SEASONAL EVAPOTRANSPIRATION, GROWTH, AND WATER USE EFFICIENCY BY PLANTATION GROWN *Pinus eldarica* Medw. DERIVED FROM FIELD AND WEIGHING LYSIMETER STUDIES

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ABSTRACT

Water use efficiency (WUE) is essential to agricultural production in arid and semiarid regions. Plant productivity in these regions is directly related to the availability of water. Pinus eldarica Medw. has gained rapid popularity as a short rotation Christmas tree or ornamental crop in Southern New Mexico. The tree also has potential for woody biomass production. Because the tree is a recent introduction to the area, effective irrigation guidelines for its production were unavailable as were guidelines for irrigated pine tree plantations in general. The objectives of this study were to determine crop evapotranspiration (ETc) ($\text{mm} \cdot \text{day}^{-1} \cdot 6.25\ \text{m}^{-2}$) and water use efficiency (WUE) ($\text{kg DM} \cdot \text{m}^{-3}\ H_2O$) for above ground biomass of P. eldarica under three flood irrigation regimes. Irrigation regimes equivalent to 173, 298, and 457 mm in addition to 159 mm precipitation during the 1983 growing season were applied. The resultant ETc was 527.9, 558.7 and 604.4 mm in the respective treatments. Much of the water was lost as evaporation from the soil surface due to the widely spaced test plots. Trees in the lowest irrigation regime relied heavily on stored soil water to maintain growth rates similar to other regimes. Height growth increased 0.80, 1.04 and 1.05 m, while biomass increased 3185.6, 3524.8, and 4323.2 $\text{kg DM} \cdot \text{ha}^{-1}$ in the 60, 80 and 100 percent irrigation regimes. Water use efficiency ranged from 0.32 to 5.18 $\text{kg DM} \cdot \text{m}^{-3}\ H_2O$ consumed as ETc.

Key words: water use efficiency, evapotranspriation, irrigation, field studies, weighing lysimeter, eldarica pine

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INTRODUCTION

Plant productivity in arid or semiarid regions is directly related to the availability of water and secondarily to the availability of nutrients. Arid and semiarid regions generally have low productivity, due to lack of available water. Soils in these regions generally contain adequate amounts of plant nutrients. However, the availablity of these nutrients may be limited due to high alkalinity.

With supplemental water, these regions are earmarked for agricultural expansion or agroforestry to provide fuelwood or timber resources. Agroforestry is a recent term defined as the use of intensive agricultural management practices for the production of forest species. Few studies have been conducted on forest species that deal with supplemental irrigation and fertility in an intensive agronomic sense. Atwill and Cromer (1982) studied photosynthesis and transpiration of _Pinus radiata_ D. Don in response to irrigation with wastewater in a non-uniform plantation receiving irrigation plus precipitation up to 1500 mm. Few conifers are tolerant the alkaline soils or limited water availability that characterize arid or semiarid regions. _P. eldarica_ has demonstrated rapid growth with supplemental irrigation on alkaline soils of the Rio Grande flood plain, Las Cruces, N. M. (Fisher, Widmoyer and McRae 1982). _P. eldarica_ is native to a small area in southern Russia that receives up to 150 mm annual precipitation (Kolesnikov and Gussein 1961).

A requirement for productivity studies in arid or semiarid regions is the efficient use of water, because water conservation is paramount to the continued productivity of these regions. The ultimate goal, particularly in areas where supplemental irrigation is required for maximum productivity, is to fully meet the water requirements of the plant without excessive applications of the water resource.

The objective of this study was to measure non-restricted evapotranspiration (ET_c), to determine above ground biomass accumulation and to evaluate water use efficiency (WUE) by *P. eldarica* under intensive irrigation management. The literature is virtually devoid of studies dealing with these parameters, particularly for juvenile conifers having uniform age and spacing, in semiarid regions.

REVIEW OF METHODOLOGY USED

Evapotranspiration (ET) is defined as the combined water vapor leaving a system by evaporation from soil and plant surfaces. Crop evapotranspiration (ET_c) refers to ET from a particular crop of interest, in this case the crop is *P. eldarica*. Reference evapotranspiration (ET_r) is further defined as the rate of water use from a reference crop and is used to provide a standardized basis for comparing measured ET_c rates. The Penman combination is generally accepted as the reference to water use by grass. The Penman equation was originally developed using a short green crop of uniform height completely shading the ground and never stressed for water. The rates of water use expressed in this report were derived from direct measurements of the changes in soil water content by the neutron scattering technique, in conjunction with the water balance equation for determining ET_c, Feder (1970), and from estimated ET_r derived from the Penman combination equation as modified by Cuenca and Nicholson (1982). Water use efficiency (WUE) is defined here as the amount of water used as ET_c to accumulate a unit of above ground biomass. Water use efficiency was calculated for *P. eldarica* using measured ET_c and estimated above ground biomass.

Site and Plot Description

Crop evapotranspiration and WUE studies were conducted on *P. eldarica* (afghan, eldarica, Russian or 'Mondell' pine) during the third growing season. The plantation was located at the New Mexico State University, Fabian Garcia Horticulture Farm, Mesilla Park, New Mexico.

The site is described as nearly level flood plain alluvium typical of the Mesilla Valley, southern New Mexico. The soils were deep well drained torrifluvents consisting of three soil series; Brazito very fine sandy loam, Glendale loam and Harkey clay loam (Bullock and Neher 1980).

The 0.8 ha plantation was established in April 1981 with one-year-old container grown stock. The seedlings were grown in 160 cm^3 Ray Leach super cells, (Ray Leach, Canby, Or.) by the NMSU-Silviculture Research Unit (NMSU-SRU). The seedlings were approximately 30 cm when planted, and saplings were 0.92 to 1.16 m in height and had basal diameters 2.43 to 3.16 cm when ET_c and WUE measurements commenced in May 1983.

The study used a randomized complete block design (RCBD) (Steele and Torrie 1960) having three treatments and four replicated blocks. This design was a subdesign imposed on a larger experiment having a RCBD with six treatments and four replicated blocks (figure 1). Each 10 x 20 m main block was devided into four 5 x 10 m split treatments containing eight trees on 2.5 x 2.5 m spacing. The four central trees in each plot were the sample trees and occuppied 25 m^2, while the two trees on either edge of the plot were considered border trees separating one main treatment from another. The split treatments were nitrogen fertility levels, while the main treatments were irrigation levels. Trees in this study received nitrogen as ammonium sulfate equivalent to 120 $kg \cdot ha^{-1}$. The main treatments consisted of three irrigation regimes applied by the flood method. The seasonal irrigation depths were equivalent to 457, 366 and 274 mm and are futher referred to as the 100, 80 and 60 percent treatments respectively. In practice, however, seasonal irrigation

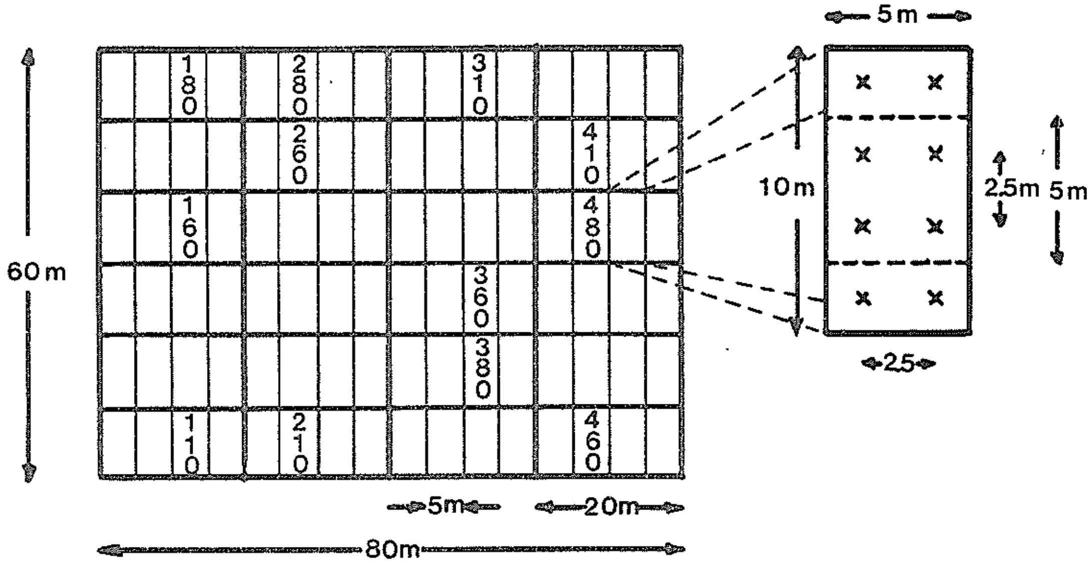

Figure 1. Study plot layout with dimensions, and randomized complete block experimental design showing randomization of replicates and treatments. Tree spacing is denoted by 'X'; area per tree = 6.25 m^2.

depths equal to 457, 298 and 173 mm were applied in addition to 159 mm season precipitation occurring from May 1983 through March 1984. The irrigations were applied on March 30, May 21, June 30 and August 30, 1983.

Evapotranspiration

Crop evapotranspiration was determined in field plots by the water balance equation defined by Feder (1970). The equation as used here is defined as follows:

$$ET_c = I + R - D \ (+/-) \ SM \qquad (1)$$

Where;

ET_c = crop evapotranspiration ($mm \cdot day^{-1}$)

I = irrigation (mm)

R = precipitation (mm)

D = deep percolation (mm)

SM = soil moisture content (mm)

Irrigations (I) were piped and metered to an accuracy of 0.38 l. To facilitate uniform irrigation distribution, a 5.00 cm pipe with 0.95 cm perforations at 15 cm intervals running the length of the pipe was used during irrigations. The water delivery pipe ran centrally the length of the plot and was capped at the terminal end.

Precipitation (R) was monitored in each plot with inexpensive gauges described by Buchanan et al. (1978). The gauges were located to one side in each plot at a 1.5 m height (figure 2). It was assummed

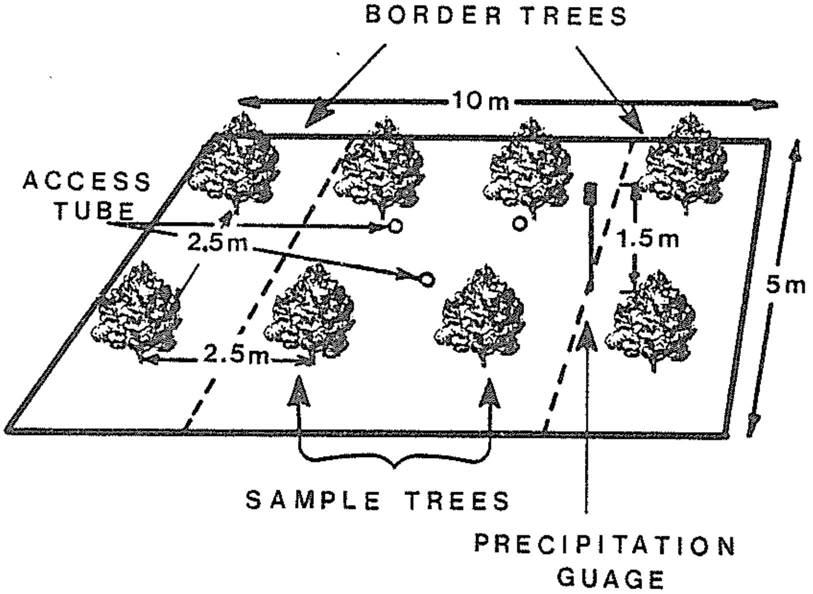

Figure 2. Study plot showing tree spacing, study trees and border trees, access tube placement, and precipitation guage location.

that canopy heights would not interfere with precipitation collection during the study, because canopy heights were not large and the gauges were located 1.25 m from any tree. Additional precipitation data were obtained from the NMSU Agricultural Experiment Station (NMSU-AES)climate observation site located 1.6 km east of the study site. Deep drainage (D) was undetermined but was regarded negligible after the March 1983 irrigation.

