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Performance of two *Eucalyptus* species at different slope positions and aspects in a contour-ridge planting system in the Negev Desert of Israel☆

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Performance of two *Eucalyptus* species at different slope positions and aspects in a contour-ridge planting system in the Negev Desert of Israel[☆]

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Abstract

The growth of *Eucalyptus occidentalis* and *Eucalyptus sargentii*, established in January 1987 at different slope positions and aspects under a water-harvesting system in Dudaim, Negev Desert of Israel, was investigated during October 1991 to January 1992 and September–December 1993. Seven years after planting, *E. sargentii* had higher above-ground biomass (AGB) than *E. occidentalis* (91.17 ± 3.99 kg vs. 45.82 ± 2.00 kg per tree) and had 70% foliage biomass as opposed to 40% in *E. occidentalis*. The two species did not differ significantly in their stem biomass (*SB*) and total height (*H*). The effect of slope position on tree growth was significant; trees in the mid-slope position (with shallower soils of high sodicity) showed the lowest AGB and *SB* yield (30% less than those of the other positions) and lower height. The effect of aspect on tree growth was also highly significant. In general, trees on northern aspects had higher *SB* and AGB and *H*, than those on western aspects; trees on southern aspects were the poorest in growth. The study suggests that *E. sargentii* is a better shade and windbreak tree, while *E. occidentalis* is a better fuelwood species under arid-zone conditions.

Keywords: Arid land; Semiarid land; *Eucalyptus occidentalis*; *Eucalyptus sargentii*; Liman; Water harvesting

1. Introduction

In many developing countries, the main motivation for tree growing in arid and semiarid lands (ASAL) is the production of firewood and fodder. However, countries such as Israel have a strong interest in creating green belts around towns and along roads for recreational and sociopolitical reasons (Nahmias, 1989). The success of these efforts depends a great deal on adopting appropriate water-harvesting systems (WHS).

Contour ridges (terraces) and the 'Liman' are the WHS that are promoted by the Israeli Forestry Department in the Northern Negev desert (Brunori, 1993). The former refers to ridges, usually 70 cm high, formed along contours on slopes, with trees planted upslope between the ridges. The ridges across the slope act as water catchment structures, and the trees that are bordered downslope by the ridges benefit from runoff water from the catchment above. In the rocky part of the Negev Desert, the rate of water infiltration into the soil has been considerably higher in the hillslope minicatchments than in natural slopes (Yair et al., 1989); moreover, soil moisture content in the catchments remains higher for a much longer time after the rains,

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and is even carried over from one season to the next (Tsemach, 1990). A Liman consists of a checkdam built at the downhill side of a watershed or landscape, where a flat area of 0.5–1.0 ha is created to collect runoff water. Trees planted in the Limans grow better than those in the terraces (Brunori, 1994). However, the Liman uses only floodwater of large catchments, and relatively flat lands (which is scarce in this hilly region) are required for their construction. Furthermore, control of soil erosion, which is a serious problem in the region, is not addressed by the Liman, whereas the contour ridges act as effective erosion-control structures. Therefore, contour ridges (terraces) are the most common water-harvesting technique in the northern Negev Desert.

For afforestation of the Negev, tree introduction trials with *Acacia*, *Cassia*, *Casuarina*, *Eucalyptus*, *Pinus*, *Prosopis* and *Tamarix* have been undertaken in more than 30 locations/sites during the past 35 years (Weinstein, 1989). The early observation that *Eucalyptus* grew well when watered with collected runoff water (Nahmias, 1989) made this the preferred genus for afforestation of the Negev. Among the various species of *Eucalyptus*, some are reported to have resistance to drought and tolerance to salt and waterlogging. These characteristics make them useful for planting with water-harvesting methods.

The present study investigated the performance of two *Eucalyptus* species planted in a contour-ridge (terrace plantation) system in the Negev Desert. Since the distribution of vegetation in desert landscapes is strongly influenced by slope position (Yair and Danin, 1980; Hillel, 1982) and aspect (Hillel, 1982; Danin, 1989), the effects of these two variables on tree growth were specifically studied.

