INTERNATIONAL JOURNAL OF SCIENCE AND NATURE

www.scienceandnature.org

Review Article

IMPACTS OF EUCALYPTUS PLANTATIONS ON GROUND WATER RESOURCES

M.V. Durai[1], N. Ravi[1], R. Raja Rishi[2], V. Shettapanavar[1], N. Mohan Karnat[3]
[1]Division of Siliviculture & Forest Management, IWST, Bangalore
[2]Division of Forest Protection, IWST, Bangalore
[3]Director, Institute of Wood Science & Technology, Bangalore
[*]Corresponding Author email: duraimv@gmail.com

ABSTRACT
The *Eucalyptus* is one of fast-growing, most cultivated tree species in the world. India has about 7.5 million ha of *Eucalyptus* plantations, which accounts for 8% of global plantations. Since a few decades, the *Eucalyptus* have attracted most intense and acrimonious debate on its perceived ills and virtues as *Eucalyptus*. The authors were synthesized the for and against views of *Eucalyptus* in this paper

KEY WORDS: Eucalyptus, water, plantation, consumption.

INTRODUCTION
Eucalyptus are the most widely cultivated forest trees in the world. The genus Eucalyptus comprises more than 900 species and various hybrids and varieties. Most *Eucalyptus* occur naturally in Australia (Cavaleri *et al*., 2014). The Eucalyptus first came to India in 1790 during the reign of Tipu Sultan and established itself as a garden tree in Nandi Hills, Karnataka. This activity was primarily intended to meet the firewood demand. Planting on a large scale in India, however began only around 1856. Along with plantations of teak and the exotic acacias, *Eucalyptus* were introduced in Nilgiri hills in 1858 where *Eucalyptus globulus* was planted along with *E. robusta.* Another species of Eucalyptus, *E. citriodora* was introduced in mid 1930 in Karnataka and Kerala. The 1960s heralded the introduction of the hybrid *E. rtereticornis x E. globulus* popularly known as *E. hybrid* on a massive scale throughout India. About 7.5 million hectares of land is currently under Eucalyptus plantations in India, accounting for about 8% of the global coverage (Vinithan and Abbasi, 2004) due to its high productivity, wide adaptability, good coppicer and multiple uses *viz*., pulp, fuel wood, and construction lumber. However, the *Eucalyptus* have become the focal point of a raging controversy over a few decades' *vis-avis* their impacts on the environment. So far, no genera of trees have attracted such intense and acrimonious debate on its perceived ills and virtues as *Eucalyptus*. For or against view on *Eucalyptus* is being added to the literature (Vinithan and Abbasi, 2004). Today, the controversial issue is about water use of *Eucalyptus* and its impacts on water resources (Albaugh *et al*., 2013; Vinithan and Abbasi, 2004). There has been extensive literature published on the hydrology of *Eucalyptus*. For instance, the Google Scholar lists more than six lakh hits for the keywords '*Eucalyptus*' and 'water'. Therefore, it is not possible to provide summaries of the entire breadth of the literature. However, the authors were tried to review the for and against views on Eucalyptus here.

Views for Eucalyptus

The most often - repeated allegation against Eucalyptus is that it consumes large amounts of water and cause very high transpiration losses as it do not have the mechanism to control transpiration, thereby reducing soil moisture as also lowering the groundwater table. According to Shyamsundar (1983a), the criticism against *Eucalyptus* that it lowers the ground water table is baseless as the roots of the *Eucalyptus* rarely go lower than 3- 4m, hence it could not tap sub-terranian water. Lima and O' Loughlin (1984) were supported his view and complimented that the shallow root system of *Eucalyptus* was not the main cause for depleting soil moisture. They are of the view that the lateral spreading and depth of penetration of the root system vary with species and this has to do with intensity of water uptake. Hence, selection of right species will prevent the problem of high water uptake. They also report that the overall soil water regime of *Eucalyptus* forests do not differ from that observed in pine plantations (Vinithan and Abbasi, 2004).

According to Foley and Bernard (1984), *Eucalyptus* roots can break up the soil structure or even a subterranean layer of impervious hard pan. Hence, the *Eucalyptus* can improve rain water percolation, creating a net positive effect on the ground water level (Vinithan and Abbasi, 2004).