The change in soil moisture content (SM) was determined by the neutron scattering technique (neutron probe). Four access tubes were located 25 cm diagonally from each sample tree toward the center of each plot, and one tube was located centrally 1.77 m in the plot (figure 2). The access tubes were inserted into hand augered holes and a soil and water slurry was poured around each tube to minimize air gaps between the exterior tube wall and soil interface. The tubes were rubber stoppered at the bottom to prevent water from entering the tube from below, while beverage cans loosely capped the top prevented the tube from filling with rain water.

Measurements of soil moisture were made at weekly intervals from May 1983 through October 1983, then bi-weekly through March 21, 1984. Standard (shield) counts were made before and after each set of nine measured (soil moisture) counts per tube. Thus soil moisture was determined at 15 cm intervals to 135 cm. The neutron probe was calibrated to the study site by the following procedure;

1. Calibration measurements were made in barrels filled with sand and clay (the two predominant textures at the study site). The two soils were at known high and low moisture contents.

2. Using the factory supplied calibration curve for neutron probe, volume water contents (cm^3 $H_2O \cdot cm^{-3}$ soil) were calculated from test measurements.

The two calibration equations are as follows;

$$Y \text{ sand} = 1.3657x - 4.5112 \qquad r^2 = .9995 \tag{2}$$

$$Y \text{ clay} = 1.4176x - 8.0233 \qquad r^2 = .9996 \tag{3}$$

Where;

Y sand or Y clay = the estimated volume water contents (cm^3 $H_2O \cdot cm^{-3}$ soil) corrected for the effects of sand or clay

x = factory estimated volume water content (cm^3 $H_2O \cdot cm^{-3}$ soil)

4. Finally, each soil depth increment in the study was visually assessed for predominant sand and/or clay presene as a depth per depth increment each 15 cm to determine the fractional influence that sand or clay had on the measured soil water content.

Volume water contents per 15 cm depth increment were finally calculated as;

$$VW = (Y\ sand)\ (frvw\ sand) + (Y\ clay)\ (frvw\ clay) \tag{4}$$

Where; VW = estimated volume water contents ($cm^3\ H_2O \cdot cm^{-3}$ soil)

$frvw$ = fractional volume water per depth

Water Use Efficiency

Tree heights were measured from the soil surface to the apical bud to the nearest 0.1 m. Basal diameters were measured at 5.0 cm above the soil surface with calipers accurate to the nearest 1.0 cm. Measurements were collected at monthly intervals (February to November) during the 1983 season by Hernandez (personal communication). Above ground biomass (kg) was estimated by the following equation adapted from data collected by Mayes-F (1984);

$$Y = 78.9646X \tag{5}$$

$$n = 31 \qquad r^2 = 0.9669$$

Where; Y = total above ground biomass at 5.0 cm (kg)

X = basal cross sectional area at 5.0 cm (cm^2)

$$WUE = kg\ DM \cdot m^{-3}\ H_2O \quad (6)$$

Where; DM = oven dried biomass above 5.0 cm determined monthly (kg)

ET_c = total monthly crop evapotranspiration (m^3)

Additional Measures and Practices

Data necessary to determine ET_r by the Penman combination equation as modified by Cuenca and Nicholson (1982) were collected by the NMSU-AES climatic observation site located 1.6 km east of the study site and from the NMSU Plant Science Research Center (NMSU-PSRC) located 16 km south of the study site. Particular modified equations for the wind function and form of the vapor pressure deficit calculation, follow Sammis et al. (1985). Reference crop evapotranspiration is related to ET_c to obtain a crop coefficient (K_c) (7) by simple derivation. The crop coefficient can then be related to ET_r to predict ET_c (8) at other sites.

$$K_c = ET_c \cdot ET_r^{-1} \quad (7)$$

$$ET_c = K_c \times ET_r \quad (8)$$

Where; K_c = the crop coefficient (unitless)

ET_c = evapotranspiration for the crop ($mm \cdot day^{-1}$)

ET_r = reference evapotranspiration ($mm \cdot day^{-1}$)

K_c was empirically determined from data collected during the study. Transpiration (T_r) was estimated from ET_r by evaluating K_c at a base level.

To establish the influence of irrigation treatment on plant moisture stress (PMS), the pressure bomb technique was used (Kaufmann 1968) as modified for conifer needles by Johnson and Nielsen (1969). Leaf water potential measurements were conducted at three day intervals for two consecutive days beginning in August 1983. A Plant Moisture Stress Co., Corvalis, Or. pressure bomb was used. Two main blocks (replications two and three see figure 1) of the study were measured on consecutive days. Leaf water potentials, measured in pressure units megapascuals (-MPa) were determined at pre-dawn (0430-0600 hrs) and at mid-day (1145-1315 hrs) on three-needled fascicles from one-year-old tissues at mid-crown of the south-facing canopy. At least three fascicles were measured per sampling and pressure readings were required to close within +/- 0.5 MPa. Two saplings were measured in each plot. Samples were measured within one minute of sample collection and inflow pressure in the chamber was set at 200 $\text{psi} \cdot \text{min}^{-1}$ as per Kaufmann (1968). Measurements were made by this procedure and scheduled through October 1983.

To confirm transpiration estimates in field studies, six field grown eldarica pines were purchased from a local grower (Archer Farms, La Mesa, N.M.), transplanted into larger containers and were used for weighing-type lysimeter studies during May and June 1984. The trees were approximately the same height and caliper (2.1 m and 6.4 cm respectively) as those in the main study during the previous year. The trees had been recently dug (approximately three weeks prior) and had root balls trimmed to fit 37.8 l containers. The trees were transplanted to 64.4 l containers by January 15, 1984. The container dimensions were 40.6 cm diameter by 55.9 cm in height. The containers had drainage holes and were filled with 7.5 cm of coarse gravel in the bottom to assure adequate drainage. A sandy loam soil was used as supplemental fill during transplanting, because this soil texture was similar to the field soil where the trees were grown. A 10 cm surface mulch of coarse black scoria gravel was used to provide a soil surface evaporative barrier.

The weighing lysimeter trees were grown in the NMSU-SRU greenhouse from January 15 to March 15, then moved to an outdoor shade house to acclimate until May 15, 1984. During this period the trees were watered to saturation every three days and were fertilized once with granular ammonium sulfate equal to 120 $\mathrm{kg\text{-}N \cdot ha^{-1}}$ on April 1, 1985. (This fertilizer rate was equal to that received by field trees during 1983). The lysimeters were moved to full sun conditions for two weeks prior to final placement within the main study site on June 1, 1984. Due to substantial heating of the metal containers in the full sun, the cans were wrapped with 1.9 cm polyfoam sheeting to provide insulation from rapid thermal fluxes and to prevent excessive temperatures within the root environment that could cause increased resistance to water absorption by the roots. While soil temperature was not measured, it was conceded that root temperatures could approach maximum air temperatures.

The weighing lysimeters were placed at 2.0 m intervals in a single row running east to west 2.5 m from trees in the main study. The row location was previously occupied by border row trees in block three of the main experiment; these trees were sampled by the Mayes-F (1984) study. The six weighing lysimeters were randomly assigned one each of three irrigation regimes equal to three, six and nine days between irrigations. Thus, two replicates each were measured daily and varying levels of water stress could be observed.

The following measurements were made daily on the weighing lysimeter trees during June 1984: (1) leaf water potentials at pre-dawn and mid-day as described above; (2) soil water potential by 0.1 MPa tensiometers at 15 and 30 cm; and (3) change in weighing lysimeter weight by strain gauge accurate to 0.05 kg and equivalent to 0.05 l. With the exception of leaf water potentials all measurements were made prior to 0800 hr daily. Climatic data were collected from the previously described NMSU-AES and NMSU-PSRC operated climatic observation sites located 1.6 and 16 km respectively from the study site.

The strain gauge was calibrated to metric units by making successive measurements with increasing weights measured to the nearest 1.0 g. The strain gauge was suspended from a tripod and the increasing weights and measurements produced the following equation;

$$Y = -33.685X + 124760.4 \tag{9}$$

Where; Y = weight (+/- 50.0 g)

X = strain (unitless)

During field measurements, the strain gauge was suspened from the tripod while a harness was attached to cleates bolted to each weighing lysimeter. Strain was measured first for each lysimeter, then repeated after a constant weight was added to the system. Thus two measurements were made at each weighing and individual changes in weight from with and without the added weight could be averaged. It was assumed that changes in base weight of the system (i.e. weights of the container, soil and gravel) did not change, while increasing weight associated with biomass accumulation could not be adequately detected between daily measurements and that daily weight change was due totally to transpiration, because the gravel evaporative surface barrier in each container would prevent significant water vapor losses. Transpiration ($\mathrm{mm \cdot day^{-1}}$) was calculated as;

$$\mathrm{cm}^3 = \text{change in mass (g)} \times 1\ \mathrm{cm}^3\ \mathrm{H_2O}$$

$$\mathrm{mm} = 10 \times \mathrm{cm}^3 \cdot 1297.17\ \mathrm{cm}^2 \text{ can surface} \qquad (10)$$

RESEARCH RESULTS AND DISCUSSION

Evapotranspiration

Seasonal evapotranspiration (ET_c) ($mm \cdot day^{-1}$) derived from the water balance equation for plantation grown P. eldarica under three irrigation regimes is expressed in table 1. Crop evapotranspiration differed little between the three irrigation regimes except during periods shortly after irrigations or sporadically throughout the remainder of the study. Crop evapotranspiration in the 60 percent regime was generally less than the 80 or 100 percent regimes, particularly during the latter portion of the growing season. Cumulative ET_c (mm) for the three irrigation regimes (figure 3) indicates little difference between the 60 and 80 percent regimes from May through August 1983. A separation between these regimes occurred after the late August irrigation and gradually increased through the winter months. Cumulative ET_c in the 100 percent regime gradually separated from the 60 and 80 percent regimes throughout the study. An additional irrigation (in the 100 percent regime only) during late August, was considered necessary to achieve treatment separations and resulted in a more pronounced difference between regimes. Table 1 presents the combined irrigations in the 100 percent regime as one value on September 5, 1983. Cumulative ET_c for the growing season May 4, 1983 through October 30, 1983 totaled 440.7, 469.3 and 525.0 mm in the 60, 80 and 100 percent regimes respectively, while dormant season water use by the evergreen pine (October 30, 1983 through March 21, 1984) totaled 87.3, 89.4 and 79.4 mm respectively. Cumulative ET_c for the entire study were 527.9, 558.7 and 604.4 mm respectively in the 60, 80 and 100 percent regimes.

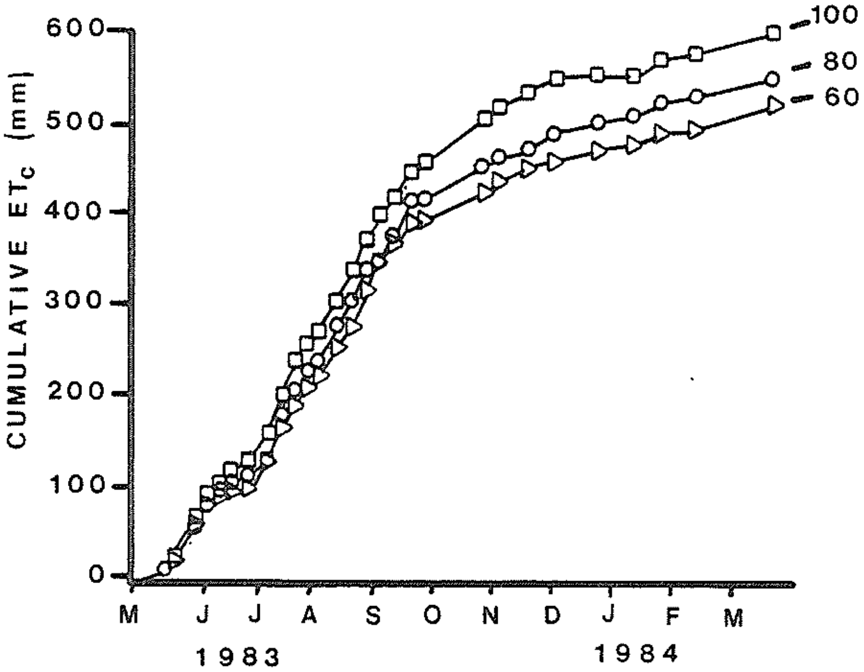

Figure 3. Cumulative evapotranspiration (ET_c) for plantation grown *P. eldarica* under three irrigation regimes from May 1983 through March 1984.

