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PLANTING *EUCALYPTUS CAMALDULENSIS* IN ARID ENVIRONMENT - IS IT USEFUL SPECIES UNDER WATER DEFICIT SYSTEM?

DIN MUHAMMAD ZAHID[1*], FAZAL-UR-REHMAN SHAH[2] AND ABDUL MAJEED[3]

[1]University College of Agriculture, Bahauddin Zakariya University, Multan, Pakistan
[2]Institute of Geology, University of the Punjab, Lahore, Pakistan.
[3]Faculty of Agriculture, University College of Agriculture, Rawlakot, AJK, Pakistan
[*]Corresponding author E-mail: fazalshah1@yahoo.com

Abstract

This paper reveals the consequences of water extraction by *Eucalyptus camaldulensis* as compared to native *Acacia nilotica* Del., *Albizia procera* [Roxb.] Benth and *Azadirachta indica* grown on cultivated lands. *Eucalyptus*, due to its fast growth rate and wide adaptability to prevailing environmental conditions, was planted ruthlessly without any concern for its impact on soil deterioration and harm to ground water. The aim of this study was to investigate whether *Eucalyptus* is of any importance in conserving water and consequently its impact on the depletion of ground water resources. The four species were grown in pots in a green house. Water consumption by one year old *Eucalyptus* [149.27 L] was almost twice that of by *Albizia* [82.84 L] and more than three times that of by *Acacia* [58.30 L], and *Azadirachta* [51.57 L].

Significant variation between the species was observed for biomass produced. When this was translated into water use efficiency [WUE], it was found as 0.32 g L^{-1}, 0.48 g L^{-1}, 0.16 g L^{-1} and 0.77 g L^{-1} while transpiration coefficient [TC] was 1042 L kg^{-1}, 872 L kg^{-1}, 1951 L kg^{-1} and 739 L kg^{-1} for *Acacia, Albizzia, Azadirachta* and *Eucalyptus* respectively. It is important to control evaporation losses [44-69% of total irrigation] which may be much higher than transpiration. Increased water use uptake by *Eucalyptus* may lead to reduction and scarcity of aquifer resources for irrigated agriculture in arid and semiarid climates. Although water use efficiency of any species is also important, but environmental concerns about the amount of water consumed by these species are also considered most important.

Introduction

Affordable afforestation programs in arid areas suffer mainly from low rainfall, high evapotranspiration [ET] demands and high salt contents (Minhas *et al.*, 1997). Ground water tables are being dried up by induced discharge from well pumping and evapotranspiration by plants. The precipitation seepage into the ground may vary from 5-50% depending upon soil permeability; the rest becomes runoff or evaporates (Qadir *et al.*, 2003). The water table can rise or fall according to the season of the year and the amount of precipitation that occurs (Tomar *et al.*, 1997). Transpiration in plants is regulated by temperature, relative humidity and air saturation deficit (Whitehead & Beadle, 2004) by plant control (Gazal *et al.*, 2006) while 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).

The climate of irrigated areas in Pakistan is mostly hot and summer temperature reaches a peak of 52^{o}C in the plains. Average annual rainfall ranges between 250–300 mm and are distributed mostly in the Monsoon [July/August receive 80% of total rainfall] (Qadir *et al.*, 2003). Evaporation losses around the year are estimated at 75% of the precipitation, while the amount of rainfall used as transpiration is estimated to be as low as 5% (Nimbkar *et al.*, 1986; Johnson *et al.*, 2005). Due to high temperature, plant growth occurs usually under lower rate of photosynthesis than normal values in summer even when water is well supplied (Sheik, 1989) and this results in reduced biomass. Sustainable wood production in drylands and irrigated pockets requires species which use water efficiently and are well adapted to the local agro-climate.

