Journal of Applied Sciences

ISSN 1812-5654

science alert

ANSInet
an open access publisher
http://ansinet.com

OPEN ACCESS Journal of Applied Sciences

ISSN 1812-5654
DOI: 10.3923/jas.2017.253.258

Research Article
Effect of Water Stress on Growth and Mineral Composition of *Salvadora persica* and *Atriplex halimus* in Al-Ahsa Oasis, Saudi Arabia

Mohammed Refdan Alhajhoj

College of Agriculture and Food Sciences, King Faisal University, Hofuf Al-Ahsa, Saudi Arabia

Abstract
Background and Objective: Water scarcity is one of the major problems faced by countries in arid regions worldwide. Saudi Arabia is an arid country where water shortage hampers land productivity. This study aimed to investigate the growth of two landscape trees under different water stress conditions, to establish sustainable windbreaks around irrigated agriculture areas and thus improve desert microclimates. **Materials and Methods:** A pot study was conducted on two tree species, *Salvadora persica* and *Atriplex halimus*, with four water stress treatments under field conditions, i.e., irrigation at 0% (T-1), 25% (T-2), 50% (T-3) and 75% (T-4) depletion of soil moisture of field capacity. Groundwater with a total salinity of 1200 mg L^{-1} was used for irrigation. Data were analyzed statistically by using SAS. **Results:** With increasing water stress, the plant height and fresh biomass of *Salvadora persica* increased, while those of *Atriplex halimus* decreased significantly. The protein content of plant tissue in *Salvadora persica* was the highest under the 75% water stress treatment. In *Salvadora persica*, with increasing moisture stress, the K and Ca concentrations increased, while P, Mg and Na concentrations decreased. In *Atriplex halimus*, with increasing water stress, the K, Ca, Mg and Na concentrations increased while P and Na concentrations decreased. **Conclusion:** Both *Salvadora persica* and *Atriplex halimus* (landscape trees) proved to be highly drought-resistant when grown under water stress conditions. Our results indicated that these two plant species could produce economical biomass yields in arid environments, when irrigated at 75% soil moisture depletion.

Key words: Water stress, plant height, biomass, mineral composition, calcium, magnesium, sodium and potassium content, protein content, drought-resistant, *Salvadora persica*, *Atriplex halimus*

Received: November 05, 2016 Accepted: March 10, 2017 Published: April 15, 2017

Citation: Mohammed Refdan Alhajhoj, 2017. Effect of water stress on growth and mineral composition of *Salvadora persica* and *Atriplex halimus* in Al-Ahsa Oasis, Saudi Arabia. J. Applied Sci., 17: 253-258.

Corresponding Author: Mohammed Refdan Alhajhoj, College of Agriculture and Food Sciences, King Faisal University, Hofuf Al-Ahsa, Saudi Arabia

Copyright: © 2017 Mohammed Refdan Alhajhoj. This is an open access article distributed under the terms of the creative commons attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited.

Competing Interest: The author has declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Water scarcity for sustainable irrigated agriculture is a major problem in many arid and semi-arid regions of the world. This problem of water shortage is aggravated by arid climatic conditions coupled with minimal and scattered annual rainfall. Plant growth is adversely affected by water stress[1-4]. Therefore, it is important to understand the mechanisms of drought resistance among various plant species[5]. Some investigators have reported that the most important criterion for selecting landscape trees for sustainable growth is their ability to cope with water stress[6-8], while some investigators have emphasized selecting drought-resistant plants, which are more suitable for landscapes in arid climates[9,10].

Liao *et al.*[11] found suppressed growth in *Sophora japonica* 'Golden stem' under increasing drought stress with special reference to the water content of plant leaves. An *et al.*[12] found a significant decrease in water consumption in various plant species under increasing drought stress, especially in *Forsythia suspensa,* followed by in *Periploca sepium* and *Syringa oblata*. Overall, the growth of shrubs was low under water stress conditions. However, all the three shrubs proved to be highly drought-resistant and adaptable to drought conditions. In a study of three Mediterranean shrubs (*Pittosporum tobira*, *Callistemon citrinus* and *Rhamnus alaternus*) Miralles-Crespo *et al.*[13] found high sensitivity for specific growth rates of *C. citrinus*, *P. tobira* and *R. alaternus* shrubs subjected to water stress. However, dendrometers proved to be useful tools for monitoring water stress in plants under severe climatic conditions. Previously, Nash and Graves[14] reported that among the five tree species they investigated, only sweet bay magnolia (*Magnolia virginiana*) and bald cypress (*Taxodium distichum*) did well in sites facing occasional drought and flooded conditions.

