

**STUDIES ON OIL CONTENT AND ITS QUALITY OF  
*Eucalyptus pellita* IN AGRO-CLIMATIC ZONE-9 OF  
KARNATAKA**

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# 1. INTRODUCTION

Forests are deteriorating rapidly in our country due to various biotic pressures at every stage of their development. This has resulted in the depletion of forest resources and consequent degradation of the environment. There is an urgent comprehensive understanding of forests as a biological system for a more rational management without prejudice to future use of resources and environmental conservation. It is the responsibility of foresters who manage nearly 23 per cent of the total land area in the country not only to produce more wood per unit area but also to meet ever increasing demand for more extensive and multipurpose use of forest lands (Kushalappa, 1988).

Essential oils are the odorous, volatile products of the secondary metabolism of an aromatic plant which are often concentrated in a particular organ of the plant such as leave, stem, bark or fruit (Prasad *et al.*, 2011). Essential oils and their components are widely used in medicine as constituents of different medicinal products, in the food industry as flavoring additives and also in cosmetic as fragrances (Patra, 2011).

One of important genera of Myrtaceae is Eucalyptus, which is a large genus of evergreen trees and shrubs containing about 700 species, although most of the plants are native to Australia and Tasmania, they have been successfully introduced worldwide and are cultivated in many other countries. The Myrtaceae family contains 133 genera and 3,800 species of trees and shrubs. This family occurs in temperate, subtropical, and tropical regions; however, it is centered in Australia, tropical to southern temperate America and Southeast Asia and has a little representation in Africa.

The genus Eucalyptus was described and named in 1788 by the French botanist Heritier. The flowers of the various Eucalyptus species are protected by an operculum, hence the generic name, from the Greek words 'eu' (well), and 'calyptos' (covered). Out of 700 different species of Eucalyptus in the world, about 500 produce a type of essential oil. Although about 300 species of Eucalyptus have been shown to contain volatile oils in their leaves, only a few are important as far as commercial production of essential oils is concerned. The oils of these species are classified in trade in three broad types according to their composition and main end-use: medicinal (cineole-rich), perfumery (citronellal) and industrial (rich in phellandrene and piperitone). The distinction is not hard and fast and all the three types of oils, for example, could be used in perfumery. Lot of research has been conducted on medicinal properties of Eucalyptus species. Eucalyptus oil and its fresh leaves are used in steam inhalation treatments, consumed in bathing. Eucalyptus species are well known for their tolerance to a wide range of soil types and climates (Adhikari *et al.*, 1992).

The Eucalyptus species are used as important source of timber, firewood, shelter belt and as a honey tree. It is also reported to be used as an anesthetic, antiseptic and astringent. Eucalyptus leaves are a traditional aboriginal herbal remedy. The leaf oil is reported to be a powerful antiseptic and used all over the world for treatment of cough and cold, sore throat and other infections. Recently it was used world wide for the treatment of swine flue (Farah *et al.*, 2002).

The leaves and oils of many Eucalyptus species are especially used for respiratory ailments such as bronchitis and croup and the dried leaves are smoked like tobacco for asthma in some countries. Some of the Eucalyptus species are also used for feverish conditions e.g. (malaria, typhoid, cholera) and skin problems like burns, ulcers and wounds. Aqueous extracts are used for aching joints, bacterial dysentery, ringworms, tuberculosis *etc.* (Sahin and Chandan, 2010)

The Eucalyptus oils and their main component (1,8-sineole) are largely used in the preparation of liniments, inhalants, cough syrups, ointments, toothpaste and also as pharmaceutical flavours in veterinary practice and dentistry. While being used as fragrance component in soaps, detergents and toiletries, they have little use as perfumes. The oils of Eucalyptus species have also antioxidant properties (Grassmann *et al.*, 2000) and anti-inflammatory effects (Santos and Rao, 2000 and Juergens *et al.*, 2003) because of 1,8-cineole. The European Pharmacopoeia monograph for Eucalyptus oil specifies a chromatographic profile: 1,8-cineole *i.e.* eucalyptol (not less than 70%), limonene (4-12%),  $\alpha$ -pinene (2-8%),  $\alpha$ -phellandrene (<1.5%),  $\beta$ -pinene (<0.5%), camphor (<0.1%) (Anon, 2005).

All the species of *Eucalyptus* contain oil, less than 20 per cent that is enough from the commercial point of view and only 10 per cent of that accounts for the entire world production of essential oil. The aromatic oils are used as component of fragrance in soaps, detergents and toiletries etc. *Eucalyptus* oil is being extracted in many countries like China, India, South Africa, Portugal, Brazil and Australia on commercial scale. In 1992, the world *Eucalyptus* oil production was estimated to be 4000 tonnes, of which 60–70 per cent was consumed in medicinal market (Anon, 2002). The percentage and composition of *Eucalyptus* oil varies significantly from species to species and region to region due to different climatic environment.

Yearly world production of all types of *Eucalyptus* oils is estimated to be 5,000 tonnes, of which about 63 per cent is medicinal oil, 33 per cent is perfumery oil, and 4 per cent is industrial oil. World production and trade is dominated by the Peoples' Republic of China, where *Eucalyptus* has been planted over an area of 670,000 ha. It produces, on an average, 3,000 tonnes of *Eucalyptus* oil per year, which is 65 to 75 per cent of global production. Chinese exports, mainly to France and Germany, range from 1,600 to 2,000 tonnes annually and account for at least 70 per cent of world trade. Portugal, India, South Africa, Australia, Switzerland, Chile and Spain are other *Eucalyptus* oil producing and exporting countries. (Anon, 2002)

*Eucalyptus pellita* F. Muell the specific name comes from the Latin word 'pellitus', meaning 'covered with a skin', which probably refers to the epidermis of the leaves. The type of description refers to the moderately thick covering. The common name refers to the fruit size in comparison with *E. resinifera* and *E. notabilis* (Dombro, 2010).

*Eucalyptus pellita* F. Muell. is a medium-size to tall tree with good form that can grow up to 40 m or more in height and 1 m in diameter. Attributes that make it an attractive species for plantations include fast growth, good coppicing ability, and adaptability to a wide range of environments, good resistance to pests and diseases and suitability for a variety of timber products. It is only in relatively recent times that *E. pellita* F. Muell has been included in research trials to test its potential in commercial forest plantations. The first seed lots for research were distributed to different countries in the 1970s. Since the 1980s, the species have been tested in many countries including China, Brazil, India, South Africa, Thailand and the Philippines as well as in Australia (Doran and Turnbull, 1997).

A suitable source of firewood and charcoal is *Eucalyptus pellita* F. Muell. The heartwood is red to dark red, strong and durable, moderately heavy with a density of 990 kg per m<sup>3</sup>. Although the grain is somewhat interlocked, the wood is not difficult to work with. It has wide range of uses for buildings, heavy construction and heavy ornamental work. The timber is similar to that of red mahogany, *E. resinifera* (Dombro, 2010).

Natural oil is another by-product of *Eucalyptus pellita* F. Muell cultivation. Oil obtained from the tree is essentially monoterpenoid. Monoterpenes are emitted by forests and form aerosols that can serve as cloud condensation nuclei. Such aerosols can increase the brightness of clouds and cool the climate, which is important in the struggle against climate change. The oil obtained from *E. pellita* F. Muell is essentially monoterpenoid but rather variable (Anon, 1987). The major components are  $\alpha$ -pinene (20-51%), limonene (11-44%),  $\gamma$ -terpinene (0.2-23%),  $p$ -cymene (0.3-11%),  $\beta$ -pinene (2-6%) and terpinolene (0.5-3%) and oil yield is about 0.1 per cent (Haq *et al.* 2007).

Nearly all species of *Eucalyptus* have oil producing glands in their leaves which produce oils which give the leaves their characteristic odour. These oils are called "essential oils" and comprise a range of natural oils which together give the leaves of *Eucalyptus* their peculiar smell, but which can be differentiated in to separate chemicals (not necessarily in the same species) which are or could be of value in industry. The main essential oils and their properties are as follows: Cineol: used in pharmaceuticals and as stain remover, Phellandrine: used in industry as a solvent and as floatation for metals- its presence is prescribed by pharmacopoeia in essences intended to be used for pharmaceuticals, Terpineol: used in perfumery, Eudesmol: fixative for perfumes, Eudesmol acetate: used as a substitute for bergamot essence-it mixes well with lavender essence and Piperitone: raw material for synthetic thymol and menthol (Anon, 1987).

The percentage and composition of Eucalyptus oils vary from species to species as well as from region to region due to different agro-climatic environments (Zafar *et al.*, 2003). Cineole rich Eucalyptus species are becoming popular and *Eucalyptus pellita* F. Muell is one of those species which is least exploited for its Cineole content.

The present investigation was therefore, carried out with the following objectives:

1. To study the effect of different climatic conditions on growth and foliage yield of *Eucalyptus pellita* F. Muell in Agro-climatic Zone-9 of Karnataka.
2. To study the effect of different climatic conditions on oil yield and its oil quality parameters of *Eucalyptus pellita* F. Muell in Agro-climatic Zone-9 of Karnataka.

## 2. REVIEW OF LITERATURE

One of the important pulp wood species planted almost all over India for large scale afforestation and plantation programme both to cover denuded and barren areas as well as for covering poor or derelict forest into fast growing monocultures of high productivity is *Eucalyptus pellita* F. Muell. Its fast growing character along with its ability to adopt to a wide range of edaphic and climatic conditions and its major role as raw material for pulp and paper industries have made it an ideal plantation species for industrial plantation as well as for many afforestation programmes. The rate of growth and productivity varies greatly with site quality and other climatic, edaphic and topographic factors. Studies on growth and productivity of *E. pellita* F. Muell in relation to site conditions are meager and hence, an effort has been made to review the existing literature relating to species-site interactions in general among various tree species.

### 2.1 Variation in physical and chemical properties of soil in different agro climatic zones

Singh and Totey (1985) reported maximum increase in cation exchange capacity, exchangeable cations and organic matter in the soil under miscellaneous plantation flowers by Teak and Eucalyptus in Bhata soil of Raipur (MP).

Stewart and Vander (1988) compared chemical properties of Kalhari sand to a depth of 150 cm under Miombo woodland and the adjacent Eucalyptus plantation in Central Zimbabwe. Soils at both sites were strongly acidic and infertile nitrogen, mineral nitrogen and available phosphorus in the surface 10 cm under Miombo were more than double the values measured under Eucalyptus and the total nitrogen was significantly higher in the 20-30 cm depth, difference in these nutrients below 30 cm exchangeable potassium and magnesium were higher under Eucalyptus between 10-15 cm and it was estimated that there was double the quantity of exchangeable potassium in soil under the plantation.

Narain *et al.* (1990) reported soil nutrient status, their dynamics and chemical characteristics of soil, under Sal, Eucalyptus and Brush wood forests in Doon valley. Organic carbon, total nitrogen, available potassium and exchangeable calcium and magnesium in soil were higher in brush wood forest followed by Eucalyptus and Sal but available phosphorus was more under Sal. Accumulation of nutrients was conspicuous in surface soil, while lower depths did not show much change in nutrient status and also reported the soil physical properties under brush wood. Eucalyptus and Sal forests increased bulk density and decreased pore space under brush wood forest followed by Eucalyptus and then Sal forests in Doon valley.