2. Materials and methods

The plantation under study is located in Dudaim, Negev Desert (Israel), 5 km northwest of Beer Sheva, at 31°21′N latitude, 34°47′E longitude, and 300 m altitude. The soil of the area is classified as loessial serozem (Dan et al., 1981); a survey done in May 1992 (S. Marish, personal communication, 1992) classified the soils of Dudaim as Inceptisols (Calicixerollic xerochrept) and Alfisols (Calcic palexeralf). Calcium carbonate content of the soil varies from 20 to 50% with higher amounts found near the bedrock; the top-soil layers are not saline, although in some places salinity above 6 dS m^{-1} is found at depths over 75 cm; pH varies from 8.3 to 9.0 with higher values in deeper layers; high sodicity, as indicated by sodium adsorption ratio (SAR) values of over 20 and exchangeable sodium percentage (ESP) values of over 15, was found at depths over 50 cm (Brunori, 1994). On steeper slopes there are patches devoid of vegetation, where small spots of bluish-violet color are found on the soil surface, possibly as a consequence of high sodium content. Rill erosion is prevalent in such areas.

The mean annual precipitation and temperature of the area are 220 ± 70 mm and 19.3 ± 0.6°C, respectively. Virtually all rain falls from November to March; the remaining periods, particularly from May to September, are typically dry. The vegetation is characterized by an association of low desert shrubs of the chenopod family, in which *Haloxylon articulata*, *Anabasis hausknechti* and *Anabasis aticulata* predominate. In relatively wet seasons, smaller grassy plants, such as sedge (*Carex* spp.) and feather grass (*Stipa tortilis*) may grow profusely, albeit ephemerally, in the open ground between the shrubs (Hillel, 1982).

The study site that had previously been under pasture was ripped with bulldozers to a depth of 50 cm along the planting line, and simazine (a preemergent herbicide) was applied by an airplane. The terraces were built by bulldozers, 30 m apart along the slopes.

Two species were planted: *Eucalyptus occidentalis* Endle and *Eucalyptus sargentii* Maiden. All tree seedlings were raised in the main nursery of the Forestry Department of the Jewish National Funds (J.N.F.) in Gilat. The seedlots were bulked collections from local trees selected for their shape and superior growth. The seedlings were placed in plastic bags with small holes at the bottom. In the field, the bottom parts of the bags were removed and the seedlings were planted along ridge contours at 6 m intervals and to 50 cm depth after the first big storm in January 1987 when the soil was wet.

In 1991, 5-year-old trees without any disease or mechanical damage by wind or tractors were identified at random for further studies. The study area was then stratified by slope position (upper, middle, and lower) and aspect (north, west, and south). Soil depth was also a major factor in delineation of the three positions: shallow in the upper slope, shallowest in the middle

Table 1
Number of measured trees in Dudaim plantations in 1991 and 1993

Species	Position	Aspect
Eucalyptus occidentalis ($n=129$)	Upper ($n=42$)	N ($n=14$)
		W ($n=16$)
		S ($n=12$)
	Middle ($n=64$)	N ($n=24$)
		W ($n=20$)
		S ($n=20$)
	Lower ($n=23$)	N ($n=8$)
		W ($n=10$)
		S ($n=5$)
Eucalyptus sargentii ($n=131$)	Upper ($n=16$)	N ($n=4$)
		W ($n=10$)
		S ($n=2$)
	Middle ($n=76$)	N ($n=30$)
		W ($n=21$)
		S ($n=25$)
	Lower ($n=39$)	N ($n=24$)
		W ($n=13$)
		S ($n=2$)

position, and relatively deep in the lower slope. The trees in all positions/aspects had been planted at equal spacing. The middle slope had relatively more plants than the upper and lower positions, and therefore the greatest number of observations (Table 1).

All selected trees were measured first in October 1991 to January 1992 and again in October–December 1993 for total height (H) of the dominant stem (some trees had multiple stems), diameter at breast height (DBH) of each stem, and basal diameter (DB) of the main trunk. Total above-ground biomass (AGB) for *E. occidentalis* was estimated using a prediction equation suggested by Zohar and Karschon (1984) for *Eucalyptus camaldulensis* in the Negev Desert, given similar growth habits of the two species (Y. Zohar, personal communication, 1993). For multistemmed trees, the average diameter of each stem was converted to basal area as recommended by MacDicken et al. (1991). The basal areas of all stems were summed and the corresponding diameter calculated (Jama et al., 1989; Lovenstein and Berliner, 1993). For *E. sargentii*, no equations or yield tables were available. Therefore, prediction equations for the oven-dry weights of biomass components were determined by appropriate models for AGB and SB (Brunori, 1994).