The availability of soil water to growing plants depends on the physical and chemical properties of soil[15]. Higher organic matter content improves the physical properties of soil, such as porosity, water holding capacity and fertility[15-18]. However, some studies did not consider original soil characteristics when comparing growth rates under local environmental constraints[19]. Plant growth is also considerably affected in shallow soils due to high soil temperatures and poor aeration for root development[16,20]. Generally, conifer growth is not possible in soils with high organic matter content, but proved most drought-resistant[21,22]. In another study, Del Campo *et al.*[23] showed that root growth and development of Aleppo pine (*Pinus halepensis* Mill.) might be useful indicators of seedling survival under stress conditions.

Recently, Amissah *et al.*[24] evaluated seedlings of 10 tree species in Ghana, growing under severe drought during the growing season. Drought resistance of plants and biomass production were lower when growing under shade than in the open. Elfeel and Al-Namo[25] found significant growth variation among various tree species, with growth being higher for *S. persica* than for *A. tortilis* and *L. pyrotechnica*. Conversely, survival rate was much higher for *A. tortilis* and *L. pyrotechnica* than for *S. persica*. Overall, *A. tortilis* and *L. pyrotechnica* showed excellent potential for commercial production in arid zones.

Saudi Arabia is an arid country with inadequate groundwater resources (i.e., limited and non-renewable). Inadequate groundwater is further worsened by the extreme arid conditions associated with minimal annual rainfall (<70 mm), especially in the eastern region of the country[26]. Therefore, it is essential to conserve and manage the available irrigation supplies, based on scientifically supportable data, not only to sustain irrigated agriculture but also to improve micro-climatic conditions for landscape development. Therefore, the objective of this study was to evaluate the effects of water stress on the growth of landscape trees under the climatic conditions characteristic of the Al-Ahsa Oasis.

MATERIALS AND METHODS

The study was conducted in 2015 at the Agricultural and Veterinary Training and Research Station, King Faisal University, Hofuf Al-Ahsa, Saudi Arabia.

The experimental treatments were as follows:

- Landscape trees = 2 tree species (*Salvadora persica*, *Atriplex halimus*)
- Irrigation treatments = 4 water applications at: 0% (T-1), 25% (T-2), 50% (T-3) and 75% (T-4) of field capacity of soil
- Irrigation water quality = 1 water salinity (1200 mg L^{-1})
- Replications = 3
- Total number of pots = $2\times4\times1\times3 = 24$

Statistical experimental design: A completely randomized design was used.

Preparation of pots: Sandy soil was collected from the research station, air-dried and passed through a 2 mm sieve before filling the experimental pots. Each pot was filled with 85 kg of soil based on the basin size ($40\times40\times40$ cm^3).

The total salinity of saturated soil paste was 1.4 dS m^{-1} and the Sodium Adsorption Ratio (SAR) was 2.35. The field capacity of the soil was 10% water on a weight basis. The total amount of water for optimum irrigation was 9 L per pot.

Irrigation of trees: The plants were irrigated to bring the soil moisture level at field capacity. Soil moisture deficit was monitored by installing tensiometers in each treatment pot. The readings of tensiometer were recorded before each irrigation to determine the amount of soil moisture deficit.

Data statistical analysis: Experimental data were analyzed statistically using analysis of variance and regression techniques as described in the SAS Institute[27] User's Guide.

RESULTS AND DISCUSSION

Salvadora persica

Plant height: The mean plant height ranged 169.09-197.89 cm under the various water stress treatments (Table 1). A significant increase in mean plant height was observed for the various treatments, relative to the control treatment ($LSD_{0.05}$ = 15.593). Although a trend of increase in plant height was observed when the water stress was increased from 25-75% (soil moisture depletion at field capacity), plant height was not significantly different among the T-2, T-3 and T-4 treatments. From these data, it was observed that application of water stress did not have any adverse effects on plant growth or plant height relative to the existing plant growth conditions.