Vadiraj and Rudrappa (1990) reported nutrient status of soil under five year plantation of *Casurina equisetifolia*, *Eucalyptus camaldulensis*, *Tamarindus indica* and *Mangifera indica* at Hoskote near Bengaluru. They observed decrease in pH, available P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O and increase in organic carbon in all the plantations. However, electric conductivity remained unaffected.

Balagopan *et al.*, (1992) reported the nature and properties of soils in monocultures of Teak, Eucalyptus and mixed stands of Teak and Bombax plantations. Among the soil properties studied, the chemical properties differed in these plantations in comparison to physical properties. The relatively low values for pH, organic carbon, exchangeable bases and exchange acidity in Teak and Eucalyptus in relation to Teak and Bombax plantations necessitate positive measures in the former plantations to preserve and enhance the fertility of the land.

Soil physical properties such as bulk density, porosity and water holding capacity were distinctly improved under plantations of *Casurina equisetifolia*, *Eucalyptus tereticornis*, *Cieba pentandra* and *Leucania leucecephala* as compared to rest of the species (Prathiban and Rai, 1994).

Forest tree species such as *Tectona grandis*, *Terminalia tomentosa*, *Pongamia pinnata*, *Gmelina arboria*, *Eucalyptus tereticornis*, *Acacia auriculiformis* and *Casurina equisetifolia* grown on lateritic soil showed that organic carbon, available nitrogen, potassium and phosphorus increase significantly in the surface layer under plantations (Chavan *et al.*, 1995).

Animon *et al.* (1999) reported soil pH under *Acacia auriculiformis* and *Eucalyptus tereticornis* plantation at three soil depths viz., 0-10, 10-30 and 30-60 cm revealed that *A. auriculiformis* did not show any trend with increase in depth (5.4, 5.3 and 5.5), whereas *E. tereticornis* showed increase in pH with depth (5.0, 5.6 and 5.7). Potassium content was highest under *A. auriculiformis* (244.3, 209.1 and 134.4 kg/ha) as compared to *E. tereticornis* (128.8, 76.5 and 61.6 kg/ha) at three depths, respectively. Phosphorus content was lower under *A. auriculiformis* (14.9, 10.7 and 6.9 kg/ha) as compared to *E. tereticornis* (15.9, 14.3 and 12.6 kg/ha) at three depths, respectively. Organic carbon content of soils was found to decrease under all the plantations with soil depth. Higher organic carbon content was noticed under Acacia soils, while it was lower under Eucalyptus. Comparatively more organic carbon content under Acacia was attributed to high accumulation of litter and its slow decomposition.

Guo *et al.* (2002) reported that accumulation of biomass and nutrients (N, P, K, Ca, Mg and Mn) during the first 3-year rotation of three Eucalyptus short rotation forest species (*E. botryoides*, *E. globulus* and *E. ovata*) irrigated with meat works effluent compared with no irrigation. *E. globulus* had the highest biomass and nutrient accumulation either irrigated with effluent or without irrigation. After 3 year growth, *E. globulus* stands irrigated with effluent accumulated 72 oven dry tonnes per ha of above ground total biomass with a total of 651 kg nitrogen, 55 kg phosphorus, 393 kg potassium, 251 kg calcium, 35 kg magnesium and 67 kg manganese. Effluent irrigation increased the accumulation of biomass, nitrogen, potassium, phosphorus and manganese, but tended to reduce the leaf area index and leaf biomass, and decreased the accumulation of calcium and magnesium.

Syed *et al.* (2006) reported that soil samples collected at a distance of 5, 10, 15, and 20 m from the Eucalyptus trees with two different depths indicated that soil pH of both the depths was alkaline. Electrical conductivity (EC) of the samples varied from 0.08 to 0.35 dS per m. The organic matter content was low in both the depths. The effect of distance on various soil properties, pH, EC, organic matter, phosphorus and potassium decreased with distance from the trees in the surface soil, while in the subsoil, organic matter and phosphorus decreased, whereas pH, EC and potassium increased with distance.

The soil surface properties underneath *Acacia salicina*, *Pinus halepensis* and *Eucalyptus occidentalis* in a 10 year-old common garden experiment established on a degraded *Stipa tenacissima* steppe in southern Tunisia have improved soil properties as compared to those of open areas (Jeddi *et al.*, 2009).

## 2.2 Variations in growth and productivity of Eucalyptus species in different agro climatic zones

De Jesus (1988) reported that at the age of 7 years, the Eucalyptus trees were all single-stemmed with an average height of about 20 m and DBH of about 19 cm.

The *Eucalyptus grandis* and *E. tereticornis* showed standing volume of 88.5 and 205 m<sup>3</sup> per ha at the age of 4 and 10 years, respectively in Asarori (Dehradun) (Dwivedi, 1993).

The *Eucalyptus tereticornis* when grown at Jodighalli (Bengaluru) with the spacing of 2 x 2 m produced 4.44 m height and DBH growth of 4.227 cm, respectively at the age of 5 years, 6.35 m and 5.211 cm, respectively at 6 years, 7.31 m and 6.513 cm, respectively at the age of 7 years and 9.76 m and 8.683 cm, respectively at the age of 11 years (Kushalappa, 1993).

Hossain *et al.* (1997) reported the growth and biomass production of some Acacia and Eucalyptus species in degenerated Sal forest areas of Bangladesh. *A. auriculiformis* and *E. urophylla* produced higher growth and biomass in comparison to other species or seed lots.

Growth performance of some tree species at the age of 9 and 12 years with the 2 x 2 and 4 x 4 m spacing, respectively revealed that at the age of 9 years, *Leucaena leucacephala*, *Eucalyptus camaldulensis*, *Acacia albida* and *A. auriculiformis* produced 29.3, 26.2, 21.3 and 18.4 m height and the DBH of 24.1, 24.1, 27.4 and 20.9 cm, respectively. *Albizia lebbek* (4 x 4 m), *Azadiractha indica* (4 x 4 m), *Acacia nilotica* (3 x 3 m) and *Tamarindus indica* (4 x 4 m) showed highest growth of 12.2, 11.4, 10.5 and 11.2 m and the DBH of 18.2, 13.7, 15.2 and 12.7 cm, respectively at the age of 12 years (Rao *et al.*, 2000).

Among *Eucalyptus*, branch and foliage weight formed a relatively small fraction of the total above-ground biomass in more mature stands (Madgwick *et al.*, 2003).

Dogra and Sharma (2009) reported that *Eucalyptus hybrid* trees with diameter at breast height ranging between 7.1 and 56.3 cm and height from 10.0 to 42 m across Punjab state in *E. hybrid* grown under Punjab's climatic conditions attained an average air dry timber density of  $550 \pm 28$  kg per m<sup>3</sup>.

### 2.3 Variation in herbage and oil yield of *Eucalyptus* in different agro climatic zones

The Biomass distribution in 2.5 year old *Eucalyptus grandis* showed that 9 per cent leaves, 7 per cent limbs and 83 per cent stems were among the components of the stand (Poggiani and Couto, 1983).

De Jesus(1988) reported that the biomass yields varied between 31 and 46 m<sup>3</sup> per ha per year with maximum yield in the pure *Eucalyptus* treatment at the age of 7 years.

Dan *et al.* (1999) assessed foliar yields of oil of all nine taxa of *Eucalyptus* for 2.5 or 3 year-old saplings cut respectively in summer or winter at Western Australia, and for corresponding coppice biomass produced over the following 12 months from the same trees. Average leaf oil yields for the relative best performing taxa varied widely between species and sites, with sapling harvests producing 12 to 130 (mean 49) kg oil per km of twin-row hedge as compared to 1 to 68 (mean 23) kg per km for subsequent coppice harvests.

O'grady *et al.* (2000) reported *Eucalyptus miniata* and *E. tetradonta* were significant contributors to over storey leaf area index and standing biomass (>70%), and both leaf area index and biomass were strongly correlated with basal area. Leaf area index was maximum (about 1.0) at the end of the wet season and declined over the dry season by about 30 to 40 per cent. Standing biomass was about 55 tonnes per ha.

Wildy *et al.* (2000) reported four promising *Eucalyptus* species from Western Australia at six locations and reported 0.01 to 13.0 per cent oil production.

More popular among the *Eucalyptus* species is *Eucalyptus crebra* for plantation and industries. Oil yield in *E. crebra* varies up to 1.47 per cent (Zafar *et al.*, 2003).

Haq *et al.* (2007) reported the intra provenance variation of essential oil obtained from leaves of *Eucalyptus crebra*. Significant variations were observed regarding oil potential (0.29 - 1.33 %) of *E. crebra* leaves among different districts of Punjab.

Jason *et al.* (2007) reported that total above ground biomass and foliar oil concentration were significantly related between saplings and coppice of *Eucalyptus polybractea* and oil proportion showed a Pearson's correlation of 0.93 between harvests. Nevertheless, the mean foliar oil concentration in the coppice was 148 mg per g dry weight as compared with 107 in the saplings and the coppice foliage, on an average showed significantly reduced oil content.

Ravat *et al.* (2008) reported that the biomass yield from *Eucalyptus* varied from 39.4 to 738.98 kg per tree and from 77.29 to 223.46 tonnes per ha in all the sites. Productivity varied from 2.57 tonnes per ha per year (at 32 years) to 9.31 tonnes per ha per year (at 24 years). The contribution of individual tree components to total biomass varied as leaf 1.41 to 4.29 per cent, twig 2.92 to 6.31 per cent, branch 10.95 to 19.98 per cent, bark 6.65 to 10.69 per cent, root 15.29 to 20.61 per cent and bole 42.86 to 56.33 per cent. The per cent contributions of all the tree components at all the sites were in order of bole followed by root, branch, bark, twig and leaf.

Abdolhamid *et al.* (2009) reported that dried leaves and flowers of *Eucalyptus camaldulensis* produced oils with the yields ranging between 0.4 and 0.58 per cent.

The leaf essential oil of *Eucalyptus camaldulensis* plants collected from five localities of the Montenegro coastline showed oil yield variation from 0.63 to 1.59 per cent (Grbovic *et al.*, 2010).

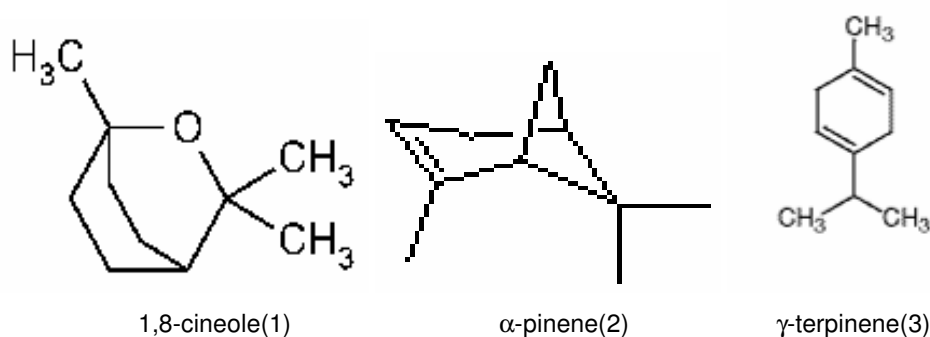
Three prominent oil bearing species (*Eucalyptus citriodora*, *E. Globulus* and *E. camaldulensis*) in a managed stand showed mean leaf oil yield ranging between 0.20 and 5.23 per cent on dry weight basis. Seven out of the 20 species examined contained leaf oil below 1 per cent, six species between 1 and 2 per cent, three species between 2 and 3 per cent and only four species showed oil yield values above 3 per cent. The mean oil yield at subgenus level varied significantly in the order of *Corymbia* (2.64%), *Symphomyrtus* (1.82%) and *Monocalyptus* (0.79%). Leaf oil yield from juvenile leaf samples (0.49 - 4.08 % dry weight) was higher than the corresponding mature leaves (0.77- 4.51%). The effect of leaf type was markedly significant in the case of *E. camaldulensis* than *E. globulus* and *E. citriodora* (Yoseph *et al.*, 2010).

