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Comparative Water Use Efficiency of *Eucalyptus camaldulensis* Versus *Dalbergia sissoo* in Pakistan

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ABSTRACT

Two species shisham (*Dalbergia sissoo*) and Eucalyptus (*Eucalyptus camaldulensis*) were grown to determine the difference in physiological responses and water use efficiency (WUE) of indigenous and exotic tree species, their adaptation in arid conditions and the environmental concern about the amount of water consumed by *Eucalyptus*. The plants were grown in a lathe house. Significant variation between two species was observed for WUE and transpiration coefficient (TC). WUE and TC of Shisham were 0.89 and 7.94 g L^{-1} as compared to that of *Eucalyptus*, which were 0.93 and 4.06 g L^{-1}, respectively. However, evaporation losses were higher (0.99 g L^{-1}) for shisham than for *Eucalyptus* (0.84 g L^{-1}). The increased water use (lower TC) by *Eucalyptus* may lead to desertification and lowering ground water table and resulting scarcity of aquifer resources for deep-well-irrigated-agriculture in arid and semi arid climates like one in Pakistan.

Key Words: Evaporation; Transpiration; Girth; Height; Shoots and root biomass

INTRODUCTION

Pakistan has total area of 79.6 million hectare (M ha), out of this area 41.00 M ha is under rainfed cultivation, 16.20 M ha is canal commanded area, 6.33 M ha (17% of the total area) is irrigated with deep wells only and 14.40 M ha (38.7% of the total area) is irrigated with dual system of irrigation (canal & tube well water). While some other non-traditional sources of irrigation cover 05.16 M ha area. Annual groundwater recharge is 56 billion m^3. The usable water from groundwater recharge is 36 billion m^3, while total amount of pumping out of water by tube wells is about 56 million m^3 (41.6 million acre-foot/MAF) (FAO, 2006). Water use efficiency of row crops in Pakistan is 35.5%. Due to uneven distribution of water resources (erratic precipitation), only 4.2 M ha area is under forests. World average of forest area per capita is 1.0 ha, while it is 0.05 ha in Pakistan.

The climate of Pakistan is such that winter temperature reaches bottom of - 26°C in northern hilly areas and summer temperature touches the peak of 52°C in plains. Average annual rainfall ranges between 250 – 300 mm and distributed mostly in Monsoon (July/August receive 80% of total rainfall. Winter rainfall & snowfall on hills occurs from December to February). Evaporation losses round the year are estimated 75% of the precipitation. The amount of rainfall used as transpiration is estimated to be 5%. If this amount could be increased from 5 - 10%, the vegetation yield in the region could be doubled (Qadir *et al*., 2003).

Eucalyptus species (*E. camaldulensis, E. teretecornis* & *E. globules*) were introduced in Pakistan in early 20th century and had been widely planted in all parts of the country. Recently due to acute water shortage for agricultural, drinking and industrial uses in the country, it was highly felt that *Eucalyptus* species are taking more water and lowering ground water status, where natural recharge is already too slow. *D. sissoo* plantations are made in irrigated pockets in Pakistan. While *Eucalyptus* is being grown in a wider ecological conditions particularly in saline, sub-mountainous, waterlogged and irrigated areas (Zahid & Ahmad, 2002).

The amount of water used by *Eucalyptus* plantation is a relevant ecological question worldwide (Stape *et al*., 2004). *Eucalyptus* is native to Australia, where arid climate is dominant and it has several mechanisms for drought avoidance e.g., dynamic changes in leaf area index, near vertical arrangements of leaves, high stomatal sensitivity to air saturation deficit, deep rooting ability and osmotic manipulation (Whitehead & Beadle, 2004). Being evergreen species it has greater access to water at grater depth than deciduous species (Baker *et al*., 2002). In Pakistan, short rotations (7 - 10 years) of *Eucalyptus* are preferred. It led to potential risk of water and nutrient deficiencies and non-sustainable production. Stape *et al*. (2004) concluded that increased water use efficiency was due to increased water supply under water-limited environment (dry years). Considerable research has been done to characterise and evaluate different traits, affection, biomass production and yield of *Eucalyptus* in drought prone environment (Ehdaie & Waines, 1993).

A producer likes to make full use of a limited or low-volume water supply to apply precise amounts of water to the individual trees. Improved irrigation-scheduling methods offer the potential for further savings in water (litres per day for a mature tree) and energy for wood production. Excessive water applications promote fungal diseases of the trunk, increase the costs of pumping and decrease the acreage that could be irrigated (Marshall *et al*., 1982).