Four tree species were chosen for the current study based on their drought tolerance, adaptability to local conditions, commercial potential and aesthetic values. *Acacia nilotica* Del., is grown in low rainfall tracts of the world and growth is relatively fast (Nimbkar *et al.*, 1986; Johansson *et al.*, 1993). Sheik (1989) and Parrotta (2006) reported that in the riverside-forests, a maximum mean annual increment of 13-10.5 cubic metres per hectare was decreasing with age. It has long been one of most popular farm trees throughout the Indian subcontinent and other parts of the world due to easy propagation and multiple uses such as timber, fuelwood, fodder, tannins and gum (Gill *et al.*, 1987; Devi & Prasad, 1991; Bhatnagar *et al.*, 1993; Alam *et al.*, 2005; Smith *et al.*, 2005). Acacias form a deep and extensive root system on dry sites where the tap root develops first and then followed by the laterals roots, which become compact and massive in future (Ingleby *et al*., 1997).

Albizia procera (Roxb.) Benth., belongs to the family Leguminosae-Mimosoideae (Fabaceae). It is a fast-growing deciduous tree. Depending on site conditions, annual height growth ranges from 1 to 2 m and annual diameter increment varies from 1.5 to 2 cm during the first 15 years (Parrotta, 2006) and attains a maximum height of 20 m and 60 cm d.b.h. It is grown for forage and wood biomass in tropical and semi-arid irrigated areas (Lugo *et al.*, 1990).

Azadirachta indica A. Juss. thrives well in dry areas throughout the tropics and sub-tropics with rainfall as low as 150-250 mm per annum. It is very resistant to weed competition. The *Azadirachta* tree is gaining importance throughout the world because it provides solutions to rehabilitation to degraded ecosystem (Peer *et al.*, 2008) for its medicinal value (Palsson & Jaenson, 1999; Gajalakshmi & Abbasi, 2004; Kumar *et al.*, 2006; Xuan *et al.*, 2004; Rugutt *et al.*, 2006; Senthil *et al.*, 2007), source of pesticide for crops (Deans *et al.*, 2003; Arya, 2006; Jabbar *et al.*, 2006; Prakash & Srivastava, 2006; Bakshi & Wadhwa, 2007) and generation of income for small farmers (Zahid & Ahmad, 2002).

Eucalyptus species were introduced in Pakistan in the early 20th century and millions of hectares were planted in all parts of the country (Zahid & Ahmad, 2002). Considerable research has been done to characterize Mahmood *et al*., (2009) and evaluate different traits affecting biomass production and yield of *Eucalyptus* in drought-prone environments (Ehdaie & Waines, 1993) but the ecophysiology of the water resource limitation on growth remained poorly quantified. As an evergreen species, it has greater access to water at greater depth than other deciduous species (Baker *et al.*, 2002; Deans & Munro, 2004; Whitehead & Beadle, 2004). Short rotations (7-10 years) of *Eucalyptus* are preferred that led to potential risk of water and nutrient deficiencies and non-sustainable production. It is well documented that *Eucalyptus* is the species that pumps a huge amount of water from underground watertables (Cohen *et al.*, 1997; Kallarackal & Somen, 1997; Whitehead & Beadle, 2004; Zahid & Nawaz, 2007). On the other hand, the comparative growth of *Acacia, Albizia* and *Azadirachta* species in relation to water consumption has been less studied. Recently due to acute water shortage for agriculture and other increasing demands for water in the country, it is believed that *Eucalyptus* species are extracting more water than recharge, depleting groundwater in cultivated fields and disturbing the water balance of aquifers.

A comparative production ecology and water use of indigenous *Acacia*, *Albizzia*, *Azadirachta* and the exotic *Eucalypus camaldulensis* was, therefore, investigated. Wood production was measured and water use to quantify its potential impacts on socio economic and environmental concerns of the aquifer of the agricultural lands was estimated. No comparative studies have been made so far to assess the water uptake, transpiration demands and water use efficiency of *Acacia*, *Albizzia*, *Azadirachta* and *Eucalyptus* species in arid regions such as in Multan, Pakistan where evaporation rate is high. With an understanding of physiological responses relative to water uptake and the traits associated with it, is possible to develop reliable forecasting systems for selection of tree species to grow on cultivated farmlands, particularly in water-starved and canal-irrigated areas.

Water demands exceed supply due to increased municipal-industrial-agricultural competition. These factors attract much attention to the possible conservative management of available meagre water resources. Therefore, the main objective of the present study was to quantify the relationship of dry matter and water uptake of exotic and indigenous species under irrigated conditions. After determining the physiological responses of the trees, including yield comparing WUE and TC of the indigenous and exotic tree species, management guidelines may be developed to utilize efficiently the irrigation water by these species in arid cultivated lands.

