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Impact of eucalyptus plantations on ground water and soil ecosystem in dry regions

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Abstract
Eucalyptus is one of the first forest species largely cultivated throughout the world. No other tree genus except Eucalyptus has ever been so widely propagated throughout the world since it contains remarkably wide range of tree species in regard to adaptation to site, types of management systems and multipurpose uses. More than 700 eucalyptus species are mostly native to Australia, all with great environmental value; 37 of these species are of interest for the forest industry while only 15 are used for commercial purpose. Eucalyptus can grow in a wide variety of soil conditions but requires deep, fertile, well-drained loamy soil with adequate moisture for best growth. Eucalyptus was given immense importance in large-scale afforestation especially in social forestry and agro- forestry programmes during seventies and early eighties. Raising of eucalyptus on field boundaries under different patterns of agro- forestry had been a common practice adopted by the farmers. The small farmers along with activist groups all over the country vis-à-vis environmentalists started raising alarm against the expansion of eucalyptus monoculture in the arid and semi-arid regions. Today eucalyptus is spread over more than 22 million hectares around the world (to which we would have to add over 11 million hectares of native eucalyptus woodland in Australia), which represent 13.4 per cent of global forest plantations. However, it is estimated that only 13 million hectares of these plantations are really of interest for industrial production. Eucalyptus plantations with industrial productivity account for 59 per cent of eucalyptus forests.

Keywords: Eucalyptus, ground water, soil ecosystem, dry regions

Introduction
Eucalyptus is one of the first forest species largely cultivated throughout the world. No other tree genus except Eucalyptus has ever been so widely propagated throughout the world since it contains remarkably wide range of tree species in regard to adaptation to site, types of management systems and multipurpose uses. The species *Eucalyptus globules* or white eucalyptus was described by the French botanist Labillarolière in 1799. The name *Eucalyptus* is derived from the Greek *eu* (well) and *kalyptus* (covered), and refers to the protection afforded to the sexual organs by the operculum. The word *globules* refers to the fact that its fruit are similar to certain buttons with that name which were fashionable in France at the time. It is a diverse genus of flowering trees and shrubs in the family Myrtaceae. More than 700 eucalyptus species are mostly native to Australia, all with great environmental value; 37 of these species are of interest for the forest industry while only 15 are used for commercial purpose.
Eucalyptus can grow in a wide variety of soil conditions but requires deep, fertile, well-drained loamy soil with adequate moisture for best growth. Eucalyptus was given immense importance in large-scale afforestation especially in social forestry and agro- forestry programmes during seventies and early eighties. Raising of Eucalyptus on field boundaries under different patterns of agro- forestry had been a common practice adopted by the farmers. The small farmers along with activist groups all over the country vis-à-vis environmentalists started raising alarm against the expansion of Eucalyptus monoculture in the arid and semi-arid regions.

The expansion of Eucalyptus
Eucalyptus began to be used in plantations outside its natural distribution area over 200 years ago in Europe. European botanists described the generous and its main species. The first reference in the Iberia Peninsula dates from 1829 in Portugal. In the United States it was introduced in the mid-nineteenth century as a result of the migratory flow with New Zealand and Australia, which also prompted the introduction of the pine tree to Australia. Eucalyptus has expanded all over the world from Australia due to its great degree of ecological spread and its ability to adapt. Through the British, French, Spanish, Portuguese and Dutch colonies, Eucalyptus was able to reach other countries.

Today eucalyptus is spread over more than 22 million hectares around the world (to which we would have to add over 11 million hectares of native eucalyptus woodland in Australia), which represent 13.4 per cent of global forest plantations. However, it is estimated that only 13 million hectares of these plantations are really of interest for industrial production. Eucalyptus plantations with industrial productivity account for 59 per cent of eucalyptus forests.

