



تأثير نقص ماء الري في النمو و الأداء الفسيولوجي لأشجار *Conocarpus erectus* و *Eucalyptus microtheca* تحت ظروف الحقل

Effects of Water Deficit on the Growth and Physiological Performance of *Conocarpus erectus* and *Eucalyptus microtheca* Trees under Field Conditions

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المُلخَص

درس نمو اشجار *Conocarpus erectus* L و *Eucalyptus microtheca* Mull. و اداؤها الفسيولوجي تحت تأثير نقص ماء الري من خلال تجربة حقلية استمرت مدة عام كامل. كانت المعاملات المستعملة في هذه التجربة هي الري عند 100 و 200 و 400 ملليمتر بخر طبقاً لقراءات وعاء البخر من طراز Class-A، تمثل ري كافٍ و نقص ماء متوسط 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 باستعمال تصميم قطاعات عشوائية كاملة ذي أربع قطاعات في ترتيب عاملي شمل نوعين من الأشجار وثلاث معاملات ري.

أظهرت النتائج أن الري عند 400 ملم بخر سبب انخفاضاً معنوياً في معظم صفات النمو لأشجار *Conocarpus erectus* و *Eucalyptus microtheca* بالمقارنة مع الري عند 100 ملم بخر. من جهة أخرى، تسبب الري عند 200 ملم بخر نقصاً في 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. و قد نقص الجزء من الوزن الجاف المخصص للفروع بسبب نقص ماء الري، في حين 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 الورقية النوعية 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 *Conocarpus erectus* بالمقارنة مع قيم الصفات لأشجار *Eucalyptus microtheca* نفسها. يبدو أن اشجار *Eucalyptus microtheca* كانت تحافظ على الماء من خلال زيادة معدل امتصاصه إلى داخل النبات لكي تؤجل عملية التجفيف خلال فترة نقص الماء، في حين استجابت اشجار *Conocarpus erectus* لنقص الماء بزيادة الجزء من الوزن

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 treatments used in this experiment were three irrigation levels mainly at 100 mm evaporation (sufficient irrigation), at 200 mm evaporation (moderate water stress) and, at 400 mm evaporation (severe water stress) according to accumulation evaporation readings of a Class-A evaporation pan.

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 due to decreasing both specific leaf area and leaf area ratio.

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.

Keywords: *Conocarpus erectus*, *Eucalyptus microtheca*, water deficit, growth

Introduction

As a result of its location within the arid and semi-arid 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 comprise changing in the tree species selected for planting during a short period without attributes. For instance, *C. erectus* tree was spread overall the country through the last ten years, while other species like *Eucalyptus* were disappeared. *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). *Eucalyptus sp.* has been extensively planted during the early afforestation programmes in a way similar to planting *C. erectus* now.

Recently, any more water supplies have become difficult to be secured in Saudi Arabia. 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. 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 *C. erectus* and *Eucalyptus microtheca* trees under deficit of irrigation water in the field. This comprises the effects of water stress upon the growth of both species, defining the mechanisms by which each species facing drought and, conducting growth analysis.

Materials and methods

Site description:

The experiment was carried out at the experiments and Research Station of The Faculty of Food Sciences and Agriculture 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 10°C in winter and 37°C 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 information of the site where the experiment was carried out is presented in Table (1).

Plant material:

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

Experimental design:

The experiment was carried out in the field using a randomized complete block design in factorial arrangement (Steel and Torrie, 1986) 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 m² and has six trees; three from each species.

Table1. Temperature, precipitation and accumulative evaporation in the location of the experiment

Season/year	month	mean temperature (°C)		precipitation (mm)		accumulative evaporation (mm)	
		monthly	seasonally	monthly	seasonally	monthly	seasonally
Summer 2004	June	33.86	34.64	00.00		209.94	654.85
	July	35.24		00.00	00.00	226.36	
	Aug.	34.81		00.00		218.55	
Autumn 2004	Sept	30.77		00.00		183.87	
	Oct.	25.46	25.89	00.00	00.00	143.60	433.5
	Nov.	21.45		00.00		106.03	
Winter 2005	Dec.	14.34		10.67		65.01	
	Jan.	14.34	14.92	8.12	61.46	78.77	229.28
	Feb.	16.09		42.67		85.50	
Spring 2005	Mars	21.18		5.59		130.88	
	Apr.	27.75	26.78	0.25	5.84	169.94	492.44
	May	31.42		0.00		191.62	

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

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). Table (2) shows the number of irrigation times and the season of application throughout the course of the experiment.