Material and Methods

This study was conducted at University College of Agriculture, funded by Bahauddin Zakariya University, Multan, Pakistan. The study site lies between 30° N latitudes and 71° E longitudes, with an elevation of 166 m above sea level. Homogeneous fertile soil medium collected from the de-silting of river-fed canal banks was used. Its textural composition was clay:sand:silt corresponding to 9% :15% :76% respectively. Five hundred clay pots [100 per treatment] were used. The size of each pot was 30 cm diameter x 30 cm height and containing 7 kg of soil. The seedlings of almost uniform size 18-20 cm height were transplanted in February 2004. The seedlings were procured from different nurseries, therefore exact dates of seed sowing were not known.

Seedlings of indigenous *Acacia*, *Albizzia*, *Azadirachta* and exotic *Eucalyptus camaldulensis* were grown and kept under green net-shade conditions to test for potential interspecific differences in growth performance. The irrigation treatment and data recording started one month after transplanting the seedlings so that root system was established in pots for a total period of one year for each treatment. All pots were manually irrigated with measured quantity when water potential reached 35–80 centibars (occasional stress), because farmers usually irrigate their fields with tubewells or canal irrigation at this level. To measure evaporation losses 100 pots of the Control treatment (without plants) were placed alternately between the planted pots to account for the shading factor that might reduce evaporation losses from the planted pots. A similar methodology was also used by Yin *et al.*, 2005.

Total dry biomass and shoot biomass (important traits for water use efficiency), root biomass (Important for increasing soil organic matter and C sequestration), height (Important for shade effect on associated crops), root: shoot ratio (higher ratio more water uptake and greater ability to withstand stress) were measured. Evaporation [from open pots] transpiration [irrigation applied minus evaporation] (Ehdaie & Waines, 1993), intrinsic transpiration coefficient [TC], and WUE were also estimated. Water use efficiency [WUE] may be defined as the amount of biomass produced as per litre of irrigation applied and TC is described as the amount of water transpired as per kg of biomass produced. In many studies modern instruments are being used to measure water uptake, for example through sapflow using thermal probes, dynagauages (Deans &

Munro, 2004), and infrared gas analysers (Zahid *et al*., unpublished). Some studies have shown that these instruments have many limitations and readings may be quiet misleading with error more than 100% (Do & Rocheteau, 2002a, b), depending on the type of instrument, methods, tree girth, size and number of trees used for estimation (Whitehead & Beadle, 2004), and depth between the pith and the bark (Cohen *et al*., 1997).

The present study was based on a destructive method to precisely quantify biomass and water use on unit seedling basis and excluding the chances of interaction of different roots for extraction of water from soil. While other studies (Deans & Munro, 2004) were based on non-destructive estimations of biomass and water use having different sources of variation such as tree age, size, canopy area and season. A similar approach was used by Wildy *et al*., (2004) to express water budget on unit tree basis for tree belts. Soil conditions, tree densities, age and growth rate may vary from place to place. These sources of variation affect data analysis and conclusions may not be reliable. Performance on an individual tree basis is more realistic and rational for experimental purposes. For destructive measurement of biomass, plants were harvested green, air dried for 60 days at room temperature and weighed. Shoots were removed from roots at root collar near the soil surface. Soil was removed and washed carefully from the roots. Plastic sheets were spread beneath the potted plants to collect litter.

Analyses of variance were performed by using MS Excel data analysis tool (ANOVA-Single Factor) and GenStat (version 8) to determine the interspecific differences (main effects) in responses considering water as the main focus. All analyses were performed at a significance level of 0.05.

Results

The growth performance of tree species and other derived values such as WUE and TC comparisons are given in Table 1. Survival rate of *Acacia*, *Albizzia, Azadirachta* and *Eucalyptus* was 84%, 82%, 81% and 100% respectively. The data analysis for various parameters (dry weight of shoot and root, height, girth, and total biomass) indicated highly significant differences (F_{cal}>F_{crit}) of the response by these species.