Eucalyptus at present- India and Karnataka

Most of the Eucalyptus plantations in India were raised during 2 decades between 1960-1980. Some 170 species, varieties and provenances of eucalypt were tried in India (Bhatia, 1984), out of which the most outstanding and favoured has been the *E*. hybrid, a form of *E. tereticornis* known as Mysore gum. The most important characteristics of *E*. hybrid contributing to its popularity under Indian conditions are: it is fast growing, capable of over topping weeds, coppices well, is fire hardy, browse resistant and it has the ability to adapt to a wide range of edaphoclimatic conditions (Kushalappa, 1984). Other species which are grown on plantation scale are *E. grandis*, *E. citriodora*, *E. globulus*, and *E. camaldulensis.*

Over 1,000,000 ha of eucalypt plantations have been established, mostly by State Forest Departments and Forest Development Corporations. Apart from these, around 6,000 million seedlings have been planted in private lands (Sandu, 1988). There are several reasons for raising large scale eucalypt plantations in the country; some are common and some are specific to each State. The most important common reason is to reclose the denuded and barren hilly areas and replacing low value natural forests.

About 4.8 m ha of land is currently under Eucalyptus plantations in India, accounting for about14.5 per cent of the global coverage. In Karnataka more than 2.1 lakh ha (Karajagi *et al*., 2009) [7] of forest and rainfed farmland have been diverted for Eucalyptus plantation.

Reasons for rapid spread

The spurt in population growth and industrialization during the post-independent years enhanced the demand for wood products in India accentuating the pressure on the forest resources. The demand was far in excess of supply. Several strategies were adopted to increase the output of wood, to meet the industrial and domestic demands. One of the steps was to introduce fast growing species in plantation forestry which till the mid-50s had been dominated by the slow growing hardwood. This is how eucalyptus, among the fastest growing trees, came into the picture and has since then remained as a favourite in social forestry programmes.

Adverse effects of Eucalyptus

1. Allelopathy

Allelopathy refers to the deleterious effect of one plant on another through the production of chemical retardants that escape into the environment. The allelochemical and toxic effects of Eucalyptus have been scientifically recorded and studied both in India and abroad. Del Moral and Muller were the first to scientifically study allelopathy in Eucalyptus plantations and to analyse this factor as responsible for the absence of herbaceous annuals. Al-Mousawi and Al-Maib studied the pronounced paucity of herbaceous plants in Eucalyptus plantations in Iraq. Commenting on the reduction of seed germination due to Eucalyptus, Swami Rao and Reddy reported, Investigations revealed that the reduction was not due to soil moisture, nutrient elements and shading. On the other hand, leaf extracts, decaying leaves and soil collected under Eucalyptus canopies inhibited seed germination and seedling growth of associated species. In subsequent research three volatile inhibitors and five water soluble inhibitors were found to be produced by Eucalyptus leaves which inhibited germination of seeds.

2. Loss of soil fertility

Table 1: Nutrient deficit created by *Eucalyptus hybrid* plantations (kg/ha/year)

	Nitrogen	**Phosphorus**	**Calcium**
Eucalyptus require	217	100	1594
Eucalyptus returns	35	14	335
Annual nutrient deficit	182	86	1260
Deficit after 2nd rotation (20 years)	3640	1720	25200

Anon., 2000

The nutrient requirements of eucalyptus for rapid growth are excessively high. For this reason it grows well only on fertile soils like clear felled natural forests or good agricultural lands. Quantitative information on the nutrient requirements of eucalyptus is available. It is known, for example, that eucalyptus hybrid requires 217 kg of Nitrogen, 100 kg of Phosphorus and 1,594 kg of Calcium per hectare per year. The high nutrient requirement of eucalyptus for good growth shows that on sites of poor quality and poor nutrient status growth rates fall to 0.9 CuM per hectare compared to 12 CuM per hectare in fertile soils. Eucalyptus is being planted on fertile agricultural soils for harvesting at short rotations. This creates nutrient deficits because compared to its high uptake of nutrients, eucalyptus ecology and the politics of survival returns a very small quantity of nutrients to the soil through leaf litter. Its annual return in leaf litter is only 35 kg of Nitrogen, 14 kg of Phosphorus and 335 kg of Calcium per hectare per year the wide gap between the nutrient uptake and nutrient return implies that eucalyptus plantations create a massive deficit in soil nutrients. At this rate, at the end of the second rotation, after twenty years the total nutrient deficit of the land will be 3,540 kg of Nitrogen, 1,720 kg of Phosphorus and 25,200 kg of Calcium

3. Effects on local food security

Eucalyptus was promoted as a profitable, no maintenance low investment crop in cultivated lands, in the style of farm forestry (1,40,000 ha). However, the major spread of Eucalyptus was restricted to two districts namely, Bangalore (rural) and Kolar, replacing 70,000 ha ragi, a staple food. Almost 90 per cent of existing Eucalyptus area in Karnataka is in these two districts.

