1 (N=55 obs.) Factor A: Soil Moisture Content % and Factor B: Photosynthetic Active Radiation. Sum of Squares (SS) = Variation due to this factor Mean Square (MS) = Sum of squares/DF Hypothesis tests for the importance of each factor in the model: F-Tests measure the amount of variation explained by each factor relative to the variation associated with the errors. (Minitab Inc., 1998).

RESULTS AND DISCUSSION

Maximum *Pn* of 3.66μmolm^{-2}s^{-1} was recorded in *Acacia seyal* seedlings kept at 4% *SMC* (Fig 1-b) at 2250μmolm^{-2}s^{-1} (*PAR*). Otherwise negative values of *Pn* were recorded in *Acacia seyal* seedlings (-0.72μmol m^{-2}s^{-1}) at 12% *SMC* and (-0.25, -0.26, -0.27μmol m^{-2}s^{-1}) at 9% *SMC* and (-0.87μmol m^{-2}s^{-1}) at 6% *SMC* and (-0.85, -1.16, -1.77μmol m^{-2}s^{-1}) at 4% *SMC* and (-1.58, -1.45, -1.15μmol m^{-2}s^{-1}) at 2% *SMC* at *PAR* ranged from 0 to 500 μmol m^{-2}s^{-1}. From two-way analysis of variance (Table 1), *Pn* in *Acacia seyal* showed significant changes attributed to differences in both *SMC* and *PAR*, where: $F=3.66$; $P<0.01$ and $F=15.53$; $P<0.0001$, respectively (Table 1.).

Acacia seyal exhibited maximum *E* of 1.45mmol m^{-2}s^{-1} at 9% *SMC* (Fig 2-b) at highest *PAR* (2500μmol m^{-2}s^{-1}). From two-way analysis of variance (Table 1), *E* significant changes of

Acacia seyal were attributed to differences in both *SMC* and *PAR*, where: F=82.93; P<0.0001 and F=3.23; P<0.0001, respectively (Table 1.).