Average air dried total biomass per plant produced from one year old plants of *Acacia*, *Albizzia*, *Azadirachta* and *Eucalyptus* was 56 g, 95 kg, 24 g and 203 g; average dry shoot biomass per plant was 36.55 g, 42.07 g, 6.79 g and 102 g; and average root biomass (dry) per plant was 19.52 g, 52.93 g, 19.26 g and 100 g respectively. The low shoot biomass yield of *Azadirachta* was partially compensated by its greater root biomass (Table 1).

The data on growth parameters including height as growth parameter were the average of survived tree saplings only. Average height of one-year-old *Acacia*, *Albizzia*, *Azadirachta* and *Eucalyptus* was 115 cm, 107 cm, 55 cm and 200 cm against the average girth of plant at root collar, which was 34 mm 54 mm, 19 mm and 62 mm respectively. Shirazi *et al*., (2006) reported the height of 9 month old *Acacia* and *Eucalyptus* about 200 cm and 190 cm respectively. Silviculturally, species with height gain of >1 m yr^{-1} and diameter increment >1 cm yr^{-1} are considered fast growing (Marcar *et al.*, 1995)**.** The proportionate stem girth of the individual species measured in terms of gains was similar [3%] to gains in their heights except that of *Albizia* [5%]. The *Azadirachta* showed little increase in girth or height; it showed little growth during establishment but may subsequently show exponential increase in size (Do & Rocheteau, 2002a). The reported height of *Eucalyptus* and *Azadirachta* grown in container under salt-stress condition is 43.1-168.4 cm and 13.5-52.5 cm respectively (Suriyan & Kirdmanee, 2008)

Table 1. Growth responses and water use of some tree species in hot dry climate.

S. No	Parameters	*Acacia*	*Albizzia*	*Azadirachta*	*Eucalyptus*
1.	No. of plants survived out of 100 plants of each species planted	84	82	81	100
2.	Total air dried [root + shoot] biomass (kg) produced from all survived plants (s.e.d. = ± 6.52 g)	4.71 b*	7.79 a	2.11 d	20.20 c
3.	Average air dried weight [root + shoot] (g) per plant	56	95	24	203
4.	Average girth (mm) of plant at root collar (s.e.d. = ± 1.45 mm)	34 b	54 a	19 d	62 c
5.	Average plant height (cm) (s.e.d. = ± 5.75 cm)	115a	107a	55 c	200 b
6.	Total air dried shoot biomass (kg)	3.07 a	3.45 a	0.55 c	10.20 b
7.	Average shoot biomass per plant (g) (s.e.d. = ± 4.99 g)	36.55	42.07	6.79	102
8.	Total air dried root biomass (kg) (s.e.d. = ± 3.76 g)	1.64 b	4.34 a	1.56 b	10.0 c
9.	Average root biomass per plant (g)	19.52	52.93	19.26	100
10.	Root: shoot ratio of total biomass of individual species	0.53	1.26	2.84	0.98
11.	Total amount of water applied (litres) to surviving pants during a year	14529	16196	13405	26394
12.	Average amount of water applied per pot (litres) [mm m^{-2}]	172.96 [2369.48]	197.51 [2705.80]	165.49 [2267.14]	263.94 [3615.86]
13.	Amount of water evaporated during the year [% evaporation]	9632 {66%}	9403 {58%}	9288 {69%}	11467 {44%}
14.	Total amount transpired (litres) [cubic meters, 1L=10^{-3} m^3]	4897 [4.897]	6793 [6.793]	4117 [4.117]	14927 [14.927]
15.	Average amount transpired (litres) per plant during the year	58.30	82.84	51.57	149.27
16.	Transpiration coefficient (TC) (L/kg)	1042	872	1951	739
17.	T:E Index [amount of transpiration / amount evaporation in litres]	0.5	0.7	0.4	1.3
18.	Transpiration Efficiency– g L^{-1} ANPP [kg m^{-3}]	0.63	0.51	0.13	0.68
19.	Irrigation efficiency (WUE) total dry weight per litre of water applied (g/L)	0.32	0.48	0.16	0.77
20.	Average potential annual rate of evaporation losses (Control) [mm m^{-2} yr^{-1}]	1570**			

*Note: the letters a, b, and c denote the values with statistically significant difference from one another, but values having similar letter are not significantly different.