Emara and Emad (2011) reported seasonal variation of fixed and volatile oil percentage of four Eucalyptus species *viz.* *E. camaldulensis*, *E. cinerea*, *E. citriodora* and *E. globulus*. Total lipids and essential oils significantly varied by the seasons. The amount of total lipids in Eucalyptus species reached its peak in spring, but the amounts of essential oils in different species were higher in summer, autumn and spring seasons, than in winter.

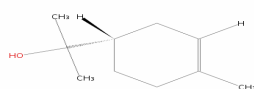
Sadaf *et al.* (2011) reported that essential oils from three different varieties of Eucalyptus species *viz.* *E. saligna*, *E. tereticornis* and *E. tetragona* with oil yield of 2.0, 1.0 and 1.5 per cent, respectively.

## 2.4 Variation in chemical compositions of Eucalyptus oil in different agro climatic zones

Li and Madden (1995) reported volatile leaf oils from adult leaves of five Eucalyptus species growing in a common environment. Oil yields from adult leaves of *E. nitens* (0.7%) and *E. denticulata* (0.8%) were markedly lower than those from other three species (3.0 - 6.1%). Volatile leaf oils of *E. delegatensis* and *E. regnans* were rich in  $\alpha$ - and  $\beta$ -phellandrine, *cis*- and *trans*-p-menth-2-en-1-ol, while *E. regnans* oil was rich in  $\alpha$ -,  $\beta$ - and  $\gamma$ -eudesmol. In contrast, volatile leaf oils of *E. globulus* were rich in 1,8-cineole and  $\alpha$ -pinene (1 and 2) and *E. denticulata* was rich in  $\gamma$ -terpinene (3) and p-cymene. Differences in oil yield and oil composition between species indicated a strong genetic basis for these variables.

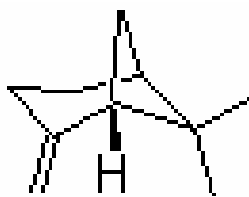


Dan *et al.* (1999) reported variations in the amount and composition of leaf oil of Eucalyptus in sites across the Western Australian wheat belt. At six locations in respect of oil composition, 1,8-cineole comprised 65 to 92 per cent of the total oil. Up to 32 constituents of oils were present in proportional amounts ranging between 0.01 and 13 per cent. Further, 26 trace components were recorded in certain species. Relative abundances of cineole, limonene,  $\alpha$ -terpineol (4) and terpinen-4-ol varied significantly between sites for all the four species, with the evidence of reduced levels of cineole being compensated for by increases in the later three compounds.



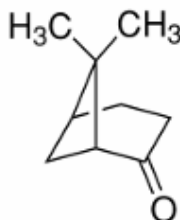
$\alpha$ -terpineol (4)

Najum *et al.* (2005) reported that among the 15 different *Eucalyptus crebra* oils, the major components were  $\alpha$ -pinene,  $\beta$ -pinene (5),  $\Delta^3$ -carene, phellandrine, limonene and 1, 8-cineole. The principal constituent 1,8-cineole, found in the fifteen oils of different trees ranged between 11.87 and 43.80 per cent. The other major components were  $\beta$ -pinene (0.20-12.13%),  $\alpha$ -pinene (1.68-18.23%),  $\Delta^3$ -carene (1.32-5.63%) and  $\alpha$ -phellandrine (0.55-7.98%).



$\beta$ -pinene (5)

Essential oils isolated by hydro-distillation from the leaves of *Eucalyptus gillii* and *E. microcarpa* showed main components in *E. gillii* oil as 1,8-cineole (79.5%), trans-pinocarveol (8%) (6) and  $\alpha$ -pinene (2.7%), and in *E. microcarpa* as 1, 8-cineole (77.3%),  $\alpha$ -pinene (5.6%) and terpin-1-ol (5.1%). Oils with high content of 1, 8-cineole are classified as “Eucalyptol or medicinal compounds” (Kamkar, 2006).



trans-pinocarveol (6)

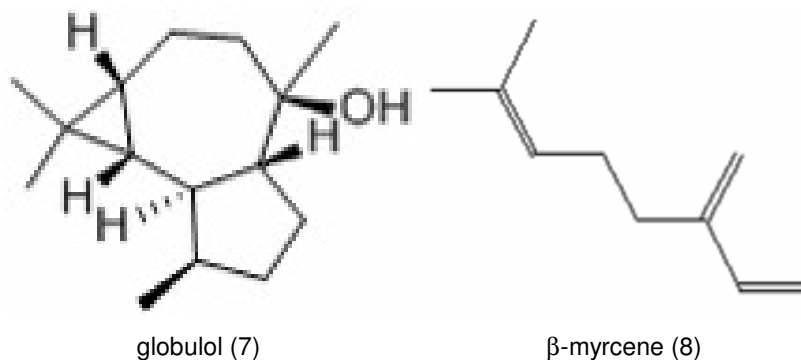
Haq *et al.* (2007) reported the intra provenance variation in oil chemical composition of essential oil obtained from leaves of *Eucalyptus crebra*. The oil principally comprised of 1,8-cineole (11.87-43.80%) and  $\alpha$ -pinene (1.6-18.23%), whereas  $\beta$ -pinene (0.54-2.13%),  $\alpha$ -phellandrene (0.55-7.98%),  $\Delta^3$ -limonene (2.7%) and  $\Delta^3$ -carene (1.32-5.63%) were present as minor constituents.

Twenty two components were identified in the leaf oil of *E. microtheca* with 1,8-cineole (34.0%), p-cymene (12.4%),  $\alpha$ -pinene (10.7%) and  $\beta$ -pinene (10.5%) as main constituents. Twenty one compounds were identified in the leaf oil of *E. spathulata* with 1, 8-cineole (72.5%) and  $\alpha$ -pinene (12.7%) as main components. Twenty six compounds were characterized in the leaf oil of *E. largiflorens* with 1,8-cineole (37.5%), p-cymene (17.4%) and neoisoverbenol (9.1%) as main components. Sixteen compounds were characterized in the leaf oil of *E. torquata* with 1, 8-cineole (66.9%)  $\alpha$ -pinene (13.9%) and trans-pinocarveol (6.3%) as main constituents. The results showed that although 1,8-cineole was the main component of the essential oils of all *Eucalyptus* species, its relative content was higher in the oil of *E. spathulata* and *E. torquata* (Fatemeh *et al.*, 2007).

Patricia *et al.* (2007) reported about the leaf-essential oil from *Eucalyptus robusta* and *E. saligna*. The major constituent in *E. robusta* oil was the monoterpene  $\alpha$ -pinene (73.0%). The oil composition of the *E. saligna* was dependent of the phenologic stage.

In the vegetative phase, the major constituents were *p*-cymene (54.2%) and  $\gamma$ -terpinene (43.8%), while during the blossoming  $\alpha$ -pinene became the major constituent followed by *p*-cymene (22.5%).

The main oil components of essential oil from dried leaves and flowers of *Eucalyptus camaldulensis* were 1,8-cineol (Eucalyptol), *trans*-pinocarveol, and  $\alpha$ -pinene in leaves and 1,8-cineol,  $\alpha$ -pinene,  $\delta$ -cadinene,  $\beta$ -myrcene (8) and globulol (7) in flowers oils (Abdolhamid *et al.*, 2009).



Forty seven compounds were identified in the essential oils obtained from the leaves of *Eucalyptus globulus*. The main constituents of the essential oils were 1,8-cineol (72.71 %),  $\alpha$ -pinene (9.22 %),  $\alpha$ -terpineol (2.54 %), globulol (2.77 %),  $\alpha$ -terpineol acetate (3.11 %) and alloaromadendrene (2.47 %) (Aihua, 2009).

Jaimand *et al.* (2009) reported essential oils from the leaves of two *Eucalyptus viridis* and *E. oleosa*. The main components identified in *E. viridis* oil were 1,8-cineole (84.7%),  $\alpha$ -pinene (4.4%), *trans*-pinocarveol (2.2%) and in *E. oleosa* were 1,8-cineole (89.4%),  $\beta$ -pinene (1.2%) and  $\alpha$ -pinene (1%).

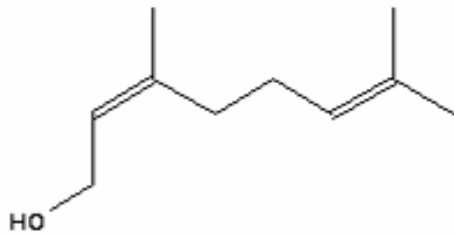
Monoterpene hydrocarbons were a major class of compounds found in leaf essential oil of *Eucalyptus camaldulensis* plants collected from five localities of the Montenegro coastline. Among them, dominant compounds were *p*-cymene (17.38-28.60%),  $\alpha$ -phellandrene (12.35-14.47%) and  $\alpha$ -pinene (0.94-11.48%). The second largest group was oxygenated monoterpenes with cryptone (4.97-7.25) and terpinene-4-ol (2.75-4.21%) as predominant compound. Besides high content of sesquiterpene alcohol spathulenol (7.83-14.15%) was found (Grbovic *et al.*, 2010).

Sisay (2010) reported that use of Eucalyptus oil for pharmaceutical industry depends on the chemical composition of the oil and the species as well. Oils rich with cineol greater than 80 per cent are used in pharmaceutical industry, whereas in perfumery industry the oil has to be rich with citronellal. Constituents of the oils are mainly monoterpene and sesquiterpene hydrocarbons, oxygenated compounds derived from these hydrocarbons like alcohols, aldehydes, esters, ethers, ketones, phenols and oxides.

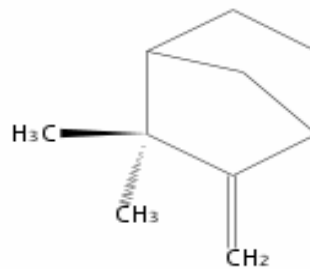
Zafar *et al.* (2010) reported that *Eucalyptus polybractea* plants contained 1,8-cineole as the major compound (91.7–94.2%), while the other identified compounds were  $\alpha$ -pinene (0–1.2%),  $\beta$ -pinene (0.4–2.3%), limonene (0.2–1.3%), *p*-cymene (1.23–2.75%), and terpinene-4-ol (0.6–0.92%). The extracted oils from *E. polybractea* plants contained high amount of 1,8-cineole (>90 %) and therefore classified as species of high quality medicinal oil.

Essential oils obtained by hydrodistillation from the different parts (stems, adult leaves, immature flowers and fruits) of *Eucalyptus oleosa* were screened for their chemical composition. The principal compound of the stem, immature flowers and the fruit oils was 1,8-cineole, representing 31.5, 47.0 and 29.1 per cent, respectively. Hajer *et al.* (2011) reported that spathulenol (16.1%) and  $\gamma$ -eudesmol (15.0%) were the two principal compounds of adult leaf oil.