Water stress is the most important limiting factor for forest production in arid and semi arid regions of the world. The quantity of water required for the photosynthesis process amounts to only about 0.01% of the total quantity of water used by the plant (Mengel & Kirkby, 1987). Water use efficiency is considered as most important component of adaptation to drought. Ponton *et al*. (2002) stated that the high WUE of a tree might contribute significantly to its survival during dry years, whereas the low WUE may account for the frequently observed declines in adult trees following drought. This view might be explored further for large scale dieback in old trees of *D. sissoo* in the sub-continent.

Studies related to water use efficiency of *D. sissoo* are scarce, while those of water use efficiency of *Eucalyptus* are many. There was a need to compare of the two species to know the consequences of evapotranspiration on aquifer. The present study was aimed at to determine the difference in physiological responses, WUE for the indigenous and exotic tree species, association of plant characteristics with WUE and its adaptation in arid conditions. The environmental concern about the amount of water consumed by *Eucalyptus* as compared with indigenous *D. sissoo* associated with higher efficiency of water use and management guidelines to efficiently utilize irrigation water by the trees was another important focus.

MATERIALS AND METHODS

A one year study in lathe house was initiated in February 2004 to March 2005 at University College of Agriculture, Bahauddin Zakariya University, Multan – Pakistan. Homogeneous soil medium (silt loam “Bhal” available from de-silting of river-fed canal banks) was used. One hundred pots of individual species (indigenous *Dalbergia sissoo* & exotic *Eucalyptus camaldulensis*) were planted and 100 empty pots without plant (as control to measure evaporation losses) were kept. Each pot (12” x 12”) contained 7 kg of soil. Seedlings thus transplanted were 6 to 9 inches in height. Control (empty/bare) pots to measure evaporation losses were placed alternate in between the planted pots to counter the shading factor that might reduce evaporation losses from the planted pots.

Methods employed in the past by Fairbourn (1982) used only eight pots to compare water use efficiency with some assumptions that the mean water loss of the bare pots was assumed to be the average water lost by evaporation. However, to avoid errors in data and to get more reliability 100 pots were used to study the results. Fairbourn (1982) placed planted and bare pots separately and then calculated shading factor, while *Eucalyptus* plants had much shade to cover both the pots uniformly. Precipitation was measured with a standard rain gauge in the field in calculating water addition. Daily meteorological data were collected from Meteorological Station Multan (Table I).

Plastic sheet was spread beneath the potted plants kept in rows to collect litter falling from time to time. The irrigation started from very first day and water was supplied with measured quantity. The pots were fitted with tensiometer at 20 cm depth. These were saturated with water and allowed for evaporation until water potential at 20 cm depth reached between 35 - 50 centibars and then irrigated with 1 or 2 L of water. The similar method has been employed by DehghaniSanij *et al*. (2005) for computing Et model, by Ehdaie and Waines (1993) and Yin *et al*. (2005) for irrigation and measuring evaporative losses.

Biomass yield (root, shoot & total biomass) of the two species was related to plant water use through determining TC and WUE. For destructive measurement of biomass, plants were harvested green and weighed then they were dried up. Shoots were removed from roots at the soil surface. Soil was removed and washed carefully from the roots.

The important factors measured were physiological responses like shoot biomass (green & dry) root biomass (green & dry), girth, height and total amount of water applied. However, it was not possible to count some essential parameters like leaf number, area orientation and number of stomata per leaf etc., due to un-availability of skilled-labour.

In general, efficient water use is defined as the ratio between the actual volume of water used for a specific purpose and the volume extracted or derived from a supply source for that same purpose.

Functionally expressed, $E_f = \frac{V_u}{V_e}$

Where, Ef = Efficiency, Vu = Volume utilized (m^3), Ve = Volume extracted from the supply source (m^3) (Palacios, 2005).

The data recorded was tabulated and analysed with MS-Excel. Water-use efficiency was considered as amount of organic matter produced by a plant divided by the total amount of water applied and transpiration coefficient is basically the amount of organic matter produced by a plant divided by the actual amount of water used by the plant in producing it.

RESULTS AND DISCUSSION

Physiological responses of the two tree species. The data analysis for various parameters and their comparison indicated highly significant differences (Table III) (except root biomass & shoot biomass) in various responses of *D. sissoo* (Shisham) and *Eucalyptus* (Table II).

This is major finding of our study that under site-limited conditions in clay pots, shoot biomass yield of *D. sissoo* is higher than that of *Eucalyptus*, while root biomass was almost equal. Crombie (1997) reported that root system, become more extensive and accessing greater soil volume with age.