**[pot area=0.072995 m^2; Evaporation 114.67 L per pot per year; and 1 L = 1 mm m^{-2}]

The authors assessed the ability of the species to alter the water table depth of aquifer by measuring total evapotranspiration [total irrigation applied] for each species and water uptake on a per plant basis because in agroforestry system where trees are usually in single lines on the boundary. The total amount of evapotranspiration was 172.96 L, 197.51 L, 165.49 L, and 263.94 L out of which transpiration per plant were 58.30 L, 82.84 L, 51.57 L and 149.27 L for *Acacia, Albizzia, Azadirachta* and *Eucalyptus* respectively. The percentage of water evaporated from pots containing one year old seedling of *Acacia, Albizzia, Azadirachta* and *Eucalyptus* was 66%, 58%, 69% and 44% respectively. Average TC was 1042 L kg^{-1}, 872 L kg^{-1}, 1951 L kg^{-1} and 739 L kg^{-1} for *Acacia, Albizzia, Azadirachta* and *Eucalyptus* respectively.

The *Eucalyptus* produced highest average biomass per litre of water [WUE of 0.77 g L^{-1}], about two times more than that by *Acacia and Albizia* [0.32 g L^{-1}, 0.48 g L^{-1}] and five times more than that of *Azadirachta* [0.16 g L^{-1}]. Transpiration efficiency taken as aboveground net primary productivity [ANPP] by Mengel & Kirkby (1987) was calculated as 0.63 g L^{-1}, 0.51 g L^{-1}, 0.13 g L^{-1} and 0.68 g L^{-1} for *Acacia, Albizzia, Azadirachta* and *Eucalyptus* respectively. WUE varied from 2 to 5 times between species and was highest for *Eucalyptus*.

Discussion

This study is the part of strategy to improve current water use and its conservation to decrease the intensity of water shortage. Precipitation contribution to ground water is 2% or less in hot and dry climates. This estimate depicts the approximate amount of water that might be pumped from the aquifer without depleting the ground water resources. About 30% of water used as irrigation is lost in storage and conveyance and 63% of the remaining is lost as runoff and drainage (Qadir *et al*., 2003). The farming communities in Pakistan, like many others over the world, have an adverse opinion for growing *Eucalyptus* on farmland due to consumption of huge volumes of irrigation as well as ground water. This was confirmed in the present study when comparing water use of *Eucalyptus* with indigenous *Acacia, Albizzia* and *Azadirachta* tree species.

The increased availability of fuel and fodder and other benefits depend on the quantity of biomass a tree species can produce (James *et al*., 2008). In fact, when wood production is the major objective of the landowner, fast-growing tree species must use less water per m^3 of wood produced. However the cost to pay for wood production on cultivated lands is the precious canal water for crops and the amount of ground water extraction, which is higher as regards seasonal time period or rotation age of plantation.

Overall biomass produced by the *Eucalyptus* was 2-8 fold higher than native species while water use [transpiration] was 2-3 fold. Translating this into TC and WUE, *Eucalyptus* growth performance was better than native species. Data showed that *Eucalyptus* was very efficient water users with TC of 739 L kg^{-1} as compared to *Acacia, Albizzia,* and *Azadirachta* which used 1042 L, 872 L and 1951 L of water to produce one kg of biomass. It was reported by Kallarackal & Somen, (1997) that under low relative humidity and without supply of nutrients the TC becomes higher. However, our major concern was total water extraction by individual species over time span compared to water availability. Tree species such as *Eucalyptus* showed higher water extraction per plant [149.27 L] compared to *Acacia, Albizzia* and *Azadirachta* which extracted 58.30 L, 82.84 L, and 51.57 L respectively during the year. Water use efficiency for *Eucalyptus* as reported by Cohen *et al.*, (1997) and Whitehead & Beadle (2004) was 1-5 g dry matter per kg of water. Considerable uptake of water by *Eucalyptus* as compared to indigenous *Acacia, Albizia* and *Azadirachta* clearly restricts its cultivation in water starved areas.

Morris *et al*., (2006) reported about 3 times more water use by *Eucalyptus camaldulensis* in Pakistan environments as compared to that in Australia due to increased vapour pressure deficit.