Dinesh Kumar (1984) stated that several trials in Australia have proved that *Eucalyptus* is the most efficient utilizer of scarce water resources. He concludes that the species itself is a good drought resistant one. He also refuted the allegation that Eucalyptus has a higher transpiration rate. According to him, the *Eucalyptus* being a xerophyte has a low transpiration rate and it controls stomatal openings according to water availability without serious reduction in biomass production (Vinithan and Abbasi, 2004). Similar findings have been reported by Brown *et al.* (1976), Ackerson (1980), Singh *et al*. (1993) and (Vinithan and Abbasi, 2004). As far as the possibility of *Eucalyptus* plantations lowering the ground water table is concerned, the Economic and Planning Council of Karnataka (EPCK) report (CSE, 1985b) argues that the roots of *E. hybrid* rarely go lower than 3 to 4 meters deep and usually do not spread out (laterally) more than 1.5 metres. This means that *E. hybrid* only consumes subsurface seepage water, and it cannot tap subterranean groundwater. This being so it is unlikely that *E. hybrid* is responsible for wells running dry. The later phenomenon can be due to several other factors such as enormous increase in the number of irrigation pumpsets, continuous drought for consecutive years and very high density of tree planting. In Davanahalli and Hoskote taluks of Karnataka State, India, for instance the number of energised irrigation wells has been doubled within six years. Similar intensity of exploiting underground water is visible in several parts of Kolar district, Karnataka, India. Chaturvedi (CSE, 1985b) argues that the Terai region of Uttar Pradesh. India, where *Eucalyptus* plantations have allegedly lowered the water table, is actually full of tube-wells which might be the real culprits (Vinithan and Abbasi, 2004).

Ray (CSE, 1985c) reported that the streams have dried up in Nilgiris after the removal of the original Shola forests, but it is uncharitable to blame it on *Eucalyptus*. The Eucalyptus plantations would have helped in recuperating the subsoil water and the leaf litter get converted into humus. But all the leaves are removed for distilling Eucalyptus oil and cooking purposes. In such a situation the soil is not in a position to absorb water and recuperate the water table (Vinithan and Abbasi, 2004).

CSE (1985c) has mentioned that the foresters repeatedly cite the 1972 study from the Nilgiris which reports that the annual transpiration of water in a *Eucalyptus-E globulus* plantation corresponds to a rainfall of 34.75 cm whereas potato fields use 65 cm of rainfall. The total rainfall in the area was 130 cm thus making available the balance 95.25 cm to cover interception loss, surface run-off, evaporation, deep percolation, water yield and soil moisture storage (Vinithan and Abbasi, 2004).

Mathur (CSE 1985c) believes that it is agriculture crops which are responsible for depletion of water resources and not *Eucalyptus* plantations. Water use for some of the agricultural crops like wheat (*Triticum vulgare*), paddy (*Oryza sativa*), sugarcane (*Sacchorum* sp.) and millet (*Panicum* sp.) is 38 cm. 104 cm. 163 cm and 64 cm respectively (Vinithan and Abbasi, 2004).

Patel (CSE, 1985c), one of the first *Eucalyptus* farmer of Gujarat, India, switched over to *Eucalyptus* because there was not enough water to grow cotton. Now he claims that, the water table in this region has been stabilized. He also claims that the plantation has improved the water absorption capacity of the land as compared to neighbouring farms because *Eucalyptus* roots break the soil and thus increase the seepage. During one night in 1976, 12 inches of rain water was accumulated in his farm and it was absorbed within one hour Eucalyptus. On the contrary, the water on some of the neighbouring farms stood for three to four days after the rain (Vinithan and Abbasi, 2004).

Poore and Fries (1987) have quoted that drawing of soil moisture depends on stand density, soil and environmental conditions. Further they say that in alpine dry sclerophyll condition, soil water regime does not differ between Eucalyptus forest, grassland, and herb field. They also reported that the effect of Eucalyptus in reducing water yield is probably less than that of pine and greater than that of other broad - leaved species, but all species of trees reduce water yield compared with scrub or grass. The yield of Eucalyptus timber ($11.1m^3$ mean annual increment) by far offsets the value of that part of the water losses that would have been added to the ground water. They are of the opinion that though the water yield was reduced by about 20% compared with that from open ground; it is probable that a somewhat similar loss would have occurred under any other tree crop. They also have reported that the overall soil water regime of Eucalyptus forest does not differ from that observed in pine plantations, which is also a fast-growing tree. Majority of Eucalyptus species do have some control over the rate of transpiration, which helps them to survive during water stress which is apparently related to the rainfall regimes of their natural habitats. They also have reported that average annual evapotranspiration in pine plantations is in the same order of magnitude as that observed in Eucalyptus forests (Poore and Fries, 1987; Vinithan and Abbasi, 2004).

The study conducted by John Davidson which is considered to be one of the earliest, made on “ecological impacts of Eucalyptus plantation” in 1989 shows that water use per total biomass in respect of Eucalyptus is 785L/kg and when it is compared to other plants like cotton, paddy, soya bean, potato etc., the utility of water by Eucalyptus is not that much (Table 1).