4. Prime cause for various hydro-ecological imbalances of an eco-system

Eucalyptus is a unique tree species as compared to other perennial trees, as regards its adaptability to water relations. It can efficiently adjust to surplus water situations, when its water requirement rises to as high as 90 litres per plant per day. It can also successfully grow under water scarcity, when its water requirement comes down to 40-50 litres per plant per day. Unlike other perennial species, it is able to draw water from large area in the vicinity of its root system. In stress situation, its roots can grow even up to 6-9 m and extract more water. In fact, eucalyptus along with *Dalbergia* is recommended as bio-drainage species to poorly drained areas suggesting its great potentiality of water uptake.

Effect of eucalyptus plantations on ground water

Mukund Joshi and Palanisami (2011) [10] The results indicated that the depth of freshly dug bore wells was 26.3 to 47 per cent more in situations where the bore wells were located within 1 km of Eucalyptus plantations of more than 2 hectares. Against the average depth of 177 m, the depths of freshly dug bore wells in the vicinity of Eucalyptus plantations were in the range of 224-261 m. This effect was found more prominent in downstream areas of the watershed. However, the negative impact of Eucalyptus plantation was mitigated slightly, when the new bore wells located between 1 to 3 km were considered. The depth of such bore wells was 25.2 to 31.9 per cent more as compared to average depth in the area. The rainfall pattern, percolation rates of soil and rock formations being similar in the entire area.

Mukund Joshi and Palanisami (2011) [10] The study also recorded the water yield levels from 44 bore wells of 3-5 years age. It indicated that the bore wells dug within a distance of 1 km from Eucalyptus plantation of more than 2 hectares recorded 35-42 per cent reduced water yields as compared to their original discharge. For the remaining 16 bore wells located between 1-3 km distance from Eucalyptus plantation of more than 2 hectares, the reduction in the water yields was to the tune of 25-37 per cent in the span of 3-5 years. The observations regarding the reduced bore wells yields in the areas around Eucalyptus plantation of more than 2 hectares must have been due to excessive drawl of percolated water by well grown Eucalyptus plantations. It may be noted that all other factors like soil type, its percolation rate, rock formations, rainfall variations over the years and even cropping patterns remained common for both the set of observations.

Hazrat *et al.* (2014) [5] The data showed that eucalyptus has adverse impact on ground water it has lowered the water table by 0.76 m (0.83 yards) per year in the study area. The water table in village Totai has become deeper up to 20.11 m (22 yards) while in village Kot the water table got deeper to 15.54 m (17 yards). The water table was at depth of 4.57 m (5 yards) before Eucalyptus plantation in village kot but now because of the excessive uptake of water by Eucalyptus plantation the depth of water table has significantly increased to 20.11 m (22 yards). On the other hand in village Totai the depth of water table was 3.657m (4 yards) before Eucalyptus which has increased now to 23.77 m (26 yards). The worse water scarcity was observed in 2006-2007 in both villages when wells were dug up to 6.40 m (7 yards). The results indicate that introduction of Eucalyptus species plantation has adverse impacts on surface and ground water in district Malakand.

Hazrat *et al.* (2014) [5] The expansion of Eucalyptus plantations raises concern over their effect on local water resources. Aforestation can also have the less desirable effect of reducing water yield of an area. The data revealed that 64 per cent springs have been dried out so far in village Kot. There were 22 natural springs before Eucalyptus which are reduced to 8 springs and many of them have become seasonal. On the other hand there is a 75 per cent reduction in spring's numbers in village Totai. Before Eucalyptus plantation there were 40 natural springs which are reduced to 10.