Table 1. Crop evapotranspiration (ET_c) derived from the water balance equation for plantation grown P. eldarica under three irrigation regimes during 1983.

Date	Regime	Days	I	R	D	SM	ETc
			-------	+/-	mm	-------	$mm \cdot day^{-1}$
5/04/84	**						
5/18/83	60	14	-----	-----	-----	16.25a*	1.16
	80	14	-----	-----	-----	18.76a	1.34
	100	14	-----	-----	-----	15.49a	1.11
5/24/83	60	6	62.09	-----	-----	-35.05a	4.51
	80	6	81.28	-----	-----	-77.68b	0.60
	100	6	102.22	-----	-UD--	-81.34b	3.48
6/01/83	60	8	-----	-----	-----	24.63a	3.08
	80	8	-----	-----	-----	41.31b	5.16
	100	8	-----	-----	-----	36.21ab	4.53
6/06/83	60	5	-----	-----	-----	11.12a	2.22
	80	5	-----	-----	-----	20.85ab	4.17
	100	5	-----	-----	-----	23.26b	4.65
6/13/83	60	7	-----	-----	-----	12.54a	1.79
	80	7	-----	-----	-----	14.50a	2.07
	100	7	-----	-----	-----	10.65a	1.52
6/20/83	60	7	-----	-----	-----	9.95a	1.42
	80	7	-----	-----	-----	14.36a	2.05
	100	7	-----	-----	-----	17.22a	2.46
6/27/83	60	7	-----	-----	-----	5.80a	0.83
	80	7	-----	-----	-----	4.42a	0.63
	100	7	-----	-----	-----	9.40a	1.34
7/04/83	60	7	51.56	-----	-----	-21.94a	4.23
	80	7	69.78	-----	-----	-55.49a	2.04
	100	7	84.64	-----	-----	-52.86a	4.54
7/11/83	60	7	-----	5.50	-----	27.82a	4.76
	80	7	-----	5.50	-----	42.87a	6.91
	100	7	-----	5.50	-----	37.71a	6.17
7/18/83	60	7	-----	9.80	-----	16.82a	3.80
	80	7	-----	9.80	-----	23.41ab	4.75
	100	7	-----	9.80	-----	29.23b	5.58

Table 1 continued

Date	Regime	Days	I	R	D	SM	ETc
			--------	+/-	mm	--------	$mm \cdot day^{-1}$
7/25/83	60	7	-----	0.51	-----	17.82a	2.63
	80	7	-----	0.51	-----	18.11a	2.66
	100	7	-----	0.51	-----	13.58a	2.01
8/02/83	60	8	-----	2.30	-----	9.66a	1.50
	80	8	-----	2.30	-----	11.31a	1.70
	100	8	-----	2.30	-----	12.66a	1.87
8/09/83	60	7	-----	10.60	-----	22.40a	4.71
	80	7	-----	10.60	-----	27.50a	5.44
	100	7	-----	10.60	-----	24.06a	4.95
8/16/83	60	7	-----	8.10	-----	14.65a	3.25
	80	7	-----	8.10	-----	15.76a	3.41
	100	7	-----	8.10	-----	23.82a	4.56
8/24/83	60	8	-----	37.10	-----	3.75a	5.11
	80	8	-----	37.10	-----	3.34a	5.06
	100	8	-----	37.10	-----	0.19a	4.66
8/30/83	60	6	50.78	13.20	-----	-28.75a	5.87
	80	6	69.96	13.20	-----	-76.97a	1.03
9/05/83	100	12	107.54	13.20	-----	-91.73	2.42
9/07/83	60	8	-----	-----	-----	18.74a	2.34
	80	8	-----	-----	-----	30.03a	3.75
	100	2	-----	-----	-----	15.59a	7.80
9/15/83	60	8	-----	1.00	-----	20.54a	2.69
	80	8	-----	1.00	-----	35.18b	4.52
	100	8	-----	1.00	-----	31.35ab	4.04
9/22/83	60	7	-----	0.20	-----	-0.12a	0.01
	80	7	-----	0.20	-----	0.29a	0.07
	100	7	-----	0.20	-----	8.79a	1.29
10/22/83	60	30	-----	11.34	-----	17.66a	0.97
	80	30	-----	11.34	-----	27.26ab	1.29
	100	30	-----	11.34	-----	36.49b	1.59
10/30/83	60	8	-----	2.39	-----	9.87a	1.53
	80	8	-----	2.39	-----	7.07a	1.18
	100	8	-----	2.39	-----	8.79a	1.40

Table 1 continued

Date	Regime	Days	I	R	D	SM	ETc
			---------	+/-	mm	--------	$mm \cdot day^{-1}$
11/13/83	60	11	-----	34.54	-----	-17.99a	1.51
	80	11	-----	34.54	-----	-27.29a	0.66
	100	11	-----	34.54	-----	-17.97a	1.51
11/29/83	60	16	-----	2.54	-----	7.68a	0.64
	80	16	-----	2.54	-----	17.20b	1.23
	100	16	-----	2.54	-----	9.78ab	0.77
12/17/83	60	18	-----	2.54	-----	9.48a	0.67
	80	18	-----	2.54	-----	9.94a	0.69
	100	18	-----	2.54	-----	3.99a	0.36
1/06/84	60	20	-----	5.59	-----	-0.06a	0.28
	80	20	-----	5.59	-----	1.26a	0.34
	100	20	-----	5.59	-----	-6.17a	-0.03
1/21/84	60	15	-----	8.89	-----	4.34a	0.88
	80	15	-----	8.89	-----	5.63a	0.97
	100	15	-----	8.89	-----	8.39a	1.15
2/08/84	60	18	-----	-----	-----	2.17a	0.12
	80	18	-----	-----	-----	6.28a	0.35
	100	18	-----	-----	-----	4.16a	0.23
3/21/84	60	42	-----	2.79	-----	25.90a	0.68
	80	42	-----	2.79	-----	19.45a	0.53
	100	42	-----	2.79	-----	20.31a	0.55

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* values followed by different letters are significant a=0.05
** date of first observations
UD deep drainage undetermined this date

The relation between ET_r (reference crop ET for a short grass), ET_c for P. eldarica under three irrigation regimes and estimated transpiration is expressed as monthly rates ($mm \cdot month^{-1}$) in figure 4. Crop evapotranspiration was determined by the Penman combination equation, while transpiration was estimated from ET_r using a crop coefficient ($K_c = 0.2057$) determined by ploting the ratio ET_c/ET_r versus time in figure 5. The lower baseline in figure 5 can be regarded as representing periods of transpirational water use and not of combined evaporation and transpiration since rates of ET_c (table 1 and figure 3) differed little between irrigation regimes and transpiration rates determined in weighing lysimeter studies were similar (table 2). It can therefore be considered that ET_c values greater than the estimated transpiration curve in figure 4 are representative of evaporation.

Indeed, evaporation was a large component in this study because only approximately 30 percent of the 2.5 X 2.5 m area per tree was covered by canopy and this tree crop, unlike typical crops that achieve rapid canopy closure resulting in reduced soil evaporative losses, could not achieve rapid canopy closure in the time span of the study. Thus, evaporative losses were great particularly during July and August when nearly two thirds of total ET_c apparently was the result of evaporation (figure 4). This result relates well to the frequent occurence of precipitation during these months (table 1). The 80 and 100 percent regimes had slightly more evaporation than the 60 percent regime during June and July probably because more water was available in the surface soil due to the irrigation regime. The greater evaporation that occur in the 60 percent regime than in either of the 80 or 100 percent regimes

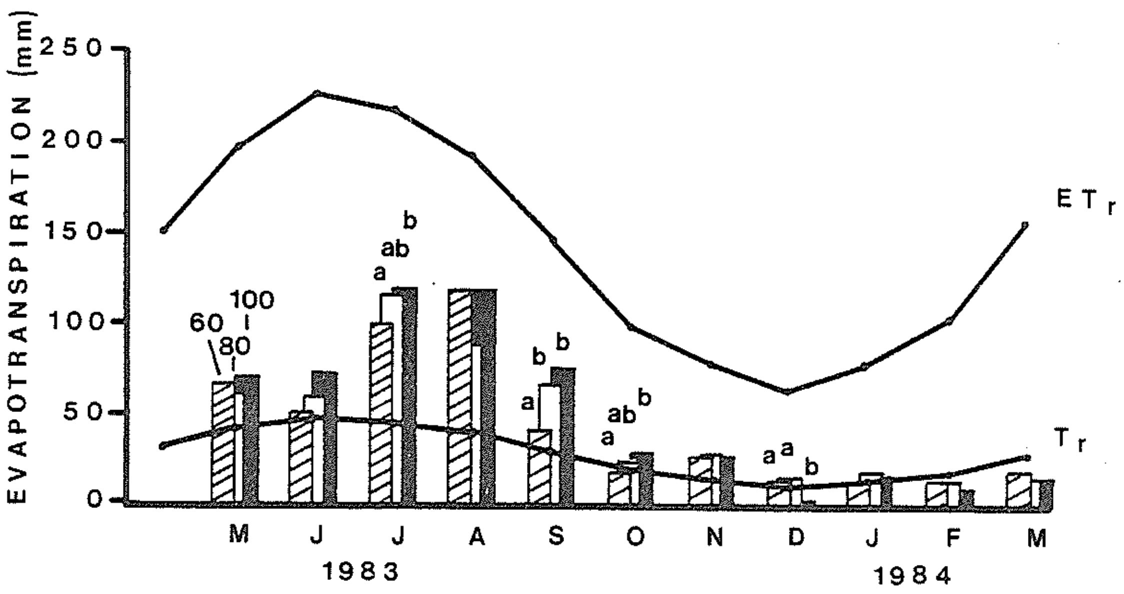

Figure 4. Reference crop evapotranspiration (ET_r), estimated transpiration (T_r), and crop evapotranspiration (ET_c) for plantation grown P. eldarica under three irrigation regimes from May 1983 through March 1984.

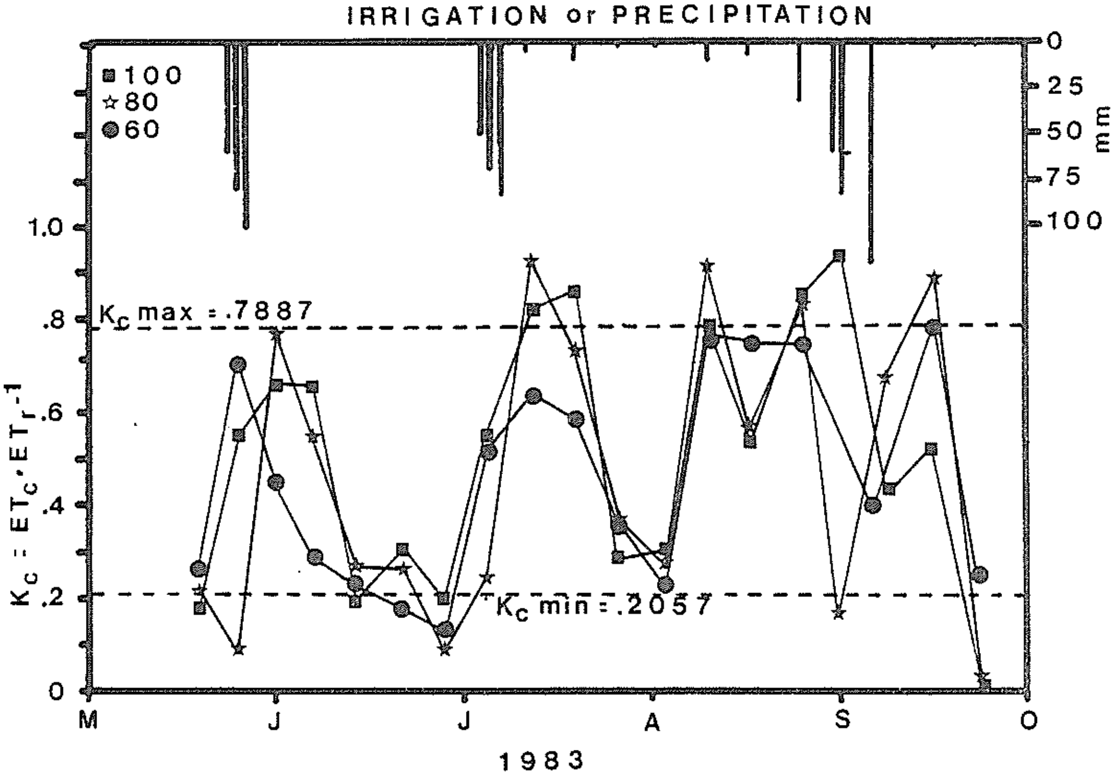

Figure 5. Weekly crop coefficients (K_c) and irrigation or precipitation inputs for plantation grown _P. eldarica_ under three irrigation regimes from May 1983 through September 1983.