The Eucalyptus has high water holding capacity in the soil. According to his study conducted in the arid region in Surat District of Gujarat State, India, there was more soil moisture under Eucalyptus than nearby open area even after three consecutive drought years (Srivastav 1993;Vinithan and Abbasi, 2004).

Rao (1995) denied, the argument that *Eucalyptus* absorbed as much as 60 gallons of water in a day. He argued that a *Eucalyptus* plantation (2x2m) should receive 9cm of rain per day for this much of water. Taking half of this as average, the yearly uptake of water should be 1642.5 cm, which is unbelievably high. But no part in India, the *Eucalyptus* is receiving that much of rain. In fact, the *Eucalyptus* grown in Nilgiri, Tamil Nadu, India, for over a century uses only 35cm of the 135cm of rainfall there. Further, Rao (1995) stated that the *Eucalyptus* hybrid adopted in the Indian subcontinent is not a wasteful consumer of water and on the contrary, is one of the most efficient utilizers of scarce water, producing more timber for water consumed than many other native species (Vinithan and Abbasi, 2004). In fact, water use efficiency in *Eucalyptus* actually increases with greater water availability (Stape *et al,* 2004a,b).

TABLE 1: Water use by plants through evapotranspiration

Plant	Water use per total biomass (litres/kg)	Harvest index	Water use per harvested biomass (litres/kg)
Cotton/Coffee/Bananas	3200	0.25	800
Pongomia pinnata (T)	2600	0.50	1300
Sunflower	2400	0.25	600
Field Pea	2000	0.30	600
Paddy Rice	2000	0.30	600
Horse Bean	1714	0.35	600
Cow Pea	1667	0.30	500
Conifers (T)	1538	0.65	1000
Dalbergia (T)	1483	0.60	890
Soybean	1430	0.35	500
Acacia (T)	1323	0.65	860
Syzygium (T)	1017	0.60	610
Potato	1000	0.60	600
Sorghum	1000	0.25	250
Albizia (T)	967	0.60	580
Eucalyptus (T)	785	0.65	510
Finger Millet	592	0.40	225

(Source: Davidson 1989)

Sunder (1995) reported that the overall use of water by *Eucalyptus* is limited to the total rainfall of the area, in the absence of access of the tree to the water table. He concluded that there is equilibrium between rainfall and evapotranspiration in *Eucalyptus* and that this does not differ significantly from other trees. As an example, monthly evapotranspiration of a *E. globulus* plantation in Portugal was the same as that of a natural open stand of cork oak (*Quercus suber*) with a developing understory of shrubs (de Almeida and Riekerk, 1990). A meta-analysis study suggest that commonly held assumptions about water use of invasive species are not always correct. For example, recent studies of assumed invasive 'water spender' saltcedar (*Tamarix ramosissima*) have shown that salt-cedar transpires at similar rates compared with native cottonwoods and willows (Sala *et al.*, 1996; Nagler *et al.*, 2003), but its tolerance of drought, salt and fire enable it to out-compete natives very successfully (Glenn and Nagler, 2005). Additional studies in Australia have shown results contrary to expectation, where invasive willow species (*Salix* spp.) and native Red River Gum trees (*Eucalyptus-E camaldulensis*) had similar transpiration rates when growing on river banks (Doody *et al.*, 2011; Cavaleri *et al*., 2014).

Conventional wisdom that invasive tree species are 'water spenders' in comparison to co-occurring natives is based on little to no actual field measurements of transpiration at the tree scale or stand scale. Global meta-analysis found that invasive species were more likely to have higher rates of stomatal conductance than co-occurring natives (Cavaleri and Sack, 2010), patterns of water use found at the leaf level are not necessarily applicable to whole-plant or ecosystem-level water use (Cavaleri and Sack, 2010). Without additional information about microclimate, canopy structure, sapwood area, leaf area index, interception and root architecture, it is very difficult to extrapolate leaf-level information to whole-tree transpiration and ecosystem evapotranspiration rates. Transpiration rates per unit sapwood of invasive species measured here (705–925 kg m^{-2}sw day−1) were on the high side compared with previously reported rates of tropical woody species. For *Eucalyptus-E globulus* and *Cupressus lusitanica* in a tropical mountain forest in Ethiopia, mean daily rates per sapwood area were 200–400 kg m^{-2}sw day^{-1} (Fetene and Beck, 2004), compared with ~500 kg m^{-2}sw day^{-1} for non-native plantations of *Fraxinus uhdei* and *Eucalyptus saligna* in Hawaii (Kagawa *et al.*, 2009). Invasive species may acquire water from more shallow, more deep or the same soil depth as co-occurring natives; each case would result in differing responses in rooting depth or above-ground vs below-ground allocation of native species (Cavaleri *et al.*, 2014). There is no clear evidence that plantations of *Eucalyptus* use more water per year than either *Pinus* plantations or other types of tree plantations, including rubber. The *Eucalyptus* trees on paddy bunds use more water than trees in blocks but did not affect rice yield in a study in central Thailand. Further, the *Eucalyptus* plantations will not have an important effect on annual stream flow in large primary catchments in South-East Asia and China. They also stated that *Eucalyptus* plantations are deep-rooted perennial crops with an indeterminate growth habit. These characteristics result in slightly higher water use by these plantations than by alternative land uses (White *et al.*, 2016).

