

## Impact of Water Stress on Growth of Two Fuelwood Plants of Saudi Arabia

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**Abstract:** This investigation reports impact of water stress on growth of *Calligonum comosum* and *Haloxylon persicum*, both of which are a good source of fuelwood. *Haloxylon* experienced a significantly higher degree of water deficit than *Calligonum*. At the irrigated site *Calligonum* had significantly higher water content in relation to its dry matter content of green assimilating shoots than *Haloxylon*. The water deficit influenced all growth parameters. The green photosynthetic shoots were thicker and more compressed in unirrigated samples than those taken from irrigated sites, thus resulting in the accumulation of significantly higher dry matter per unit area of green shoots in both the species. *Haloxylon*, being a C<sub>4</sub> plant, exhibited vigorous growth. Irrigated *Haloxylon* produced more wood than irrigated *Calligonum* when compared to their counterparts growing on the unirrigated sites. The growth of *Haloxylon* was enhanced due to its significantly higher chlorophyll content coupled with the water supply at the irrigated site. *Haloxylon* was more water saving as well as drought tolerant.

**Key words:** *Calligonum*, *Haloxylon*, irrigated, fuelwood, water stress, assimilating shoot.

*Calligonum comosum*, locally called erta, and *Haloxylon persicum*, locally called ghada, are a good source of fuelwood (Chaudhary, 1999). *Calligonum comosum* L., a member of family polygonaceae, is shrubby glabrous plant and may attain a height of 2 m. It has rigid and lignified basal white branches and weak young branches (Migahid, 1978). *Haloxylon persicum* Bge, member of Chenopodiaceae, is large shrub or small tree (Netchaeva *et al.*, 1973), 4 to 5 m tall with woody base yellowish white in color and pendulous weak terminal green branches. Leaves are highly reduced or apparently absent in both the species. In arid lands, these plants play a major role in the productivity and stability of desert environment (Sankary, 1978; Farraj, 1989).

The availability of soil water to plant roots and the demand of atmosphere for water vapor are among the major ecological factors governing the distribution of higher plants. The degree of water stress in plants is controlled by the relative rate of water absorption. Water deficits can be induced either by lack of available soil moisture or too slow absorption or rapid loss of water, or most often by a combination of all the three. The decline in tissue moisture content is due to lower resistance to withdrawal of water from turgid plant tissue than the resistance to uptake through the root. Thus as rate of transpiration increases, absorption does not begin to increase until the decreasing leaf water potential produces sufficient tension in the xylem sap to

overcome the resistance to water flow through the xylem duct (Kramer and Kozlowski, 1979). As described by Levitt (1972) and Kalapos (1994), species classified as water savers have a number of characteristics like: lower osmotic potential, more rigid cell walls, narrow xylem ducts and strong stomatal control to minimize water loss through transpiration.

The main objectives of this study were to compare the performance of *Calligonum* and *Haloxylon* and to suggest best irrigation management for afforestation program of fuelwood plants in the Saudi Arabian desert.

## Materials and Methods

Five plants of *Calligonum comosum* and *Haloxylon persicum* having comparable age were tagged for present investigation at unirrigated and irrigated sites. Unirrigated site was located on the outskirts of Unaiza town of Qassim District in the north-west of Riyadh. The irrigated site, a horticultural farm, was within the region. Samples of green assimilating shoots were collected from four sides of each plant of both the species from irrigated and unirrigated sites. The green shoot pieces were pooled together. Fresh weight, turgid weight and oven dry weight were recorded to calculate the saturated water deficit (SWD), relative water content (RWC) and water content following Weatherley (1950).

Data of growth parameters such as crown area, plant height, number and circumference of main branches were recorded for each plant of the two species. Wood volume of the main branches up to 10 cm height from the base was calculated

and pooled together for each tagged plant for analysis.

The photosynthetic pigments of green assimilating shoots were extracted in N, N-Dimethyl Formamide (DMF) and total chlorophyll content was determined spectrophotometrically following Moran (1982) using the formula:

$$Ct = 7.04 A_{664} + 20.27 A_{647}$$

Thin transverse sections (TS) of green assimilating shoots and wood, cut at 8-12 millimicron thickness and stained in haematoxylin and saffranin (Johansen, 1940) were studied under Nova Vision Series Brightfield Microscope. The data were analyzed statistically for standard deviation and student's 't' test according to Snedecor and Cochran (1973). Computed mean values for all parameters of each tagged plant were used as replicates.