Table 2. Transpiration (mm·day^{-1}), pre-dawn leaf water potential (-MPa), and mid-day leaf water potential (-MPa) for *Pinus eldarica* in weighing-type lysimeters during a nine period in June 1984.

Date	1A	2A	3A	1B	2B	3B
			mm·day^{-1}			
6/19/84						
mm	2.99	3.99	2.05	1.90	1.52	2.63
Ylpd	-0.80	-0.83	-0.76	-0.73	-0.90	-0.83
Ylmd	-1.59	-1.92	-1.82	-1.67	-1.71	-1.66
6/20/84						
mm	1.81	2.25	2.83	2.48	2.90	2.32
Ylpd	-0.70	-0.88	-0.74	-0.71	-0.81	-0.79
Ylmd	-1.75	-2.01	-1.90	-2.03	-2.05	-1.97
6/21/84						
mm	2.36	2.14	2.34	2.43	2.16	3.37
Ylpd	-0.64	-0.71	-0.64	-0.55	-0.72	-0.67
Ylmd	-1.79	-1.83	-1.76	-1.87	-1.82	-1.83
6/22/84						
mm	1.58	1.74	1.52	1.78	1.49	1.29
Ylpd	-0.76	-0.85	-0.77	-0.65	-0.74	-0.79
Ylmd	-1.67	-2.29	-2.05	-2.08	-2.01	-2.21
6/23/84						
mm	1.81	1.09	0.87	0.60	1.25	0.76
Ylpd	-0.81	-1.66	-1.30	-0.99	-1.03	-1.45
Ylmd	-2.36	-2.84	-2.68	-2.66	-2.34	-2.86
6/24/84	*					
mm	0.33	-4.75	-8.43	0.47	-4.30	-9.05
Ylpd	-1.46	-2.63	-2.35	-2.19	-1.90	-2.52
Ylmd	-2.79	-2.50	-2.16	-3.34	-2.09	-2.18
6/25/84						
mm	0.07	1.29	1.90	0.25	2.43	1.72
Ylpd	-2.31	-1.20	-1.01	-2.83	-1.00	-1.31
Ylmd	-3.17	-1.49	-1.35	-3.50	-1.54	-1.66
6/26/84						
mm	0.47	1.96	2.52	0.30	1.58	1.65
Ylpd	-2.88	-1.03	-0.83	-3.19	-1.58	-1.65
Ylmd	-3.44	-1.78	-1.62	-3.82	-1.96	-1.62
6/27/84	**					
mm	-1.20	0.08	-1.20	0.05	1.26	1.17
Ylpd	-3.26	-1.15	-0.84	-3.73	-1.29	-0.96
Ylmd	-3.88	-2.62	-1.74	-4.23	-2.76	-1.87

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* Irrigation this date for 2A, 2B, 3A and 3B

** Precipitation the night of 6/26 - 6/27 during August, probably was due to the greater amounts of precipitation and the reduced ground area covered by the canopy in this regime. Evaporation losses between regimes again reversed positions in September due to less frequent precipitation and recent irrigation. The amount of evaporation could be seen to decline after September as ET_r declined and the winter months approached.

Crop evapotranspiration was at or near estimated transpiration from December 1983 through February 1984 but remained constant during March 1984 as ET_r and estimated transpiration increased. These results indicate that either soil moisture was limiting transpiration or that the trees remained in a dormant state due to low night temperatures. The latter explanation is more likely correct because nightly low temperatures during March 1984 were less than 6 - 7 C except for three non-consecutive nights. On-site observations indicate that dormancy (shoot growth) is not overcome until after 10 - 14 days when minimum night temperatures are greater than 6 - 7 C are present (NMSU-AES 1984 climatic record and personal observations 1983 - 1984). Figure 6 presents the change in soil volume water contents throughout the study. While the soil water content may have been limiting during March 1984, particularly in the 60 percent regime, the 80 and 100 percent regimes had soil water contents similar to the 60 percent regime the previous September. As well, the 60 percent ET_c rate during March 1984 (figure 4) was greater than the 80 and 100 percent regimes and therefore does not support the likelihood of limiting soil water content affecting the rates of ET_c.

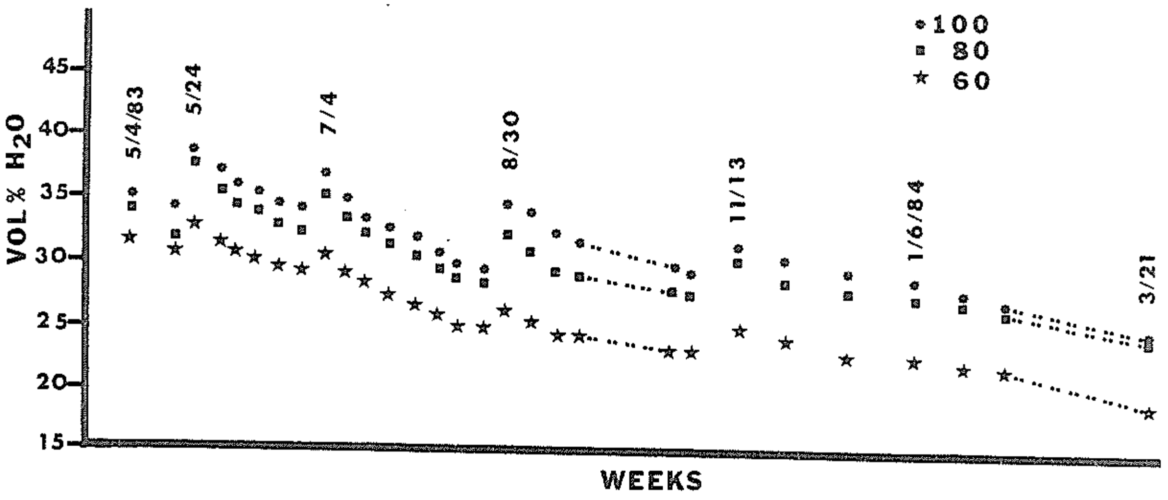

Figure 6. The change in soil volume water content per 135 cm depth for plantation grown P. eldarica under three irrigation regimes from May 1983 through March 1984.

Table 3 contains ET_r, ET_c, K_c and estimated transpiration (using $K_c = 0.2057$) and evaporation expressed as $mm \cdot day^{-1}$ and also includes the respective monthly totals. Figure 5 (previously introduced) plots K_c versus time and establishes an upper baseline for maximal $K_c = 0.7887$ as well as the lower baseline for minimal $K_c = 0.2057$ used to estimate transpiration. The upper baseline $K_{c\ max}$ may be safely used to predict irrigation requirements by the basin method for P. eldarica from ET_r by the Penman combination equation, when plantations are similar in age and spacing. The upper (maximal) and lower (minimal) K_c values were determined by averaging the largest and smallest K_c values; sample sizes n=19 and n=22 respectively.

Figure 6 confirms an important assumption that was made while using the water balance equation; i.e. that no deep drainage water losses occurred after irrigations. With the possible exception of the 100 percent regime after the May 24, 1983 irrigation (figure 6), no greater soil water contents were observed in any irrigation regime or on any date other than in the 100 percent regime. It can therefore be safely assumed, that no other deep drainage occurred throughout the study.

Physiologic Parameters

Measures were conducted using the pressure bomb technique to determine the plant water status of the trees in the study. These studies were intended to confirm or deny water stress resulting from irrigation regimes. Tissue water potential can be considered to be equivalent to an amount of work done by tissues as compared to the work capable by a pool of pure, free water at standard temperature and

Table 3. Crop evapotranspiration (ET_c), reference crop evapotranspiration (ET_r), crop coefficient (K_c), estimated transpiration (T_r), and estimated evaporation (E) for plantation grown *P. eldarica* under three irrigation regimes during 1983.

Date	Regime	Days	ETc	ETr	Kc	Tr	E
			$mm \cdot day^{-1}$			$mm \cdot day^{-1}$	
5/04/83**							
5/18/83	60	14	1.16	6.07	0.265	0.24	0.92
	80	14	1.34	6.07	0.221	0.28	1.06
	100	14	1.11	6.07	0.183	0.23	0.88
5/24/83	60	6	4.51	6.32	0.714	0.93	3.58
	80	6	0.60	6.32	0.095	0.12	0.48
	100	6	3.48	6.32	0.551	0.72	2.76
6/01/83	60	8	3.08	6.84	0.450	0.63	2.45
	80	8	5.16	6.84	0.755	1.06	5.48
	100	8	4.53	6.84	0.622	0.93	3.60
6/06/83	60	5	2.22	7.62	0.291	0.46	1.76
	80	5	4.17	7.62	0.547	0.86	3.31
	100	5	4.65	7.62	0.610	0.96	3.69
6/13/83	60	7	1.79	7.67	0.233	0.37	1.42
	80	7	2.07	7.67	0.270	0.43	1.64
	100	7	1.52	7.67	0.198	0.31	1.21
6/20/83	60	7	1.42	7.76	0.183	0.29	1.13
	80	7	2.05	7.76	0.264	0.42	1.63
	100	7	2.46	7.76	0.312	0.51	1.95
6/27/83	60	7	0.83	6.73	0.123	0.17	0.66
	80	7	0.63	6.73	0.094	0.13	0.50
	100	7	1.34	6.73	0.199	0.28	1.06
7/04/83	60	7	4.23	8.13	0.520	0.87	3.36
	80	7	2.04	8.13	0.251	0.42	1.62
	100	7	4.54	8.13	0.558	0.93	3.61
7/11/83	60	7	4.76	7.41	0.642	0.98	3.78
	80	7	6.91	7.41	0.932	1.42	5.49
	100	7	6.17	7.41	0.832	1.27	4.90
7/18/83	60	7	3.80	6.46	0.589	0.78	3.02
	80	7	4.75	6.46	0.736	0.98	3.77
	100	7	5.58	6.46	0.864	1.15	4.32

Table 3 continued

Date	Regime	Days	ETc	ETr	Kc	Tr	E
			mm·day^{-1}			mm·day^{-1}	
7/25/83	60	7	2.63	7.01	0.375	0.54	2.09
	80	7	2.66	7.01	0.379	0.55	2.11
	100	7	2.10	7.01	0.287	0.41	1.60
8/02/83	60	8	1.50	6.16	0.243	0.31	1.19
	80	8	1.70	6.16	0.276	0.35	1.35
	100	8	1.87	6.16	0.303	0.39	1.49
8/09/83	60	7	4.71	5.91	0.796	0.97	3.74
	80	7	5.44	5.91	0.920	1.12	4.32
	100	7	4.95	5.91	0.771	1.02	3.93
8/16/83	60	7	3.25	6.07	0.535	0.67	2.58
	80	7	3.41	6.07	0.562	0.70	2.71
	100	7	4.56	6.07	0.751	0.94	3.62
8/24/83	60	8	5.11	5.99	0.853	1.05	4.06
	80	8	5.06	5.99	0.845	1.04	4.02
	100	8	4.66	5.99	0.778	0.96	3.70
8/30/83	60	6	5.87	6.22	0.944	1.21	4.66
	80	6	1.03	6.22	0.166	0.21	0.82
9/05/83	100	12	2.42	6.01	0.398	0.50	1.92
9/07/83	60	8	2.34	5.53	0.424	0.48	1.86
	80	8	3.75	5.53	0.679	0.77	2.98
	100	2	7.80	4.30	1.814	1.60	6.20
9/15/83	60	8	2.69	5.05	0.533	0.55	2.14
	80	8	4.52	5.05	0.895	0.93	3.59
	100	8	4.04	5.05	0.800	0.83	3.21
9/22/83	60	7	0.01	5.07	0.002	0.00	0.01
	80	7	0.07	5.07	0.014	0.01	0.06
	100	7	1.29	5.07	0.254	0.27	1.03
10/22/83	60	30	0.97	3.40	0.285	0.20	0.77
	80	30	1.29	3.40	0.379	0.27	1.03
	100	30	1.59	3.40	0.467	0.33	1.26
10/30/83	60	8	1.53	2.64	0.654	0.32	1.22
	80	8	1.18	2.64	0.447	0.24	0.94
	100	8	1.40	2.64	0.531	0.29	1.11

