Effects of Water Deficit on the Growth and Physiological Performance of Conocarpus Erectus and Eucalyptus Microtheca Trees Under Field Conditions

Loutfy. I. El-Juhany[1], I. M. Aref [2] and A. A. Al-Harby[3]
1. Prince Sultan Research Centre for Environment, Water and Desert, Riyadh, King Saud University, Saudi Arabia
2. Plant Production Department, Faculty of Food Sciences and Agriculture, Riyadh, King Saud University, Saudi Arabia
3. Afforestation Directorate, Riyadh, King Saud University, Saudi Arabia

Abstract

The growth and physiological performance of *Conocarpus erectus* and *Eucalyptus microtheca* trees under deficit of irrigation water were studied through a field experiment lasted for a year. The experiment was carried out at The Experiments and Research Station of The Faculty of Food Sciences and Agriculture, King Saud University, 50 km south of Riyadh City. The treatments used in this experiment were irrigation at 100, 200 and 400 mm evaporation according to accumulation evaporation readings of a Class-A evaporation pan evaporation represent sufficient irrigation, moderate water deficit and severe water deficit, respectively. The statistical design used in carrying out this experiment was RCBD with four blocks in a factorial arrangement included the species and treatments with two and three levels, respectively.

The results showed that irrigation at 400 mm evaporation caused significant reductions in most of the growth characteristics of *C. erectus* and *E. microtheca* trees comparing with irrigation at 100 mm evaporation. On the other hand, irrigation at 200 mm evaporation only decreased branch and root dry weight, branch weight ratio, relative leaf water content and soil water content comparing with irrigation at 100 mm evaporation. The fraction of dry weight partitioned to the branches decreased due to water deficit while that partitioned to the roots increased. Root to shoot dry weight ratio increased with decreasing water availability. Relative growth rate decreased with increasing water deficit mainly due to decreasing specific leaf area.

Both Relative leaf water content and soil water content were decreased with increasing water deficit. In most of the growth characteristics measured, C. erectus trees had lower values comparing with those of *E. microtheca* trees.

It seems that *E. microtheca* trees were conserving water through increasing the rate of water uptake into the plant in order to postpone desiccation during water deficit, while C. erectus trees responded to water deficit by increasing root dry weight and consequently increased root to shoot ratio.

Keywords: *Conocarpus erectus*, *Eucalyptus microtheca*, Water Deficit, Growth

Introduction

As a result of its location within the arid and semiarid area, Saudi Arabia has harsh environmental conditions represented in high summer temperatures; scarcity of rain and warm wind, all consequently cause aridity. Therefore, efforts regarding planting trees for protection purposes were accelerated and expanded during the last three decades. Unfortunately, these efforts comprised changing the tree species selected for planting each time during a short period without attributes. For instance, *Conocarpus erectus* tree was spread overall the Country through the last ten years, while other species like *Eucalyptus sp*. was escaped. *Eucalyptus sp*. has been extensively planted during the early afforestation programmes in a way similar to planting *Conocarpus erectus* at the present. Nevertheless, *Eucalyptus microtheca* showed excellent adaptation to the environmental conditions at the different regions of Saudi Arabia where it succeeded in Riyadh City with 96-100% survival percentage (Mana *et al*. 1996). Moreover, it tolerated drought more than other eucalypt specie (Zoghet 1997).

Recently, any more water supplies have become difficult to be secured in Saudi Arabia as general. Thus, only tree species with low watering requirement should be adopted. The right tree species for the local environment have known with emphasizing must be directed to endemic ones. However, some exotic species are promising to be adapted, so that evaluation of their growth under local environmental conditions should be done through elaborated experiments. However, studies on the exotic tree species and their performance and adaptation to the prevailing environmental conditions are limited.

The present study was designated to evaluate the growth and physiological performance of *Conocarpus erectus* and *Eucalyptus microtheca* trees under deficit of irrigation water in the field. This comprises investigating the effects of water deficit upon the growth of both species and defining the mechanisms by which each species respond to water deficit.

Materials and methods

Site description

The experiment was carried out at The Experiments and Research Station of The Faculty of Food Sciences and Agriculture, King Saud University, 50 km south of Riyadh City. The site where the experiment was carried out has the following characters: 24° 6` N, latitude; 46° 5` E, longitude, 650 m above sea level; temperature ranged between 10ºC in winter and 37ºC in summer (as an average of season); and 50 mm rainfall, annually. The soil of the site was sandy loam with average content of 61, 23 and 15% for sand, silt and clay, respectively (Aref, 1987). Meteorological data for the site concurrent with the time of conducting the experiment are presented in table (1).