Although this study was of an observational nature (i.e. trees not planted in a planned experimental design and samples sometimes lacking a sufficient number of trees in specific combinations of species, position, and aspect), the data were analyzed as in factorial experiments. The general linear model (GLM) procedure of the Statistical Analysis Systems Institute Inc. (Cary, NC) was used, with the 1991 measurements as the covariate in each parameter under study. The three discrete variables included in the model were tree species, slope position, and aspect. Least square means (LSM) were used to assess significance of effects ($P=0.05$), after adjusting for other terms in the model. Differences between means of treatments were determined by pairwise contrasts of the LSM. Type III mean squares for the residual were used as the error term to test the effects of all the main factors and interactions. When the tests for the main effects were not conclusive, the polynomial effect of one factor at fixed levels of the other was tested.

3. Results

3.1. Species

Across all positions and aspects, some species differences were noted (Table 2). *Eucalyptus sargentii* had higher AGB than *E. occidentalis* at ages 5 and 7 years. The actual but not relative AGB increment in *E. sargentii* was larger than in *E. occidentalis*. The actual SB increment in *E. occidentalis* was higher than in *E. sargentii*. The species did not differ in SB and H.

3.2. Slope position

The effects of some slope positions were consistent across aspects and species for certain characteristics. Middle-slope plants were shorter ($P<0.012$) and had less SB ($P<0.01$) and AGB ($P<0.002$) than plants in the other two positions (e.g. seventh-year AGB of 55.85 ± 2.43 kg, 72.96 ± 4.90 kg, and 76.67 ± 4.84 kg per tree for middle, upper, and lower slopes, respectively). Upper and lower slope position effects were typically similar.

The effect of slope position differed somewhat for each species (Table 3). In *E. occidentalis*, the increment in H of the upper-slope plants was significantly larger than that of middle-slope plants ($P=0.007$), lower-slope trees had the largest DBH ($P<0.035$),

Table 2
Height (*H*), stem biomass (*SB*), and above-ground biomass (AGB) means (±SE) and their adjusted increments (1991–1993) for *Eucalyptus occidentalis* and *Eucalyptus sargentii*

Characteristics[a]	*E. occidentalis*	*E. sargentii*	*P* values
H 1991	5.52 ±0.10	5.72 ±0.14	0.232
H 1993	6.92 ±0.09	7.02 ±0.13	0.572
% *H* increment	27.74 ±3.80	24.43 ±3.88	0.659
AGB 1991[b]	22.751 ±1.84	49.088 ±2.63	0.001
AGB 1993[c]	45.821 ±2.00	91.166 ±3.99	0.001
% AGB increment	138.54 ±9.61	103.31 ±11.48	0.057
SB 1991[b]	12.843 ±0.82	12.096 ±1.18	0.603
SB 1993[c]	27.729 ±1.42	27.972 ±2.02	0.922
% *SB* increment	150.98 ±13.87	233.24 ±18.15	0.003

[a] Biomass is expressed in kilograms per tree and height in meters.
[b] AGB and *SB* assumed DBH = 10.35 cm for *E. occidentalis*, *DB* = 8.66 cm for *E. sargentii*.
[c] AGB and *SB* assumed DBH = 14.52 cm for *E. occidentalis*, *DB* = 13.07 cm for *E. sargentii*.