Table 3 continued

Date	Regime	Days	ETc	ETr	Kc	Tr	E
			mm·day^{-1}			mm·day^{-1}	
11/13/83	60	11	1.51	3.20	0.472	0.31	1.20
	80	11	0.66	3.20	0.206	0.14	0.52
	100	11	1.51	3.20	0.472	0.31	1.20
11/29/83	60	16	0.64	2.61	0.245	0.13	0.51
	80	16	1.23	2.61	0.471	0.25	0.98
	100	16	0.77	2.61	0.295	0.16	0.61
12/17/83	60	18	0.67	2.37	0.282	0.14	0.53
	80	18	0.69	2.37	0.291	0.14	0.55
	100	18	0.36	2.37	0.152	0.74	0.29
1/06/84	60	20	0.28	1.64	0.171	0.58	0.22
	80	20	0.34	1.64	0.208	0.07	0.27
	100	20	-0.03	1.64	-----	----	----
1/21/84	60	15	0.88	2.41	0.366	0.18	0.70
	80	15	0.97	2.41	0.403	0.20	0.77
	100	15	1.15	2.41	0.478	0.24	0.91
2/08/84	60	18	0.12	2.87	0.042	0.03	0.10
	80	18	0.35	2.87	0.122	0.07	0.28
	100	18	0.23	2.87	0.080	0.05	0.18
3/21/84	60	42	0.68	4.23	0.161	0.14	0.54
	80	42	0.53	4.23	0.125	0.11	0.42
	100	42	0.55	4.23	0.130	0.11	0.44

pressure. When soil water becomes limiting, the plant must work harder to obtain water and is in turn reflected by water held at greater tensions in the tissues. A threshold may be established beyond which stomata partially to fully close resulting in reduced transpiration caused by turgor loss in the guard cells.

Clearly, a relationship between pre-dawn tissue water potentials (generally xylem measures) and leaf conductance have been established for conifers as well as broad leaved tree species. Hinckley et al. (1978) cite many in their Monograph. Kaufmann (1979) established a relationship between xylem pressure potentials and transpirational flux density ($\mu g \cdot cm^{-2} \cdot s^{-1}$) for _Picea engelmannii_ Engelm. (Engelmann spruce) seedlings and, Whitehead and Jarvis (1981) cite the work of Jarvis (1976) that relates leaf water potential and canopy transpiration rates of _Pinus sylvestris_ (Scots pine) and _Picea sitchensis_ (Sitka spruce). Whitehead (1980) demonstrated the relation between leaf water potential and leaf conductance in Scots pine and Running (1980) discussed the relationship in _Pinus contorta_ (lodgepole pine). While the units and tissues measured vary in these studies and many variables (ie. radiation, air temperature, humidity and water potential) effect conductance or transpiration, a general relationship exists. Growth or productivity of the plant is reduced when water stress occurrs.

Figure 7 shows the relationship between leaf water potential and daily transpiration for both pre-dawn and mid-day measurements of _P. eldarica_ in weighing-type lysimeters. Clearly, a threshold of -0.8 to -0.9 MPa at pre-dawn and -1.9 to -2.0 MPa at mid-day has been established, beyond which transpiration was reduced. The linear

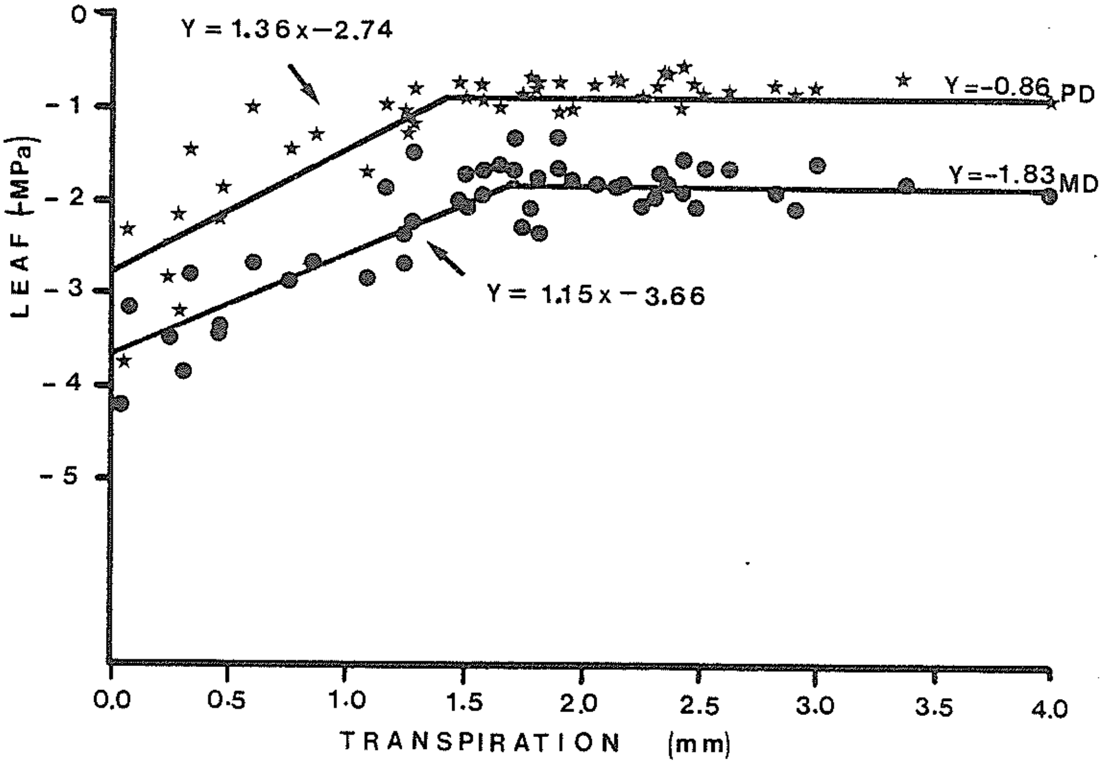

Figure 7. The relationship between leaf water potential (- MPa) and transpiration (mm). The relationship indicates a water stress threshold for lysimeter grown P. eldarica from both pre-dawn (PD) and mid-day (MD) measurements and current daily transpiration.

relationship $Y = 1.36x - 2.74$ ($r = .77$) has been established as the pre-dawn stress threshold, while $Y = 1.15x - 3.66$ ($r = .83$) has been established for the mid-day stress threshold relationship (figure 7). These equations may be useful when conducting water stress studies, using the pressure bomb technique with this species. Figures 8 and 9 more clearly delimit these threshold values. Because this topic could be developed at great length in another discussion, no attempt has been made to express the results in Figure 7 on a per unit leaf area or other standard unit basis; these relations will be developed further in a subsequent publication.

Because the measurements were made on similar sized trees, under similar environmental demands but differing water regimes, it is safe to assume that leaf water potential values near these reported values, identify the threshold for this species. Running (1976) reported -2.0 MPa as the threshold for Pseudotuga menziesii (Douglas fir) and -1.8 MPa for Pinus ponderosa (ponderosa pine), Rook et al. (1978) reported -1.1 MPa for Pinus radiata (Monterey pine) and Beadle et al. (1978) report -2.7 MPa for Sitka spruce. Except for the -1.1 MPa value reported for P. radiata the mid-day leaf water potentials reported by others are similar to those determined in this study.

Figure 10 relates leaf water potentials to time of year (August 10, 1983 to October 30, 1983) for P. eldarica under the three irrigation regimes in the main portion of this study. Pre-dawn values ranged from -7.3 to -4.0 MPa, while mid-day values ranged from -2.3 to -0.9 MPa; the -0.9 MPa value and other low mid-day values less negative than -1.5 MPa occurred as a result of precipitation during the day of measure. As

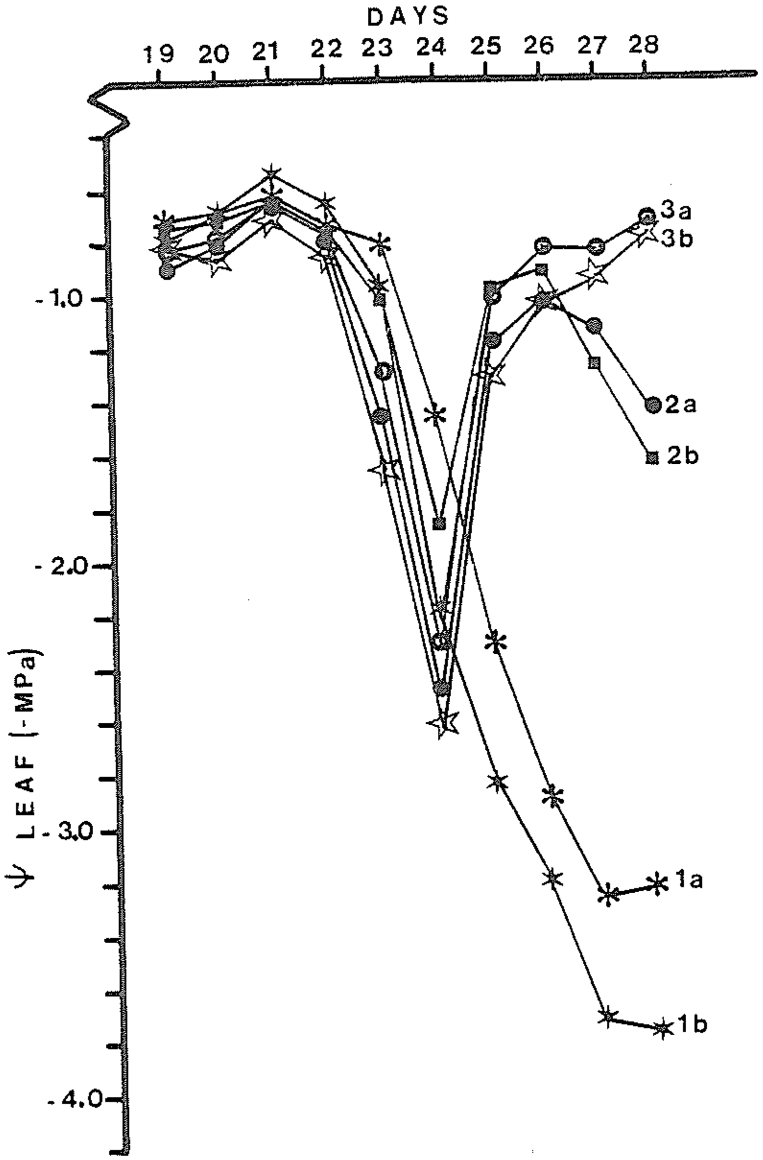

Figure 8. The relationship between leaf water potential (-MPa) and consecutive daily pre-dawn measure of lysimeter grown P. eldarica during June 1984. The relationship indicates non-stress, increasing water stress, and recovery from water stress.