Plant material

Six months-old seedlings of *Conocarpus erectus* (L.) produced from terminal cuttings and *Eucalyptus microtheca* (F.J. Muell.) produced from seeds, all were collected from local vigorous trees.

Table (1): Temperature, precipitation and accumulative evaporation in the location of the experiment

Season/ year	month	mean temperature (ºC)		precipitation (mm)		accumulative evaporation (mm)	
		monthly	seasonally	monthly	seasonally	monthly	seasonally
Summer 2004	June	33.86	34.64	00.00	00.00	229.94	734.85
	July	35.24		00.00		296.36	
	Aug.	34.81		00.00		208.55	
Autumn 2004	Sept	30.77	25.89	00.00	00.00	183.87	433.5
	Oct.	25.46		00.00		143.6	
	Nov.	21.45		00.00		106.03	
Winter 2005	Dec.	14.34	14.92	10.67	61.46	65.01	229.28
	Jan.	14.34		8.12		78.77	
	Feb.	16.09		42.67		85.5	
Spring 2005	Mars	21.18	26.78	5.59	5.84	130.88	492.44
	Apr.	27.75		0.25		169.94	
	May	31.42		0.00		191.62	

Source: Meteorology unit, Research and Experiments Station (Dirab), Faculty of Food Sciences and Agriculture, King Saud University.

Experiment design

The experiment was carried out in the field using a randomized complete block design in a factorial arrangement included tree species with two levels and irrigation treatments with three levels. The land area devoted to the experiment was divide into four blocks each includes six experimental units of 14 m^2 and has six trees; three from each species.

Treatments

The treatments used in this experiment were three irrigation levels according to accumulation evaporation readings of a Class-A evaporation pan from June 2004 and lasted for a year. The irrigation treatments comprise irrigation at 100 mm evaporation (sufficient irrigation), at 200 mm evaporation (moderate water stress) and, at 400 mm evaporation (severe water stress).

Planting technique

Six months-old seedlings of both *C. erectus* (L.) and *E. microtheca* (F.J. Muell.) were planted in December 2003 in pits of 1 × 1 m and with 3 m apart in the field. The seedlings were distributed randomly over the experimental plots as six trees in each treatment (three from each species). Just before planting, primary measurements (*i. e*. stem diameter and height, dry weight of tree components and leaf area) of five seedlings of each species were carried out.

Harvesting and measurements

All the trees in the experiment were harvested after 12 month from the date of applying the treatments (*i. e*. May 2005). The trees were severed at soil surface then the root system was extracted from a circle with one meter diameter and 60 cm deep. Stem height and diameter of all the fallen trees were measured Stem diameter of all trees in the experiment was measured using a steel caliper and. Stem height of each tree was also measured from soil surface to the top of the tree using a telescopic hypsometer.

Fresh weight of the leaves, branches, stem and roots of each tree was measured separately. Samples were taken from the fresh leaves of each tree and weighed then used for determining total leaf area. Samples from each tree component were taken to determine dry weight. Length of the tallest root and diameters of all the secondary roots >0.5 cm of each tree were measured.

Total leaf area of each tree was scaled through taking a sample with known fresh weight within a few hours from the time of harvesting and determining its area using an automatic area meter (Model AAC-400, Hayshai Denkoh Co., LTD. Tokyo, Japan) and drying it, then calculated total tree leaf area as the following:

Total leaf area (cm^2 $tree^{-1}$) = [total leaf dry weight (g $tree^{-1}$) × (sample leaf area (cm^2)] / sample leaf dry weight (g)

For determining dry weight of each tree components (*i. e*. leaves, branches, stem and roots), samples with known fresh weights of leaves were dried in the oven at 70ºC and others of branches, stem and roots were dried at 105ºC until constant weight. Dry weight of each component was measured to the nearest 0.1 g. Dry weight percentage in the samples of each component was calculated and multiplied by the total fresh weight of the component to produce its dry weight. Total tree dry weight was gained by adding dry weights of all components together. The proportion of each component (leaf, branch, stem and root weight ratio) was calculated as its dry weight divided by total tree dry weight multiplying by 100.

Soil water content (SWC) at 20 cm under each tree in the experiment was estimated for each sample separately through the gravimetric method according to Kramer (1969). SWC was measured before each watering time, where the soil samples was taken and enclosed immediately in aluminum cans, weighted then placed in the oven at 105ºC until constant weight and their dry weight was estimated. Soil water content (SWC) of each sample was calculated as: SWC = (wet weight – oven dry weight) / oven dry weight. Measurements were expressed as g (H_2O) g (dry soil)$^{-1}$.