Fresh biomass yield: Fresh biomass yield ranged 1.6-2.72 kg $plant^{-1}$ under various water stress treatments (Table 1). Mean fresh plant biomass increased significantly under the various water stress treatments as compared to that under the control treatment ($LSD_{0.05}$ = 0.629). Our data showed that fresh biomass yield was significantly different between treatments T-2 and T-4 and among treatments T-1, T-2 and T-3. Survival of plants were also higher under high water stress conditions. The study results agree with the findings of Sevik and Cetin[28] who observed that plant species such as *Pinus nigra*, *Cupressus sempervirens* and *Pinus brutia* proved to be more resistant to water stress than *Cupressus arizonica* and *Sophora japonica*. In addition, previous studies have reported that conifer tree species showed more drought resistance under greenhouse conditions, in organic media[29-31]. However, the results of Elfeel and Al-Namo[25] are consistent with our results, in that they found significant variations in growth among various tree species, with growth being higher for *S. persica* than for *A. tortilis* and *L. pyrotechnica*. In addition, the survival rate of *A. tortilis* and *L. pyrotechnica* were much better than for *S. persica*.

The figures in parentheses showed the relative percentage of plant biomass relative to the control treatment.

Mineral composition of plants: Mean mineral content (expressed as %) of various minerals among all water stress treatments ranged 9.01-11.26 (protein), 0.80-0.86 (P), 1.47-1.66 (K), 5.46-6.06 (Ca), 0.58-0.70 (Mg) and 0.120-0.197 (Na) (Table 2). The protein content of plants decreased to a greater extent in the T-2 and T-3 water stress treatments than in the T-4 treatment, which showed a substantial increase with even more water stress; this could be attributed to the concentration effect ($LSD_{0.05}$ = 1.524). The other mineral elements (K and Ca) showed a slight increase in concentration with increased water stress, while Na, P and Mg concentrations were not affected. This differential behavior of plants regarding the uptake of various mineral elements may be attributed to differences in plant physiological characteristics under various water stress conditions.

Atriplex halimus

Plant height: Mean plant height ranged 191.27-225.19 cm under various water stress treatments (Table 3). There was a significant reduction in mean plant height with increasing water stress relative to the control treatment ($LSD_{0.05}$ = 20.153). Mean plant height showed a significant difference between treatments T-1 and T-4. In addition, the difference in plant

Table 1: Effect of water stress on different plant growth parameters

Water stress (Depletion%)	Mean plant height (cm)	Fresh biomass (kg $plant^{-1}$)
0	169.09[a]	1.60[b] (100)
25	189.88[a]	2.16[ab] (135)
50	197.89[a]	1.81[b] (113)
75	196.77[a]	2.72[a] (170)

Mean values with the same superscript in a column are not significantly different at $LSD_{0.05}$

Table 2: Effect of water stress on chemical composition (%) of *Salvadora persica*

	Treatments			
Parameters	T-1	T-2	T-3	T-4
Protein	10.13[ab]	9.21[b]	9.01[b]	11.26[a]
Phosphorus (P)	0.80[a]	0.86[a]	0.85[a]	0.76[a]
Potassium (K)	1.65[a]	1.66[a]	1.47[b]	1.50[b]
Calcium (Ca)	5.46[a]	5.57[a]	5.72[b]	6.06[c]
Magnesium (Mg)	0.70[a]	0.58[a]	0.60[a]	0.70[a]
Sodium (Na)	0.197[a]	0.134[b]	0.99[c]	0.120[c]

Mean values with the same superscript in a column are not significantly different at $LSD_{0.05}$

Table 3: Effect of water stress treatments on mean values of various growth parameters of *Atriplex halimus*

	Treatments			
Parameters	T-1	T-2	T-3	T-4
Plant height (cm)	225.19[a]	211.81[ab]	211.81[ab]	191.27[b]
Fresh biomass (kg plant^{-1})	16.08[a]	11.00[ab]	7.03[b]	8.23[b]

Mean values with the same superscript in a row are not significantly different at $LSD_{0.05}$