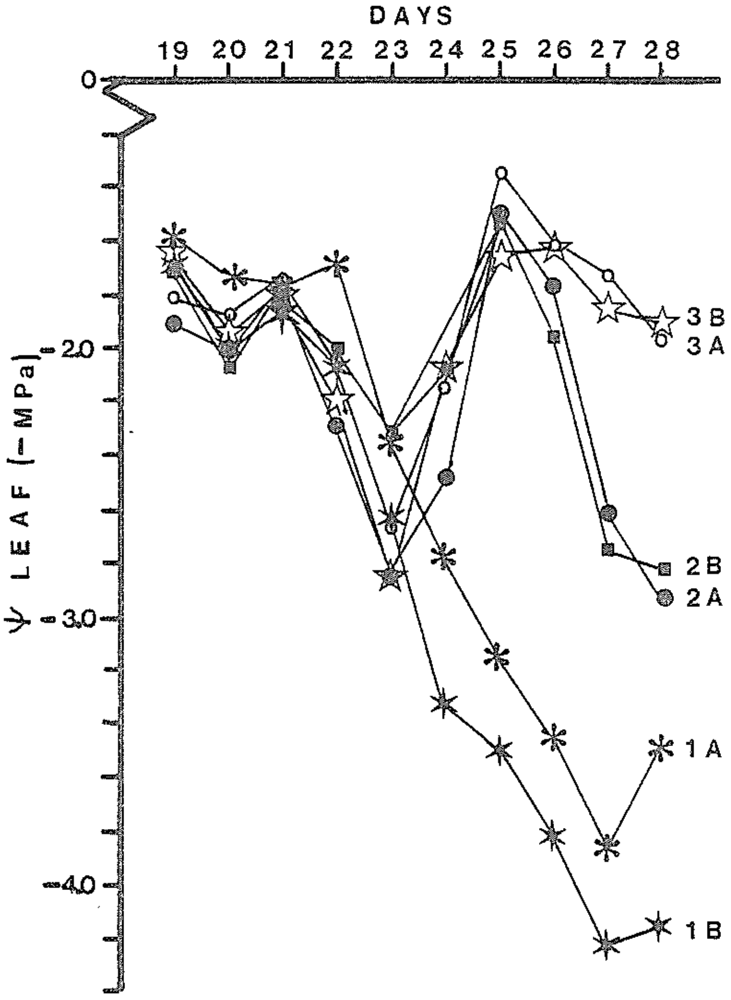

Figure 9. The relationship between leaf water potential (-MPa) and consecutive daily mid-day measure of lysimeter grown P. eldarica during June 1984. The relationship indicates non-stress, increasing water stress, and recovery from water stress.

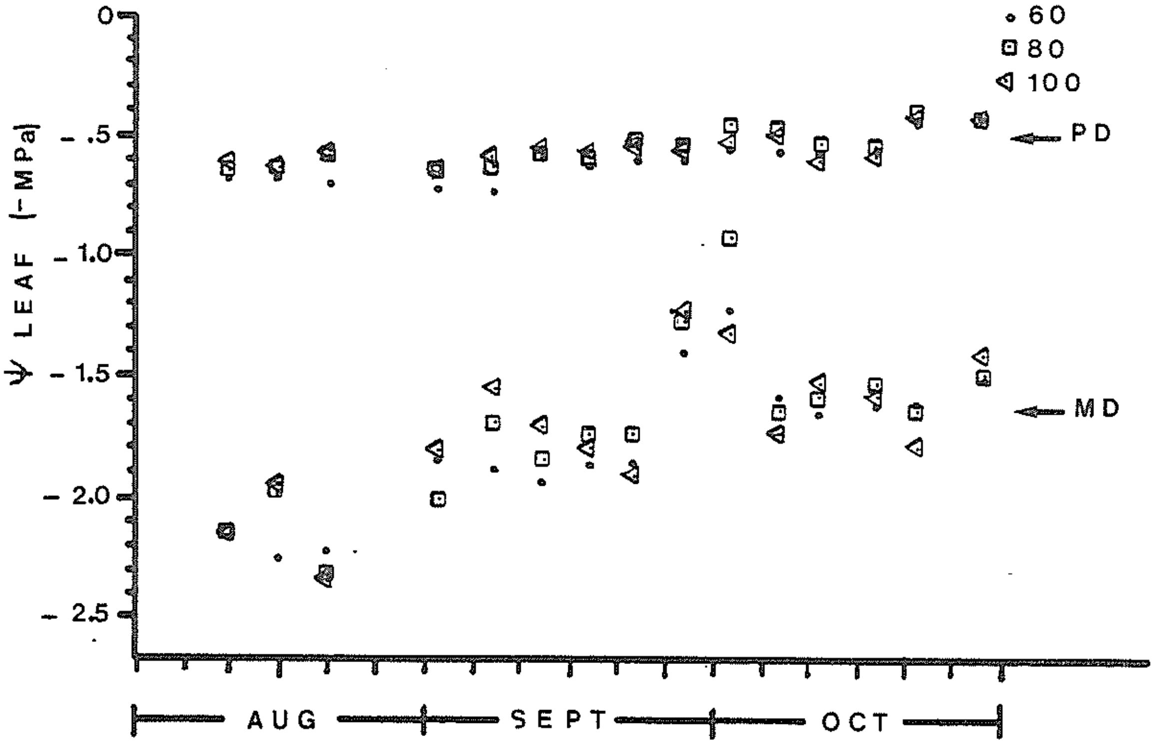

Figure 10. The relationship between pre-dawn and mid-day leaf water potential of field grown P. eldarica from August through October 1983 under three irrigation regimes.

Beadle et al. (1978) report, the values vary with time of year, where some fluctuation occurs but a general trend toward less negative leaf water potentials was apparent as the season approached winter. Either decreasing day lengths resulting in less daily water use and more time for tissue water recovery or reduced vapor pressure deficits resulting from reduced environmental demand, may both explain this result. This result may explain why pre-dawn leaf water potentials of -0.6 to -0.9 MPa were observed during June 1984 in the wieghing lysimeter studies, when they were under no apparent water stress. If the slope of pre-dawn leaf water potentials in Figure 10 were extrapolated from the August measures to June, the pre-dawn values would be within the range of those found in the weighing lysimeter studies. We can none-the-less conclude from figure 10 that trees in the main study were under no apparent water stress except for a brief period during late August 1983 prior to irrigation. Since pre-dawn leaf water potentials ranged from -0.6 MPa in the 100 and 80 percent regime to -0.7 MPa in the 60 percent regime, and mid-day potentials dropped to -2.3 MPa in the 100 and 80 regimes but only to -2.2 MPa in the 60 percent regime, it may be concluded that trees in the respective irrigation regimes were under a slight water stress at most. This result can be emphasized when compared to well stressed leaf water potentials obtained in the weighing lysimeter studies (figures 8 and 9), that dropped to as low as -3.8 MPa at pre-dawn and to -4.2 MPa for the same plant at mid-day.

Productivity Parameters

Height growth response of P. eldarica to three irrigation regimes during the 1983 growing season was significant (a = 0.05). However, significant differences were only detected between the 100 and 60 percent regimes (figure 11). Relative height growth (ln Ht2 - ln Ht1$\cdot$ time^{-1}) (figure 12) was not significantly different among regimes over the 1983 season. Figure 11 shows that saplings in the 100 percent regime were initially larger by chance than saplings in the 80 or 60 percent regimes. This fact coupled with slightly elevated height growth in the 100 percent regime over the height growth in the 60 percent regime probably caused this result. Height growth during the 1983 growing season increased 0.80, 1.04 and 1.05 m in response to the 60, 80 and 100 percent regimes respectively.

Similarly, basal diameter growth increased over the 1983 growing season in response to irrigation regime. However, diameter growth was not significantly different among regimes (figure 13). Relative basal diameter growth, shown in figure 14, demonstrated no significant differences among irrigation regimes during any month throughout the 1983 season. The 80 percent regime experienced significantly less relative basal diameter growth than the 60 or 100 percent regimes during July, but reversed this relationship during August for undetermined reasons, when the greatest amount of precipitation was occurring (figure 5). Over the season, basal growth increased 2.95, 3.12 and 3.40 cm for the 60, 80 and 100 percent irrigation regimes, respectively.

Above ground biomass increased 1.99, 2.20 and 2.70 kg. in the 60, 80 and 100 percent regimes respectively (figure 15) during the measured

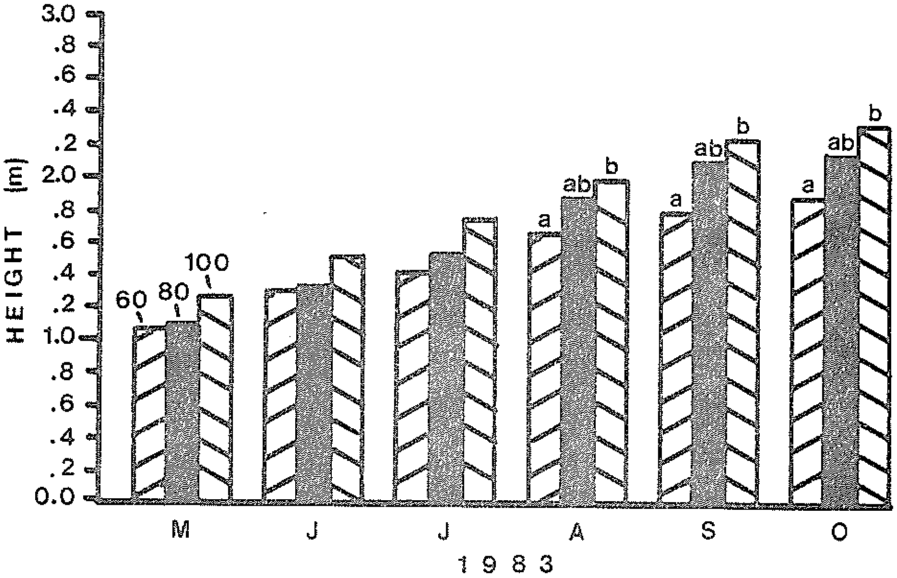

Figure 11. Height growth of plantation grown P. eldarica under three irrigation regimes from May through October 1983. Means having different letters are significant (a=.05).

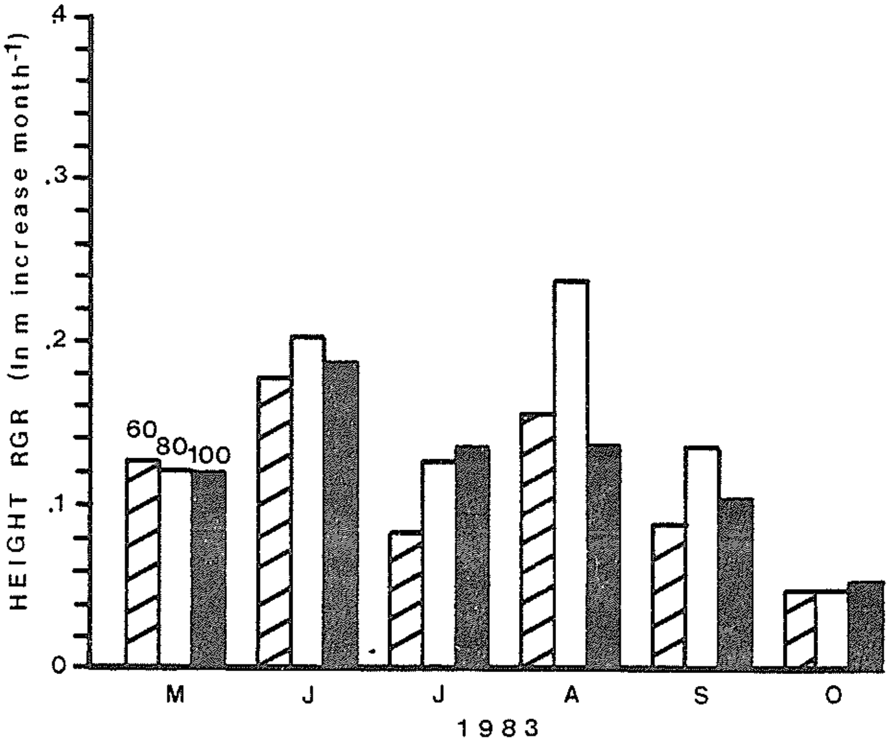

Figure 12. Relative height growth of plantation grown *P. eldarica* under three irrigation regimes from May through October 1983.