Determining leaf relative water content (RWC) was done for each tree in the experiment before each watering time according to Barrs (1968), through taking three leaves and quantifying their fresh weight then placed them in distilled water for 24 hours to saturation. Thereafter, saturated leaves were weighed and placed in the oven at 70ºC for 48 hours then their dry weight was measured. Leaf relative water content was calculated as following: RWC = (FW – DW) / (SW – DW) × 100, where RWC = leaf relative water content, FW = leaf fresh weight, SW = leaf saturated weight and, DW = leaf oven dry weight

Growth analysis

Just before starting the experiment, five seedlings of *C. erectus* and other five of *E. microtheca* were harvested and divided into leaves, stems and roots. Total leaf area of each seedling was scaled. Leaves, stem and roots of each seedling were oven dried and weighed then total plant dry weight was calculated. Relative growth rate, RGR (the increase in plant material per unit of material present per unit time) was calculated over a period of four weeks. RGR was calculated from the conventional formula:

$RGR = \log_e W_2 - \log_e W_1 / t_2 - t_1$,

where: W_1 and W_2 are initial and final total dry weight of the tree at t_1 and t_2.

Leaf area ratio (LAR) (which characterizes the relative size of the assimilatory apparatus) was calculated by dividing total leaf area of the tree by total tree dry weight. Specific leaf area (SLA) (the ratio between of the leaf area related to leaf dry weight) was calculated through dividing total leaf area of the tree by leaf dry weight (Evans 1972). Net assimilation rate (NAR) as the increase in plant material per unit of assimilatory material per unit of time was calculated from the conventional formula:

$NAR = (W_2 - W_1 / L_2 - L_1) \times (\log_e L_2 - \log_e L_1 / t_2 - t_1)$,

where L_1 and L_2 are the total leaf areas and W_1 and W_2 are the total dry weights of tree at times t_1 and t_2.

Statistical analysis

The obtained data were analyzed through analysis of variance procedure using the SAS (SAS Institute 1988) computer programme. Means were compared by L.S.D. test (P <0.05). Data were log or arcsine transformed when necessary.

Results

Growth of tree stem

Analysis of variance procedure shows that stem diameter was significantly affected by irrigation treatment (P=0.0003). Across species, mean stem diameter of the trees irrigated at 400 mm evaporation had the least value (3.34 cm tree^{-1}) comparing with those of the trees irrigated at 100 and 200 mm evaporation, (3.44 and 4.25 cm tree^{-1}, respectively) (Table 2). *E. microtheca* trees had stem diameter across treatments with 4.6 cm tree^{-1} which was significantly greater than that of *C.* erectus trees (2.77 cm tree^{-1}) (P<0.0001) (Table 2). Irrigation treatments had no effect on tree height but**,** *C.* trees had mean stem height across treatments that was only 36% of that of *E. microtheca* trees (P<0.0001) (Table 2).

Total leaf area

Total leaf area was significantly affected by water deficit (*P*<0.0001). Across species, leaf area of the trees irrigated at 400 mm evaporation was 29,783 cm^2 $tree^{-1}$ comparing with 56,481 and 59,774 cm^2 $tree^{-1}$ for those grown under irrigation at 200 and 100 mm evaporation, respectively (Table 2). The two species of the experiment differed significantly in their mean total leaf area across treatments (*P*<0.0001), where that of *E. microtheca* trees was 2.8 folds that of *C.* trees (Table 2). There was a species × treatment interaction indicating changing the magnitude of treatment effects on total leaf area due to species (*P*=0.0023).

Growth of the roots

Irrigation treatments had significant effects on mean root length of the trees across species (*P*=0.0322). The trees grown under severe water stress treatment (irrigated at 400 mm evaporation) had mean root length was lower than those of the trees grown in the other two treatments (Table 3). *C. erectus* trees had mean root length (77 cm^2 $tree^{-1}$) and was significantly lower than that of *E. microtheca* trees (95 cm^2 $tree^{-1}$) (*P*<0.0001).