Table 4: Effect of water stress treatments on chemical composition (%) of *Atriplex halimus*

	Treatments			
Parameters	T-1	T-2	T-3	T-4
Protein	9.35[a]	8.81[a]	9.32[a]	7.88[a]
Phosphorus (P)	0.090[a]	0.083[a]	0.067[b]	0.064[b]
Potassium (K)	2.17[a]	1.76[b]	2.65[a]	2.28[a]
Calcium (Ca)	0.89[b]	0.75[b]	1.28[a]	1.13[a]
Magnesium (Mg)	0.63[b]	0.59[b]	0.93[a]	0.85[a]
Sodium (Na)	2.45[a]	2.22[a]	2.42[a]	2.19[a]

Mean values followed by the same superscript in a row are not significantly different at $LSD_{0.05}$

height was not significant between treatments T-1 and T-2 and among treatments T-2, T-3 and T-4. Our data indicated that the plant height was adversely affected under high water stress treatments, that is, higher than the normal (typical) irrigation level (control treatment).

Plant fresh biomass: Mean biomass per plant ranged 7.03-16.08 kg under various water stress treatments (Table 3). A significant decrease in mean fresh biomass per plant was observed when the water stress was increased from 25% soil moisture depletion (normal irrigation) to 75% water stress level ($LSD_{0.05}$ = 5.423). In addition, mean biomass yield was significantly different between treatment T-1 and the higher water stress treatments (T-3 and T-4). However, the difference in mean biomass yield was not significant between treatments T-1 and T-2 or among treatments T-2, T-3 and T-4. It was also observed that water stress adversely affected plant growth rate, mainly due to the inadequate supply of irrigation water when soil moisture depletion was 50% or more. However, the results of many studies did not agree with our findings, in that the previous studies found a combined influence of both the water stress and soil type on the root growth of plants. For example, seedling growth of Ponderosa pine (*Pinus ponderosa* P.) and other landscape trees was reduced under water stress[7-11,13,24,25,32-34]. In contrast, this study found that the growth of *Atriplex halimus* increased under conditions of high water stress. This may be attributed to different physiological characteristics of plants exposed to water stress (i.e., the difference might be due to the difference in physiological characteristics of the two species). Similar results were reported by Belkheiri and Mulas[35], who investigated the effect of water stress on the growth of two *Atriplex* species (i.e., *A. halimus* and *A. nummularia*). They found that water stress decreased the dry weight of both plant species.

Mineral composition of plants: Mean mineral content (expressed as %) of various elements among all water stress treatments ranged from 7.88-9.35 (protein), 0.064-0.090 (P), 1.76-2.65 (K), 0.75-1.28 (Ca), 0.59-0.93 (Mg) and 2.19-2.45 (Na) (Table 4). A decreasing trend in mean protein content was found with increasing water stress, but the trend was not significantly different among the various treatments ($LSD_{0.05}$ = 1.942). The concentration of mineral elements (such as K, Ca, Mg and Na) increased in plant tissues in response to higher water stress, while P slightly decreased and the Na was not affected.

CONCLUSION

This study showed that range plants such as *Salvadora persica* and *Atriplex halimus* produce more biomass under water stress than when receiving water at typical irrigation amounts (at 25% moisture depletion at field capacity). This indicates that these two landscape plants can survive under high water stress conditions and that they can be grown to provide shelter belts around irrigated agricultural and industrial areas and improve agroclimatic conditions in desert environments. The results of the chemical analysis conducted in the present study suggest that these two plant species are highly drought-resistant and can produce economical biomass yield when irrigated at 75% soil water depletion.

SIGNIFICANCE STATEMENT

Water scarcity is one of the major problems faced by countries in arid regions around the world. This study investigated the growth of two landscape trees (*Salvadora persica* and *Atriplex halimus*) under different water stress conditions. Plant height and fresh biomass of *Salvadora persica* increased, while those of *Atriplex halimus* decreased, when subjected to increasing water stress (25-75% depletion of soil moisture below field capacity). Both *Salvadora persica* and *Atriplex halimus* (landscape trees) proved to be highly drought-resistant in an arid environment. The results indicate that these two plant species can produce economical biomass yields when irrigated at 75% soil water depletion under an arid environment, important when there is limited water supplied by irrigation.