Table 3
Effect of three slope positions on height (*H*,m), DBH (cm) or basal diameter (*DB*,cm), stem biomass (*SB*), and above-ground biomass (AGB) of *E. occidentalis* (EO) and *E. sargentii* (ES). Values are given as means ± SE. Biomass is expressed in kilograms per tree

Characteristic	Species	Upper	Middle	Lower
H 1991	EO	5.52 ± 0.16ab	5.26 ± 0.12a	5.77 ± 0.22b
	ES	6.92 ± 0.50a	5.84 ± 0.20b	6.42 ± 0.20ab
H 1993	EO	7.07 ± 0.15a	6.57 ± 0.12b	7.12 ± 0.21a
	ES	7.28 ± 0.29	6.70 ± 0.11	7.07 ± 0.25
H % increrment	EO	29.65 ± 3.99	25.97 ± 3.72	27.58 ± 4.43
	ES	24.91 ± 4.90	23.63 ± 3.58	24.73 ± 4.51
1991 DBH	EO	10.02 ± 0.47	9.29 ± 0.38	11.72 ± 0.66
DB	ES	9.73 ± 0.98a	7.49 ± 0.37b	8.77 ± 0.84ab
1993 DBH	EO	14.00 ± 0.50a	13.70 ± 0.40a	15.90 ± 0.70b
DB	ES	13.91 ± 0.91a	11.68 ± 0.35b	13.63 ± 0.78a
% increment DBH	EO	41.60 ± 2.70a	50.90 ± 2.20b	46.60 ± 3.80ab
DB	ES	50.9 ± 5.9	51.3 ± 2.3	53.2 ± 5.1
SB 1991	EO	11.27 ± 1.29a	10.42 ± 1.04a	16.84 ± 1.81b
	ES	14.24 ± 2.57a	8.48 ± 0.99b	13.55 ± 2.21a
SB 1993	EO	25.47 ± 2.24a	23.82 ± 1.81a	33.90 ± 3.14b
	ES	33.23 ± 4.43a	20.65 ± 1.67b	30.04 ± 3.78a
SB % increment	EO	130.7 ± 18.1a	175.1 ± 15.1b	147.2 ± 25.8ab
	ES	216.0 ± 34.4	240.3 ± 14.5	243.4 ± 30.1
AGB 1991	EO	24.52 ± 5.01ab	22.62 ± 3.82a	31.52 ± 6.63b
	ES	52.59 ± 5.76a	39.70 ± 2.17b	54.97 ± 4.91a
AGB 1993	EO	42.68 ± 4.42ab	39.98 ± 3.57a	54.80 ± 6.18b
	ES	103.23 ± 8.75a	71.72 ± 3.30b	98.55 ± 7.46a
AGB % increment	EO	122.8 ± 11.8a	156.0 ± 10.1b	136.8 ± 16.2ab
	ES	114.4 ± 20.6	85.3 ± 9.2	110.2 ± 18.3

Different letters indicate significant differences among positions within species.

DBH increment of middle-slope plants was significantly larger than that of upper-slope trees ($P=0.008$), and the AGB of lower-slope trees was the highest ($P<0.03$). In the middle slope position, AGB increment of *E. occidentalis* was higher than that of *E. sargentii* ($P=0.0001$).

In *E. sargentii*, middle-slope trees had the smallest DB ($P<0.025$) and the lowest AGB ($P<0.001$) (Table 3). The AGB increment of upper-slope plants was larger than that of middle-slope plants ($P=0.003$).

3.3. Slope aspect

The effects of aspect on seventh-year AGB of the combined species were highly significant. Trees on the north aspect were larger ($P<0.006$) than those on the west and south aspects (78.97 ± 3.56 kg, 65.86 ± 3.14 kg, and 60.64 ± 5.56 kg per tree, respectively). The north-aspect trees had more H ($P<0.005$) and SB ($P<0.02$). Trees on the west aspect had more H than those on the south ($P=0.012$).

No species differences were detected in the south aspect, but the other aspects influenced the two species somewhat differently (Table 4). For *E. occidentalis*, the south aspect had the lowest H ($P<0.002$), smallest DBH ($P<0.002$), and lowest AGB ($P<0.004$). The DBH, DBH increment, and AGB increment in the west aspect were significantly larger. In the west aspect, *E. occidentalis* had higher SB and AGB increment ($P=0.002$) than *E. sargentii*. For *E. sargentii*, the north aspect had the highest H ($P<0.002$), AGB ($P<0.001$), and AGB increment ($P<0.019$). In the north, *E. sargentii* produced higher SB than *E. occidentalis*. The west aspect had significantly smaller DB ($P<0.001$) for *E. sargentii*.