Table (2): Means of stem diameter, stem height and total leaf area of C. erectus and E. microtheca grown under irrigation at 100, 200 and 400 mm evaporation for 12 month in the field

Trait	Species	Irrigation treatments at mm evaporation			Species mean
		100	200	400	
Stem diameter ($cm\ tree^{-1}$)	*C. erectus*	2.42	3.241	2.638	2.77^{b}
	E. microtheca	4.47	5.282	4.057	4.60^{a}
Treatment mean		3.445^{b}	4.262^{a}	3.347^{b}	
Stem height ($m\ tree^{-1}$)	*C. erectus*	1.14	1.058	0.85	1.02^{b}
	E. microtheca	2.787	2.929	2.742	2.82^{a}
Treatment mean		1.964^{a}	1.994^{a}	1.796^{a}	
Total leaf area ($cm^2\ tree^{-1}$)	*C. erectus*	28195.7	33958.5	15843.8	25999^{b}
	E. microtheca	91353	83508.9	43722.5	72861^{a}
Treatment mean		59774^{a}	56481^{a}	29783^{b}	

On the other hand, irrigation treatments had no effect on the number or diameters of the woody roots with diameters more than 0.5 cm. However, the two species differed significantly in these two traits where *C. erectus* trees had lower number (*P*<0.0001) and mean diameter (*P*=0.0027) of woody roots >0.5 cm than those of *E. microtheca* trees (Table 3).

Table (3): Mean root length, number and diameter of the woody roots (>0.5 cm) of *C. erectus* and *E. microtheca* trees grown under irrigation treatments at 100, 200 and 400 mm evaporation for 12 month in the field

Trait	Species	irrigation treatments (at mm evaporation)			Species mean
		100	200	400	
Root length (cm $tree^{-1}$)	*C. erectus*	87.9	71.7	71.3	77.0^{b}
	E. microtheca	96.7	96.3	91.7	95.0^{a}
Treatment mean		92.3^{a}	84.0^{ab}	81.5^{b}	
Number of woody roots (root $tree^{-1}$)	*C. erectus*	9.0	7.3	7.2	7.8^{b}
	E. microtheca	10.0	10.3	10.8	10.4^{a}
Treatment mean		9.5^{a}	9.0^{a}	8.8^{a}	
Diameter of woody roots (cm $root^{-1}$)	*C. erectus*	1.402	1.325	1.223	1.3^{b}
	E. microtheca	1.485	1.588	1.545	1.5^{a}
Treatment mean		1.44^{a}	1.46^{a}	1.38^{a}	

Dry weight production

Analysis of variance procedure showed that leaf, branch, stem, root and consequently total dry weight of the trees was significantly reduced due to water deficit treatments (P<0.0001), (P=0.0002), (P=0.0057), (P=0.0069) and (P<0.0001), respectively. However, there was a cognation between the values of dry weigh of the trees in the sufficient irrigation treatment (irrigated at 100 mm evaporation) and those in the moderate water deficit one (200 mm evaporation); except for roots where the cognation was between those in the moderate and in the severe water deficit (irrigated at 400 mm evaporation) treatments (Table 4).

E. microtheca trees produced greater dry weights for leaves, branches, stem, roots and consequently total dry weights comparing with those produced by *C. erectus* trees (P<0.0001). Leaf, branch, stem, root and total dry weight of *E. microtheca* were 3.8, 4.3, 5.4, 2.6 and 3.7 as much as those of *C. erectus* trees, respectively (Table 4). There were species × treatment interactions indicating changing the magnitude of treatment effects due to species on leaf (P=0.0003), branch (P=0.0057) and total (P=0.011) dry weight.

Partitioning of dry weight

Reducing the amount of irrigation water caused significant alteration in partitioning of dry weight into different tree parts. The trees grown under moderate water stress treatment (irrigated at 200 mm evaporation) had significantly greater leaf weight ratio (LWR) and stem weight ratio (SWR) across species comparing with those of the other two treatments (P=0.0004) and (P=0.0003) which had almost similar values (Table 5). The fraction of dry weight partitioned to branches (branch weight ratio, BWR) decreased significantly (P=0.0015) due to reducing irrigation water, where it was 26.6, 23.7 and 22.2% for the trees grown in sufficient, moderate and severe water stressed treatment, respectively (Table 5). Root weight ratio (RWR) and root: shoot ratio (RSR) increased markedly in the trees grown under severe water deficit treatment (P<0.0001).

Table (4): Dry weight production of *C. erectus* and *E. microtheca* trees grown under irrigation treatments at 100, 200 and 400 mm evaporation for 12 month in the field