Abd EL-Mageed *et al.* (2011) reported that the major components identified in *Eucalyptus citrodera* oil



*cis*-geraniol (8)



camphene (9)

were 3-hexane-1-ol, *cis*-geraniol (8), citronellol acetate, 5-haptane-1-ol, 2,6-dimethyle and citronellal. In *E. camaldulensis* they were magastigma-3,7,9-triene, dihydrocarveol acetate, *cis*-nerolidol, and spathulenol, whereas in *E. gomphocephala* they were dihydrocarveol acetate, *p*-cymene and citral. The major components of *E. resinifera* were eucalyptol, camphene (9), spathulenol,  $\alpha$ -terpineol acetate and *trans*-nerolidol.

Based on these reviews, an experiment was planned to study the growth and productivity parameters of *Eucalyptus pellita* F. Muell, leaf biomass, leaf oil yield and its chemical composition and the analysis of soil under its canopy.

### 3. MATERIAL AND METHODS

The present study was conducted in Agro-climatic Zone-9 of Karnataka. An experiment was conducted in the already established four year old *Eucalyptus pellita* F. Muell plantations. Four experimental plots were chosen in the Western Ghats based on the rainfall data of that area.

#### 3.1 Study area

The Western Ghats constitute a chain of hills that run along the entire West coast of India for about 1200 km. The part of Western Ghats in Karnataka is located between 13° to 16° N latitude and 74° to 76° E longitude and extended over an area of 2000 km<sup>2</sup>. Uttar Kannada and Shimoga districts exhibit a wide range of climate and topographic situations. These districts come under the Agro-climatic Zone-9 of Karnataka *i.e.*, Hilly Zone, which is highly deforested with consequent laterization forming flat hills with practically no vegetation. The step edge of the plateau occurring at an average altitude of 600 m above MSL is well forested (Table 1 and Plate 1).

#### 3.2 Site conditions

The Uttara Kannada and Shimoga districts lie between 14° 09' N to 14° 41' N latitude and 75° 02' E to 75° 14' E longitude. The districts under Hilly zone were divided in to four sites based on the topography and other climatic variables *viz.*, rain fall, number of rainy days, temperature *etc.* The rainfall in these sites ranges between 500-3500 mm per year and the altitude ranges between 596 and 622 m. Plantations with uniform spacing of 2 m x 2 m were located in each of the rainfall areas (Table 2 and Plate 2a).

#### 3.3 Stand enumeration

Enumeration of *Eucalyptus pellita* F. Muell stands was carried out in selected plantations. Four quadrates of size 20 m x 20 m were laid out randomly in each plantation.

##### 3.3.1 Diameter at breast height

The diameter at breast height (DBH) was recorded in cm with the help of tree caliper at 1.37 m above the ground level (Plate 2b).

##### 3.3.2 Total height

The total height (m) of the tree from base to tip was recorded using Ravi multimeter (Chaturvedi and Khanna, 1982).

##### 3.3.3 Bole height

The height (m) of the main stem from base to first branch of the tree having more than 5 cm diameter was recorded by using Ravi multimeter (Chaturvedi and Khanna, 1982).

##### 3.3.4 Crown diameter

The spread of crown of the tree (m) was measured in two directions perpendicular to each other. The average of two values was recorded as the crown diameter.

##### 3.3.5 Basal area

The basal area of the tree (m<sup>2</sup>) was determined by using following formula,:

$$\text{Basal area} = \pi d^2/4.$$

##### 3.3.6 Total volume

Total volume of the tree (m<sup>3</sup>) was obtained by multiplying basal area, total height and form factor (Chaturvedi and Khanna, 1982).

**Table 1. Details of the area selected for the current study**

<b>Place</b>	<b>Taluk</b>	<b>District</b>	<b>Age of the plantation (years)</b>
Sammasagi	Sirsi	Uttar Kannada	4
Sorab	Sorab	Shimoga	4
Sagar	Sagar	Shimoga	4
Teerthahalli	Teerthahalli	Shimoga	4

**Table 2. Site factors of the study area**

<b>Name of the treatment</b>	<b>Locality</b>	<b>Latitude</b>	<b>Longitude</b>	<b>Altitude (in m)</b>	<b>Mean annual rain fall (mm)</b>	<b>Annual No of rainy days</b>	<b>Mean annual temperature (°C)</b>	<b>Relative humidity (%)</b>
T <sub>1</sub>	Sammasagi	14 <sup>0</sup> 41' N	75 <sup>0</sup> 02' E	612	500-1000	75	33	75
T <sub>2</sub>	Sorab	14 <sup>0</sup> 22' N	75 <sup>0</sup> 05' E	597	1500-2000	95	31	79
T <sub>3</sub>	Sagar	14 <sup>0</sup> 09' N	75 <sup>0</sup> 02' E	596	2000-2500	100	29	86
T <sub>4</sub>	Teerthahalli	13 <sup>0</sup> 41' N	75 <sup>0</sup> 14' E	622	3000-3500	115	28	90

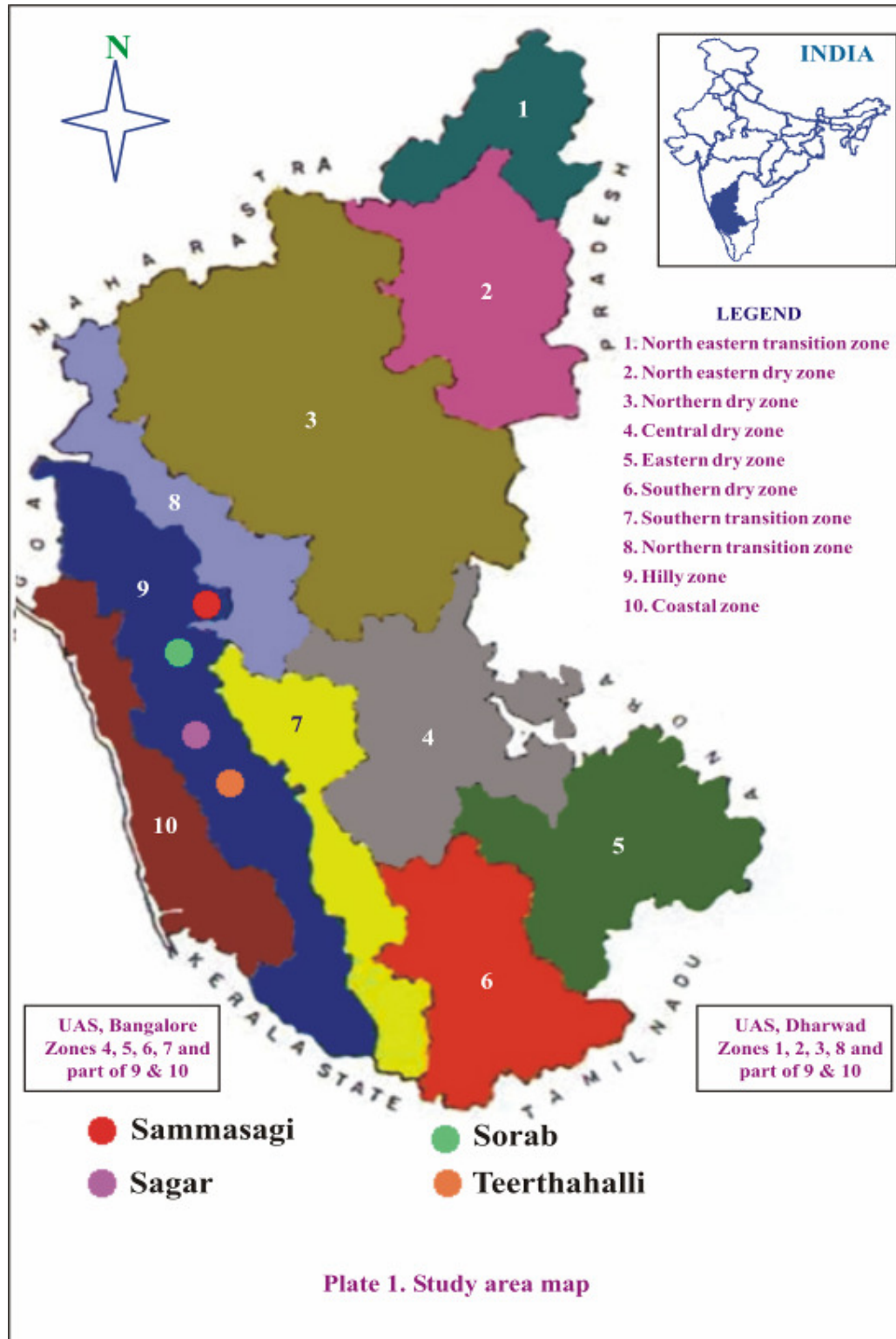


Plate 1. Study area map



**Plate 2a . Eucalyptus pellita plantation**



**Plate 2b. Measurement of DBH of  
Eucalyptus Pellia tree**



**Plate 2c. Collection of leaves and leaf  
Biomass from harvested Eucalyptus pellia tree**

Form factor : is defined as the ratio of volume of a tree or its part to the volume of a cylinder having the same length and cross section as the tree

or

It is the ratio between the volume of a tree to the product of basal area and height.

$$\text{Form factor (F)} = \frac{V}{Sh}$$

Where,

V = Volume of tree

S = Basal area

h = Height of tree

## 3.4 Soil analysis

### 3.4.1 Collection and preparation of soil sample

The soil samples were collected from the field and brought to the laboratory in polythene bags. The soil samples were dried under shade, pounded with wooden pestle and mortar, passed through 2 mm sieve for the analysis of available N, P, and K. For organic carbon, soil samples were again pounded in an agate mortar and passed through 0.5 mm sieve and preserved in polythene bag for further analyses.

### 3.4.2 Soil properties

#### 3.4.2.1 Available nitrogen

The available soil nitrogen (kg/ha) was estimated by micro-Kjeldahl method (Black, 1965). Soil sample was digested in Conc.H<sub>2</sub>SO<sub>4</sub> with a pinch of digestion mixture comprising salicylic acid, K<sub>2</sub>SO<sub>4</sub> and Na<sub>2</sub>SO<sub>3</sub>. The digested sample was distilled with excess of 40 per cent sodium hydroxide. Ammonia thus released was trapped in 2 per cent boric acid and the ammonium borate thus formed was titrated against previously standardised 0.05 N HCl (Table 3).

#### 3.4.2.2 Available phosphorus

Available soil phosphorus in the soil samples was extracted by Ascorbic acid method (Jackson, 1973). The phosphorus content in the extractant was determined colourimetrically by developing blue coloured complex. The intensity of the complex was measured at 660 nm in a spectrophotometer (Table 3).

#### 3.4.2.3 Available potassium

Available soil potassium (kg/ha) was determined by extracting the soil sample with neutral ammonium acetate solution and estimated by using flame photometer as outlined by Jackson (1973) (Table 3).

#### 3.4.2.4 Particle size analysis

Particle size distribution was measured at surface layer (0-15) by international pipette method using sodium hydroxide as the dispersing agent (Table 3).

#### 3.4.2.5 Bulk density

Bulk density was determined at surface layer (0-15) by core sampler method as prescribed by Black (1965) (Table 3).

#### 3.4.2.6 Soil reaction

pH: The pH of the soil-water suspension was determined by using a digital pH meter.

Electrical conductivity: Electrical conductivity was determined by using Conductivity Bridge (Table 3).

#### 3.4.2.7 Organic carbon

The organic carbon content of the soil sample was determined by wet oxidation method of Walkley and Black as described by Jackson (1967) (Table 3).