Planting technique:

Six months-old seedlings of both *C. erectus* L. and *E. microtheca* (Dehn) were planted in pits of 1 × 1 m and with 3 m apart in the field. The seedlings were distributed randomly over the treatments plots as six trees (three from each species) in each treatment. 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. 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 hypsometer.

Fresh weight of leaf, branches, stem and roots of each tree was measured separately and samples were taken from the leaves of each tree and weighed then used for scaling 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 ($\text{cm}^2 \text{ tree}^{-1}$) = [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 70°C and others of branches, stem and roots were dried at 105°C 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.

Table 2. Number of irrigation times and the season of application

Treatment	Season				Total number of irrigation times per year
	Winter	Spring	Summer	Autumn	
100 mm	3	3	6	4	16
200 mm	1	2	3	2	8
400 mm	1	1	1	1	4

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 were taken and enclosed immediately in aluminum cans, weighted then placed in the oven at 105°C until constant weight and their dry weight was estimated. Soil water content (SWC) of each sample was calculated as: $SWC = (\text{wet weight} - \text{oven dry weight}) / \text{oven dry weight}$. Measurements were expressed as $g (H_2O) g (\text{dry soil})^{-1}$.

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 70°C for 48 hours then their dry weight was measured. Leaf relative water content was calculated as following:

$$RWC = (FW - DW) / (SW - DW) \times 100$$

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 2001) computer programme. Means were compared by L.S.D. test ($P < 0.05$). Data were log or arcsine transformed when necessary (Steel and Torrie, 1986).

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 ($3.34 \text{ cm tree}^{-1}$) comparing with

those of the trees irrigated at 100 and 200 mm evaporation, (3.44 and 4.25 cm tree⁻¹, respectively) (Table 3). *Eucalyptus* trees had stem diameter with 4.6 cm tree⁻¹ which was significantly greater than that of *C. erectus* trees (2.77 cm tree⁻¹) across treatments ($P<0.0001$) (Table 3). Irrigation treatments had no effect on tree height but, *Conocarpus* trees had mean stem height across treatments that was only 36% of that of *Eucalyptus* trees ($P<0.0001$) (Table 3).

Total leaf area:

Total leaf area was affected significantly by water deficit ($P<0.0001$). Across species, leaf area of the trees irrigated at 400 mm evaporation was 29,783 cm² tree⁻¹ comparing with 56,481 and 59,774 cm² tree⁻¹ for those grown under irrigation at 200 and 100 mm evaporation, respectively (Table 3).

The two species of the experiment differed significantly in their mean total leaf area across treatments ($P<0.0001$), where that of *Eucalyptus* trees was 2.8 folds that of *Conocarpus* trees. 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. *C. erectus* trees had mean root length (77 cm² tree⁻¹) and was significantly lower than that of *E. microtheca* trees (95 cm² tree⁻¹) ($P<0.0001$) (Table 4). 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 4).

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 ($P<0.0001$), ($P=0.0002$), ($P=0.0057$),

Table 3. 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)	<i>C. erectus</i>	2.42	3.241	2.638	2.77 ^b
	<i>E. microtheca</i>	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)	<i>C. erectus</i>	1.14	1.058	0.85	1.02 ^b
	<i>E. microtheca</i>	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)	<i>C. erectus</i>	28195.7	33958.5	15843.8	25999 ^b
	<i>E. microtheca</i>	91353	83508.9	43722.5	72861 ^a
Treatment mean		59774 ^a	56481 ^a	29783 ^b	

($P=0.0069$) and ($P<0.0001$), respectively. However, there was a cognation between the values of dry weigh of the trees in the will-watered treatment (irrigated at 100 mm evaporation) and those in the

medium stressed one (200mm evaporation); except for roots where the cognation was between those in the middle and in the severe water stressed (irrigated at 400 mm evaporation) treatments (Table 5).