Table 2. Monthly irrigation (flood) requirements (mm m^{-2}) of different tree species during early establishment (at soil depth 30 cm) in hot dry climate.

Month	***Eucalyptus***	***Acacia***	***Albizzia***	***Azadirachta***	**Control (evaporation loss)**
January	93.16	68.50	66.85	63.29	59.18
February	147.54	82.20	102.41	85.21	73.76
March	201.38	123.30	183.66	150.01	121.93
April	279.74	191.79	308.60	198.98	171.24
May	464.41	273.99	395.78	309.88	255.58
June	370.16	197.00	321.94	300.98	194.53
July	438.93	327.56	379.07	318.10	213.88
August	403.45	270.15	285.09	259.74	143.84
September	451.81	356.19	301.25	264.40	135.63
October	327.97	259.74	177.00	147.68	86.31
November	246.04	123.30	69.05	63.29	57.54
December	191.25	95.90	115.08	105.49	57.54
Total	**3615.84**	**2369.62**	**2705.78**	**2267.05**	**1570.96**

Source: data summed and calculated from amount of water applied during experiment.

Measurements for water applied showed that a major portion of irrigation plus rainwater was being evaporated (1570 mm m^{-2} yr^{-1}). It is obvious from the data that about 44–69% of the total amount of irrigation applied was evaporated which is a big water loss due to hot dry climate. The maximum evaporation losses (0.62 mm day^{-1}) were reported by Cohen *et al*., (1997); Kallarackal & Somen, (1997) and Wildy *et al.*, (2004) at maximum temperature (33^{o}C) and rainfall (114 mm). In our study it accounted for 4.3 mm day^{-1}. Although with canopy closure evaporation losses from soil decrease, this is more than compensated by tree extraction from groundwater to satisfy transpiration.

When transpiration was compared with evaporation (Fig. 1), it showed that *Albizia* and *Eucalyptus* had higher transpiration as compared to evaporation. *Acacia* and *Azadirachta* had lower transpiration with higher evaporation losses; physiologically such plants may go under stress and produce less biomass (Whitehead & Beadle, 2004). The transpiration to evaporation T: E index changes during the season and increases with the increasing age of species, but at early plantation stage it gives better indication (Fig. 2) for selection of species and amount of irrigation required for successful establishment (Table 2). The present rate of transpiration was 0.058 m^3, 0.083 m^3, 0.052 m^3 and 0.15 m^3 per plant from one year old seedling of *Acacia, Albizzia, Azadirachta* and *Eucalyptus* respectively. Although it cannot be extrapolated precisely over time, however, the 2-3 times higher rate of transpiration by *Eucalyptus* indicated that it was not such a favourable species to be grown in water-starved conditions.

Transpiration efficiency (g/L) alternatively called Aboveground Net Primary Productivity ANPP [kg m^{-3}] of *Acacia, Albizzia, Azadirachta* and *Eucalyptus* was 0.63, 0.51, 0.13 and 0.68 respectively (Table 1). Stoneman *et al*., (1996) reported a quite high ANPP [3.21 kg m^{-3}] of *Eucalyptus tereticornis* plantation with added nitrogen fertilizer in tropical soils having high fertility and high rainfall. They concluded that by increasing availability of water, increased use of light and nitrogen by *Eucalyptus*, was another competitive threat to crops in *Eucalyptus*-based agroforestry system where more fertilizer and water are applied to crops.