Trait	Species	irrigation treatments (at mm evaporation)			Species mean
		100	200	400	
Leaf dry weight ($g\ tree^{-1}$)	*C. erectus*	409.41	567.95	311.95	433.38^{b}
	E. microtheca	2059.66	1782.27	1004.96	1660.03^{a}
Treatment mean		1309.5^{a}	1175.1^{a}	678.8^{b}	
Branch dry weight ($g\ tree^{-1}$)	*C. erectus*	350.45	371.86	200.63	313.20^{b}
	E. microtheca	1782.69	1268.18	832.80	1343.37^{a}
Treatment mean		1131.7^{a}	820.0^{b}	535.3^{c}	
Stem dry weight ($g\ tree^{-1}$)	*C. erectus*	164.11	232.42	93.60	165.99^{b}
	E. microtheca	941.07	1120.94	633.95	902.89^{a}
Treatment mean		676.68^{a}	587.91^{a}	379.67^{b}	
Root dry weight ($g\ tree^{-1}$)	*C. erectus*	514.08	398.36	347.31	426.09^{b}
	E. microtheca	1347.23	981.12	983.28	1128.21^{a}
Treatment mean		968.53^{a}	689.74^{b}	684.00^{b}	
Total dry weight ($g\ tree^{-1}$)	*C. erectus*	1438.05	1570.59	953.50	1338.7^{b}
	E. microtheca	6130.64	5152.51	3455.00	5034.5^{a}
Treatment mean		3997.6^{a}	3361.6^{a}	2277.8^{b}	

Across treatments, *E. microtheca* trees had greater BRW (P=0129) and SWR (P<0.0001) but had lower RWR (P<0.0001) and RSR (P<0.0001) than those of *C. erectus* trees (Table 5). There was a species × treatment interaction indicating changing the magnitude of treatment effects on LWR (P=0.005) due to species.

Growth analysis

Growth analysis was carried out by means of calculating relative growth rate and its components (*i. e.* leaf weight ratio; LWR, specific leaf area; SLA, leaf area ratio; LAR and net assimilation rate; NAR). Analysis of variance procedure showed that SLA of the trees grown under severe water deficit treatment (irrigated at 400 mm evaporation) was significantly lower than that of the trees grown either under sufficient or moderate water deficit treatments (P<0.001) Table 6). SLA of *C. erectus* trees was significantly greater than that of *E. microtheca* trees (P<0.0001). There was a species × treatment interaction indicating changing the magnitude of treatment effects on SLA (P=0.0048) due to species. Water deficit treatments had no effects on LAR and NAR, but *C. erectus* trees had significantly lower values than those of *E. microtheca* trees (P<0.0001) and (P<0.001), respectively (Table 6). The trees grown under irrigation at 400 mm evaporation had relative growth rate (RGR) was significantly lower than those of the trees grown at the other two treatments (P<0.0001). *C. erectus* trees had significantly lower mean RGR across treatments than that of *E. microtheca* trees (P<0.0001) (Table 6).

Table (5): Partitioning of dry weight into different tree parts of *C. erectus* and *E. microtheca* trees grown under irrigation treatments at 100, 200 and 400 mm evaporation for 12 month in the field

Trait	Species	irrigation treatments (at mm evaporation)			Species mean
		100	200	400	
Leaf weight ratio (LWR)	*C. erectus*	27.67	36.23	31.86	31.76^{a}
	E. microtheca	33.69	35.49	28.95	32.81^{a}
Treatment mean		30.95^{b}	35.86^{a}	30.32^{b}	
Stem weight ratio (SWR)	*C. erectus*	12.04	15.20	9.02	12.20^{b}
	E. microtheca	15.26	21.36	17.69	17.82^{a}
Treatment mean		13.80^{b}	18.28^{a}	13.61^{b}	
Branch weight ratio (BWR)	*C. erectus*	23.63	23.36	20.86	22.72^{b}
	E. microtheca	29.05	23.97	23.33	25.81^{a}
Treatment mean		26.59^{a}	23.66^{b}	22.17^{b}	
Root weight ratio (RWR)	*C. erectus*	36.66	25.21	38.25	33.32^{a}
	E. microtheca	22.00	19.19	30.02	23.56^{b}
Treatment mean		28.66^{b}	22.20^{c}	33.90^{a}	
Root: shoot ratio (RSR)	*C. erectus*	0.58	0.34	0.64	0.52^{a}
	E. microtheca	0.28	0.24	0.45	0.32^{b}
Treatment mean		0.42^{b}	0.29^{c}	0.54^{a}	

Table (6): Means of specific leaf area (SLA), leaf area ratio (LAR) net assimilation rate (NAR) and relative growth rate (RGR), of *C. erectus* and *E. microtheca* trees grown under irrigation treatments at 100, 200 and 400 mm evaporation for 12 month in the field