## Results and Discussion

### *Green assimilating shoots*

*Haloxylon* has green cylindrical photosynthetic shoots. Microscopic studies of TS of green shoots revealed that stem was more or less circular in outline. Epidermis was two layered covered with 13  $\mu$  thick cuticle, one layered subepidermis of isodiametric cells rich in chloroplasts and two layered chlorenchyma, an outer layer of radially elongated, compactly arranged cells of palisade zone and an inner layer of bundle sheath cells. Four to six large vascular bundles were present in the center, besides many small ones adjacent to the bundle sheath cells (Fig. 1). The central bundles were separated from kranz-type cells by water storage tissue (Vladimir *et al.*, 1999).

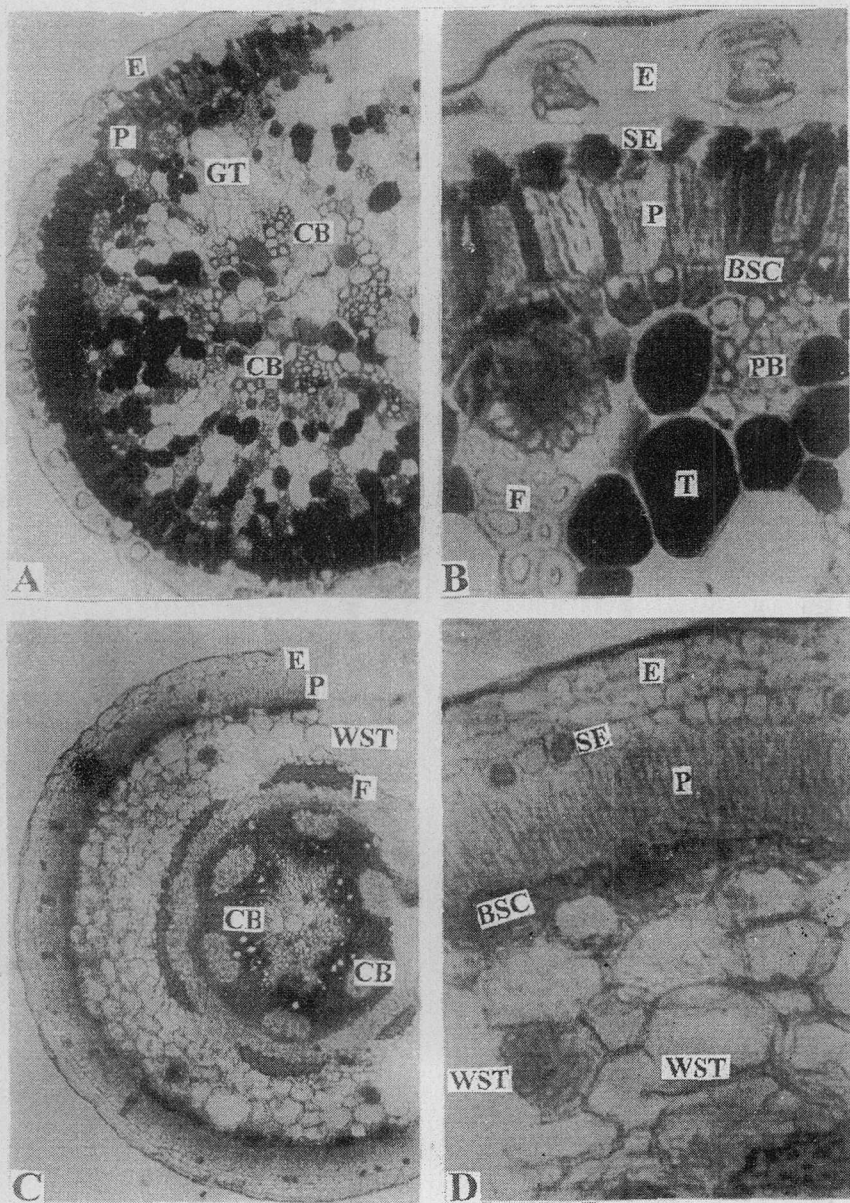


Fig. 1. Microphotographs of transectional view of green assimilating shoots of *Calligonum comosum* and *Haloxylon persicum* showing structural details. A- TS of *Calligonum* at 10 x 10, B- TS of *Calligonum* at 10 x 40, C- TS of *Haloxylon* at 10 x 10, D- TS of *Haloxylon* at 10 x 40. E- Epidermis, SE- Sub-edpidermis; P- Palisade layer, BSC- Bundle sheath cells, PB- Peripheral vascular bundle, CB- Central vascular bundle, WST- Water storage tissue, F- Fibres, GT- Ground tissue, T- Tannin.