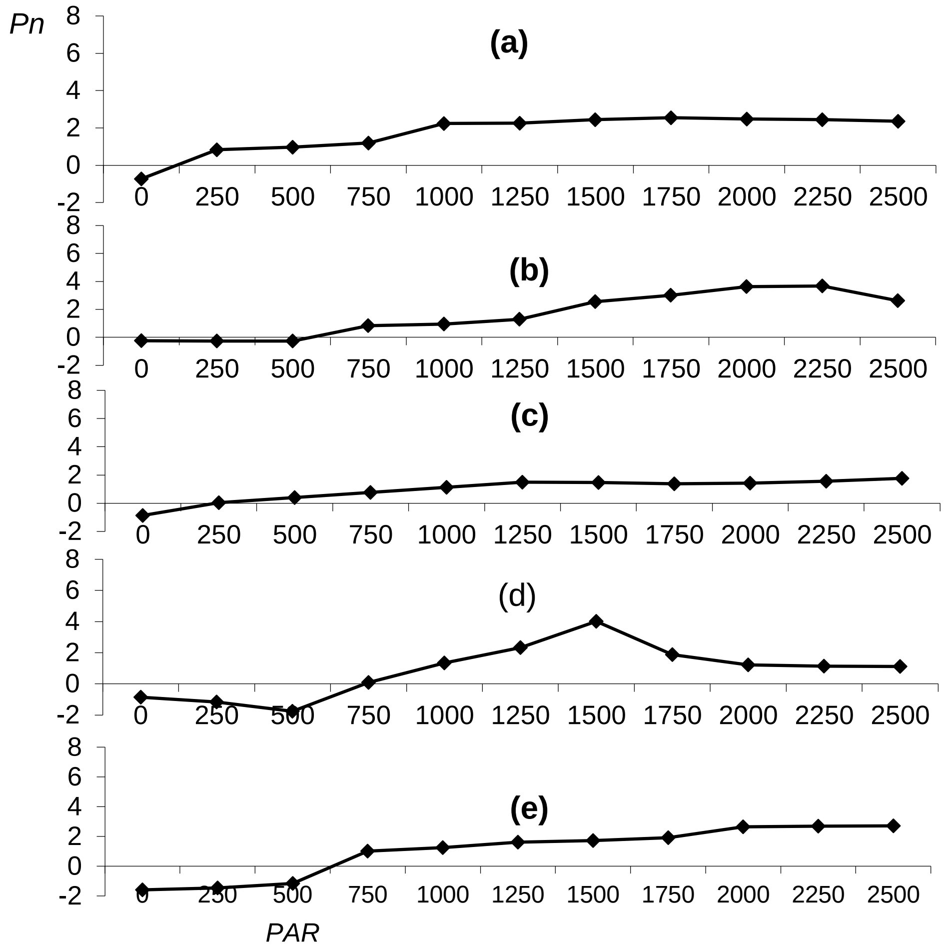

Fig. 1a-e.Photosynthesis rate *Pn* (µmol $m^{-2}s^{-1}$) of *A. seyal* under water depletion (12%, 9%, 6%, 4% and 2%) and at photosynthetic active radiation (PAR) ranged from 0 to 2500 (µmol $m^{-2}s^{-1}$), F=3.66; P<0.01 and F=15.53; P<0.0001, respectively.

The maximum *WUE* (30.8µmol$m^{-2}s^{-1}$/mmol $m^{-2}s^{-1}$) was recorded in *Acacia seyal* seedlings kept at 4% watering regime (Fig 3-d) at *PAR* of 1500µmol $m^{-2}s^{-1}$. From two-way analysis of variance (Table 1), *WUE* changes of *Acacia seyal* showed significant changes attributed to differences in both *SMC* and *PAR*, where: F=9.56; P<0.0001 and F=4.14; P<0.01, respectively (Table 1).

During this study, *Acacia seyal* exhibited different high tolerance mechanisms to drought. Many authors found that drought tolerance is characterized by high productivity via maximizing assimilation in relation to the amount of water availability (Jones, 1992; Radwan, 2007). *Acacia seyal* showed maximum *Pn* under 4% *SMC* at high *PAR* levels. One of the main physiological responses of plant to soil dryness is minimize in leaf conductance to water for keeping sufficient turgor in plant tissues (Nunes *et al.*, 1989; Radwan, 2008). Negative *Pn* values were noticed in *Acacia seyal* seedlings under low *PAR* (0 to 500 µmol $m^{-2}s^{-1}$) accompanied with water depletion. Jones (2014) stated that negative *Pn* values were associated with dark respiration, in order to produce energy during plant growth. Drought promoted stomatal closure (Flexas *et al.*, 2004), shoot and root growth in desert plants (Bageat-Triboulot *et al.*, 2007; Radwan *et al.*, 2007). Drought stress affects photosynthesis rate due to the minimized CO_2 availability resulted from stomatal closure (Flexas *et al.*, 2006; Chaves *et al.*, 2009; Osakabe *et al.*, 2014). Reduced gas exchange of leaf minimized transpiration in leaf and carbon assimilation (Parolin, 2001; Baraloto *et al.*, 2007; Wang *et al.*, 2017). Under limited water supply or high evaporation, plants exhibit different strategies for survival and growth (Jones, 2004; Tambussi *et al.*, 2007; El Atta *et al.*, 2012).

According to this study's results, *Acacia seyal* showed high transpiration rate at 9% watering regime. In drought conditions plants attain survival mechanisms by decrease the potential dry matter productivity through decreasing total photosynthesis by stomatal closure. The main effects of drought stress in plants are declined leaf size, stem elongation, water use efficiency (*WUE*) (Li *et al.*, 2009; Farooq *et al.*, 2009; Farooq *et al.*, 2012).

The ideal plants tend to exhibit optimum balance between water conservation and productivity mechanisms depending on the aridity of the environment, productivity of plants in dry environments is enhanced by maximizing assimilation and minimizing water evaporated in relation to water availability to improve *WUE* (Sambatti and Caylor, 2007; Jones, 2014). The photosynthetic water use efficiency (*WUE*) is associated with the plant's optimum water use (Robinson *et al.*, 2001; Larcher, 2003; Novriyanti *et al.*, 2012).

Table (1) Two-way Analysis of Variance of Photosynthesis rate (*Pn)*, Transpiration (*E*) and instantaneous water use efficiency (*WUE*) of *A. seyal* under different soil moisture contents (%) and at full range of photosynthetic active radiation (*PAR*).