Trait	Species	irrigation treatments (at mm evaporation)			Species mean
		100	200	400	
Specific leaf area (cm^2 leaf dry weight g^{-1})	*C. erectus*	71.18	69.39	55.88	65.48^{a}
	E. microtheca	44.51	45.84	44.1	44.76 ^{b}
Treatment mean		57.85^{a}	58.68^{a}	49.99^{b}	
Leaf area ratio (cm^2 total dry weight g^{-1})	*C. erectus*	10.31	15.29	12.07	12.31^{b}
	E. microtheca	53.88	39.97	37.25	44.06^{a}
Treatment mean		31.06^{a}	28.35^{a}	26.23^{a}	
Net assimilation rate (g cm^2 $month^{-1}$)	*C. erectus*	0.012	0.01	0.011	0.011^{b}
	E. microtheca	0.018	0.017	0.028	0.021^{a}
Treatment mean		0.015^{a}	0.014^{a}	0.019^{a}	
Relative growth rate (g g^{-1} $month^{-1}$)	*C. erectus*	0.245	0.246	0.226	0.239^{b}
	E. microtheca	0.347	0.345	0.327	0.340^{a}
Treatment mean		0.296^{a}	0.295^{a}	0.276^{b}	

Leaf relative water content (RWC)

Leaf relative water content of the trees grown under irrigation at 400 mm evaporation was significantly lower than those of the trees grown under irrigation at 100 mm evaporation but, did not differ from those of the trees grown under irrigation at 200 mm evaporation (P=0.0021) (Table 7). The two species did not vary significantly in their RWC. There was a species × treatment interaction indicating changing the magnitude of treatment effects on RWC (*P*=0.051) due to species.

Soil water content (SWC)

Irrigation at 400 mm evaporation significantly reduced soil water content (SWC) comparing with those of soil irrigated at either 100 or 200 mm evaporation (*P*<0.0001) (Table 7).

Table (7): Means values of leaf relative water content (RWC) and soil water content (SWC) of *C. erectus* and *E. microtheca* trees grown under irrigation treatments at 100, 200 and 400 mm evaporation for 12 month in the field

Trait	Species	irrigation treatments (at mm evaporation)			Species mean
		100	200	400	
Leaf relative water content (RWC) (%)	*C. erectus*	80.42	50.18	53.73	61.44[a]
	E. microtheca	72.23	68.64	63.37	68.07[a]
Treatment mean		76.33[a]	59.41[b]	58.55[b]	
Soil water content (SWC) (g (H_2O) g (dry soil)$^{-1}$)	*C. erectus*	2.857	0.698	1.194	1.58[a]
	E. microtheca	2.574	0.529	1.414	1.51[a]
Treatment mean		2.72[a]	0.61[b]	1.30[b]	

Discussion

Decreasing growth of trees due to water deficit has been well-documented (*e. g*. Kozlowski, 1982). Analysis of variance procedure revealed that irrigation at 400 mm evaporation (severe water deficit) caused significant reductions in most of the growth characteristics of *C. erectus* and *E. microtheca* trees comparing with those irrigated at 100 mm evaporation (sufficient irrigation). On the other hand, irrigation at 200 mm evaporation (moderate water deficit) only decreased some growth characteristics (*e. g*. branch and root dry weight, branch weight ratio, relative leaf water content and soil water content) comparing with irrigation at 100 mm evaporation (sufficient irrigation). Stem diameter of the trees irrigated at 400 mm evaporation (severe water deficit) decreased while stem height did not change. Decreasing the growth of stem diameter of woody species due to water deficit has been previously proven (*e. g*. Linder *et al*., 1987; Roden *et al*.; 1990; El-Juhany and Aref, 1999; Leustahner *et al*. 2001). Stem diameter of *C. erectus* seedlings decreased in low water treatment by 17% (El-Juhany and Aref, 2005). *C. erectus* trees had diameter and height were 60 and 36% as much as those of *E. microtheca* trees, respectively.

Total leaf area of the trees grown in severe water deficit treatment (across species) decreased by 50% comparing with that of those grown at sufficient irrigation one. *E. microtheca* trees had mean total leaf area (across treatment) was only 36% of that of *C. erectus* trees. Under severe water deficit, the reduction in total leaf area of *E. microtheca* was greater than that of *C. erectus* trees. This may a result of the growth nature of the former as it has a spreading open crown and/or of dropping its larger leaves acrobatically due to water deficit conditions, comparing with *C. erectus* tree which has dense foliage. Nevertheless, El-Juhany and Aref (2005) reported a 77% reduction in total leaf area of *C*. *erectus* seedlings subjected to low water supply.

Decreasing root length of trees due to water deficit by 12% in the present study concurs with the finding of Ibrahim (1995). *E*. *microtheca* trees had greater root length and more woody roots with larger diameter comparing with those of *C*. *erectus* trees. This variation may reflect the inherent differences between the two species.