The green shoots of *Calligonum* also exhibited a circular outline. Histologically it resembled *Haloxylon*, in its basic structure. However, epidermis was single layered. Epidermal cells were rectangular in shape, highly thickened (12-15  $\mu\text{m}$ ) with narrow lumen, covered with thick cuticle (13-22  $\mu\text{m}$ ). Few chloroplasts were present. Subepidermis consisted of a single layer of parenchyma rich in chloroplast, interrupted by patches of collenchyma cells. Chlorenchyma was two layered, outer layer of radially elongated cells made up the palisade zone and inner layer of bundle sheath cells. Ground tissue was made up of large parenchyma cells having abundant tannin. Eight large vascular bundles were found to be arranged in a ring in the centre enclosing pith of thick walled lignified-pitted parenchyma cells with many starch granules. Eight to nine patches of fibers alternating with small peripheral vascular bundles were present close to the bundle sheath cells. Fibre patches were opposite to collenchyma patches. All three tissues, palisade, bundle sheath and ground tissue contained chloroplasts, but their concentration in ground tissue was very low in comparison with either the palisade or bundle sheath cells (Fig. 1).

Our findings on anatomy of green shoots of *C. comosum* were found to be quite different from those of Al-Yahya *et al.* (1990). Our description of internal structure of green shoots of *H. persicum* was in full agreement with that of Vladimir *et al.* (1999) for the same species.

The green assimilating shoots were found to be thicker and compressed having a thick cuticle and thick walled epidermis on the

unirrigated site. These were mainly because of reduced cell expansion due to water stress condition. Foliar morphology is a simple and rapid indicator to assess the impact of drought on plants (Kubiske *et al.*, 1996). Such plants develop thick and more cutinized leaves (Tipton and White, 1995). Leaf cuticular waxes reduce non-stomatal water loss and diffusion of solutes across the cuticle (Post-Beittenmiller, 1996). Similar features have also been found in drought tolerant species of other semi-arid and arid areas (Levitt, 1972; Cheung *et al.*, 1975; Lo Gullo and Salleo, 1988; Kalapos, 1994).

#### *Plant water relationships*

*Calligonum* plants growing in unirrigated condition exhibited a significantly lower RWC (76.7%) and a higher SWD (23.2%) than those of irrigated plants. The irrigated plants absorbed more water, as their RWC was 83.9%, thereby decreasing significantly its SWD to 15.9%. Water content is quantum of water present in relation to dry matter. It was found to be 2.43 times higher in the irrigated samples than the unirrigated ones (Table 1). Data on dry matter accumulation and water content per centimeter of green assimilating shoot revealed a significantly higher value for the samples of *Calligonum* collected from the unirrigated site than the irrigated one. The green shoots were found to be thicker and compressed because of water stress condition at unirrigated site that led to poor growth. The water content in green assimilating shoots was significantly higher in irrigated samples while dry matter per 100 g fresh weight was significantly higher in unirrigated samples (Table 1).

*Haloxylon* is more deficient in water as it showed a significantly higher SWD

(26.7%) and a low RWC for the samples collected from unirrigated site. RWC was as high as 83.5% in irrigated samples thus resulting in a significant decrease in SWD (16.3%). Water content in relation to dry matter was found to be significantly higher in the irrigated samples. Dry matter accumulation and water content per centimeter of green assimilating shoots was significantly higher in *Haloxylon* samples collected from unirrigated sites than those from irrigated sites. *Haloxylon* growth was also affected by water stress that resulted in a thick and compressed green photosynthetic shoot at unirrigated site. The dry matter per 100 g fresh weight of green assimilating shoots was significantly higher in samples from unirrigated trees. Irrigated samples did not differ statistically from unirrigated samples in water content per 100 g fresh weight. (Table 1).

Response to irrigation was different in both the species as SWD showed a positive relationship with dry matter accumulation in *Calligonum*. The same parameters exhibited positive relationship with the RWC in *Haloxylon*. A significant positive correlation has been observed between species in productivity and their water content (Migahid and Elhaak, 2001).