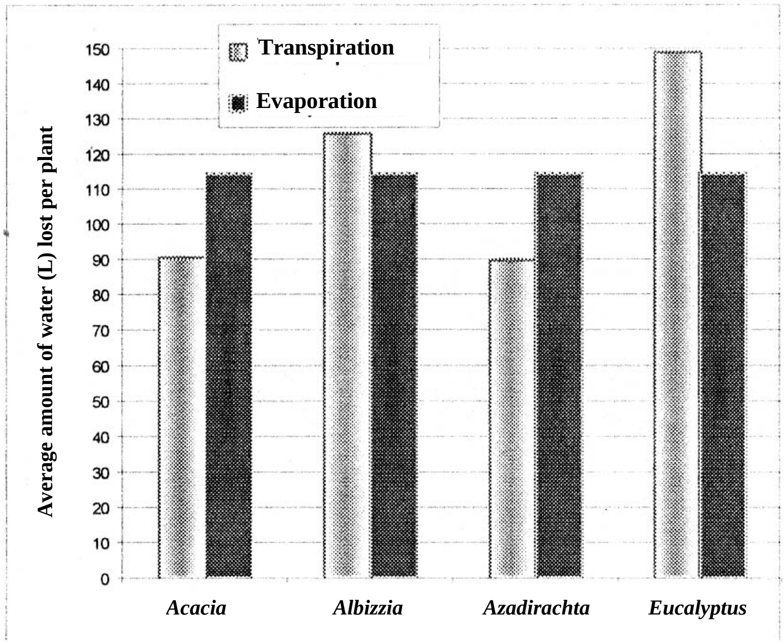

Fig. 1. Comparative transpiration and related evaporation in tree species.

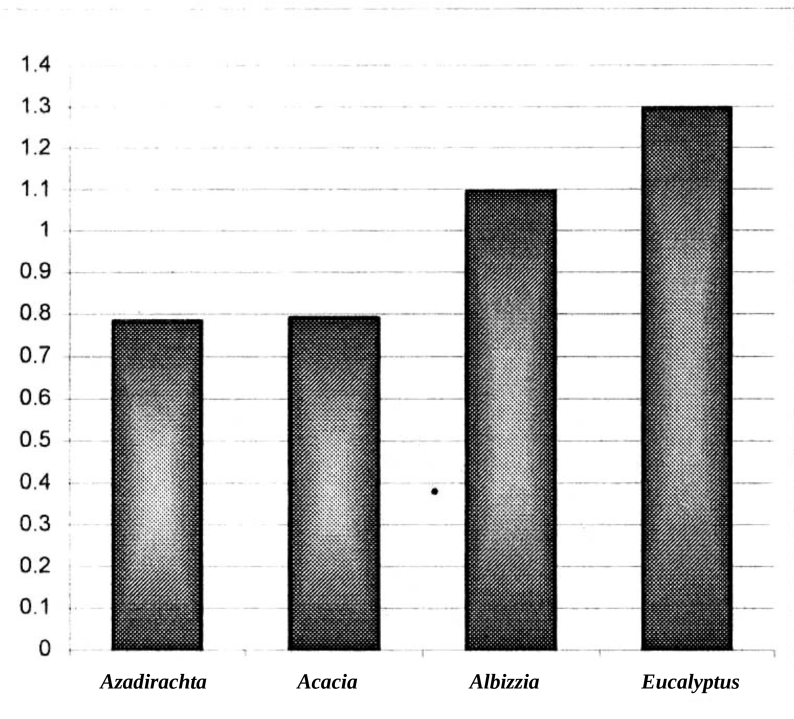

Fig. 2. Transpiration: Evaporation (T:E) Index of different tree species.

The root to above ground biomass ratio varied significantly, 2-6 times among species. The lowest was for *Acacia* [0.53] and highest for *Azadirachta* [2.84], while *Albizia* [1.26] and *Eucalyptus* [1.0] had the similar ratio. This is important for resource partitioning relevant to C sequestration into the below-ground parts. Seedlings of *Azadirachta* grow at a moderate rate by attaining height of 20-30 cm by the end of first season and 2-3 cm mean annual girth increment on good soils (Tewari & Kishan, 2002; Bhattacharyya & Sharma, 2004). The high root:shoot biomass ratio of *Azadirachta* was due to unfavourable cold temperature during early growth. Therefore maximum assimilated resources were allocated in roots, which can be attributed to early success of *Azadirachta* tree in any stress condition.

Water use efficiency is considered as the most important component of adaptation to drought conditions. It is suggested that further research be undertaken to investigate site specific crop coefficients for *Eucalyptus, Acacia, Albizia* and *Azadirachta* and other native tree species that would result in optimum irrigation to save precious water resources in arid climates of Pakistan and other similar parts of the world. Now the question is whether we are focused on more C assimilation or more water conservation? Which priority is more challenging? There is need to explore these venues, and there is also a need to focus more on minimizing C release as well, by using alternate energy resources rather than merely emphasizing vegetation as a C sinks at the cost of higher water use.

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