Hazrat *et al.* (2014) [5] showed that, eucalyptus has a special root system consists of a shallow rooting system beneath the soil surface and deep tap roots that penetrate deep into the soil reaching the water table. The shallow roots are used to absorb surface soil moisture these extend horizontally to more than 3 to 5 meter. The tap roots can grow up to 9 meters into deeper soil layers to take up ground water from aquifers. In dry period Eucalyptus shift their water uptake to the deep roots this makes them able to survive and even grow during dry periods. Because of this root system Eucalyptus plantation has adversely affected the discharge rate of natural springs in both villages. Of the three selected springs in village Kot, the discharge rate of first spring has reduced to 2.2 lps from 5 lps. The discharge rate of second spring was 1.5 lps which is completely dry now. While spring third has reduced to 0.5 lps from 2lps. In village Kot 14 springs have been dried out so far and the number of dry springs is increasing at a very fast rate.

In village Totai the impact of Eucalyptus plantation on springs is much more. The data showed that 30 springs have been dried out. Of the selected springs, spring first has reduced from 3lps to 0.3 lps while spring second and third with past discharge rate of 1 lps and 1.5 lps are completely dry now.

Brites and Vermeulen (2011) [4] reported that, the Eucalyptus species indicated a significant impact with the lowering of the groundwater table between 10 and 16 meters over a period of 13 years within the plantation area. A less significant impact was evident within the adjacent indigenous areas with a decline ranging between 4.5 to 7.3 meters over the same period, indicating the impact extends beyond the plantation area. This proves that timber plantations, specifically Eucalyptus utilize higher quantities of water in comparison to indigenous vegetation.

Ram *et al.* (2011) [12] opined that, eucalyptus can also be used as a bio drainage plant because of its high water usage capacity especially in water logged areas. The result indicated that during April 2005, the mean groundwater table was 1.43 m in the control (in observation well nos 1 and 11) and 1.61 m underneath the central strip plantations II and III (in observation well nos 5 and 7), resulting in a drawdown of 0.18 m by 2-yr-old plantations. Similar trend was observed during April 2006, 2007 and 2008, and the total drawdown of groundwater table during 3 years (April 2005–April 2008) was 0.84 m. Thus, the average drawdown of groundwater table during 3 years was 0.85 m. Water table drawdown could mainly be due to the luxurious water use by *Eucalyptus*.

Ram *et al.* (2011) [12] reported that, the average rate of transpiration in *E. tereticornis* trees ranged from 44.5 to 56.3 in May, 30.5 to 34.0 in July, 24.1 to 28.3 in October, and 14.8 to 16.2 l day^{-1} $tree^{-1}$ in January. The transpiration values varied because of variation in radiation, temperature and vapour pressure gradient prevailing during the period. The overall average rate of transpiration in the 5 year old *E. tereticornis* was 30.9 l day^{-1} $tree^{-1}$, which was 268 mm $annum^{-1}$ by 240 trees ha^{-1} against the mean annual rainfall of 212 mm. It clearly indicated that the discharge of groundwater by the strip-plantations of clonal *E. tereticornis* was 1.3 times more than the recharge by rainfall resulting in reclamation of waterlogged areas.

Effect of eucalyptus plantations on soil ecosystem

Jeddi *et al*. (2009) [6] opined that, mean values of total soil nitrogen ranged between 0.69 mg g_1 and 1.21 mg g_1 for A. salicina and open areas, respectively. The type of cover had a significant effect on soil nitrogen, A. salicina remarkably uniform and showed no significant effect of cover. The three tree species showed similar values of available soil P, which were higher than the ones observed in open areas. Block or the interaction between species and block had no significant effect on any of the soil properties evaluated.

Nampakdee *et al*. (2010) [11] The physical, chemical and biological soil properties in Eucalyptus plantation (> 3 years) are compared with the dry dipterocarp forest nearby. The results indicated that, the soil physico-chemical properties like pH (4.87), organic matter (0.67 %), available P (2.05 ppm) and extractable K (50.67 ppm) also less compare to dry dipterocarp forest. According to the results, indicated that eucalyptus plantation has some adverse effect of soil microbial activity in soil ecosystem.