Views against *Eucalyptus*

The *Eucalyptus* had a great water demand in closed plantations. This together with an extensive and dense root system enables it to compete successfully for available soil moisture, especially with smaller, shallow, rooted plants. Thus *Eucalyptus* uses all the water available to the soil (Vinithan and Abbasi, 2004). According to Heith and Karschon (1967), a study conducted in the central coastal plains of Israel (rainfall 600 mm, a dry period of 3 to 5 months) where *Eucalyptus* plantation was compared with an open ground, showed that *Eucalyptus* made use of all the water available to it (Vinithan and Abbasi, 2004). Pryor (1976) has reported that the transpiration rate of *Eucalyptus* remain high even when the water supply from the soil has dwindled. *Eucalyptu also had high* transpiration rate (Shiva and Bandyopadhyay – 1987; Vinithan and abbasi, 2004)

Maheshwata Devi (1983) and Bahuguna (1984) also believe that *Eucalyptus* consumes more water than other trees. According to them the streams feeding agricultural lands in the vicinity of *Eucalyptus* plantations have gone dry. They also claim that in arid regions the high water uptake by *Eucalyptus* interferes with processes which replenish soil moisture and recharge ground water leading to soil aridisation and ground water depletion.

Chaturvedi (CSE, 1985b) says that in any area the same number of *Eucalyptus* trees will consume more water than any other species during the same period**.** Gupta (CSE, 1985b) points out that in low rainfall areas, *Eucalyptus* roots form a dense network just below the soil surface to extract every bit of moisture (Vinithan and Abbasi, 2004). The Economic and Planning Council of Karnataka (EPCK) report (CSE, 1985b) agrees that *Eucalyptus* plantations are heavy consumers of water. But, it argues that one has to look at the total water balance including the impact of transpiration losses and the extent of percolation into the soil. The statement that *Eucalyptus* is drought resistant is strongly questioned by Shiva and Bandyopadhyay (1987). According to them, the shallow root system of *Eucalyptus* prevents it from surviving through permanent water scarcity, unlike the indigenous species that have been proved to be genuinely drought resistant. They also have mentioned a study conducted by the hydrological division of the CSIRO in Australia on the hydrological impact of *Eucalyptus* on water resources to say that the efficiency of utilizing water by *Eucalyptus* is greatly controlled by the rain-fall regime of the area. During years with precipitation less than 100mm, deficits in soil moisture and ground water were created by *Eucalyptus*. A permanent water deficit was avoided by significantly high rain fall of 1477 mms in one of the 5 years studied. Table 2 summarizes the results of the long term hydrological study showing that when rain fall is of the order of 1000mm or less, *Eucalyptus* plantations create deficits both in the soil moisture and ground water (Vinithan and Abbasi, 2004).

TABLE 2: The influences of Eucalyptus plantations in soil moisture and ground water (mm)

Sl No	Year	Precipitation	Soil Moisture	Ground water
1	1975	1477	+29	+27
2	1975	914	-87	-14
3	1976	883	-49	-33
4	1977	983	+49	-12
5	1978	900	+30	-19

The accusation of Shiva and Bandyopadhyay (1987) against *Eucalyptus* is that its fast growth requires excessive water and its lateral roots are spread in such a way that recharge of water through percolation becomes impossible. Hence, ground water does not get recharged. Also the vast network of root system just below the soil surface extracts every bit of moisture made available to the soil by precipitation. They also question the statement that the roots of *Eucalyptus* rarely go lower than 3-4 meters and that it cannot tap subterranian water. According to them, the talk of the tapping of the underground water resources through the tap root as the only process of depleting ground water by the trees is either sheer illiteracy of elementary arithmetic and biology or it is a calculated attempt in misinforming the lay public and non-specialists in the decision-making bodies (Vinithan and Abbasi, 2004). White (1995) stated that large plantings of *Eucalyptus* may reduce water yield and lower water tables. To study the effect of *Eucalyptus* on water use and water table in Karnataka, Calder (1991) conducted an investigation in three sites receiving identical annual rainfall (800mm) viz., Devabal and Puradal (Shimoga) and Hosakote, Bangalore. The data of this studies revealed that the water use by the young eucalypt plantation was not greater that of dry deciduous forest at Puradal and annual water use of *Eucalyptus* and natural forest was equal to the annual rainfall at both Puradal and Devabal sites. Further, it highlights that the water use of forests was higher than that of agriculture crops, for example the water use of ragi - a small millet was about 2 times higher than that of forests at all sites (Calder 1991).

