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Assessing biodrainage potential of tropical forest trees through lysimeter experiments in central India

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ABSTRACT

The lysimeter experiments with seven tropical forest tree species were conducted in non–weighing type lysimetric tanks. Waterlogged conditions were artificially created in the tanks at 0-0.25 m, 0.25-0.50 m and 0.50 -0.75 m levels. Water consumption, growth characteristics and transpiration rate of trees planted in the tanks were recorded and Pearson correlation among different parameters was established. *E.* hybrid and *P. pinnata* showed steady rate of transpiration, more water use and higher growth under waterlogged conditions, hence recommended for raising plantations to reclaim waterlogged sites along canal command areas with almost similar climatic conditions. The biodrainage potential of the selected tree species was found in the order *E.* hybrid> *P. pinnata*> *A. lebbek*> *A. procera*> *D. sissoo*> *T. arjuna*> *A. nilotica*.

Key words : *Biodrainage, Waterlogging, Lysimeter, Transpiration rate, Tropical forest, Central India.*

Introduction

India accounts for about 17% of the World's population but only 4% of the fresh water resources, the distribution of which across the vast expanse of the country is also uneven. The increasing demands demands of water water resources by India's burgeoning population and diminishing quality of existing water resources due to pollution and the additional requirements of India's spiraling industrial and agricultural growth have led to a situation where the consumption of water is rapidly increasing while the supply of fresh water remains more or less constant (Goyal *et al*., 2005). Surveys conducted by the Tata Institute of Social Sciences (TISS) showed most of urban cities are water deficient and nearly 40% of water demand in urban India is met by ground water. As a result ground water tables in most cities are falling at alarming rate of 2-3 meters per year.

Canal irrigation is an important means of irrigation and is more common in northern plains in the states of U.P., Punjab, Haryana, Rajasthan and Bihar because rivers are perennial, water is stored in dams across rivers, which is distributed to the farmers' fields through the network of canals. Waterlogging is one of the major drawbacks of canal irrigation, which is mainly the result of increased water table in command areas. It occurs due to intensive irrigation in poorly drained soil where water can't penetrate deeply and enters the soil faster than it drains away (Goyal *et al*., 2005). More than 33% of the World's irrigated land is affected by salinization and waterlogging. In India alone, 8.4 million hectare land is affected by soil salinity and alkalinity, of which about 5.5 million hectare is waterlogged (Pandey, 2013).

Biodrainage is the vertical drainage of waterlogged soils in irrigated commands through strategically planted tree vegetation and is catching the fancy of techno-scientific community in agricultural soil water management (Denecke, 2000; Kapoor and Denecke, 2001; INCID, 2003; Angrish *et al*., 2006; Ram *et al*., 2007). The consumptive use of water by trees and consequent lowering of water table through biodrainage can be quantified through lysimeter experiments. There is lack of information on the biodrainage potential of different tree species and on their morpho-physiological traits in central India. Therefore, the present study has been undertaken to evaluate biodrainage potential of seven tropical forest tree species through lysimeter experiments.

Materials and Methods

Raising seedlings of tree species in nursery

Seeds from phenotypically superior trees of *Albizia lebbek, Albizia procera, Acacia nilotica, Dalbergia sissoo, Terminalia arjuna* and *Pongamia pinnata* were collected, while seeds of FRI-4 and FRI-5 clones of *Eucalyptus* were procured from Forest Research Institute, Dehradun (Uttarakhand). The seedlings of these species were raised in Modern Technical Nursery of Tropical Forest Research Institute, Jabalpur and maintained for one year in polybags through regular watering, weeding, cleaning and shifting.

Growth characteristics of seedlings *viz.* height and girth were recorded using measuring tape on quarterly basis for 3 years starting from September (Post-monsoon) of first year to June (Pre-monsoon) of fourth year.

Conducting lysimeter experiments

The in filled non-weighing type of lysimeters were used for the experiment, which were constructed in Tropical Forest Research Institute, Jabalpur, Madhya Pradesh (India) campus located at $23^0$5′54" N and $79^0$59′23" E. The experiments were set up in the lysimetric tanks with seven tropical forest tree species abundantly available in central India, except *Eucalyptus* which is exotic and generally available on waterlogged areas surrounding the dams or along the canals and rivers. One healthy sapling of each species with almost similar height and girth was planted in different lysimetric tanks. Waterlogged conditions were artificially created in the tanks at three levels of 0-0.25m, 0.25-0.50m and 0.50 -0.75m and the experiment was replicated thrice. Control was maintained in three tanks, where no waterlogged condition was created and the planted saplings were watered as per their requirement.