### 3.5 Foliage Biomass

For foliage biomass estimation, leaves from the representative trees were collected; fresh weight of the foliage was measured with the help of appropriate Spring Scale, based on which total foliage biomass of the plantation was calculated (Plate 2c).

### 3.6 Estimation of oil yield and oil quality parameters of *Eucalyptus pellita* F. Muell

#### 3.6.1 Collection of samples

Fresh leaf samples from mature *Eucalyptus pellita* were collected from different regions of Hilly Zone of Karnataka, India. The leaves were immediately packed in polyethylene bags and transferred to laboratory (Plate 2c).

#### 3.6.2 Oil isolation

Freshly collected 100 to 200 g leaves were hydro distilled for three hours for complete extraction of essential oil by using a commercial Clevenger-type apparatus. The moisture in the oil samples was removed by adding anhydrous sodium sulfate (Plate 3).

#### 3.6.3 Yield of oil

The amount of extracted oil was determined and yield (%) of the extracted oil from each sample was calculated on the basis of *Eucalyptus* leaves by using the following formula:

$$\text{Yield of oil (\%)} = \frac{\text{Weight of oil}}{\text{Weight of Eucalyptus leaves}} \times 100$$

#### 3.6.4 Colour and aroma of *Eucalyptus* oil sample

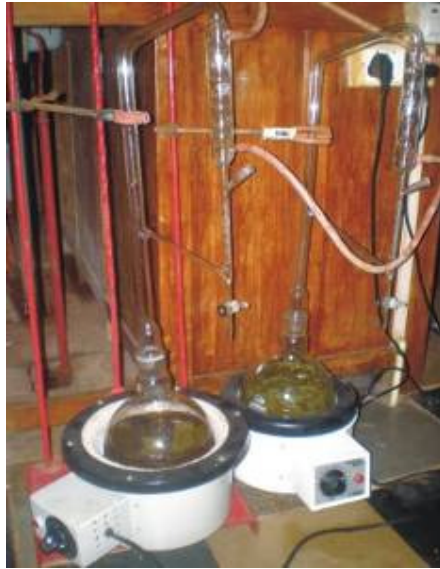
Colour and aroma of the oil samples were recorded by visual observations and smell (Plate 4b).

#### 3.6.5 Gas Chromatographic- Mass spectrometry analysis of oil

The chemical composition of essential oil was determined by chromatography technique. GC-MS analyses were carried out on a Shimadzu Chromatopac GC-MS QP2010S GC-MS system equipped with a DB-5 fused silica column (30 m x 0.25 mm i.d.). Oven temperature was 40°C increasing to 250°C at a rate of 4°C, transfer line temperature 260°C. The carrier gas was helium with a linear velocity of 31.5 cm/s, split ratio 1/60, Ionization energy 70 eV, scan time 1 sec and mass range of 40-300 atomic mass unit (1 Atomic mass unit =  $1.66 \times 10^{-27}$ ). The compounds were quantified by the area normalization method without considering response factors. The components of the oils were identified by comparison of their mass spectra with those of a computer library or with authentic compounds, and confirmed by comparison of their retention indices either with those of authentic compounds or with data published in the literature (Plate 4c).

### 3.7 Statistical analysis

The data on growth and foliage yield of *E. pellita* F. Muell were analyzed by Randomized Block Design (RBD) where site conditions were the treatments. The data were analyzed by using MSTAT C programme on a PC.



**Clavenger-type oil extraction unit**



**Extracted *Eucalyptus pellita* leaf oil**

**Plate 3. Oil extraction by Clavenger-type apparatus**

**Table 3. Methodology adopted for studying of different properties of the soils of the experimental sites**

<b>Properties</b>	<b>Methods</b>
<b>Physical properties</b>	
Bulk density	Keen's cup method (Black 1965).
Particle density	Keen's cup method (Black 1965).
<b>Chemical properties</b>	
pH	Digital pH meter (Jackson 1967)
EC (dS/m)	Conductometry method (Jackson 1967)
OC (%)	Walky-Black wet oxidation method (Jackson 1967)
N (kg/ha)	Black's (Jackson 1967)
P (kg/ha)	Bray's (Tandon 1995)
K (kg/ha)	Flame photometer (Jackson 1973)



**Plate 4a. Harvested biomass dumped in forest**



**Plate 4b. Eucalyptus leaf oil samples**



**Plate 4c. Shimadzu Chromatopac GC-MS (QP 2010S)**

## 4. EXPERIMENTAL RESULTS

The experimental results obtained in the present investigation are presented in this chapter.

### 4.1 Growth and productivity performance of *Eucalyptus pellita* F. Muell in different regions of Hilly zone

The data on growth and productivity performance of *Eucalyptus pellita* viz. diameter at breast height (cm), total height (m), bole height (m), crown diameter (m), basal area (m<sup>2</sup>) and total volume (m<sup>3</sup>) are presented in Table 4.

#### 4.1.1 Diameter at breast height

The diameter at breast height of *E. pellita* varied from 9.52 to 13.44 cm. Among these experimental sites, Teerthahalli plantation showed highest DBH (13.44 cm) followed by Sammasagi (10.9 cm), Sorab (10.3 cm) and Sagar (9.52 cm). Teerthahalli showed significantly highest DBH when compared to other regions. However, the plantation of Sammasagi significantly differed from Sagar plantation. Sorab plantation was non-significant with Sammasagi and Sagar plantations (Table 4 and Fig. 1a).

#### 4.1.2 Total height

The total height of *E. pellita* varied from 12.20 to 14.80 m. Among these experimental sites, Sagar plantation showed highest total height (14.8 m) followed by Teerthahalli (14.54 m), Sorab (13.35 m) and least plant height was observed in Sammasagi plantations (12.20 m). The plant height of *E. pellita* at Sagar showed significant difference from Sammasagi and Sorab regions, except Teerthahalli. However, Sammasagi was non-significant when compared with Sorab which was non-significant with Teerthahalli (Table 4 and Fig. 1b).

#### 4.1.3 Bole height

The bole height of *E. pellita* varied from 9.14 to 12.71 m. Among these experimental sites, Sagar plantation showed highest bole height (12.71 m) followed by Teerthahalli (12.32 m), Sorab (9.80 m) and Sammasagi plantations (9.14 m). Among these four regions, bole height of Sagar plantation was significantly different from Sammasagi and Sorab plantations, except the plantation at Teerthahalli. However, Sammasagi plantation was non-significant with Sorab plantation (Table 4 and Fig. 1c).

#### 4.1.4 Crown diameter

The crown diameter of *E. pellita* varied from 1.53 to 2.27 m. Among the experimental plantations, Teerthahalli showed highest crown diameter (2.27 m) followed by Sagar (2.08 m), Sorab (1.92 m) and Sammasagi (1.53 m). Among these four regions, Teerthahalli plantations showed significant difference in crown diameter as compared to Sammasagi and Sorab plantations, except Sagar plantation (Table 4 and Fig. 1d).

#### 4.1.5 Basal area

The basal area of *E. pellita* varied from 17.75 to 35.35 m<sup>2</sup> per ha. Among these, experimental site of *E. pellita* in Teerthahalli plantations showed highest basal area (35.35 m<sup>2</sup>/ha) followed by Sammasagi (23.55 m<sup>2</sup>/ha), Sorab (19.7 m<sup>2</sup>/ha) and Sagar plantations (17.75 m<sup>2</sup>/ha). The basal area of *E. pellita* found at Teerthahalli differed significantly from the other three plantations (Table 4 and Fig. 1e).

#### 4.1.6 Total volume

The total volume of *E. pellita* varied from 183.5 to 360 m<sup>3</sup> per ha. Among these experimental sites, the plantations of *E. pellita* grown at Teerthahalli showed highest volume (360 m<sup>3</sup>/ha) followed by Sammasagi (200.5 m<sup>3</sup>/ha), Sagar (184 m<sup>3</sup>/ha) and Sorab (183.5 m<sup>3</sup>/ha). All the plantations showed significant difference in total volume (Table 4 and Fig. 1f).

## 4.2 Soil properties of *Eucalyptus pellita* plantations in different regions of Hilly zone

### 4.2.1 Bulk density

The bulk density of soil under *E. pellita* varied from 1.27 to 1.34 g per ml. The four regions of Hilly zone showed the bulk density of soil as follows under the plantations of Sammasagi (1.34 g/ml), Sorab (1.31 g/ml), Sagar (1.34 g/ml) and Teerthahalli (1.27 g/ml). Among these plantations, Sammasagi (1.34 g/ml) and Sagar (1.34 g/ml) showed highest soil bulk density followed by Sorab (1.31 g/ml) and Teerthahalli (1.27 g/ml). There was significant difference between the plantation soils of Teerthahalli and other three plantation soils. The bulk density was lower under plantations as compared to respective control site. The bulk density under control condition showed Sammasagi (1.8 g/ml), Sorab (1.41 g/ml), Sagar (1.45 g/ml) and Teerthahalli (1.38 g/ml) (Table 5).

### 4.2.2 Particle density

The particle density of soil under *E. pellita* varied from 2.28 to 2.37 g per ml. The particle density was as follows: Sammasagi (2.35 g/ml), Sorab (2.28 g/ml), Sagar (2.36 g/ml) and Teerthahalli (2.37 g/ml) among these regions of plantations, Teerthahalli (2.37 g/ml) showed highest soil particle density followed by Sagar (2.36 g/ml), Sammasagi (2.35 g/ml) and Sorab (2.28 g/ml). The particle density was low under plantations as compared to respective control sites. The particle density under control condition was as follows: Sammasagi (2.45 g/ml), Sorab (2.39 g/ml), Sagar (2.5 g/ml) and Teerthahalli (2.52 g/ml) (Table 5).

### 4.2.3 Soil pH

The pH of soil under *E. pellita* varied from 5.10 to 6.1. The pH was as follows: Sammasagi (5.44), Sorab (5.74), Sagar (6.1) and Teerthahalli (5.1). Among these regions of plantations, Sagar (6.1) showed highest soil pH followed by Sorab (5.74), Sammasagi (5.44) and Teerthahalli (5.1). There was significant difference in pH among *E. pellita* plantations. Soil pH under control condition was slightly higher (Sammasagi, 6.8, Sorab, 6.3, Sagar, 6.9 and Teerthahalli, 5.9) (Table 5).

### 4.2.4 Electrical conductivity

The electrical conductivity (EC) of soil under *E. pellita* varied from 0.31 to 0.39 dS per m. Among the plantations, Teerthahalli (0.39 dS/m) showed highest soil EC followed by Sammasagi (0.37 dS/m), Sorab (0.36 dS/m) and Sagar (0.31 dS/m). Under control condition, soil EC was as follows: Sammasagi (0.35 dS/m), Sorab (0.34 dS/m), Sagar (0.35 dS/m) and Teerthahalli (0.38 dS/m) (Table 5).

### 4.2.5 Available soil nitrogen

The available soil nitrogen under *E. pellita* varied from 140 to 173 kg per ha. The Sammasagi plantation (173 kg/ha), showed highest soil nitrogen followed by Sagar plantation (151 kg/ha) and lowest in Sorab and Teerthahalli plantations (140 kg/ha). Among the four regions, the soil nitrogen at Sammasagi significantly differed from other regions. Soil nitrogen under control condition was as follows: Sammasagi (168 kg/ha), Sorab (154 kg/ha), Sagar (140 kg/ha) and Teerthahalli (126 kg/ha) (Table 5).