Calder (1997) reported that whilst the *Eucalyptus* roots are penetrating into deeper soil layers, they are able to extract from a reservoir of water additional to that available from the rainfall each year. He also stated that the development of the drying front under the *E. camaldulensis* plantations is very rapid, indicating average root extension rates in excess of 2.5 m per year, whilst those under *Tectona grandis* and *Artocarpus heterophyllus* advanced at approximately half the rate. Further, he highlighted that the deep-rooted *E. species* were able to tap into water resources not previously utilized by short-rooted species. According to him, water use by *E. camaldulensis* in Hosekote, Karnataka, India exceeded the input supply of water from rainfall, albeit over a drier-than-average three year period.

Binkley and Stape (2004) concluded that in semi-arid environments afforestation with any species of trees may increase water use, lower ground water levels and reduce stream flow. Whitehead and Beadle (2004) concluded that in the case of South Africa, where planted *Eucalyptus* replaced native grasslands, the decreased water yields resulted from increased transpiration in the evergreen and deep rooted *Eucalyptus* during the dry season compared to the seasonally dormant grasses. It is well established that forests have greater evapotranspiration than grasslands (Zhang et al, 1999). According to Tilashwork (2009), since *Eucalyptus* is fast growing, and deep and dense rooted, the reducing and drying status of previously functional nearby water stores in the watershed is as a result of its greatest water sucking ability besides soil hydrophobicity and poor undergrowth that reduce infiltration and water table. He also stated that there is a frustration that the potential ecosystem will be exhausted in the future because of the described worse environmental modification. For the sustainability and efficiency of the Koga irrigation project, *Eucalyptus* should not be planted in close proximity to the water source since it reduces and dries up springs. Moreover, nitrogen fixing multipurpose tree species should be given preference to replace *Eucalyptus* for successful plantation since *Eucalyptu*s trees add nothing to the soil system except recycling some inputs. It is concluded that *Eucalyptus* plantation had negative effect on sustainable cropping, soil, and water conservation systems by decreasing N, P and Ca through plant uptake, lowering the soil moisture content both by its dense root system and by making the soil hydrophobic and taking light away from the crop due to its dense and long canopy. It has also been reported by local farmers that the dense *Eucalyptus* root network lowers water tables and dries up springs. Therefore, *Acacia albida, Leucaena leucocephala, Prosopis juliflora and Albizia procera* due to special phenology, wide adaptability, drought resistance and timber quality, respectively are promising species (Tilashwork, 2009).

Accordong to Zahid and Nawaz (2007), water use efficiency and transpiration coefficient (TC) of *Dalbergia sissoo* were 0.89 and 7.94 g L-1 as compared to that of *E. amaldulensis*, which were 0.93 and 4.06 g L-1, respectively. They were conclude that 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. The *Eucalyptus* is not only use ground water but also use water from upper vadose zone, which is the source of supply to ground water and further, it can use of available water from surrounding areas through inducing steeper hydraulic gradient towards the plantation area (Engel 2005; Thorbum and Walker, 1993). Since surface soil dried out, the proportion of groundwater used by *Eucalyptus* trees was increased from 40 to 63% from the distant places, which means that water was still being extracted from the surface soil even at soil water potentials <-2.0 MPa (Thorbum and Walker, 1993). The fibrous roots of *Eucalyptus* can expand upto 18 m within the soil depth of 30-60 cm (Dabral et al, 1987; Engel 2005; Thorbum and Walker 993). In Udigram Swat valley of Pakistan, it was found that the *Eucalyptus* plantation was led to drying of wells or digging them to deeper layers and also it caused change in the flow of underground water from spring to summer months causing drier springs (Khan and Mohammad-Ul-Hasan, 2007).

Even if many authors like Prabhakar (1998) have argued that *Eucalyptus* is more efficient water user based on biomass productivity as compared to native tree species. Even though it can produce more dry matter per unit of water used, *Eucalyptus* exhausts more water rapidly thereby disturbing the water balance in deeper strata due to its rapid growth, i.e. 8-10 times than native tree species (Joshi and Palansami 2011). Sargent (1998) reported that fast growing plantations of *Eucalyptus* can increase the drought potential of the area at the downstream.