Measuring water consumption by trees

Water logging in lysimeters was created through water supply on daily basis from adjacently placed 100 litre water tanks at 0-0.25m, 0.25-0.50m and 0.50 -0.75m levels from the surface. The amount of water transpired by plants and water evaporated through the surface of lysimeters was equal to the amount of water added to each 100 litre tank every day. The surface of lysimeters was covered with polythene sheet to check the evaporation loss from the surface. Hence the addition of water in the 100 litre supply tank represented water consumption per day by individual tree.

Measuring transpiration rate of trees

Diurnal and species variation in transpiration rate (E) of the trees planted in lysimeters was measured using CID Inc. make Photosynthesis System (CI – 340 PS) from 6 AM to 8 PM. The flow rate was maintained between 0.25–0.30 litre per minute and E (milli mole/m^2/s) was calculated with following formula:

$$E = \frac{e_0 - e_i}{P - e_0} \times W \times 10^3$$

Where, $e_0(e_i)$ – outlet (inlet) water vapour (bar)
P – Atmosphere pressure (bar)
W – Mass flow rate per leaf area (mol/m^2/s)

Statistical analysis

The water consumption data was statistically analysed using SX software. Analysis of variance (ANOVA) was calculated and critical difference at 1% and 5% significant level was determined. Standard error mean was also calculated. Pearson correlations among growth parameters, transpiration rate and water consumption by tree species was calculated.

Results and Discussion

The growth data of trees planted in lysimeters after three years of plantation exhibited maximum height in *E.* hybrid (9.1m), followed by *P. pinnata* (8.1m) and *A. lebbek* (7.4m). *A. nilotica* and *T. arjuna* showed minimum height (5.5m each) after experimentation period. Similarly, girth was found maximum in *E.* hybrid (34.2cm), followed by *P. pinnata* (32.9cm) and minimum by *A. nilotica* (24cm) (Fig. 1). *Eucalyptus* is a fast growing forest species largely domesticated throughout the world, the plantations of which have been raised in India for the last 2-3 decades as part of a drive to reforest the subcontinent and create an adequate supply of fuel and timber for rural communities, livelihood generation and carbon sequestration. Environmentalists oppose to *Eucalyptus* due to its perceived higher water consumption and other ecological hazards, however foresters support it due to meeting increasing wood demands from dwindling natural forests, supplying local communities and industry (Sunder and Parameswarappa, 1989; Jenkins *et al*., 2016).

Table 1. Average water consumption (litre/day) by tree species under different water regimes in lysimeters.

Species	Water level (m)		
	0 - 0.25	0.25 – 0.50	0.50 – 0.75
Eucalyptus hybrid	44.75	42.58	38.92
Pongamia pinnata	41.17	39.83	35.83
Dalbergia sissoo	32.42	31.08	28.50
Acacia nilotica	31.92	29.17	28.00
Albizia procera	37.25	35.50	32.58
Albizia lebbek	37.92	35.25	33.75
Terminalia arjuna	34.25	31.83	31.25
For Species			
$CD_{0.05}$	1.2462		
$CD_{0.01}$	1.6466		
SE ±	0.6300		
For Water level			
$CD_{0.05}$	0.8158		
$CD_{0.01}$	1.0779		
SE ±	0.4124		

Height of *E.* hybrid showed 37.36% decrease in 0-0.25m, 14.29% in 0.25-0.50m and 13.19% in 0.50-0.75m level and girth showed 46.49% decrease in 0-0.25m, 8.19% in 0.25-0.50m and 7.60% in 0.50-0.75m water level in the lysimeter tanks depicting the resistance shown by this species upto certain limit under waterlogged conditions. Toky *et al*. (2011) observed excellent survival and establishment of *Eucalyptus* hybrid clone (*E. tereticornis* x *E. camaldulensis*) and *P. pinnata* in waterlogged sites and observed a 'cone of depression' of water table immediately beneath each strip plantation as compared with no depression in the control.