Table 4. 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	<i>C. erectus</i>	87.9	71.7	71.3	77.0 ^b
	<i>E. microtheca</i>	96.7	96.3	91.7	95.0 ^a
Treatment mean		92.3 ^a	84.0 ^{ab}	81.5 ^b	
Number of woody roots	<i>C. erectus</i>	9.0	7.3	7.2	7.8 ^b
	<i>E. microtheca</i>	10.0	10.3	10.8	10.4 ^a
Treatment mean		9.5 ^a	9.0 ^a	8.8 ^a	
Diameter of woody roots	<i>C. erectus</i>	1.402	1.325	1.223	1.3 ^b
	<i>E. microtheca</i>	1.485	1.588	1.545	1.5 ^a
Treatment mean		1.44 ^a	1.46 ^a	1.38 ^a	

Table 5. 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)	<i>C. erectus</i>	409.41	567.95	311.95	433.38 ^b
	<i>E. microtheca</i>	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)	<i>C. erectus</i>	350.45	371.86	200.63	313.20 ^b
	<i>E. microtheca</i>	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)	<i>C. erectus</i>	164.11	232.42	93.60	165.99 ^b
	<i>E. microtheca</i>	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)	<i>C. erectus</i>	514.08	398.36	347.31	426.09 ^b
	<i>E. microtheca</i>	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)	<i>C. erectus</i>	1438.05	1570.59	953.50	1338.7 ^b
	<i>E. microtheca</i>	6130.64	5152.51	3455.00	5034.5 ^a
Treatment mean		3997.6 ^a	3361.6 ^a	2277.8 ^b	

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. There were species \times treatment interactions indicating changing the magnitude of treatment effects on leaf ($P=0.0003$), branch ($P=0.0057$) and total ($P=0.011$) dry weight due to species (Table 5).

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 almost had similar values. 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 well-watered, moderate and severe water stressed treatment, respectively (Table 6).

Root weight ratio (RWR) and root: shoot ratio (RSR) increased markedly in the trees grown under severe water stressed treatment ($P<0.0001$). Across treatments, *E. microtheca* trees had greater BRW ($P=0.0129$) and SWR ($P<0.0001$) but had lower RWR ($P<0.0001$) and RSR ($P<0.0001$) than those of *C. erectus* trees (Table 6). There was a species \times treatment interaction indicating changing the magnitude of treatment effects on LWR ($P=0.005$) due to species (Table 6).

Table 6. 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)	<i>C. erectus</i>	27.67	36.23	31.86	31.76 ^a
	<i>E. microtheca</i>	33.69	35.49	28.95	32.81 ^a
Treatment mean		30.95 ^b	35.86 ^a	30.32 ^b	
Stem weight ratio (SWR)	<i>C. erectus</i>	12.04	15.20	9.02	12.20 ^b
	<i>E. microtheca</i>	15.26	21.36	17.69	17.82 ^a
Treatment mean		13.80 ^b	18.28 ^a	13.61 ^b	
Branch weight ratio (BWR)	<i>C. erectus</i>	23.63	23.36	20.86	22.72 ^b
	<i>E. microtheca</i>	29.05	23.97	23.33	25.81 ^a
Treatment mean		26.59 ^a	23.66 ^b	22.17 ^b	
Root weight ratio (RWR)	<i>C. erectus</i>	36.66	25.21	38.25	33.32 ^a
	<i>E. microtheca</i>	22.00	19.19	30.02	23.56 ^b
Treatment mean		28.66 ^b	22.20 ^c	33.90 ^a	
Root: shoot ratio (RSR)	<i>C. erectus</i>	0.58	0.34	0.64	0.52 ^a
	<i>E. microtheca</i>	0.28	0.24	0.45	0.32 ^b
Treatment mean		0.42 ^b	0.29 ^c	0.54 ^a	

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-stressed treatment (irrigated at 400 mm evaporation) was significantly lower than that of the trees grown either under well-watered or moderate water stressed treatments ($P<0.001$) (Table 7). SLA of *C. erectus* trees was significantly greater than that of *E. microtheca* trees ($P<0.0001$).