Joshi and Palansami (2011) conducted a study to document and quantify the adverse impacts of growing *Eucalyptus* in Kolar district of Karnataka state in India where soil, rainfall, rock formations and cropping patterns are identical. Their findings indicated that 20 years of continuous cultivation of *Eucalyptus* in private and public lands deepened the water level in freshly dug bore wells to 260 m, as compared to the mean depth of water level in bore wells (177 m) in 21 villages of Kolar district. The distance from the *Eucalyptus* plantation had negative correlation with the depth of freshly dug bore wells. The bore well yields were reduced by 35 to 42 per cent in the study area during the span of 3-5 years, when they were located within a distance of 1 Km from *Eucalyptus* plantations. The reduction was to the tune of 25 to 37 percent, when bore wells were located within a distance of 1-3 km from such plantations. Thus, *Eucalyptus* plantation has dwindled the ground water level alarmingly in two districts viz., Bangalore (rural) and Kolar, as compared to other districts during the these 20 years period. The Central Ground Water Board is classified these districts as most critically over- exploited areas, which evidenced the truth behind. *With reference to adaptability to water relations, Eucalyptus* is a unique tree species as compared to other perennial trees. Just like human being, it can efficiently adjust to prevailing water situations. For example, when water is surplus, its water requirement rises to as high as 90 liters per plant per day and during water scarcity, its water requirement comes down to 40-50 liters per plant per day. Unlike other perennial species, it is able to draw water from adjacent area in the vicinity of its root system. In moisture stress situation, its roots can grow even up to 6-9 m and extract more water. Due to its great water uptake capacity, it is recommended as bio-drainage species to waterlogged areas along with *Dalbergia sp* (Joshi and Palanisami 2011).

The introduction and recent expansion of fast growing plantations was accompanied by a widespread public belief that unlike natural forests, they would be detrimental to water resources. It includes a bit of everything, starting with a stigma associated with the word "*Eucalyptus*: forest plantations consume too much water", "they dry up the soil", "their roots penetrate the water table", "they inhibit cloud formation", they destabilize the hydrologic cycle", etc., and further he pointed out that "a classic popular belief involving the relationship between forest plantations and water can be summed up in the assertion that *Eucalyptus* dries up the soil (National Green Tribunal, 2015). As of 1999, commercial plantation forestry is classified as a stream flow reduction activity in the Water Act of South Africa (DWAF, 1999).

Cavaleri and others- (2014) stated that while the supply of freshwater is expected to decline in many regions in the coming decades, invasive plant species, often 'high water spenders', are greatly expanding their ranges worldwide. They were quantified the ecohydrological differences between native and invasive trees and also the effects of woody invasive removal on plot-level water use in a heavily invaded mono-dominant lowland wet tropical forest on the Island of Hawaii. They also measured transpiration rates of co-occurring native and invasive tree species with and without woody invasive removal treatments. They highlighted that the stand-level water use within the removal plots was half that of the invaded plots, even though the removal of invasives caused a small but significant increase in compensatory water use by the remaining native trees and native-dominated forests free of invasive species can be conservative in overall water use, providing a strong rationale for the control of invasive species and preservation of native-dominated stands.

Balanced views on *Eucalyptus*

From the evidence discussed above, one conclusion can be clearly drawn, as pointed out by Poore and Fries (1987), that depending upon circumstances, *Eucalyptus* has been used from time to time to lower water-tables in swampy areas either to dry out the soils or to control mosquitoes. If, however, *Eucalyptus* lead to the reduction in volume of an aquifer which is used downstream for domestic water supply or for irrigation water, the effects are likely to be considered harmful. Therefore in all such cases, it is important to consider the purpose of planting (fuel wood, shade, shelter, poles etc), the various uses that might be made of the water, and the total benefits and costs in the local socio-economic context.

According to Foley and Bernard (1984), whether a *Eucalyptus* plantation will affect the water table depends greatly on the hydrological and physical properties of the soil. It is also determined by what kind of vegetation it replaces. If the previous crop was a water hungry one, the water table may well rise. If the *Eucalyptus* is being planted to replace slow-growing scrub, on the other hand, in an area with a sensitive hydrology, it is quite possible that the water table might fall. The effects can only be predicted through a careful site survey. Further, as in the case of other aspects of *Eucalyptus* controversy, the strong views for or against *Eucalyptus s* invariably emanate from piece-meal observations made without due consideration of the context or the setting under which certain positive or negative impacts of *Eucalyptus* were observed. There is also the recurring theme of blaming the entire genus of *Eucalyptus* for the adverse impact of one or two of its species. Further, they reported that *Eucalyptus* hybrid plantations do not deplete soil moisture and its performance always compared favourably with plantation of other tree species.