Decreasing stem diameter, total leaf area, root length of the trees in water deficit treatment resulted in reductions in total tree dry weight and its components. These reductions accounted for by 48, 53, 44, 29 and 43% of those of the trees in sufficient irrigation treatment for leaf, branch, stem, root and total dry weight, respectively. Many authors reported decreases in total tree dry weight and/or its components (*e*. *g*. El-Juhany and Aref, 1999 and 2005; Aref and El-Juhany, 1999 and 2005).

Across treatments, *E*. *microtheca* trees produced leaf, branch, stem root and total dry weights were 26, 23, 18, 38 and 27% greater than those of *C*. *erectus* trees. Interactions for leaf, branch and total dry weight indicated changing the magnitude of treatment effect due to species. Irrigation at 400 mm evaporation caused reductions in these traits as 24, 43 and 34% for *C*. *erectus* and 51, 53 and 44% for *E*. *microtheca* trees. Li *et al*. (2000) found that drought decreased total biomass of *Eucalyptus microtheca*.

Water stress not only decreases the total dry matter production but also alters the partition of dry matter between the different plant organs (Ibrahim 1995). In the present study, water deficit increased the fraction of dry weight partitioned to the roots (RWR) at the expense of those partitioned to the leaves (LWR), branches (BWR) and stem (SWR). This result concurs with other findings (*e*. *g*. Khalil and Grace, 1992; Ibrahim, 1995; El-Juhany and Aref, 2005). Contradictory, some results showed that there was no effect of water deficit on dry matter partitioning of woody species (*e*. *g*. Aref and El-Juhany, 2005).

On the other hand, increasing root to shoot ratio by *ca*. 100% in the trees grown under irrigation at 400 mm evaporation concurs with the well established phenomenon that plants invest more in their roots and less in their shoots when soil resources are growth-limiting (Brouwer, 1963 and 1983, Bradshaw *et al*. 1964). Similar results were obtained for other woody species at seedling stage (*e*. *g*. Steinberg *et al*. 1990; El-Juhany and Aref, 1999). A shift in the allocation of assimilates from shoot to root is considered as one of the mechanisms of acclimation to soil drying (Khalil and Grace, 1992). Both low water supply and high salt concentration treatments caused doubling the ratio of root to shoot dry weight (El-Juhany and Aref, 2005). Hsiao and Acevedo (1974) stated that when water supply is limiting allocation of assimilates tends to be modified in favour of root growth which leads to increased root weight and consequently to root to shoot ratio increases.

Compared to *E*. *microtheca* trees, *C*. *erectus* trees partitioned more dry weight to their roots and less to their stems and branches and *vice versa*, the former had root to shoot ratio was only 0.32 comparing with 0.52 for the later.
Water deficit caused a significant reduction in mean relative growth rate of the trees. Decreasing relative growth rate under water stress conditions has been

reported by other authors (*e*. *g*. Mayers and Landesberg, 1989; Ibrahim, 1995; El-Juhany and Aref, 1999). In the present study, the reduction in RGR may resulted mainly from decreasing specific leaf area as both leaf area ratio and net assimilation rate were not affected in water deficit treatments. Poorter and Remkes (1990) concluded that SLA was the parameter which best explained that differences in RGR. Decreasing SLA in the present study due to water deficit is consistent with the results of Ibrahim (1995); El-Juhany and Aref (1999); Khurana and Singh (2000); Rodriguez *et al*. (2005) and Wu *et al*. (2008). Galmés *et al*. (2005b) concluded that the decrease in RGR caused by water deficit was mainly explained by decreases in SLA. Positive correlation between the growth rate and SLA is known in a range of species (Reich *et al*. 1997).

Growth analysis showed that *C*. *erectus* trees had lower mean RGR comparing with *E*. *microtheca* trees. This increase in RGR of *E*. *microtheca* was accompanied with increases in NAR and LAR over those of *C*. *erectus* which had greater SLA in turn. So that it appears to be a crucial attribute determining the potential RGR of a species (Poorte *et al*., 1990).

Decreased leaf relative water content due to water deficit in our study is in agreement with the results of Alberdi, *et al*. (2007). RWC decreased by 30 and 27% in the leaves of *C*. *erectus* trees grown at 200 and 400 mm evaporation while decreased by only 3.6 and 8.9% in those of the *E*. *microtheca* trees grown in the same treatments, respectively. Maintenance of high RWC has been considered to be a drought-resistance rather than drought-escape mechanism, and it is a consequence of adaptive characteristics such as osmotic adjustment and/or bulk modulus of elasticity (Grashoff and Ververke, 1991). Therefore, the rapid recovery of RWC in *E*. *microtheca* leaves and maintaining somewhat high RWC values after re-irrigation may reflects an efficient mechanism to take up water from the soil and transport it to the leaves.