ACKNOWLEDGMENT

The author gratefully thanks the King Faisal University, Hofuf Al-Ahsa, Kingdom of Saudi Arabia for providing infrastructure for conducting this study.

REFERENCES

1. Conner, J. and L. Zangori, 1998. Combined effects of water, nutrient and UV-B stress on female fitness in *Brassica* (Brassicaceae). Am. J. Bot., 85: 925-925.
2. Zhang, Z.B., H.B. Shao, P. Xu, L.Y. Chu, Z.H. Lu and J.Y. Tian, 2007. On evolution and perspectives of bio-water saving. Colloids Surf. B: Biointerfaces, 55: 1-9.
3. Maruani, T. and I. Amit-Cohen, 2009. The effectiveness of the protection of riparian landscapes in Israel. Land Use Policy, 26: 911-918.
4. Andrews, M., S. Hodge and J.A. Raven, 2010. Positive plant microbial interactions. Ann. Applied Biol., 157: 317-320.
5. Wang, Z.Q., L.H. Wu and S. Animesh, 2009. Nutrient shift in *Parthenocissus tricuspidata* seedling in response to soil water stress. Scient. Hortic., 123: 253-257.
6. Mohammadizad, H.A., I. Khazaei, M. Ghafari, M.F.F. Sinehsar and R. Barzegar, 2013. Effect of salt and drought stresses on seed germination and early seedling growth of *Nepeta persica*. Int. J. Farming Allied Sci., 2: 895-899.
7. Shitole, S.M. and K.N. Dhumal, 2012. Effect of water stress by polyethylene glycol 6000 and sodium chloride on seed germination and seedling growth of *Cassia angustifolia*. Int. J. Pharm. Sci. Res., 3: 528-531.
8. Ahmad, S., R. Ahmad, M.Y. Ashraf, M. Ashraf and E.A. Waraich, 2009. Sunflower (*Helianthus annuus* L.) response to drought stress at germination and seedling growth stages. Pak. J. Bot., 41: 647-654.
9. Bahrami, H., J. Razmjoo and A.O. Jafari, 2012. Effect of drought stress on germination and seedling growth of sesame cultivars (*Sesamum indicum* L.). Int. J. Agric. Sci., 2: 423-428.
10. Mujtaba, S.M., M. Ali, M.Y. Ashraf, B. Khanzada and S.M. Farhan *et al*., 2007. Physiological responses of wheat (*Triticum aestivum* L.) genotypes under water stress conditions at seedling stage. Pak. J. Bot., 39: 2575-2579.
11. Liao, F.Y., Y. Wen and Y. Xie, 2013. The effect of water stress on the fluorescence parameters and growth of *Sophora japonica* Golden stem. Applied Mech. Mater., 395: 626-632.
12. An, Y., Z. Liang, R. Han and G. Liu, 2007. Effects of soil drought on seedling growth and water metabolism of three common shrubs in Loess Plateau, Northwest China. Frontiers For. China, 2: 410-416.
13. Miralles-Crespo, J., M.J. Sanchez-Blanco, A. Navarro, J.J. Martinez-Sanchez and S. Banon, 2010. Comparison of stem diameter variations in three small ornamental shrubs under water stress. HortScience, 45: 1681-1689.
14. Nash, L.J. and W.R. Graves, 1993. Drought and flood stress effects on plant development and leaf water relations of five taxa of trees native to bottomland habitats. J. Am. Soc. Hortic. Sci., 118: 845-850.
15. Foth, H.D., 1990. Fundamentals of Soil Science. 8th Edn., John Wiley and Sons, Inc., New York, ISBN-13:780471522799, Pages: 360.
16. Scott, H.D., 2000. Soil Physics: Agricultural and Environmental Applications. Iowa State University Press, Ames, Iowa, USA., ISBN: 9780813820873, Pages: 421.
17. Havlin, J.L., J.D. Beaton, S.L. Tisdale and W.L. Nelson, 2005. Soil Fertility and Fertilizers: An Introduction to Nutrient Management. 7th Edn., Pearson Prentice Hall, New Delhi, India, ISBN: 9780130278241, Pages: 515.
18. Azuaje, E.I., N.B. Comerford, W.G. Harris, J.B. Reeves and S. Grunwald, 2012. Loblolly and slash pine control organic carbon in soil aggregates and carbon mineralization. For. Ecol. Manage., 263: 1-8.
19. Torreano, S.J. and L.A. Morris, 1998. Loblolly pine root growth and distribution under water stress. Soil Sci. Soc. Am. J., 62: 818-827.
20. Del Campo, A.D., R.M. Navarro-Cerrillo, J. Hermoso and A.J. Ibanez, 2007. Relationships between site and stock quality in *Pinus halepensis* Mill. reforestation on semiarid landscapes in Eastern Spain. Ann. For. Sci., 64: 719-731.
21. Scholes, M.C. and T.E. Nowicki, 1998. Effects of Pines on Soil Properties and Processes. In: Ecology and Biogeography of Pinus, Richardson, D.M. (Ed.). Cambridge University Press, Cambridge, UK., pp: 341-353.
22. Richardson, D.M. and P.W. Rundel, 1998. Ecology and Biogeography of Pinus: An Introduction. In: Ecology and Biogeography of Pinus, Richardson, D.M. (Ed.). Cambridge University Press, Cambridge, UK., pp: 3-46.
23. Del Campo, A.D., R.M. Navarro-Cerrillo, J. Hermoso and A.J. Ibanez, 2007. Relationship between root growth potential and field performance in Aleppo pine. Ann. For. Sci., 64: 541-548.
24. Amissah, L., G.M. Mohren, B. Kyereh and L. Poorter, 2015. The effects of drought and shade on the performance, morphology and physiology of Ghanaian tree species. PloS One, Vol. 10. 10.1371/journal.pone.0121004.
25. Elfeel, A.A. and M.L. El-Namo, 2011. Effect of imposed drought on seedlings growth, water use efficiency and survival of three arid zone species (*Acacia tortilis subsp. raddiana*, *Salvadora persica* and *Leptadenia pyrotechnica*). Agric. Biol. J. N. Am., 2: 493-498.