As in other aspects of *Eucalyptus* controversy, the stress has been on the 'black' or 'white' areas with little regard to the 'grey' areas in between. There is as much hard data suggesting that *Eucalyptus* causes heavy transpiration losses as there is evidence that *Eucalyptus* does not. Several species of *Eucalyptus* have the ability to adjust to different ranges of habitats. If *Eucalyptus* are grown in an area where there is surplus ground water, they would make use of the water for their growth. At the same time, if they are grown on moisture-lean soils, they adopt themselves to that habitat. This can be possible only, if they have some mechanism to control their water usage, including rate of transpiration. Or else it would be impossible for them to survive in drought like conditions. It has been established that the *Eucalyptus* hybrid plantations were not wasteful utilizers of water resources and their effects on the soil moisture were always comparable with other tree plantations advocated as being ecologically superior to *Eucalyptus* by a section of environmentalists.

The *Eucalyptus* plantation should not be totally banned in interest of environment, ecology or public at large. However, the National Green Tribunal has made it clear that the State should encourage farmers to plant *Eucalyptus* trees preferably in the water logged area or the areas which are declared as safe by the Central Ground Water Authority. The Tribunal has categorically found that plantation of *Eucalyptus* would better serve environmental causes and it cannot be disputed that these trees yield more biomass and therefore more carbon sequestering trees as compared to other species of trees (National Green Tribunal, 2015).

CONCLUSION

From the above-said studies, it is concluded that site-specific, long term studies on ecological aspects of *Eucalyptus* should be conducted to draw a logical conclusions and any generalization on this aspects may not hold true reality.

REFERENCES

Abbasi, S. A and Vinithan**, S.** (2004). Eucalyptus: Enduring Myths, Stunning Realities, Discovery Publishing House, New Dlhi 144Pp (ISBN: 8171418929, 9788171418923).

Albaugh, J.M., Dye, P.J., King, J.S., 2013. Eucalyptus and water use in South Africa. Int. J. Forest Res.

Bahuguna, S (1984). My experience of eucalyptus. Presentation at workshop on social and econmic impacts of eucalyptus. Planning commission (May 21), New Delhi.

Binkley,D. and Stape, J. L. (2004) Sustainable Management of *Eucalyptus* Plantations in a Changing World. In: Borrelho, N., et al., *Eucalyptus* in a Changing World Proc. IUFRO Conference, Aviero, 11-15, October 2004.

Calder I.R., Rosier, P.T.W., Prasanna, K.T. and Parameswarappa, S. (1997) *Eucalyptus* water use greater than rainfall input-a possible explanation from southern India. Hydrology and Earth System Sciences. 1, 244-256.

Calder, I.R. (1991). The Soil Moisture regimes beneath Forest and Agricultural Crop in Southern India - Observation and Modelling. In: Proc. of International seminar on Growth and Water use of Forest Plantations, Bangalore.

Cavaleri MA, Ostertag R, Cordell S, Sack L (2014). Native trees show conservative water use relative to invasive trees: results from a removal experiment in a Hawaiian wet forest. *Conserv Physiol* 2: doi:10.1093/conphys/cou016.

Cavaleri MA, Sack L (2010). Comparative water use of native and invasive plants at multiple scales: a global meta-analysis. *Ecology* 91: 2705–2715.

Cavaleri Molly A, Rebecca Ostertag, Susan Cordell and Lawren Sack (2014). Native trees show conservative water use relative to invasive trees: results from a removal experiment in a Hawaiian wet forest, *Conservation Physiology. 2, 1-14.*

CSE (1985b,c). The State of India's Environment 1984-85: the Second's citizens report, Centre for Science and Environment, New Delhi.

Davidson, J (1985). Setting aside the idea that eucalyptus are always bad. Working paper 10, Bangaladesh.

de Almeida, P.A. and Riekerk, H. (1990). Water balance of *Eucalyptus globulus* and *Quercus suber* forest stands in south Portugal. *For. Ecol. Manage*., **38**: 55-64.

Doody T, Nagler P L, Glenn E P, Moore G W, Morino K, Hultine K R, Benyon R G (2011). Potential for water salvage by removal of non-native woody vegetation from dryland river systems. *Hydrol Process* 25: 4117–4131.

DWAF (1999) Water-Use Licensing: the Policy and Procedure for Licensing Streamflow Reduction Activities, Department of Water Affairs and Forestry, Pretoria, South Africa.

Engel, Vic (2005). Hydrological consequences of Eucalyptus afforestation in the Argentine Pampas Water Resources Research, VOL. 41, W10409, 14 Pp., 2005

Fetene M and Beck E H (2004) Water relations of indigenous versus exotic tree species, growing at the same site in a tropical montane forest in southern Ethiopia. *Trees-Struct Funct* 18: 428–435.