There was a species \times treatment interaction indicating changing the magnitude of treatment effects on SLA ($P=0.0048$) due to species. Water

stress treatment 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 7).

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 7).

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 8).

Table (7): Means of relative growth rate and its components 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)	<i>C. erectus</i>	27.67	36.23	31.86	31.76 ^a
	<i>E. microtheca</i>	33.69	35.49	28.95	32.81 ^a
Treatment mean		30.95 ^b	35.86 ^a	30.32 ^b	
Specific leaf area (cm ² Leaf dry weight g ⁻¹)	<i>C. erectus</i>	71.18	69.39	55.88	65.48 ^a
	<i>E. microtheca</i>	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)	<i>C. erectus</i>	10.31	15.29	12.07	12.31 ^b
	<i>E. microtheca</i>	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)	<i>C. erectus</i>	0.012	0.01	0.011	0.011 ^b
	<i>E. microtheca</i>	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)	<i>C. erectus</i>	0.245	0.246	0.226	0.239 ^b
	<i>E. microtheca</i>	0.347	0.345	0.327	0.340 ^a
Treatment mean		0.296 ^a	0.295 ^a	0.276 ^b	

Table 8. Means values of leaf relative water content (RWC) and soil water content (SWC) of *Conocarpus 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) (%)	<i>C. erectus</i>	80.42	50.18	53.73	61.44 ^a
	<i>E. microtheca</i>	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 ₂ O) g (dry soil) ⁻¹	<i>C. erectus</i>	2.857	0.698	1.194	1.58 ^a
	<i>E. microtheca</i>	2.574	0.529	1.414	1.51 ^a
Treatment mean		2.72 ^a	0.61 ^b	1.30 ^b	

Leaf relative water content (RWC):

Relative water content of the leaves of the trees grown under irrigation at 400 mm evaporation was significantly lower than that of 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 ($P=0.0021$). The two species did not vary significantly in their RWC. There was a species \times treatment interaction indicating changing the magnitude of treatment effects on RWC ($P=0.051$) due to species (Table 8).

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 stress) caused significant reductions in most of the growth characteristics of *C. erectus* and *E. microtheca* trees comparing with irrigation at 100mm evaporation (sufficient irrigation). On the other hand, irrigation at 200 mm evaporation (moderate water stress) 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 stress) 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% of 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, however, this is not surprising as the former had relative growth rate was only 30% of the later. 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 dropping larger leaves of *E. microtheca* acrobatically. El-Juhany and Aref (2005) reported 78% reduction in total leaf area of *C. erectus* seedlings subjected to low water supply.

Decreasing root length of trees due to water deficit in the present study by 12% 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 an inherent difference 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 plant 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 cause reductions in these traits were 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 almost 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. 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.

Comparing 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 and 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 concurs 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.* (2005) concluded that the decrease in

RGR caused by water deficit was mainly explained by decreases in SLA.

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. It appears to be a crucial attribute determining the potential RGR of a species (Poorter *et al.*, 1990).

Decreased 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. 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 reflect 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 SWC. 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 (H₂O)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 be 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 a drought. 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).