### 4.2.6 Available soil phosphorus

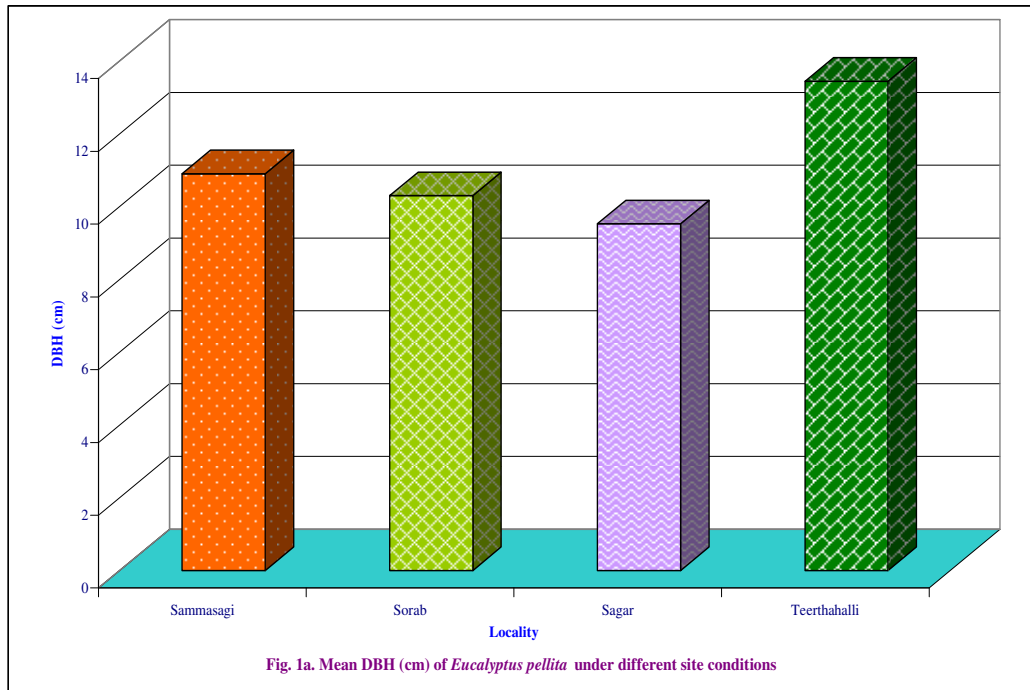
The available soil phosphorus under *E. pellita* varied from 18.88 to 25.32 kg per ha. Among the plantations, Teerthahalli (25.32 kg/ha) showed highest soil phosphorus followed by Sagar (21.68 kg/ha), Sorab (19.78 kg/ha) and Sammasagi (18.88 kg/ha). Soil Phosphorus under control condition showed lower values than the treated plots (Sammasagi, 10.1 kg/ha, Sorab, 11.2 kg/ha, Sagar, 12.3 kg/ha and Teerthahalli, 12.6 kg/ha) (Table 5).

### 4.2.7 Available soil potassium

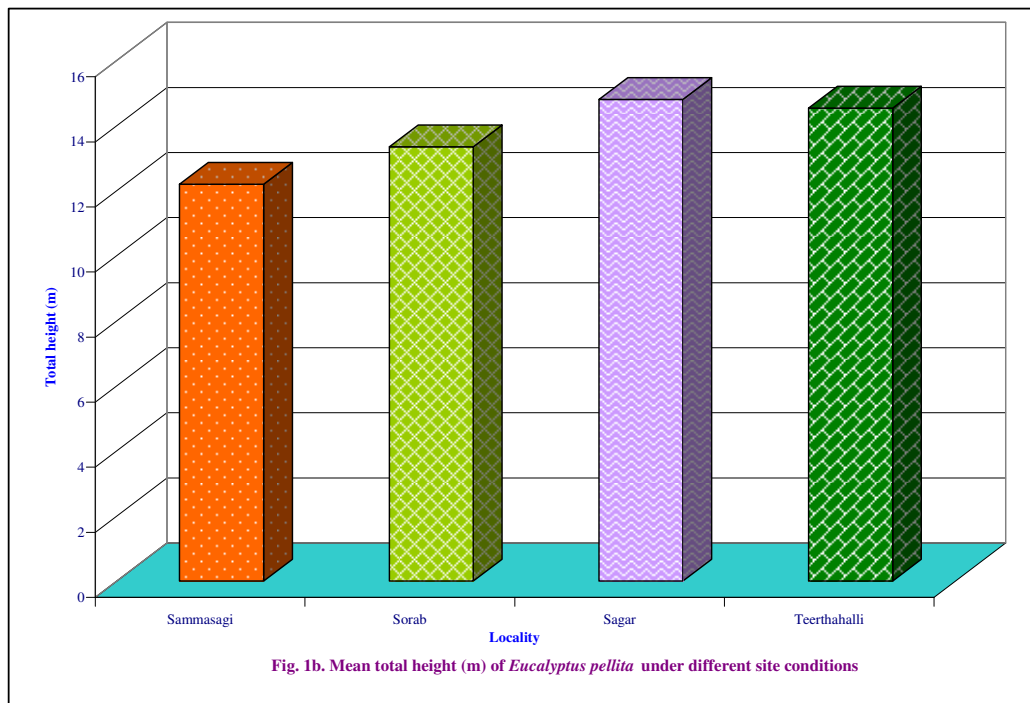
The available soil potassium under *E. pellita* varied from 88 to 333.6 kg per ha. Among the plantations, Sammasagi (333.6 kg/ha), showed highest soil potassium followed by Teerthahalli (139 kg/ha), Sorab (127 kg/ha) and Sagar (88 kg/ha).

**Table 4. Growth and productivity performance of *Eucalyptus pellita* F. Muell in different site conditions**

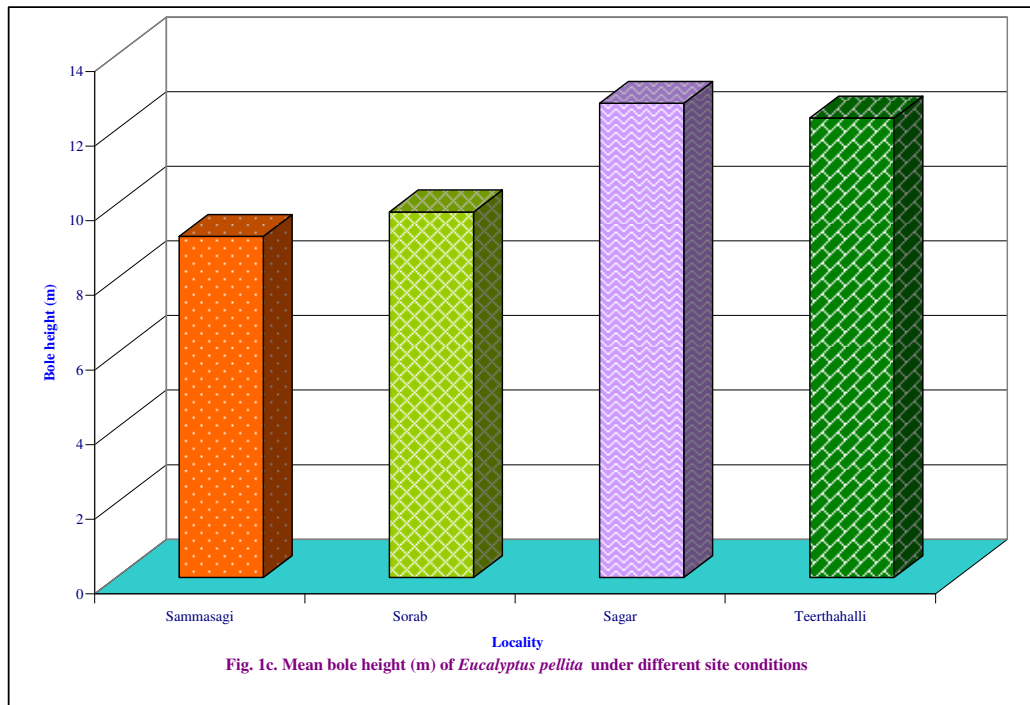
<b>Treatments</b>	<b>Locality</b>	<b>Dbh (cm)</b>	<b>Total height (m)</b>	<b>Bole height (m)</b>	<b>Crown diameter (m)</b>	<b>Basal area (m<sup>2</sup>/ha)</b>	<b>Volume (m<sup>3</sup>/ha)</b>
T <sub>1</sub>	Sammasagi	10.9	12.20	9.14	1.53	23.55	200.5
T <sub>2</sub>	Sorab	10.3	13.35	9.80	1.92	19.7	183.5
T <sub>3</sub>	Sagar	9.52	14.80	12.71	2.08	17.75	184
T <sub>4</sub>	Teerthahalli	13.44	14.54	12.32	2.27	35.35	360
SEm <sub>±</sub>		0.315	0.464	0.249	0.015	0.00055	0.007
CD (0.05)		0.971	1.430	0.768	0.281	0.0016	0.0225



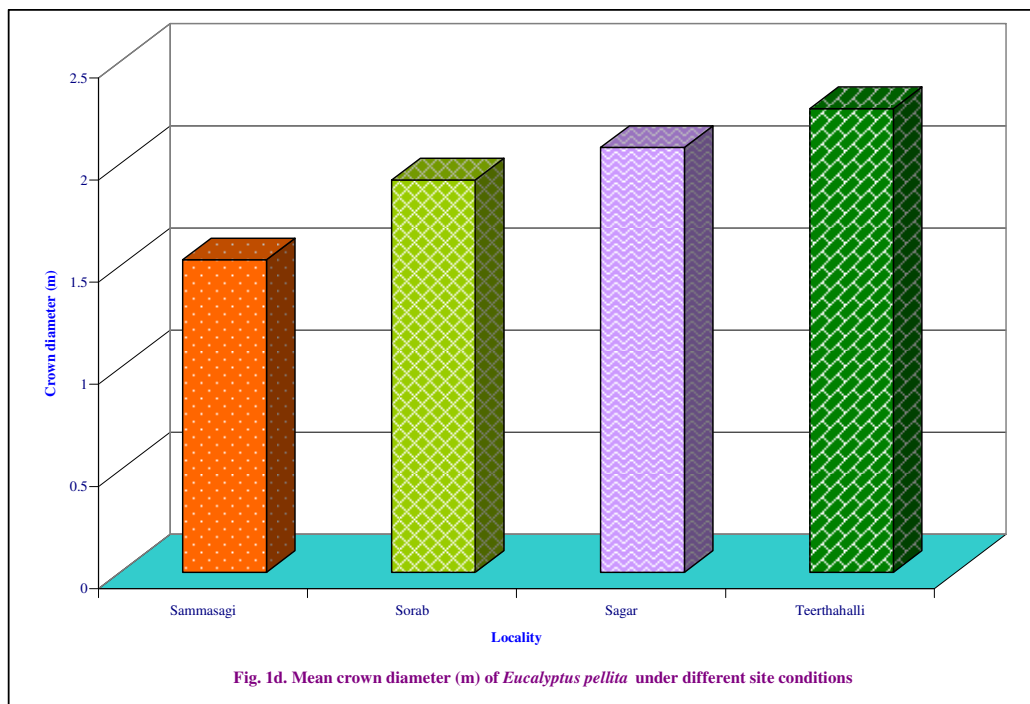
**Fig. 1a. Mean DBH (cm) of *Eucalyptus pellita* under different site conditions**