Heith, D and Karschon, R (1967). The water balance of plantations of Eucalyptus camadulensis. Contribution of eucalyptus in Israel II Iknot and Kisiat Hay in Israel, 7-34.

Kagawa A, Sack L, Duarte K and James S A (2009). Hawaiian native forest conserves water relative to timber plantation: species and stand traits influence water use. *Ecol Appl* 19: 1429–1443.

Khan, Saifulla and Mohamood-Ul-Hasan (2007). Paper presented in USEPAM conference, Hanoi, Vietnam March 6-8, 2007.

Lima, W P and EM O’ Loughlin (1984). The Hydrology of eucalytpus forests in Australia- Review. Submitted for publication in IPEF, Piraciacaba, Brazil.

Lima. (2011) The dialogue of the Brazilian forest’ on “the myth surrounding the Eucalyptus”.

Mahashweta Devi (1983). Why Eucalyptus? Economic and Political Weekly, 78(32):1379-1381.

Mathur H N J. Naveen and S S Sajwan (1980). Ground cover and undergrowth in eucalyptus and sal forests – an ecological assessment. Van Vigyan, 18(3 & 4).

Mukund Joshi and K. Palanisami (2011). Impact of eucalyptus plantations on ground water availability in South Karnataka. In Proc. Of ICID 21st International Congress on Irrigation and Drainage, 15-23 October 2011, Tehran, Iran, 255-262.

Nagler P L, Glenn E P and Thompson T L (2003). Comparison of transpiration rates among saltcedar, cottonwood and willow trees by sap flow and canopy temperature methods. *Agric For Meteorol* 116: 73–89.

National Green Tribunal (2015). Judgement regarding excess extraction of ground water in Punjab (20.07.2015).

Poore, M. E. D. and C. Fries (1985). The ecological effects of *Eucalyptus*, FAO Forestry Paper 59, FAO, Rome, Italy, 1985.

Prabhakar, V.K.(1998) Social and community forestry Pub: Satish Garg new Delhi pp: 90-106.

Pryor L D (1976). The biology of eucalyptus . Edward Arnald, London, 77Pp.

Rao, R (1985). The eucalyptus controversy. A special article to make the world forestry day, March 21, Vol. 09, Centre for Environmental Education News and Featrues Srvices.

Sala A, Smith S D and Devitt D A (1996). Water use by *Tamarix ramosissima* and associated phreatophytes in a Mojave Desert floodplain. *Ecol Appl* 6: 888–898.

Sargent C. (1998) Natural forest ro plantation ? In Plantation politics Ed: Sargent C and Bass S. Earthscan London, 16-40Pp.

Shiva, V and Bandyopadhyay, J (1987). Ecological audit of eucalyptus cultivation. Research Foundation for Science and Ecology, Dehra dun; 74Pp.

ShyamSundar S (1983a). The last word on eucalptus . Indian Express (Dec 7), Bangalore.

Stape J.L., Binkley D. and Ryan M.G (2004). Eucalyptus production and the supply, use and efficiency of use of water, light and nitrogen across a geographic gradient in Brazil. *Forest Ecology and Management* 193: 17–31.

Thorburn P.J. and Walker G.R. (1993) The source of water transpired by *Eucalyptus camaldulensis*: soil, groundwater, or streams? In: Stable isotopes and plant carbon water relations pp 511-527 Pub: CAB International

Tilashwork Chanie Alemie (2009) The effect of eucalyptus on crop productivity and soil properties in the koga warershed, Western Amhara region, Ethiopia. M.Sc.Thesis, the Graduate School of Cornell University, Ethiopia, Pp47.

White D.A, Battaglia M., Ren S. and Mendham D.S. (2016) Water use and water productivity of *Eucalyptus* plantations in South-East Asia. ACIAR Technical Reports Series No. 89. Australian Centre for International Agricultural Research: Canberra. 55pp.

White, K.J. (1995) Silviculture of *Eucalyptus* Plantings – Learning from the Region (Australia). In: Proceedings of the Regional Expert Consultation on *Eucalyptus*, 4-8 October, 1993, Vol. 1, FAO Regional Office for Asia and the Pacific, Bangkok.

Whitehead, D. and Beadle, C.L. (2004) Physiological regulation of productivity and water use in *Eucalyptus*: A review. Forest Ecology and Management. 193, 113-140.

Zahid DM and Nawaz A. (2007) Comparative Water Use Efficiency of *Eucalyptus camaldulensis* versus *Dalbergia sissoo* in Pakistan. Int. J. Agri. Biol. 9(4), 40-44.

Zhang, L., Dawes, W.R. and Walker, G.R (1999) Predicting the effect of vegetation changes on catchment average water balance. Cooperative Research Center for Catchment Hydrology Technical report 99/12.