References

- Alberdi, M.; M. Álvarez; E. Valenzuela; R. Godoy; E. Olivares and M. Barrientos. 2007. Response to water deficit of *Nothofagus dombeyi* plants inoculated with a specific (*Descolea antarctica* Sing) and non-specific (*Pisolithus tinctorius* (Pers.) Coker & Couch) ectomycorrhizal fungi. *Revista Chilena de Historia Natural*, 80: 479-491.
- Aref, I. M. 1987. "Provenance trail of *Casuarina sp.* in Riyadh region of Saudi Arabian Kingdom." M. Sc. Thesis, King Saud University, Riyadh, Saudi Arabia.
- Aref, I. M. and L. I. El-Juhany. 1999. "Effects of water deficit on the growth of *Acacia asak* (Forsk.), *A. tortilis* (Forsk.) and *A. gerrardii* (Benth) ssp. *negevensis* (Zoh.)." *Mansoura University Journal of Agricultural Sciences*, 24(10): 5627-5636.
- Aref, I.M. and L.I. El-Juhany. 2005. "Growth response of *Acacia seyal*, *Acacia negrii* and *Acacia asak* seedling

- to water stress under field conditions.” *Journal of King Saud University, Agriculture Sciences*, 17(2): 75-83.
- Barrs, H.D. 1968. Determination of water deficits in plant tissues pp. 235-368. In T.T. Kozlowski (Ed). *Water deficits and plant growth*. Academic Press, New York, U.S.A.
- Bradshaw, A.D, M.J. Chadwick, D. Jowett and R.W. Snaydon. 1964. “Experimental investigations into the mineral nutrition of several grass species.” IV. Nitrogen level. *Journal of Ecology*, 52: 665-676.
- Brouwer R. 1963. “Some aspects of the equilibrium between overground and underground plant parts.” *Jaarb IBS 1963, Wageningen*, pp. 31-39.
- Brouwer R. 1983. “Functional equilibrium: sense or nonsense.” *Netherlands Journal of Agricultural Sciences* 31: 335-348.
- Chunyang L., F. Berninger, J. Koskela and E. Sonninen. 2000. “Drought responses of *Eucalyptus microtheca* provenances depend on seasonality of rainfall in their place of origin.” *Australian Journal of Plant Physiology*, 27(3): 231–238.
- Arizona Department of Water Resources. 2005. *Low Water Use Drought Tolerant Plant List, Official Regulatory List for the Arizona Department of Water Resources, Santa Cruz Active Management Area, Arizona, USA*. 14 p.
- de Pereira-Netto, A.B., A.C.N. de Magalhães and H.S. Pinto. 1999. “Effects of soil water depletion on the water relations in tropical kudzu.” *Pesquisa Agropecuária Brasileira*, 34(7): 1361-1365.
- El-Juhany, L.I. and I.M. Aref. 1999. “Growth and dry matter partitioning of *Leucaena leucocephala* (lam.) de Wit. trees as affected by water stress.” *Alexandria Journal of Agriculture Research*, 44(2): 237-259.
- El-Juhany, L.I. and I.M. Aref. 2005. “Interactive effects of low water supply and high salt concentration on the growth and dry matter partitioning of *Conocarpus erectus* seedlings.” *Saudi Journal of Biological Sciences* 12(2): 147-157.
- Evans, G.C. 1972. “The Quantitative Analysis of Plant Growth.” Blackwell Scientific Publication, Oxford, London, Edinburgh, Melbourne.
- Grashoff, C., D.R. Ververke. 1991. “Effect of pattern of water supply on *Vicia faba* L. 3. Plant water relations, expansive growth and stomatal reactions.” *Netherlands Journal of Agriculture Sciences*, 39: 247–262.
- Hsiao, T.C. and E. Acevedo. 1974. “Plant response to water deficits, water-use efficiency, and drought resistance.” *Agricultural Meteorology*, 14: 59-84.
- Ibrahim, L. 1995. “Effects of nitrogen supply, water stress, and the interaction between water and nitrogen on assimilate partitioning in poplar.” A Ph.D. thesis, University of Aberdeen, UK.
- Galmés, J., J. Cifre, H. Medrano and J. Flexas. 2005. “Modulation of relative growth rate and its components by water stress in Mediterranean species with different growth forms.” *Oecologia*, 145(1): 21-31.
- Khalil, A.A.M. and J. Grace 1992. “Acclimation to drought in *Acer pseudoplatanus* L. (Sycamore) seedlings.” *Journal of Experimental Botany*, 43(275): 1591- 1602.
- Khurana, E. and J.S. Singh. 2000. “Influence of Seed Size on Seedling Growth of *Albizia procera* Under Different Soil Water Levels.” *Annals of Botany*, 86: 1185-1192,
- Kozlowski, T.T. 1982. “Water supply and tree growth, Part I. Water deficits (review article).” *Forestry Abstracts*, 43(2): 57- 95.
- Kramer, P.J. 1969. “Plant and soil water relationships: a modern synthesis.” New York: McGraw-Hill, 482p.
- Leustahner, C., K. Backes, D. Hertel, F. Schipka, U. Schmitt, O. Terborg and M. Runge. 2001. “Drought responses at leaf, stem and fine root levels of