Table 4
Effect of three slope aspects on height (H,m), DBH (cm) or basal diameter (DB,cm), stem biomass (SB), and above-ground biomass (AGB) of *E. occidentalis* (EO) and *E. sargentii* (ES). Biomass is expressed as kilograms per tree. Values are given as means ± SE

Characteristic	Species	North	West	South
H 1991	EO	5.75 ± 0.16a	5.69 ± 0.15a	5.49 ± 0.16b
	ES	6.39 ± 0.19a	5.28 ± 0.34b	5.49 ± 0.16b
H 1993	EO	7.22 ± 0.16a	7.08 ± 0.15a	6.47 ± 0.18b
	ES	7.69 ± 0.18a	6.91 ± 0.15b	6.44 ± 0.33b
H % increment	EO	29.7 ± 4.5	28.6 ± 4.1	25.0 ± 3.9
	ES	26.4 ± 4.5	25.8 ± 3.8	21.1 ± 4.8
1991 DBH	EO	11.34 ± 0.49a	11.04 ± 0.47a	8.66 ± 0.58b
DB	ES	9.98 ± 0.60	7.60 ± 0.50	8.40 ± 0.84
1993 DBH	EO	15.20 ± 0.53a	15.75 ± 0.50a	12.62 ± 0.63b
DB	ES	14.59 ± 0.57a	11.98 ± 0.47b	12.65 ± 1.02b
% increment DBH	EO	43.5 ± 2.9a	54.1 ± 2.7b	41.5 ± 3.4a
DB	ES	52.8 ± 3.9	47.1 ± 3.1	55.1 ± 6.5
SB 1991	EO	14.88 ± 1.35a	15.49 ± 1.28a	8.16 ± 1.60b
	ES	17.33 ± 1.60a	9.02 ± 1.39b	9.94 ± 2.83b
SB 1993	EO	30.24 ± 2.35a	33.41 ± 2.22a	19.53 ± 2.78b
	ES	37.37 ± 2.74a	22.50 ± 2.28b	24.05 ± 4.90b
SB % increment	EO	135.8 ± 20.1a	182.2 ± 19.7b	134.9 ± 21.0a
	ES	233.7 ± 25.9	218.0 ± 19.0	248.0 ± 36.1
AGB 1991	EO	26.22 ± 3.05a	26.76 ± 2.88a	15.27 ± 3.61b
	ES	60.19 ± 3.56a	40.26 ± 2.96b	46.81 ± 6.37ab
AGB 1993	EO	49.84 ± 4.63a	54.01 ± 4.37a	33.61 ± 5.48b
	ES	108.09 ± 5.41a	77.72 ± 4.49b	87.68 ± 9.67ab
AGB % increment	EO	128.0 ± 13.0a	163.6 ± 12.7b	123.9 ± 13.2a
	ES	112.2 ± 15.4	163.6 ± 12.7	124.0 ± 13.2

Different letters indicate significant differences among aspects within species.

4. Discussion

The extent to which water harvesting techniques (1) maximize use of water made available to plants and (2) promote deep root penetration varies greatly from place to place depending upon a number of site-specific conditions. In this study, at least 60% of runoff water was harvested so that 310 mm $year^{-1}$ (as opposed to mean annual rainfall of 220 mm) was made available to the plants (Brunori, 1994). This additional amount helps the trees withstand severe drought, such as in 1988/1989.

4.1. Species

Eucalyptus occidentalis is an important tree for afforestation of ASAL in the Mediterranean countries (FAO, 1979). A native of the southern part of Western Australia, where it grows from 6 to 21 m in height in low-lying areas characterized by a mediterranean-type climate and considerable variation in habitat conditions (Zohar and Moreshet, 1987), it can withstand short periods of flooding. It has shown comparatively superior growth under semiarid, saline, and high pH conditions in Israel and can be cultivated for timber and honey production (Chippendale, 1973). *Eucalyptus sargentii* grows to a height of 8–11 m in the southern part of Western Australia, where the annual rainfall is 300–380 mm. Chippendale (1973) describes the tree as drought resistant, suitable as a windbreak and shade tree; despite its high salt tolerance, it is not used very much in afforestation.