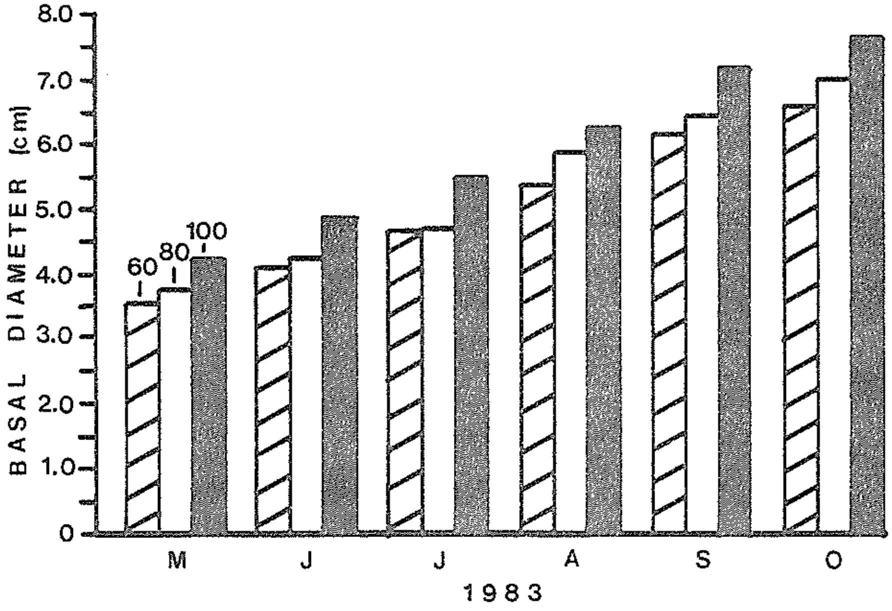

Figure 13. Basal diameter growth of plantation grown P. eldarica under three irrigation regimes from May through October 1983.

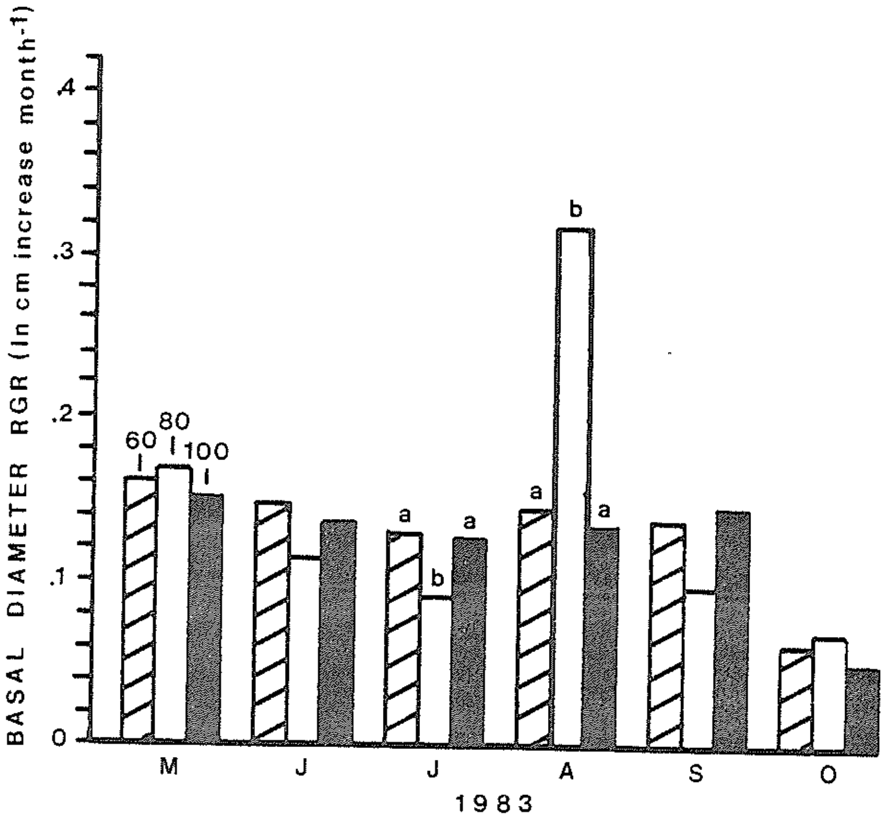

Figure 14. Relative basal diameter growth of plantation grown P. eldarica under three irrigation regimes from May through October 1983. Means having different letters are significant (a=.05).

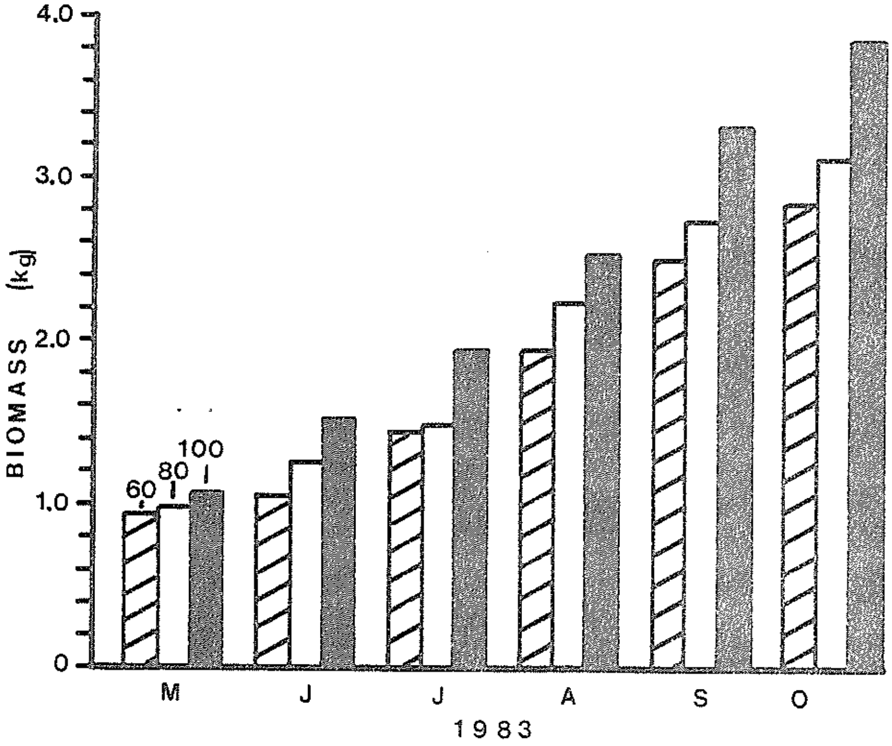

Figure 15. Biomass growth of plantation grown P. eldarica undei three irrigation regimes from May through October 1983.

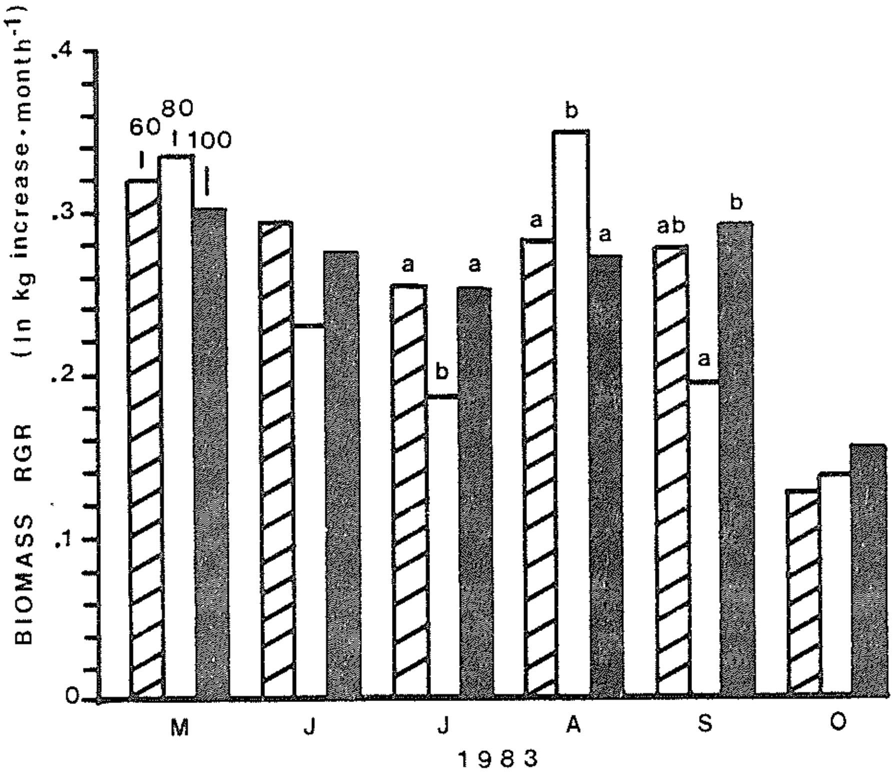

Figure 16. Relative biomass growth of plantation grown P. eldarica under three irrigation regimes from May through October 1983. Means having different letters are significant (a=.05).

growing season. Because basal diameter was used in equation (5) to predict above ground biomass, the relationships among treatments are generally similar in figures 14 and 16. However, biomass increased significantly during September but, basal diameter did not, during the same month. This affect is regarded as an artifact resulting from the use of equation (5). Equation (5) requires the conversion of the linear measurement for basal diameter (cm) to basal area (cm^2) before biomass can be determined. The squared term apparently increased the biomass value more rapidly and therefore, provided the basis for the detection of significant differences. Based on the rates of biomass accummulation under these irrigation regimes and spacing, a dry matter yield of 4323, 3525 and 3186 $kg \cdot ha^{-1}$ can be expected in similarly treated 100, 80 and 60 percent irrigation regimes, respectively.

Water Use Efficiency

Water use efficiency, expressed as $kg\ DM \cdot m^{-3}$ water evapotranspired, is presented in figure 17 for the three irrigation regimes during the 1983 growing season. Because significant differences in ETc among irrigation regimes were generally detected only after irrigations (table 1) and sporaticaly at other times, and biomass accumulation was not significantly different among regimes, significant differences in WUE among regimes would not be expected. This finding was generally true except during September. Monthly WUE ranged from 0.32 to 0.70 $kg\ DM \cdot m^{-3}$ water evapotranspired for all regimes, except the 80 percent regime during August, until September when WUE in the 60 percent regime was significantly greater than in the 80 percent regime.

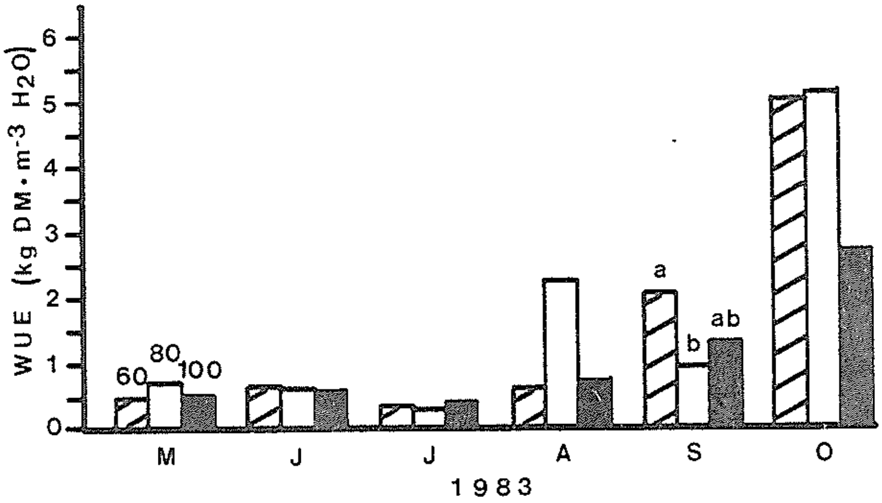

Figure 17. Water use efficiency of plantation grown P. eldarica under three irrigation regimes from May through October 1983. Means having different letters are significant (a=.05).

This result is related to significantly reduced ET_c (figure 4) and the large biomass accumulation (figure 16) occurring in the 60 percent regime during September. Water use efficiency was greater during October than in any other month across all treatment regimes. Interestingly, WUE in the 60 and 80 percent regimes reached 5.07 and 5.17 respectively and therefore indicate the potential for moderate WUE values by this species under flood irrigation management and this spacing arrangement. The large WUE values in October are attributed to two probable causes; 1) evaporative demand (figure 4) was rapidly declining resulting in reduced overall water use by trees in all treatment regimes, and 2) biomass accumulated at only a slightly reduced rate (figure 15). The WUE values in the 60 and 80 percent regimes more than doubled the WUE value in the 100 percent regime. This result most likely was related to less surface evaporative losses occuring in the 60 and 80 percent regimes than in the 100 percent regime; a lingering result after the late August double irrigation given to the 100 percent regime only. Again, these data suggest the potential by this species to use water efficiently particularly under less demanding climates or by using an alternate irrigation method such as the trickle method that eliminates large surface evaporative water losses.

Fischer and Turner (1978) discuss that WUE can increase with increasing soil water limitation until a maximum WUE is reached, beyond which greater limitation lowers WUE. It is possible that a similar condition may have occurred in the 60 and 80 percent regimes, during October. More work is therefore necessary to fully understand these relationships.