The per day water consumption by *E.* hybrid was found maximum under the selected three water levels in lysimeters, followed by *P. pinnata* and *D. sissoo* and minimum in *A. nilotica*. Moreover, water con-

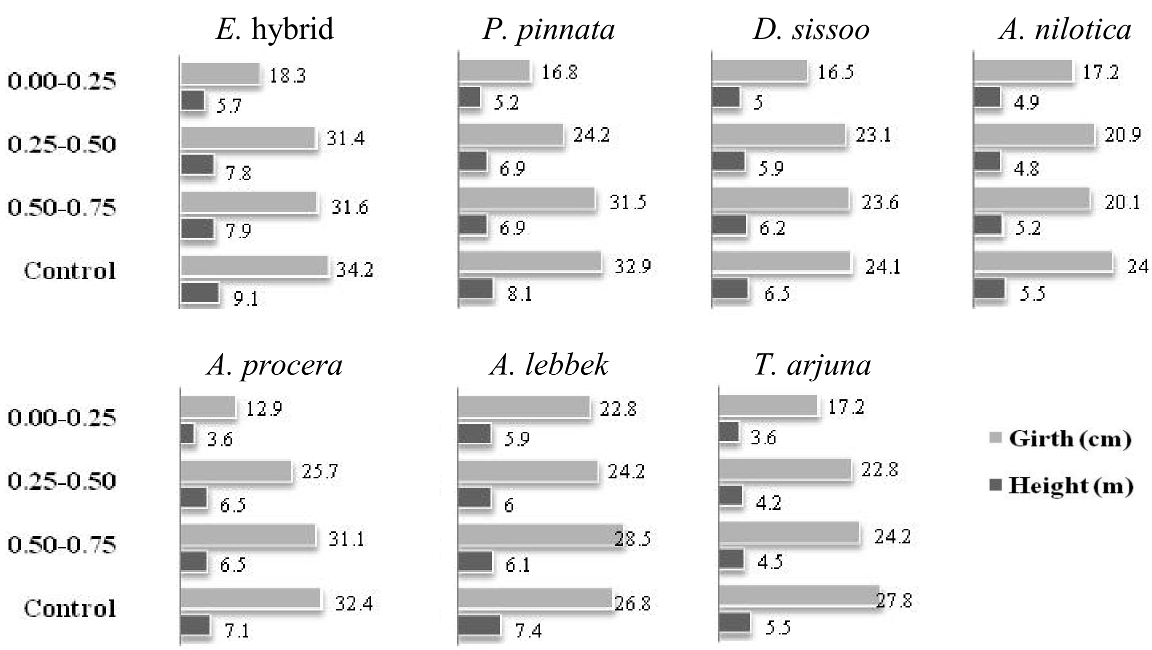

Fig. 1. Growth characteristics of trees planted in lysimeters under different water regimes after 3 years of plantation.

sumption decreased from 0-0.25 m to 0.50-0.75 m water level in the selected species and this decrease was maximum in *E. hybrid* (13.03%) and minimum in *T. arjuna* (8.76%) between the two water levels in lysimeters. Moezel *et al*. (1989) reported that long term tolerance to waterlogging by tree species may be related to transpiration, morphological and physiological functions. Ram *et al*. (2011) found that roots of *E. tereticornis* penetrated in the soil profile up to a depth of 3.30 m below the top level of 0.50 m high ridge or 2.80 m below the field surface.

Species variation in average transpiration rate showed the maximum value for *E.* hybrid (0.97 mmol H_2O $m^{-2}s^{-1}$), followed by *P. pinnata* (0.71 mmol H_2O $m^{-2}s^{-1}$) and minimum for *A. nilotica* (0.41 mmol H_2O $m^{-2}s^{-1}$), while the diurnal variation exhibited peak during 11 to 13 hours for the selected species. *Eucalyptus* grows fast and has good water-consumption capacity when the water is available in sufficient quantity (Alvares, 1982). There is a close relationship between growth and transpiration rate (Calder, 1992; Delzon and Loustau, 2005). In the present study also, trees with better growth had higher transpiration rate round the year.