(a) Analysis of variance of photosynthesis rate (*Pn*) versus phenological stages					
Source	DF	SS	MS	F	P
Phenology	3	47.01	15.67	4.77	0.004
Error	80	262.92	3.29		
Total	83	309.92			
(b) Analysis of variance of transpiration (*E*) versus phenological stages					
Source	DF	SS	MS	F	P
Phenology	3	0.10045	0.03348	4.75	0.004
Error	80	0.56335	0.00704		
Total	83	0.66380			
(c) Analysis of variance of stomatal conductance (*C*) versus phenological stages					
Source	DF	SS	MS	F	P
Phenology	3	323.48	107.83	14.24	0.000
Error	80	605.58	7.57		
Total	83	929.06			
(d) Analysis of variance of instantaneous water use efficiency (*WUE*) versus phenological stages					
Source	DF	SS	MS	F	P
Phenology	3	727.6	242.5	4.30	0.007
Error	80	4514.3	56.4		
Total	83	5242.0			

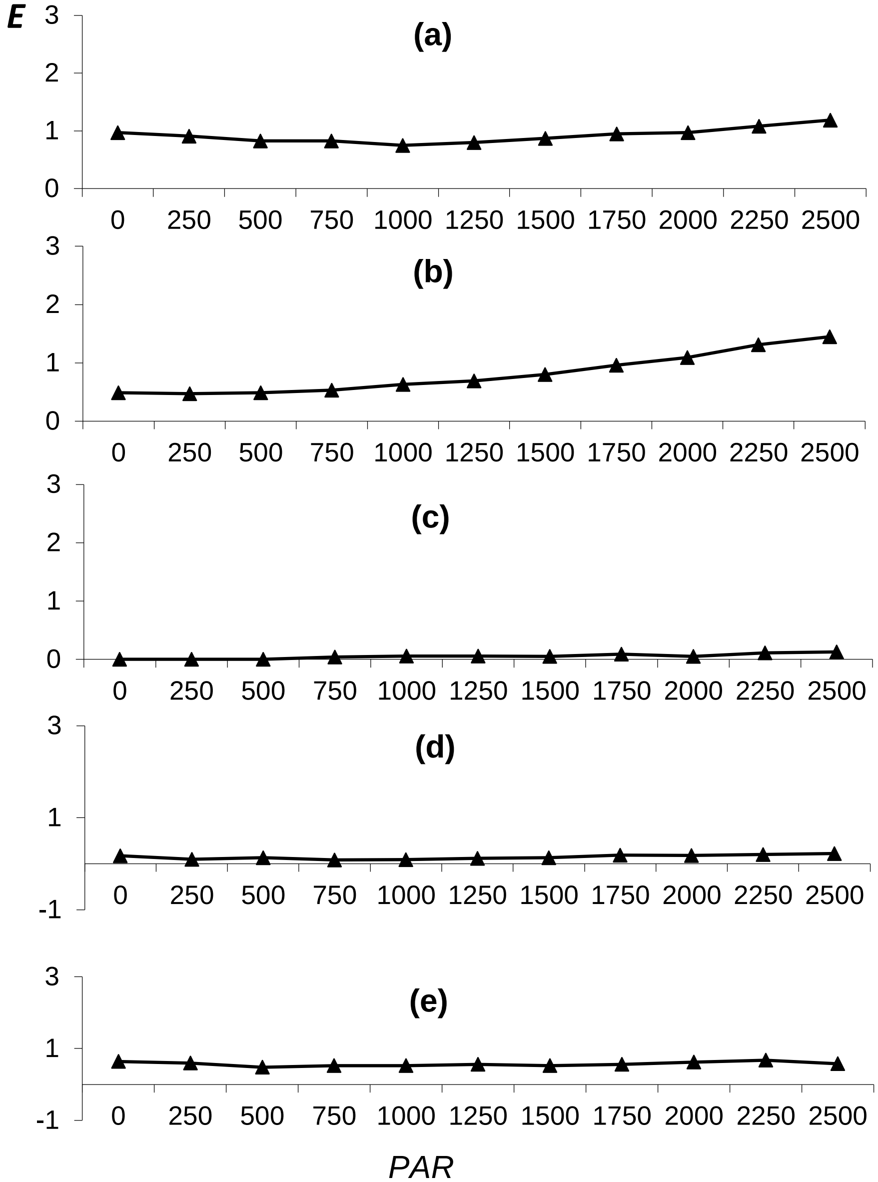

Fig. 2a-e. Transpiration rate *E* (mmol $m^{-2}s^{-1}$) of *A. seyal* under water depletion (12%, 9%, 6%, 4% and 2%) and at photosynthetic active radiation (PAR) ranged from 0 to 2500 (μmol $m^{-2}s^{-1}$), F=82.93; P<0.0001 and F=3.23; P<0.0001, respectively.