Table I. Monthly temperature range during year 2004

Month	Minimum temperature°C	Max. temperature °C
Jan	2.5	25.4
February	3.0	30.6
March	10.5	38.6
April	17.6	42.5
May	17	47.8
June	24	45.5
July	27	42.5
August	21.7	40.3
September	23	39
October	11.2	33.2
November	8.8	31
December	4.4	27.7
January 2005	2.3	23
February 05	2.8	26
March 03	12.5	33.1
April 05	12.6	41
May	19	42.5

Source: Meteorological station Multan.

Fine root density is higher in upper soil and very much low in deeper soil. However, these scarce roots play a crucial role in water uptake during dry season (Bouillet *et al*., 2002). Therefore, it is hardly recommended to grow *Eucalyptus* trees on farmland to save surface water for crop production.

Many studies on irrigation and fertilization of *Eucalyptus* fields have shown that with greater water supplies increased wood growth was reported (Stape *et al*., 2004) and the ever reported highest gain in *E. grandis X. urophylla* was 92 m^3 ha^{-1} yr^{-1}. Apparently *Eucalyptus* has adapted to the environment with some water saving mechanism and low level water supply seems to be adequate for dry matter production. Low transpiration rate in *D. sissoo* compared with other species might be considered a favourable trait if dry matter production has not been relatively low. Since available water and temperature were similar for all plant species the low transpiration rate for *D. sissoo* must have resulted from inherited species traits.

WUE and TC for the indigenous and exotic tree species. Transpiration coefficient (TC) is defined as the amount of water in liters used for the production of 1 Kg of plant dry matter. Table III shows that transpiration coefficient differed markedly between tree species; however, it depends on climate and soil fertility. Stape *et al*. (2004) concluded that water use efficiency of *Eucalyptus* species was 3.8 kg m^{-3} in irrigated plots in wet year and 1.8 kg m^{-3} in control during normal year (low rainfall).

In arid regions it is possible to increase water use efficiency by 25 - 40% through modifying practices in tillage and from 15 - 25% through nutrient management in soil. Water is strategic resource particularly for water-starved countries, where more than 40% of the present global population lives. When demand for fresh water increases, it ends up in decreased allocation to agriculture, so overall water management in water starved countries is needed (Qadir, 2003).

We suggest that under stress condition (stress due to deficiency of water & site or soil conditions, hard clay, saline, or sodic soils) water use efficiency comparison might be evaluated (with minimum supply of water).

Association of plant characteristics with WUE and its adaptation in arid conditions. This study is the part of strategy to use virtual water or improvement in current water use and its conservation to decrease the intensity of water shortage. In water stressed environment thinning should be done and plant-to-plant distance might be kept maximum possible (666 trees ha^{-1}), as thinning was associated with reduction in water stress and greater rate of photosynthesis. Application of N and P fertilizer may increase bole growth and reduce root/shoot ratio of all tree species, hence growth can be increased without additional cost of water. However, stand density is much important factor (Stoneman *et al*., 1996). Therefore, growth of selective tree species on farmland where fertilizers are applied may be favoured without additional cost of water.

D. sissoo is deciduous species, therefore it can tolerate dry season. However, larger tree species experience greater water deficiency than small trees during the dry season due to increased transpirational demands of larger canopy with

Table II. Physiological Responses of *Eucalyptus* and *D. sissoo* (shisham) in relation with WUE and TC

S. No.	Parameters	*Dalbergia sissoo* (Shisham)	*Eucalyptus*
1.	Survival percentage of plants	75	100
2.	Average (air dried weight) of organic matter produced per plant (g)	194.5	206.4
3.	Average girth (cm) of plant at base (above the soil surface)	5.7	6.2
4.	Average Height (cm)	184.7	200.2
5.	Average Shoot biomass (g) per plant (Green)	178.0	280.5
6.	Average Shoot biomass (g) per plant (Dry)	91.1	106.4
7.	Average Water contents of shoot per plant (% of dry weight)	95.4%	163.6%
8.	Average Evapotranspiration (litres) / plant (V_e)	205.7	262.5
9.	Transpiration (V_u) i.e. average amount of water (litres) consumed per plant round the year	23.1	79.98
10.	Potential evaporation rate (L g^{-1})	0.99	0.84
11.	Average Root biomass (dry) per plant (g)	103.4	100
12.	Transpiration coefficient (L kg^{-1})	119	388
13.	Irrigation efficiency (WUE) dry weight (g L^{-1}) of water applied	0.95	0.79

inability of larger root system to supply water. This may be attributed to large scale mortality of *D. sissoo* in Pakistan due to shortage of water and lowering of ground water table. Larger trees tap shallower sources of water than smaller trees during dry season in seasonally dry forests (Baker *et al*., 2002). Drought related mortality was 50% higher in tree > 60 cm dbh, compared to individuals less than 30 cm dbh.