Significant correlation (P<0.05) among height and girth of the selected species, transpiration rate and water consumed by these species was observed (Table 2). Higher growth characteristics for *E.* hybrid and *P. pinnata* and proportionately higher biomass allocation to leaves can be attributed to higher transpiration rate. According to Larcher (2002), leaf area development is the single largest trait contributing towards transpiration. Moreover, higher water use by these tree species supports the fact that these species exhibit steady rate of transpiration throughout the year in comparison to other species. If rate of transpiration is the indicator of plant water use, it was found maximum for *E.* hybrid and *P. pinnata.* In

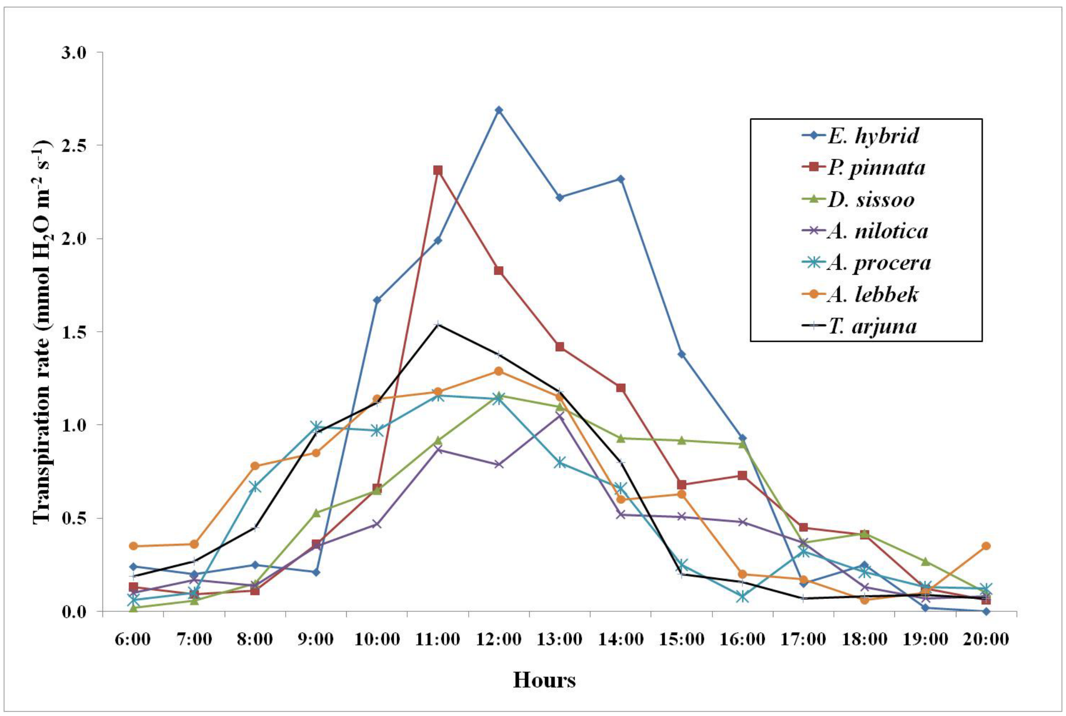

Fig. 2. Species and diurnal variation in transpiration rate of tree species planted in lysimeters

Table 2. Pearson Correlations among growth parameters, transpiration rate and water consumption by tree species.

	Height	Girth	Transpiration rate	Water consumption
Height	1	0.828*	0.813*	0.854*
Girth	-	1	0.845*	0.978*
Transpiration rate	-	-	1	0.892*
Water consumption	-	-	-	1

* Correlation is significant at 0.05 level.

contrary, *A. nilotica* has minimum growth rate resulting least transpiration rate and water consumption. *Eucalyptus* exceeds other species also due to gigantic root system vertically as well as horizontally as compared to several arid and semi- arid species reported (Toky and Bisht, 1992).

The tree species having high transpiration rate coupled with higher growth characteristics are the desirable species for the reclamation of waterlogged areas. Heuperman *et al*. (2002) and Ram *et al*. (2007) demonstrated that actively transpiring deep rooted tree canopies are analogous to pumping out of water from a bore well and causes a cone of depression in water table. Magnitude of this cone of depression is greater if force of vertical suction of water, biodrainage in case of trees, is more. In the present study, *E.* hybrid and *P. pinnata* show steady rate of transpiration, more water use and higher growth under waterlogged conditions, hence can be used for plantation purpose for reclaiming waterlogged areas. Therefore, biodrainage potential of the selected tree species in present case is in the order *E.* hybrid> *P. pinnata*> *A. lebbek*> *A. procera*> *D. sissoo*> *T. arjuna*> *A. nilotica*.

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