#### *Growth parameters*

In *Calligonum* plants at irrigated site all growth parameters, except plant height, were significantly higher than those raised on unirrigated site. The crown area showed 5.67 times increase over the unirrigated plants. Individuals growing at unirrigated sites were tough and stout and showed a better height. While the plants at irrigated sites showed a luxuriant growth with large

number of green assimilating shoots and significantly higher number of main branches than the unirrigated plants. The main branches were overweight and bent down towards the ground although their circumference was significantly larger than that of the unirrigated plants.

Irrigated *Haloxylon* also showed a significantly higher value for all the growth parameters at irrigated site except plant height. The irrigated plants exhibited 3.02 times increase for the crown area, a significantly higher value for the number of main branches ( $P < 0.05$ ) and circumference of branches over the unirrigated plants.

The growth of both woody and herbaceous plants is reduced more by water deficit than any other single factor (Zahner, 1968). It affects every aspect of plant growth, modifying anatomy, morphology, physiology and metabolism for responding and resisting drought (Auge *et al.*, 1998). *Calligonum* and *Haloxylon* showed suppressed growth on unirrigated site due to severe drought. Their crown area, number of main branches and circumference of branches were significantly reduced. Similar effects on trees having smaller leaves were observed by other workers (Kriedman, 1986; Roden *et al.*, 1990). Both the species lacked typical leaves. The photosynthetic process is performed by green shoots in *Haloxylon* (Vladimir *et al.*, 1999).

Water stress affects the wood production in tree. Water plays an important role in cambial activity. As water deficit increases, xylem differentiation slows down or ceases, and whenever internal tissue moisture is regained due to rain or irrigation cambial activity is restored. Extensive evidence

Table 1. Plant water relationships and its impact on growth of *Calligonum comosum* (Erta) and *Haloxylon persicum* (Ghada)

Parameters	<i>Calligonum comosum</i>			<i>Haloxylon persicum</i>		
	Unirrigated	Irrigated	T value	Unirrigated	Irrigated	T value
Saturated Water Deficit % (SWD)	23.23 ± 0.878	15.90 ± 2.271	6.73	26.77 ± 1.088	16.37 ± 3.003	7.28**
Relative Water Content % (RWC)	76.722 ± 0.874	83.96 ± 2.267	6.66**	73.19 ± 1.069	83.56 ± 3.014	7.25**
Water content %	142.04 ± 8.390	243.55 ± 23.349	9.15**	135.17 ± 18.309	219.18 ± 26.714	5.80**
Water content (mg/cm of green shoots)	11.388 ± 0.964	8.78 ± 0.202	5.92**	8.39 ± 0.704	6.48 ± 0.645	4.49**
Dry matter (mg/cm of green shoots)	8.08 ± 1.204	4.08 ± 0.498	6.86**	6.68 ± 0.800	4.32 ± 0.457	5.73**
Water content (g/100g FW of green shoots)	57.70 ± 2.615	64.86 ± 0.954	5.74**	56.68 ± 4.704	59.93 ± 3.889	1.19 <sup>NS</sup>
Dry matter (g/100g FW of green shoots)	42.26 ± 1.741	35.13 ± 1.234	7.47**	43.50 ± 1.216	40.06 ± 2.811	2.51*
Crown area (m <sup>2</sup> )	4.24 ± 0.762	24.07 ± 2.903	14.76**	8.25 ± 4.039	24.99 ± 3.309	7.16**
Plant height (m)	1.81 ± 0.261	1.92 ± 0.329	0.62 <sup>NS</sup>	1.87 ± 0.345	2.23 ± 0.487	1.34 <sup>NS</sup>
Number of main branches	2.20 ± 0.447	3.60 ± 0.547	4.43**	3.40 ± 0.547	4.40 ± 0.547	2.89*
Total circumference of main branches (cm)	25.14 ± 3.636	53.34 ± 4.791	10.48**	38.52 ± 5.234	101.60 ± 11.266	11.35**
Wood volume of main branches upto 10 cm height from the ground surface (cm <sup>3</sup> )	259.52 ± 42.151	627.80 ± 67.943	10.30**	375.34 ± 142.607	2059.61 ± 530.371	6.86**
Chlorophyll content (mg/g FW of green shoots.)	0.5897 ± 0.04814	0.6573 ± 0.07411	1.71 <sup>NS</sup>	0.5985 ± 0.06380	0.7242 ± 0.08619	2.62*