Tilashwork (2009) [14] reported that, the macronutrient status increased with distance from the *Eucalyptus* stand. Total N, nearest to the *Eucalyptus* stand however, was very significantly above the average. Next to it at 5 m TN was minimum. Farther from the trees, it increased up to the same value at 40 m as 1 m from the trees. The available P content calculated was in the very low range (< 5 mg kg^{-1}). Highly significant difference in upward trend with distance from the *Eucalyptus* stand. Exchangeable Ca concentrations, at 1 m distance was 7.8 (coml (+). kg $soil^{-1}$) and significantly less than the values at the other sampling points along the transect which were in range that was considered in the high range 10-20 (coml (+). kg $soil^{-1}$). In case of TN and available P the value at 5 m was the least since the *Eucalyptus* root number was the highest at that distance

Nampakdee *et al*. (2010) [11] Results indicated that, due to higher absorption water from the under ground which leads to lesser the soil moisture (12.81±6.30 %) in eucalyptus soil condition as compared to the dipterocarp soil which leads to the higher saturated hydraulic conductivity (1.16±0.54 cm/h) and there is higher bulk density (1.58±0.05 g cm^{-3}) in eucalyptus soil again it was mainly due to the heavy mechanical damage to the soil at harvesting time.

Behera and Sahani (2003) [2] reported that, comparison of soil physico-chemical characteristics, microbial biomass and activity in a tropical dry deciduous natural forest, regenerating forest and eucalyptus plantation site indicated that Porosity (48.8 %) and water holding capacity (52.5 %) was less in the soil of the Eucalyptus plantation site. Concentration of soil organic carbon (14.6 mg g^{-1} soil) and the size of soil microbial (246 µg of C and 44 µg of N g^{-1} soil, respectively) and micro fungal biomass (243 µg g^{-1} soil) was also the least in the plantation site compared to natural and regenerating forest.

Nampakdee *et al*. (2010) [11] The biological soil properties in Eucalyptus plantation (> 3 years) are compared with the dry dipterocarp forest nearby. The results indicated that microbial biomass nitrogen and microbial biomass carbon in Eucalyptus plantation were less (15.81 and 102.24 µg g^{-1} soil, respectively) than in the dry dipterocarp forest (108.64 and 244.25 µg g^{-1} soil, respectively).it was mainly due to the higher C:N of the biomass the plant leads to lower the decomposition of organic matter leads to the lesser microbial population.

Allelopathic effect of eucalyptus

Khan *et al*. (2008) [8] reported that, the result presented in this table shows that wheat varieties have been influenced by different aqueous extracts of *E. camaldulansis* L. treatments. All the concentrations had inhibitory effect on the germination of all varieties as compared to the control treatment. It can be seen from the data that only wheat variety Raj 99 produced maximum number of seedlings (66 %) over all other varieties which was non-significantly different from Bakhtawar 92, Suleman 98 and Pisabak 91. This indicates that these varieties had some tolerance to the adverse influence of allelochemicals contained in the extract. Punjab 96 and MH-97 were found most sensitive towards extract application.

Allolli and Narayanareddy (2000) [1] showed that, significant differences were observed with respect to germination per cent and seedling growth of cucumber in response to different source of extracts, concentration and their interaction effects. The highest germination percentage (94.60 %) shoot (9.46 cm) and root (10.50 cm) length were observed in cucumber when it was treated with only distilled water (control) and which was significantly superior to any other treatments or their interactions. Significantly the lowest germination percentage (50.20 %), shoot (7.04 cm) and root (6.51 cm) length were observed in cucumber due to leaf extract of eucalyptus when compared to bark and root. Germination percent and seedling growth varied due to concentration gradient and maximum being 94.60 per cent in control and which was significantly superior over different concentration gradient.

Conclusion

Continuous cultivation of eucalyptus deepened the freshly dug bore wells up to 260 m in Kolar region due to higher root interception and higher transpiration rates. Leaves of eucalyptus act as a source of allelochemicals after being released into soil or after decomposition; this affects the neighbouring or successional crops Eucalyptus plantation has some adverse effect on soil microbial activity in soil ecosystem. Thus, the improvement of soil microbial properties of barren degraded soil due to Eucalyptus plantation was less than that of the spontaneous natural regeneration.

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