Water use efficiency was slightly depressed during May, June and July. The depression was apparently related to a period of great evaporative demand, ET_r in figure 4, which in turn was related to the highest daily temperatures and greatest vapor pressure deficits. This result probably reflects a reduction in the rate of carbon fixation due to increased stomatal resistance resulting from partial stomatal closure in response to water deficits or increased mesophyll resistance resulting from high daily temperatures (Rawson and Begg, 1977). Because the effect was expressed across all irrigation regimes and particularly in terms of relative biomass growth in June and July (figure 14) and not particularly related to ET_r (figure 4) or restrictive soil water contents (figure 6), it seems most likely that a temperature optimum might have been exceeded for this species. The high temperatures apparently increased mesophyll resistance, thus restricting carbon fixation while transpiration was uneffected.

Rawson and Begg (1977) report WUE for saltbrush (Atriplex halimus L.) and sorghum (Sorghum bicolor L.) at 0.29 and 0.27 $kg\text{-}CO_2 \cdot m^{-3}\ H_2O$ respectively for container grown plants. Doorenbos and Kassam (1979) reported WUE of field grown alfalfa (Medicago sativa L.) to be 1.5 to 2.0 $kg\ yield \cdot m^{-3}\ H_2O$ at 10 - 15 percent moisture content (the comparison is made to alfalfa due to similarity in above ground biomass harvest, rather than fruit, grain or other partial harvest). Average WUE of P. eldarica was 1.56, 1.69 and 0.98 $kg\ DM \cdot M^{-3}\ H_2O$ and is comparable to other crops, even when considering the 60 to 70 percent bare soil that existed between trees in this study. Water use efficiency can only be expected to increase with increasing stand closure. As indicated by

WUE in the 60 percent irrigation regime during September, greater efficiency may be obtained if more is learned about water requirements, irrigation scheduling and methods, and optimum planting densities.

Crop Production Functions

Table 4 contains crop production functions of plantation grown *P. eldarica* under three irrigation regimes. The table contains the linear relationships for height increase, biomass increase, relative height growth, and relative biomass growth each related to the amount of crop evapotranspiration for the particular irrigation regime and all treatments combined. Statistics include the correlation coefficient (r) and sample size. While none of the relationships were particularly good for predicting an aspect of yield, the best correlation r = .60 occurred in the 60 percent regime for monthly height increase. Generally, the best relationships occurred in the 100 percent regimes in all categories except monthly biomass increase. These results tend to confirm the results found by previous analyses; *P. eldarica* grew at nearly the same rate regardless of irrigation regime. It is likely that the differences among irrigation treatments were too small to affect treatment separation and therefore caused the data analyses to be non-conclusive. Plant response to irrigation regime might be acheived if the study were conducted for more than one growing season at the current irrigation levels. Subsequent studies might also include a control treatment that recieved no supplemental irrigation.

Table 4. Crop production functions of *P. eldarica* for height increase, biomass increase, relative height growth and relative biomass growth as related to crop evapotranspiration under three irrigation regimes during the 1983 growing season.

MONTHLY HEIGHT INCREASE			
60 PERCENT	$Y = 0.0011x + 0.098$	$r = 0.60$	$n = 19$
80 PERCENT	$Y = 0.0006x + 0.181$	$r = 0.19$	$n = 18$
100 PERCENT	$Y = 0.0008x + 0.137$	$r = 0.52$	$n = 20$
ALL TREATMENTS	$Y = 0.0009x + 0.130$	$r = 0.40$	$n = 57$
MONTHLY BIOMASS INCREASE			
60 PERCENT	$Y = 0.0004x + 0.374$	$r = 0.09$	$n = 20$
80 PERCENT	$Y = -0.0010x + 0.580$	$r = -0.13$	$n = 18$
100 PERCENT	$Y = -0.0006x + 0.590$	$r = -0.11$	$n = 20$
ALL TREATMENTS	$Y = 0.0005X + 0.438$	$r = 0.07$	$n = 58$
MONTHLY RELATIVE GROWTH RATE HEIGHT			
60 PERCENT	$Y = 0.0320x + 2.483$	$r = 0.06$	$n = 19$
80 PERCENT	$Y = 0.0001x + 0.130$	$r = 0.05$	$n = 16$
100 PERCENT	$Y = 0.0005x + 0.085$	$r = 0.44$	$n = 20$
ALL TREATMENTS	$Y = 0.0006x + 0.077$	$r = 0.46$	$n = 55$
MONTHLY RELATIVE GROWTH RATE BIOMASS			
60 PERCENT	$Y = 0.0009x + 0.199$	$r = 0.41$	$n = 24$
80 PERCENT	$Y = 0.0006x + 0.187$	$r = 0.24$	$n = 21$
100 PERCENT	$Y = 0.0021x + 0.108$	$r = 0.58$	$n = 24$
ALL TREATMENTS	$Y = 0.0008x + 0.190$	$r = 0.36$	$n = 69$

CONCLUSIONS

P. eldarica grown under intensive irrigation management during the 1983 growing season demonstrated clearly that a crop of this type responds differently to irrigation management than more typical row or field crops. When an essentially wild land plant is placed under ideal conditions for growth, it evapotranspires at rates similar to field crops. However, when the plant begins to experience water stress inherent characteristics that have developed through centuries of wildland existence control the water use in the plant.

Table 5 provides the reader with summary statistics for growth parameters, relative growth rates, crop evapotranspiration, and water use efficiency of irrigated plantation grown P. eldarica during 1983. Overall height, basal diameter and biomass growth differed significantly during the 1983 growing season, however, relative growth rates for these parameters, crop evapotranspiration and water use efficiency did not differ. Significant differences for growth parameters were affected by initial differences among treatment means. Thus relative growth rates, that are more sensitve to how the plant responds to treatment irrigation regimes, indicate no differences among treatments. Additionally, evapotranspiration and water use efficiency support the same result. We can therfore conclude that irrigation regime had little effect on the growth of P. eldarica during the third growing season. Greater separation among applied irrigation treatments or continuation of the study for more than one growing season may provide more sensitive results than found in this study.

While 173, 298, and 457 mm supplemental irrigation were applied in the three irrigation regimes and 159 mm were obtained as precipitation, 527.9, 558.7, and 604.4 mm were evapotranspired. Thus a balance of 195.9, 101.7 and -11.6 mm were subsequently extracted from the stored soil water reserves to supplement the requirements of the plant. By extracting the stored soil water, trees in the lowest irrigation regime were able to grow at rates not significantly different than trees in higher irrigation regimes. While the lowest irrigation regime tended to suppress tree growth, too large a regime and too frequent precipitation during July and August apparently prevented adequate treatment separation. Overall height growth increased 0.80, 1.04, and 1.05 m, while biomass increased 3185.6, 3524.8, and 4323.2 kg DM · ha^{-1}, respectively. Water use efficiency ranged from 0.32 to 5.18 kg DM · m^{-3} H_2O consumed as ET_c.

Table 5. Summary statistics for plantation grown _P. eldarica_ under three irrigation regimes during the 1983 growing season. Means for growth parameters, relative growth rates, crop evapotranspiration and water use efficiency are presented.

TRT	HT (m)	HTRGR (1)	BAS (cm)	BASRGR (2)	BIO (kg)	BIORGR (3)	ET (mm)	WUE ($kg \cdot m^{-3}$)
	**		**		*			
60	1.52a	0.11	5.05a	0.13	1.80a	0.26	67.14	1.56
80	1.69ab	0.14	5.31ab	0.14	1.97ab	0.28	71.00	1.69
100	1.85b	0.12	5.93b	0.12	2.41b	0.26	83.91	0.98

* means followed by different letters are significant a=0.05
** means followed by different letters are significant a=0.01
(1) HTRGR (ln increase (m) · $month^{-1}$)
(2) BASRGR (ln increase (cm) · $month^{-1}$)
(3) BIORGR (ln increase (kg) · $month^{-1}$)

LITERATURE CITED

Attwill, P.M. and R.N. Cromer. 1982. Photosynthesis and transpiration of Pinus radiata D. Don under plantation conditions in Southern Australia. I Response to irrigation with waste water. Aust. J. Plant Physiol. 9:749-760.

Beadle, C.L., N.C. Turner and P.G. Jarvis. 1978. Critical water potential for stomatal closure in Sitka spruce. Physiol. Plant. 43:160-165.

Buchanan, B.A., R.L. De Velice, and N.S. Urquhart. 1978. An inexpensive precipitation guage. Soil Sci. Soc. Am. J. 42:532-533

Bullock, H.E., Jr. and R.E Neher. 1980. Soil Survey of Dona Ana County Area, New Mexico. U.S.D.A. Soil Conservation Serv. 177p.

Cuenca, R.H. and M.T. Nicholson. 1982. Application of Penman equation wind function. J. of Irrigation and Drainage Div. Proc. A.S.C.E. 108:IR1:13-23.

Doorenbos, J. and A.H. Kassam. 1979. Yield response to water. F. A. O. Irrigation and Drainage Paper 33. 57p.

Doorenbos J. and W.O. Pruitt. 1977. Guidelines for predicting crop water requirements. F.A.O. Irrigation and Drainage Pap. No. 24. 144p.

Federer, C.A. 1970. Measuring forest evapotranspiration -theory and problems. U.S.D.A. For. Ser. Res. Pap. NE-165. 25p.

Fischer, R.A. and N.C. Turner. 1978. Plant productivity in the arid and semiarid zones. Ann. Rev. Plant Physiol. 29:277-317.

Fisher, J.T., F.B. Widmoyer, and J.B. McRae. 1982. Performance of Pinus halapensis/brutia group pines in Southern New Mexico. Hortscience. 17:3:2:334p.

Hinckley, T.M., J.P. Lassoie and S.W. Running. 1978. Temporal and spatial variations in the water status of forest trees. Forest Sci. Monograph 20. Supplement to For. Sci. 24:3. 72p.

Jarvis, P.G. 1976. The interpretation of the variations in leaf water potential and stomatal conductance found in canopies in the field. Philos. Trans. R. Soc. London, Ser. B. 273:593-610.

Johnson, N.E. and D.G. Nielsen. 1969. Pressure chamber measurements of water stress in individual pine fasciles. For. Sci. 15:4:452-453.

Kaufmann, M.R. 1968. Evaluation of the pressure chamber technique for estimating plant water potential of forest tree species. For. Sci. 14:4:369-374.

Kaufmann, M.R. 1979. Stomatal control and the development of water deficit in Engelmann spruce seedlings during drought. Can. J. For. Res. 9:3:297-304.

Kolesnikov, A.I. and A. Gusein. 1961. Conditions of growth and natural restoration of the eldar pine in its native area. (Translation from Russian) Transactions of the Abkhazian Scientific Research Forestry Experimental Station, I. Sukhumi.

Mayes-F, M.M. 1984. Total leaf area determination in juvinile eldarica pine (Pinus eldarica Medw.). Mstrs. Thesis. New Mexico State Univ. 43p.

Rawson, H.M. ,J.E. Begg, and R.G. Woodward. (1977). The effect of atmospheric humidity on photosynthesis, transpiration and water use efficiency of leaves of several plant species. Planta. 134:5-10.

Rook, D.A., R.H. Swanson and A.M. Cranswick. 1978. In Proceedings of Soil and Plant Water Symposium. Referenced In For. Sci. Mono. 20. 1978.

Running, S.W. 1976. Environmental control of leaf water conductance in conifers. Can. J. For. Res. 6:1:104-112.

Running, S.W. 1980. Environmental and physiological control of water flux through Pinus contorta. Can. J. For. Res. 10:1:82-91.

Sammis, T.W., G.L. Maple, D.G. Lugg, R.L. Lansford, and J.T. McGuckin. 1985. Evapotranspiration and crop coefficient prediction using growing degree days. A.S.A.E. in press.

Steel, R.G.D. and J.H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Co. Inc. N.Y., Toronto, London. 481p.

Whitehead, D. 1980. Assessment of water status in trees from measurements of stomatal conductance and water potential. N. Z. J. For. Sci. 10:1:159-165.

Whitehead, D. and P.G. Jarvis. 1981. Coniferous forests and plantations. pp 50-152. In Water deficits and plant growth. T.T. Kozlowski (ed). Academic Press. N.Y. vol 6 582p.