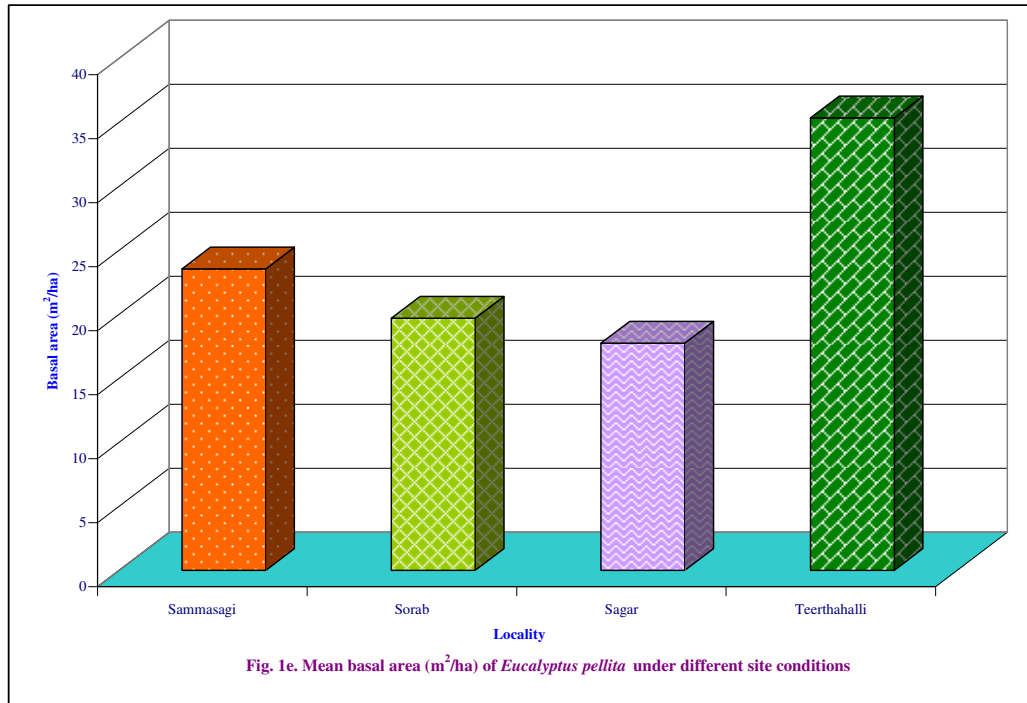
**Fig. 1b. Mean total height (m) of *Eucalyptus pellita* under different site conditions**



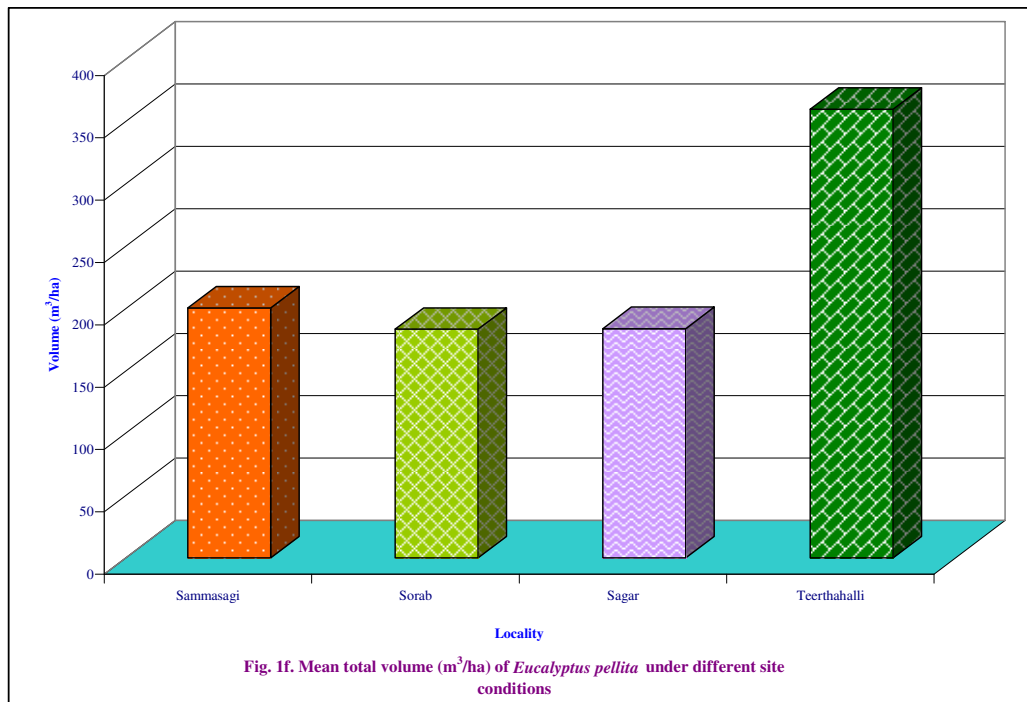
**Fig. 1c. Mean bole height (m) of *Eucalyptus pellita* under different site conditions**



**Fig. 1d. Mean crown diameter (m) of *Eucalyptus pellita* under different site conditions**



**Fig. 1e. Mean basal area ( $m^2/ha$ ) of *Eucalyptus pellita* under different site conditions**



**Fig. 1f. Mean total volume ( $m^3/ha$ ) of *Eucalyptus pellita* under different site conditions**

**Table 5. Soil properties of *Eucalyptus pellita* F. Muell plantations**

Site condition	Plantation / control	Physical properties			Chemical properties				
		Bulk density	Particle density	pH	EC (dsm <sup>-1</sup> )	N	P	K	Organic Carbon (%)
		(g/ml)				(kg/ha)			
Sammalagi	Plantation	1.34	2.35	5.44	0.37	173	18.88	333.6	0.81
	Control	1.80	2.45	6.80	0.35	168	10.10	264.0	0.71
Sorab	Plantation	1.31	2.28	5.74	0.36	140	19.78	127.0	0.89
	Control	1.41	2.39	6.30	0.34	154	11.20	84.0	0.77
Sagar	Plantation	1.34	2.36	6.10	0.31	151	21.68	88.0	0.80
	Control	1.45	2.50	6.90	0.35	140	12.30	96.0	0.74
Teerthahalli	Plantation	1.27	2.37	5.10	0.39	140	25.32	139.0	0.91
	Control	1.38	2.52	5.90	0.38	126	12.60	84.0	0.81
S.Em ±		0.018	0.048	0.266	0.0178	6.834	0.896	25.00	0.0178
CD (0.05)		0.057	NS	0.819	NS	21.05	2.762	77.05	0.076

Among the plantations, soil potassium at Sammasagi differed significantly from other three plantations. Soil potassium under control condition had lower values than the treated plots (Sammasagi, 264 kg/ha, Sorab, 84 kg/ha, Sagar, 96 kg/ha and Teerthahalli, 84 kg/ha) (Table 5).

#### 4.2.8 Organic carbon

The organic carbon of soil under *E. pellita* varied from 0.80 to 0.91 per cent. . Among the plantations, Teerthahalli (0.91%) showed highest soil organic carbon followed by Sorab (0.89%), Sammasagi (0.81%) and Sagar (0.80%). Under control conditions, soil organic carbon had lower values than the treated plots (Sammasagi, 0.71%, Sorab, 0.77%, Sagar, 0.74% and Teerthahalli, 0.81%) (Table 5).

### 4.3 Oil yield and Leaf biomass from *Eucalyptus pellita*

#### 4.3.2 Oil yield

The oil yield (%) from *E. pellita* F. Muell leaves varied from per cent. Among the plantations, Sorab (0.44%), showed highest oil yield followed by Sagar (0.39%), Sammasagi (0.33%) and the lowest was in Teerthahalli (0.26%). Among these four regions, oil yield from Sorab and Sagar plantations were not significant but differed significantly from other two regions (Table 6 and Fig. 2).

#### 4.3.1 Leaf biomass yield

The leaf biomass yield (kg/ha) from *E. pellita* leaves varied from 5,685 to 13,115 kg per ha. Among these plantations, Teerthahalli plantation (13,115 kg/ha), showed highest leaf biomass followed by Sagar (10,355 kg/ha), Sorab (5,962 kg/ha) and lowest in Sammasagi (5,685 kg/ha) (Table 7 and Fig. 3a).

When oil yield from the leaves was expressed in liters per ha, it varied from 18.76 to 41.25 lit per ha. Among these regions, Sagar (41.25 lit/ha) showed highest leaf oil yield per ha followed by Teerthahalli (34.14 lit/ha), Sorab (26.24 lit/ha) and lowest in Sammasagi (18.76 lit/ha) (Table 7 and Fig. 3b).

The local market price of Eucalyptus oil is Rs.1900 per litre and the per hectare value is given here according to their oil yields viz., Sagar recorded as highest (Rs. 78,299/ha) followed by Teerthahalli (Rs.64,790/ha), Sorab (Rs.49,856/ha) and Sammasagi (Rs.35,644/ha) (Table 7 and Fig. 3c).

### 4.4 Chemical composition leaf oil of *Eucalyptus pellita*

Results of qualitative and quantitative analysis of oil from the leaves of *Eucalyptus pellita* are shown in Tables 8 to 11 and Figs. 4 to 7. The GC-MS chromatogram of the essential oil is displayed in Fig. 8-A to O. The chemical components of the volatile oil were determined by the peak area normalization method. The presence of several overlapping peaks reveals the complexity of the mixture. Seven to 15 compounds were detected in the essential oils, of which 4 to 5 were well identified as the major compounds in the leaf oil of *E. pellita* (Tables 8 to 11) (Fig. 8-A to O). The major chemical components were  $\alpha$ -pinene,  $\beta$ -pinene,  $\beta$ -selinene, globulol and eucalyptol (1, 8-cineol) (Fig. 9).

In Sammasagi area, 10 chemical components were obtained from the leaf oil of *E. pellita*, of which the eucalyptol (52.15%) had highest percentage, followed by  $\alpha$ -pinene (23.05%), globulol (4.62%),  $\beta$ -pinene (4.09%), geraniol (2.93%),  $\beta$ -myrcene (2.29%), fenchol (0.98%),  $\beta$ -selinene (0.78%), *cis*-Geraniol (0.65%) and lowest was camphene (0.5%) (Table 8).

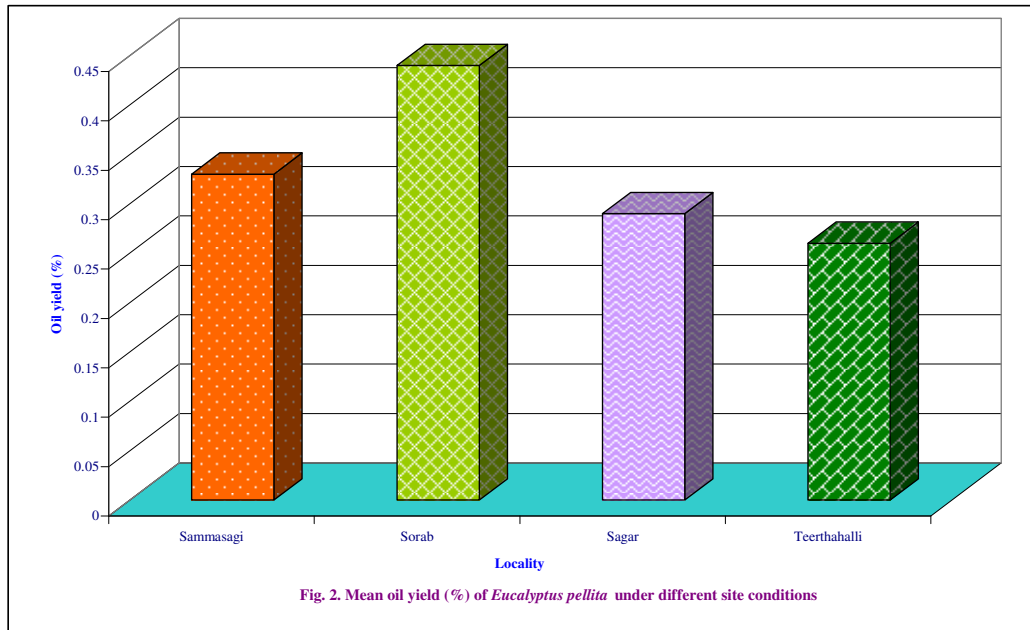
In Sorab area also 10 chemical components were obtained in the leaf oil of *E. pellita*, of which eucalyptol (42.84%) had highest percentage, followed by  $\alpha$ -pinene (28.33%),  $\beta$ -pinene (9.07%),  $\alpha$ -terpinene (7.84%), endo-borneol (2.59%), *trans*-pinocarviol (0.76%), globulol (0.77%), fenchol (0.68%),  $\beta$ -selinene (0.78%), and lowest was  $\beta$ -myrcene (0.5%) (Table 9).