In the present study, *E. sargentii* appears to be a better species for windbreaks or shade, while *E. occidentalis* is a better fuelwood species. The higher AGB and AGB increment of *E. sargentii* (double that of *E. occidentalis*) can be attributed to foliage biomass which was 70% of AGB in *E. sargentii* against 40% in *E. occidentalis*. The *SB* of the two species were similar. However, the *SB* increment was higher in *E. occidentalis*. Both *H* and *H* increment were similar, and no significant changes since 1991 were detected. The higher salt tolerance of *E. sargentii* compared with that of *E. occidentalis* (Chippendale, 1973) could be an important reason for its better performance. The high AGB increment of *E. sargentii* suggests that the water collected in the terraces was enough to sustain its growth.

While the multiple-stemmed habit and dense canopy of *E. sargentii* make it a good windbreak and shade tree, these features may have caused its decrease in *SB* on the western slope. This lower growth in stem biomass may be attributed to the strong westerly winds in the winter and early spring in this area, leading to stress and a higher carbon allocation below-ground. For example, it was observed, though the data are not present here, that the middle-slope plants had a higher number of large roots and at deeper levels than those in other positions (Brunori, 1994); this could be an adaptive mechanism to counteract the strong winds that had uprooted several trees in the past years.

4.2. Slope position

Middle-slope *E. occidentalis* and *E. sargentii* trees had the lowest AGB and *SB* (30% less than those of the other positions) and lower *H*. However, the effect of slope position on growth increment (expressed as various growth parameters) was always non significant. Thus, while the absolute values of differences in growth parameters among the trees in the three positions were different, the growth increments were not. Therefore, these differences among the trees are likely to become more conspicuous over time.

Soil depth and chemistry apparently played a major role. The B horizon, which had high ESP (Brunori, 1994), was very close to the surface in the middle slope. Soil erosion may have brought these (originally) deep soil strata close to the surface. Where the B horizon was at a depth of 65 cm or more, as observed at the upper and lower slopes, the plants grew better.

4.3. Slope aspect

The effect of aspect on tree growth was highly significant. The trees on northern slopes had higher growth in AGB and *H* than those planted in the western aspect. When the latter trees were then compared with those planted on slopes facing south, their growth was significantly higher. At the species level, *E. occidentalis* did worst on the south aspect while *E. sargentii* grew best on the north aspect.

Better microclimatic conditions may explain the higher growth of trees on the northern aspect. Differences between north- and south-facing slopes in subtropical to temperate latitudes are well-documented

(Gates, 1980). These differences in insolation cause significant dissimilarities in environmental conditions on many parts of the Earth, including the Israelian deserts (Danin, 1989).

The impact of effective rain on sloping ground should also be taken into account. Sharon (1980) reported that, in mid-latitudes, rains fall at a considerable inclination owing to strong winds during the storms, thus creating prominent differences in rainfall amounts on the windward slopes compared with the opposite slopes. Morin et al. (1991) reported that western slopes in Dudaim had twice as much runoff as other aspects (except the east, which had much less). The predominant winds during the winter rainy days come from the west, especially in hilly areas of the Negev Desert, where westward slopes receive 1.2 times more rain than other slopes. The fact that the trees there performed better than on the northern slopes which received less rain + runoff confirms that water availability was not a factor that affected the differences among the aspects. The hypothesis that prevailing winter winds could have an impact on the distribution of vegetation in the rocky Judean Desert in Israel was tested by Danin (1989). He demonstrated how biological communities were strictly linked to rain direction, mostly because of the effect of water on leaching of soil salts. However, as reported by Yair and Danin (1980), the edaphic influence of hard rocks on the moisture regime of the vegetation is much more pronounced than the impact of rain direction. According to Dan et al. (1981), the soils found in northern slope around Beer Sheva (as in Dudaim) are generally shallower than those in western and southern slopes. This also strengthens the argument that soil differences were not a major factor that caused the different behavior of trees in different slopes. Therefore, the observed differences among the three aspects could be attributed to less exposure to direct light in the northern slope. Less direct sunlight might reduce the stress caused by extreme temperatures, reducing the evapotranspiration levels, and creating better conditions for tree growth.

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