Across species, RWC decreased similarly in both water deficit treatments and by 17% with decreases of 77.5 and 52% in soil water content (SWC) comparing with their values in the sufficient irrigation treatment. de Pereira *et al*. (1999) asserted that RWC of water-stressed plants dropped from 96 to 78%, following a reduction in SWC from 0.25 to 0.17 g (H_2O) g(dry soil)$^{-1}$.

The growth of *C*. *erectus* trees in the present study was affected due to water deficit more than that of *E. microtheca* trees. In other words, *E*. *microtheca* exhibited greater drought tolerance than *C*. *erectus*. This may because *E*. *microtheca* is drought tolerant species (Arizona Department of Water Resources, 2005) while *C*. *erectus* is not (El-Juhany and Aref, 2005). Many *Eucalyptus* species are renowned for tolerance to aridity **(**Merchant *et al*., 2007). It seems that the mechanism adopted by *E*. *microtheca* trees was conserving water through increasing the rate of water uptake into the plant in order to postpone desiccation during water deficit. On the other hand *C*. *erectus* trees responded to water deficit by reducing their leaf area and allocated more growth to their roots at the expense of stem and leaves (*i*. *e*. increased root to shoot ratio). Reduction in leaf area appears to be largely affected by soil water status (Termaat *et al*. 1985). When water supply is limiting allocation of assimilates tends to be modified in favour of root growth which leads to increased root weight and consequently the root to shoot ratio increases (Hsiao and Acevedo 1974).

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تأثير نقص ماء الري على نمو أشجار كونوكاربس وكافور ميكروثيكا وأدائها الفسيولوجي تحت ظروف الحقل

لطفي الجهني[1] *و إبراهيم عارف*[2] *و عبد الله الحربي*[3]
1- مركز الأمير سلطان لأبحاث البيئة و المياه و الصحراء
2- قسم الإنتاج النباتي، كلية علوم الأغذية و الزراعة
3- إدارة التشجير
جامعة الملك سعود – الرياض – المملكة العربية السعودية

الملخّص

نمو أشجار كونوكاربس Conocarpus erectus (L.) وكافور ميكروثيكا Eucalyptus microtheca (F. Mull.) و أدائها الفسيولوجي تحت تأثير نقص ماء الري درست من خلال تجربة حقليّة استمرت لمدة عام كامل. كانت المعاملات المستخدمة في هذه التجربة هي الري عند 100 و 200 و 400 ملليميتر بخر طبقاً لقراءات وعاء البخر من طراز Class-A، تمثّل ري كافٍ و نقص ماء متوسّط و نقص ماء شديد، على التوالي. أجريت التجربة في محطة الأبحاث والتجارب الزراعية التابعة لكلية علوم الأغذية والزراعة بديراب، 50 كم جنوب مدينة الرياض. نفذت التجربة باستخدام تصميم قطاعات عشوائية كاملة ذي أربع قطاعات في ترتيب عاملي شمل نوعين من الأشجار وثلاث معاملات ري.
أظهرت النتائج أنّ الري عند 400 ملم بخر سبب انخفاضات معنويّة في معظم صفات النمو لأشجار كونوكاربس و كافور ميكروثيكا بالمقارنة مع الري عند 100 ملم بخر. من جهة أخرى، الري عند 200 ملم بخر تسبب في نقص الوزن الجاف لكل من الفروع و الجذور و نسبة وزن الفروع و المحتوى المائي النسبي للأوراق و المحتوى المائي للتربة فقط بالمقارنة مع الري عند 100 ملم بخر. هذا و قد نقص الجزء من الوزن الجاف المخصص للفروع بسبب نقص ماء الري بينما ازداد الجزء المخصص للجذور. ازدادت كذلك نسبة الجذور إلى المجموع الخضري مع نقص الماء المتاح للري. و انخفض معدل النمو النسبي مع نقص ماء الري نتيجة انخفاض المساحة الورقيّة النوعيّة SLA.
انخفض أيضاً كل من المحتوى المائي النسبي للأوراق و المحتوى المائي للتربة مع نقص ماء الري. في معظم صفات النمو المقاسة، كانت القيم الأقل لأشجار كونوكاربس بالمقارنة مع قيم نفس الصفات لأشجار كافور ميكروثيكا.
يبدو أنّ أشجار كافور ميكروثيكا كانت تحافظ على الماء من خلال زيادة معدّل امتصاص الماء إلى داخل النبات لكي تؤجّل عملية التجفيف خلال فترة نقص الماء، بينما استجابت أشجار كونوكاربس لنقص الماء بزيادة الجزء من الوزن الجاف المخصص للجذور و بالتالي زيادة نسلبة الجذور إلى المجموع الخضري.