Management guidelines to efficiently utilize irrigation water by the trees. The water requirements differ at different growth stages and time of the season (month-wise) as shown in the Table IV. It is obvious from the data (Table II) that about 89% of the total amount of irrigation applied was evaporated, which is a great water loss due to hot dry climate. For this reasons some water conservation techniques also need to be applied to make the new plantation successful. One most important technique observed is that those pots, which were deep (free board above soil was high > 6") they retained moisture for longer time. Hence, if deeper pits for new younger plants are made (1 - 2 feet or more deep form soil surface) they may conserve the moisture in arid climate. Soil hardness is important factor for ground water recharge; hence growth of forest is essential to increase groundwater table recharge capabilities.

The biological potential for biomass production is in the range of 5 - 50 times greater than current production for forest products. Trees pump the water up and use it without the capital and recurrent cost of lift irrigation (Chambers *et al*., 1989). Therefore, trees are suitable for waterlogged areas and flood volume reduction.

Where soil is limiting factor and average annual rainfall is less than 250 mm, average water availability is the decision factor influencing tree growth (Schiller *et al*., 2002). If irrigation is decreased at the establishment stage plants may develop stress resistance and can tolerate drought against those plants, which are irrigated with ample supply of water (Esler & Phillip, 1994).

The novelty in the present study is that actual problem lies with evaporation losses and needs conservation measures and emphasize in the eradication of *Eucalyptus* is vague rather selection of species according to site conditions and availability of water resources is important.

Under arid conditions water stress is of major significance. Efforts have been made to achieve partial closure of stomata by antitranspirants, without affecting CO^2 assimilation to any major extent. Monomethyle succinic acid (Ester of Decenyl) is particularly effective in stomatal closure (Mengel & Kirkby, 1987). Increasing reflection of light and lowering of leaf temperature can also reduce the transpiration losses.

The environmental concern about water consumed by *Eucalyptus*. Evapotranspiration for *D. sissoo* and *Eucalyptus* was 205.68 and 262.54 liter per pot plant, respectively which translated into transpiration coefficient, is 7.9 and 4.06 g L^{-1}. Huge uptake of water by *Eucalyptus* and less amount of biomass produced as compared to indigenous *D. sissoo* clearly restricts its propagation in water starved areas and those areas, where fresh groundwater is used for irrigation and drinking purposes. Further study will be desired to compare the water use efficiency of *Eucalyptus* and other indigenous species in term of biomass produced and transpiration and evaporation losses using different water conservation techniques. Further investigation is also required to evaluate minimum requirement of water for each species (to apply irrigation at wilting point) and frequency of irrigation as well.

Table III. ANOVA (F-value, at p < 0.05) regarding difference in physiological traits of *Eucalyptus* and *D. sissoo* (Shisham)

S. No.	Parameter	F_{cal}	F_{crit}
1.	Green Weight of Shoot	39.19	3.89
2.	Dry weight of shoot	02.57	3.89
3.	Height of plant	10.06	3.89
4.	Girth of plant	12.70	3.89
5.	Dry weight of root	00.32	3.89
6.	Total biomass	26.89	3.89

Table IV. Month-wise irrigation requirements (L plant^{-1}) of different tree species during early establishment

Month	Eucalyptus	*D. sissoo* (Shisham)	Control (Evaporation Loss)
January	6.80	4.73	4.60
February	10.57	4.80	4.20
March	14.70	8.77	8.03
April	19.92	18.36	16.00
May	33.90	26.72	25.40
June	27.02	27.56	25.90
July	32.04	30.40	27.10
August	28.75	25.64	22.50
September	32.98	25.00	22.00
October	23.94	16.70	14.32
November	17.96	8.00	6.00
December	13.96	9.00	6.50
Total	262.54	205.68	182.55

CONCLUSIONS

In essence, *Eucalyptus* commonly grown in agro-forestry consumes huge volumes of water as supported by data on WUE and TC. In fact, when wood production is the major objective of the landowner, tree species might use less water per ton of wood produced and selection of species is very important in this regard. Moreover, evaporative losses overweigh all other water consumptions and there is need to plan evaporation conservation strategies from gross root level to national scale.

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