NS - Non significant Table 't' value = 2.306 (P<0.05); \*\* Significant at (P<0.01); Table 't' value = 3.355 (P <0.01); \* Significant at (P<0.05).

summarized by Zahner (1968) showing correlation between both height and diameter growth on one hand, and available water on the other hand, indicates that 70 to 80% of the variation in the width of annual rings in humid region and 90% in arid region can be attributed to differences in water

stress. Water stress has severely affected the wood production both quantitatively and qualitatively in the present investigation. A total volume of wood calculated for the main branches upto the height of 10 cm from base in unirrigated *Calligonum* was found to be 259.5 cm<sup>3</sup> as compared to 627.8

cm<sup>3</sup> for irrigated plant (Table 1). The amount of wood produced in unirrigated *Haloxylon* (375.34 cm<sup>3</sup>) was less than one-fifth of the irrigated plants (2059.61 cm<sup>3</sup>, Table 1). Unirrigated *Calligonum* and *Haloxylon* were found to possess short, narrow and crowded vessel pores having thicker lignified cell walls. Thus the investigated species appeared to survive and grow due to narrow and numerous vessels which offer a high degree of protection under water stress conditions by resisting tension in water column (Bass, 1976; Zimmermann, 1982, 1983; Bass *et al.*, 1983; Carlquist, 1984).

#### *Photosynthetic pigments*

The total chlorophyll content in *Calligonum* was marginally higher in the irrigated samples than that in the unirrigated plants (Table 1). Irrigated *Haloxylon* samples exhibited a significantly higher ( $P < 0.05$ ) total chlorophyll content than the samples from unirrigated plants (Table 1).

Research has shown that water stress affects many enzyme-mediated processes, including respiration, dark reaction of photosynthesis and chlorophyll synthesis (Alberte *et al.*, 1975). Drought may also alter stomatal conductance (Fort *et al.*, 1997) and biomass partitioning (Graves and Wilkins, 1991). Water stress adversely affected the chlorophyll synthesis in *Calligonum comosum* as its level was less in the plants growing on unirrigated sites. *Haloxylon persicum* showed significantly less chlorophyll synthesis ( $P < 0.05$ ) due to water stress at the unirrigated sites. After irrigation the chlorophyll content increased significantly. A positive relationship was observed between chlorophyll content and RWC in irrigated *Haloxylon* to suggest that

water plays an important role directly or indirectly in chlorophyll synthesis. The relationship between growth and photosynthesis is complex. It is often assumed that plants with a high rate of photosynthesis per unit of leaf area will produce more dry matter and grow more rapidly than plants with low rate of photosynthesis. This is sometimes true, but not always (Carter, 1972). The variation in the chlorophyll did not coincide with similar variations in productivity. This was elucidated from the significant negative correlation between productivity of nine desert plant species from Mediterranean coastal area of Egypt and their chlorophyll contents (Migahid and Elhaak, 2001). The contents of chlorophyll in nine Egyptian desert species showed no relation to their productivity. This may confirm an edaphic factor control on the specific activity of the photosynthetic pigments as has been reported by Migahid *et al.* (1999) and Migahid and Elhaak (2001).

The green photosynthetic shoots of *C. comosum* were having very close resemblance with that of *H. persicum* in its internal structure. *Haloxylon* has C<sub>3</sub> photosynthesis in its cotyledons and C<sub>4</sub> cycle in the green assimilating shoots (Vladimir *et al.*, 1999). *Haloxylon* species from the Karakum Desert are reported to show CO<sub>2</sub> assimilation at an atmospheric temperature between -5 and 50°C and exhibit a broad temperature optimum between 20 to 40°C (Zalensky, 1975; Voznesenskii, 1977). The close relationship between *Haloxylon* and *Calligonum* in their physiological and ecological features suggested that they have characteristics, which allowed them to function

photosynthetically under extreme conditions, possibly through C<sub>4</sub> cycle in the desert of Saudi Arabia. A study is in progress on this aspect. It may be concluded that *C. comosum* and *H. persicum* are water savers as well as drought tolerant plant species, the latter being more so as it showed better growth in the same environment. In another investigation *H. ammodendron* has been identified as water saving and drought tolerant species (Xu *et al.*, 1998).

### Acknowledgments

The Authors are grateful to King Abdulaziz City for Science and Technology (KACST) for funding this research (Grant No. APR-20-081).

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