- competitive *Fagus sylvatica* L. and *Quercus petraea* (Matt.) Liebl. Trees in dry and wet years.” *Forest Ecology and Management*, 149: 33-46.
- Linder, S., M.L. Benson, B.J. Myers and R.J. Raison. 1987. “Canopy dynamics and growth of *Pinus radiata*. I. Effect of irrigation and fertilization during drought.” *Canadian Journal of Forest Research*, 17: 1157-1165.
- Mana, F.A., M.F. Zoghrt, and A.A. Abo-Hasan. 1996. “Studies on the suitability of some exotic tree species to planting in Riyadh Region. Research Bulletin No. 59: 5-19 (In Arabic).” Agricultural Research Centre, Faculty of Food and Agriculture Sciences, King Saud University, Saudi Arabia.
- Mayers, B.J. and J.J. Landsberg. 1989. “Water stress and seedling growth of two eucalyptus species from contrasting habitats.” *Tree Physiology*, 5(2): 207-218.
- Merchant, A., A. Callister, S. Arndt, M. Tausz and M. Adams. 2007. “Contrasting Physiological Responses of Six *Eucalyptus* Species to Water Deficit.” *Annals of Botany*, 100(7): 1507-1515.
- Poorter, H., C. Remkes. 1990. “Leaf-area ratio and net assimilation rate of 24 wild-species differing in relative growth rate.” *Oecologia*, 83: 553–559.
- Roden, J., E. Van Valkenburge and T.M. Hinckley. 1990. “Cellular basis for limitation of poplar leaf growth by water deficit.” *Tree Physiology*, 6(2): 211-220.
- Rodríguez, P., A. Torrecillas, M.A. Morales, M.F. Ortuño and M.J. Sánchez-Blanco. 2005. “Effects of NaCl salinity and water stress on growth and leaf water relations of *Asteriscus maritimus* plants.” *Environmental and Experimental Botany*, 53: 113-123
- SAS. 2001. SAS/STAT User’s Guide Release 6.03 ed. SAS Institute Inc. Cary, NC.
- Steel, R.G.D. and J.H. Torrie, 1986. “Principle and Procedure of statistics. A Biometrical Approach, 2nd edition.” Mc. Graw Hill Books Co. New York.
- Steinberg, S.L, J.R. Miller Jr. and M.J. McFarland. 1990. “Dry matter partitioning and vegetative growth of young peach trees under water stress.” *Australian Journal of Plant Physiology*, 17: 23-36.
- Termaat, A., J.B. Passioura and R. Munns. 1985. “Shoot turgor does not limit shoot growth of NaCl-affected wheat and barley”. *Plant Physiology*, 77: 869- 872.
- Wu, F., W. Bao, F. Li and N. Wu. 2008. “Effects of drought stress and N supply on the growth, biomass partitioning and water use efficiency of *Sophora davidii* seedlings.” *Environmental and Experimental Botany*, 63: 248-255.
- Zoghet, M.F. 1997. “The introduced Eucalyptus species to the research Station of the Centre for Desert Studies and their suitability to grow in Riyadh Region.” Technical Bulletin No. 7 (In Arabic), 52 p. Desert Research Studies Centre, King Saud University, Saudi Arabia.