The result of stomatal closure is minimizing transpiration rate, which leads to the improvement of water use efficiency (Lawson and Blatt, 2014; Tshikunde *et al.*, 2018). The highest *WUE* value related with the increment in drought tolerance with trees growing in arid areas (Smith and Nowak, 1990; Otieno *et al.*, 2005), which agree with the current study's results that the maximum *WUE* was noticed in *Acacia seyal* at 12% *SMC* at high *PAR* level. The plant's capability to absorb higher carbon concentrations for including high photosynthetic rates maintenance, and water loss is limited via the control of the stomatal aperture and closure (Flexas *et al.*, 2013; De Santana *et al.*, 2015; Liu *et al.*, 2016), and plants able to absorb carbon and maintain photosynthetic activities (Roel *et al.*, 2011; Broeckx *et al.*, 2014; Dos Santos *et al.*, 2017).

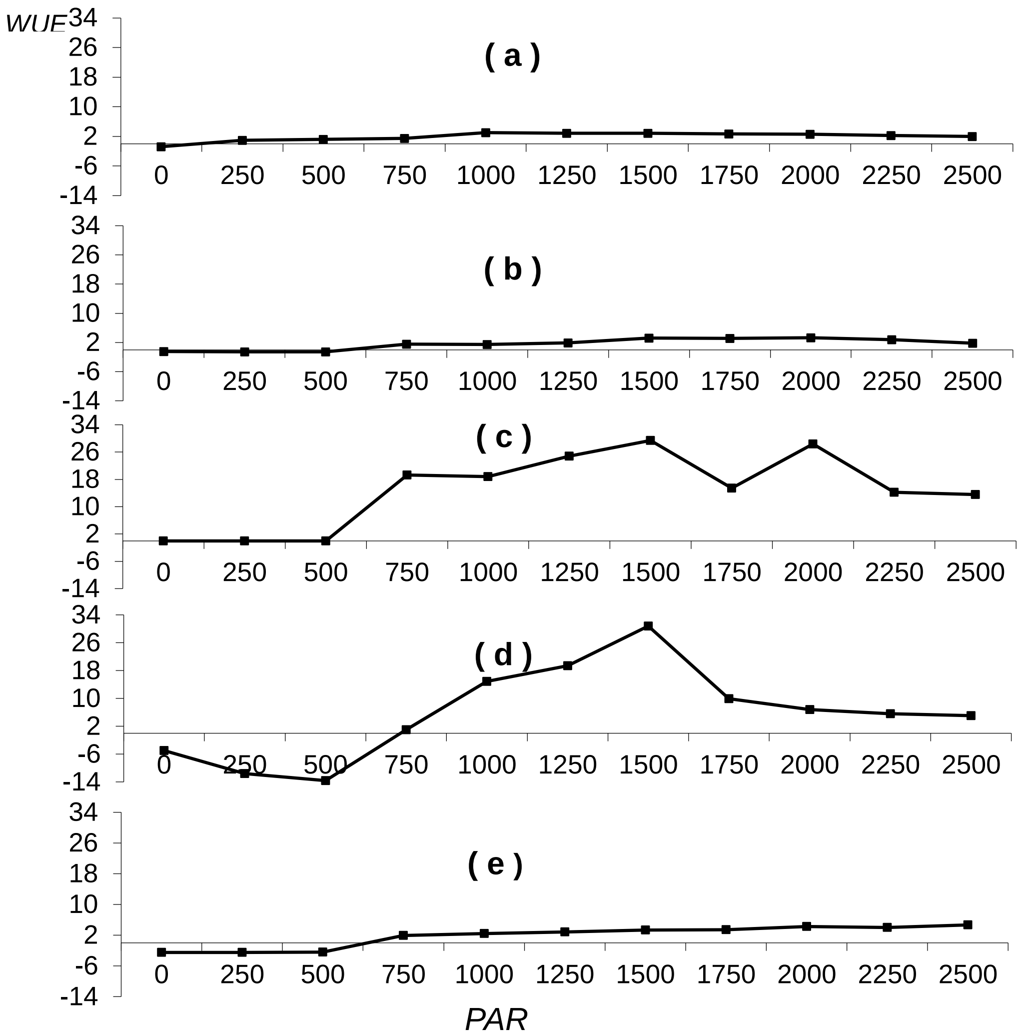

Fig. 3a-e. Water use efficiency (µmol $m^{-2}s^{-1}$/ mmol $m^{-2}s^{-1}$) of *A. seyal* under water depletion (12%, 9%, 6%, 4% and 2%) and at photosynthetic active radiation (PAR) ranged from 0 to 2500 (µmol $m^{-2}s^{-1}$), F=9.56; P<0.0001 and F=4.14; P<0.01, respectively.

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