26. Lin, M.T., 1984. Agrometeorology Study of Al-Hassa. OASIS, Al-Hofuf, Saudi Arabia.
27. SAS., 2001. SAS User's Guide: Statistics. 21st Edn., SAS Institute Inc., Cary, NC.
28. Sevik, H. and M. Cetin, 2015. Effects of water stress on seed germination for select landscape plants. Polish J. Environ. Stud., 24: 689-693.
29. McMillin, J.D. and M.R. Wagner, 1995. Effects of water stress on biomass partitioning of ponderosa pine seedlings during primary root growth and shoot growth periods. Forest Sci., 41: 594-610.
30. Aranda, I., R. Alia, U. Ortega, A.K. Dantas and J. Majada, 2010. Intra-specific variability in biomass partitioning and carbon isotopic discrimination under moderate drought stress in seedlings from four *Pinus pinaster* populations. Tree Genet. Genomes, 6: 169-178.
31. Ladjal, M., N. Deloche, R. Huc and M. Ducrey, 2007. Effects of soil and air drought on growth, plant water status and leaf gas exchange in three Mediterranean cedar species: *Cedrus atlantica, C. brevifolia* and *C. libani*. Trees, 21: 201-213.
32. Howard, J.L., 2003.. *Pinus ponderosa* var. *scopulorum*. Fire Effects Information System, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory.
33. Dumroese, R.K., D.S. Page-Dumroese and R.E. Brown, 2011. Allometry, nitrogen status and carbon stable isotope composition of *Pinus* ponderosa seedlings in two growing media with contrasting nursery irrigation regimes. Can. J. For. Res., 41: 1091-1101.
34. Pinto, J.R., J.D. Marshall, R.K. Dumroese, A.S. Davis and D.R. Cobos, 2011. Establishment and growth of container seedlings for reforestation: A function of stock type and edaphic conditions. Forest Ecol. Manage., 261: 1876-1884.
35. Belkheiri, O. and M. Mulas, 2013. Effect of water stress on growth, water use efficiency and gas exchange as related to osmotic adjustment of two halophytes *Atriplex* spp. Functional Plant Biol., 40: 466-474.