**Table 6. Oil yield, colour and odor from the leaves of *Eucalyptus pellita* F. Muell from different localities**

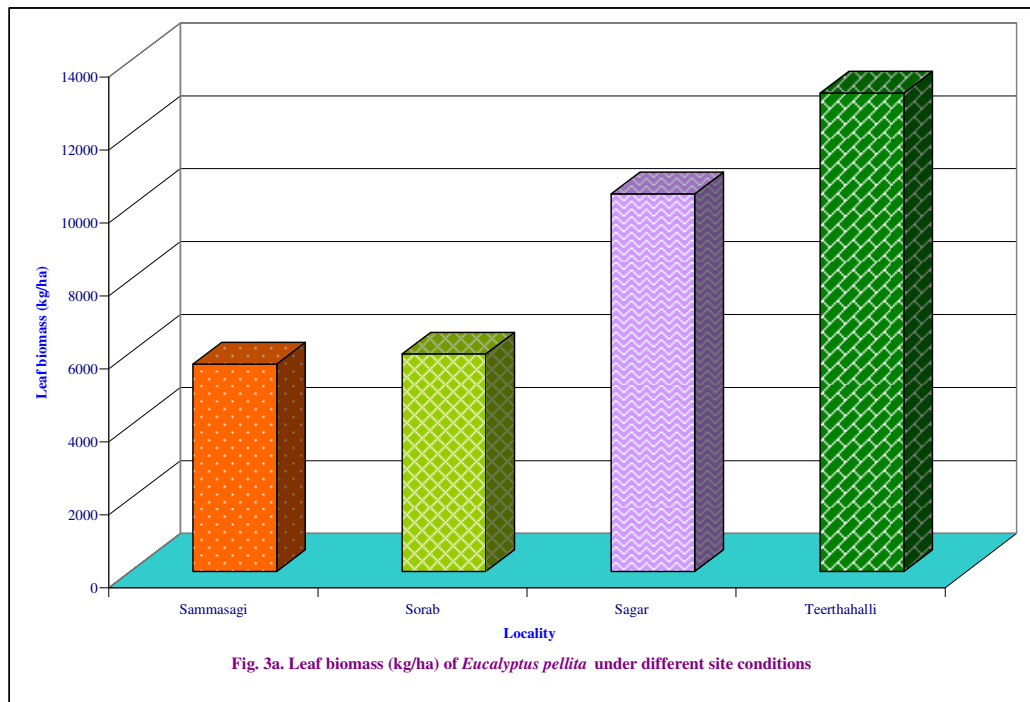
<b>Treatments</b>	<b>Locality</b>	<b>Oil yield (%)</b>	<b>Oil colour</b>	<b>Oil odor</b>
T <sub>1</sub>	Sammalagi	0.33	Yellow	Perfume
T <sub>2</sub>	Sorab	0.44	Yellow	Characteristic Perfume
T <sub>3</sub>	Sagar	0.39	Pale Yellow	Characteristic Perfume
T <sub>4</sub>	Teerthahalli	0.26	Pale Yellow	Perfume
S.Em ±	-	0.042	-	-
CD (0.05)	-	0.093	-	-

**Table 7. Leaf biomass and oil yield from *Eucalyptus pellita* F. Muell and market value of oil**

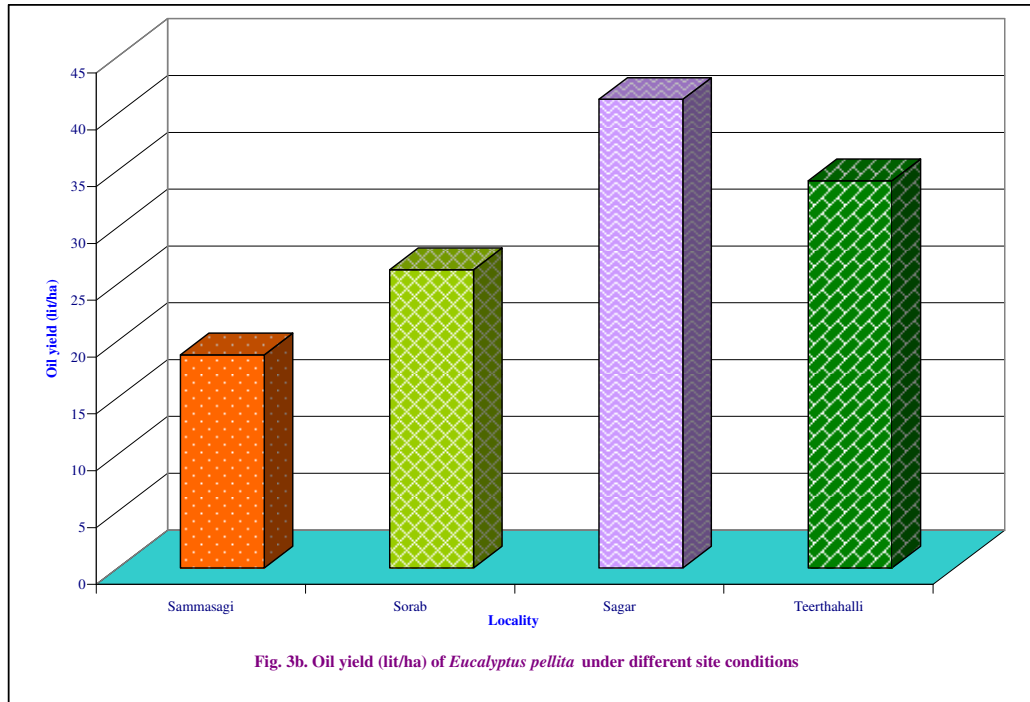
<b>Treatment</b>	<b>Locality</b>	<b>Leaf biomass (kg/ha)</b>	<b>Oil (%)</b>	<b>Oil yield (lit/ha)</b>	<b>Market rate (Rs/lit)</b>	<b>Market value of oil (Rs /ha)</b>
T <sub>1</sub>	Sammasagi	5685	0.33	18.76	1900	35,644
T <sub>2</sub>	Sorab	5,962.5	0.44	26.24	1900	49,856
T <sub>3</sub>	Sagar	10,355	0.39	41.25	1900	78,299
T <sub>4</sub>	Teerthahalli	13,115	0.26	34.10	1900	64,790



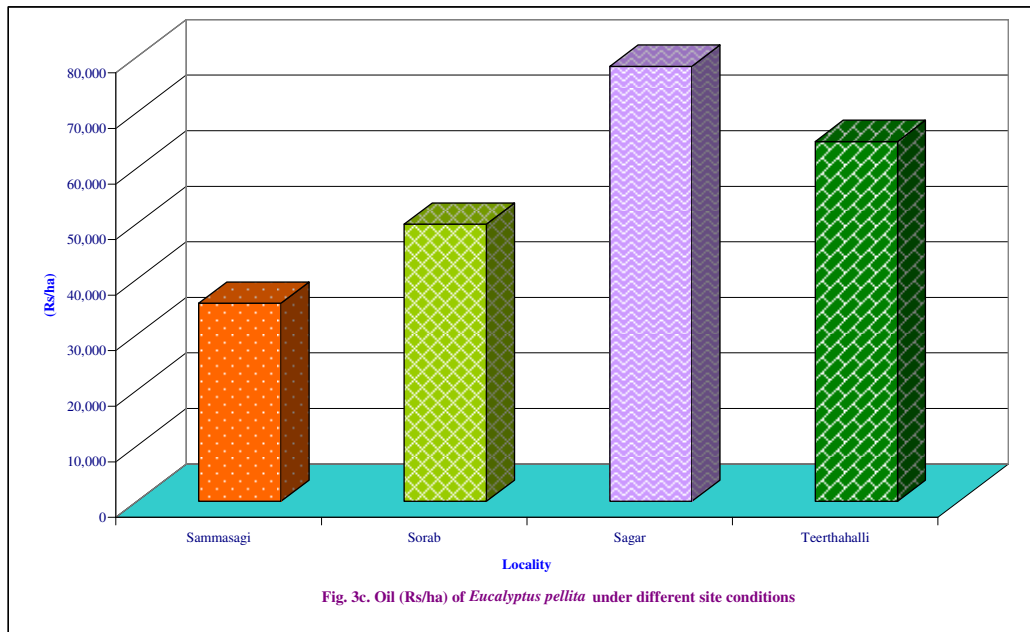
**Fig. 2. Mean oil yield (%) of *Eucalyptus pellita* under different site conditions**



**Fig. 3a. Leaf biomass (kg/ha) of *Eucalyptus pellita* under different site conditions**



**Fig. 3b. Oil yield (lit/ha) of *Eucalyptus pellita* under different site conditions**



**Fig. 3c. Oil (Rs/ha) of *Eucalyptus pellita* under different site conditions**

**Table 8. GC-MS report of essential oil of *Eucalyptus pellita* F. Muell leaves from Sammasagi**

Name	Molecular weight	% Area	Base peak	Retention Time
$\alpha$ -Pinene	136	23.05	93	2.706
$\beta$ -Pinene	136	4.09	93	2.864
Eucalyptol	154	53.15	43	3.093
Camphene	136	0.5	93	3.282
Fenchol	154	0.98	81	3.411
$\beta$ -Myrcene	136	2.29	41	3.533
Geraniol	154	2.93	69	3.649
<i>cis</i> -Geraniol	154	0.65	69	4.098
$\beta$ -Selinene	204	0.78	41	4.550
Globulol	222	4.62	43	5.033

**Table 9. GC-MS report of essential oil of *Eucalyptus pellita* F. Muell leaves from Sorab**

Chemical component	Molecular weight	% Area	Base peak	Retention Time
$\alpha$ -Pinene	136	28.33	93	2.721
$\beta$ -Pinene	136	9.07	93	2.873
Eucalyptol	154	42.84	43	3.094
<i>trans</i> -pinocarviol	150	0.79	93	3.278
Fenchol	154	0.68	81	3.409
$\beta$ -Myrcene	136	0.50	41	3.524
Endo-borneol	154	2.59	95	3.645
$\alpha$ -Terpeniol	140	7.84	59	3.717
$\beta$ -Selinene	204	0.62	41	4.551
Globulol	222	0.77	43	5.102

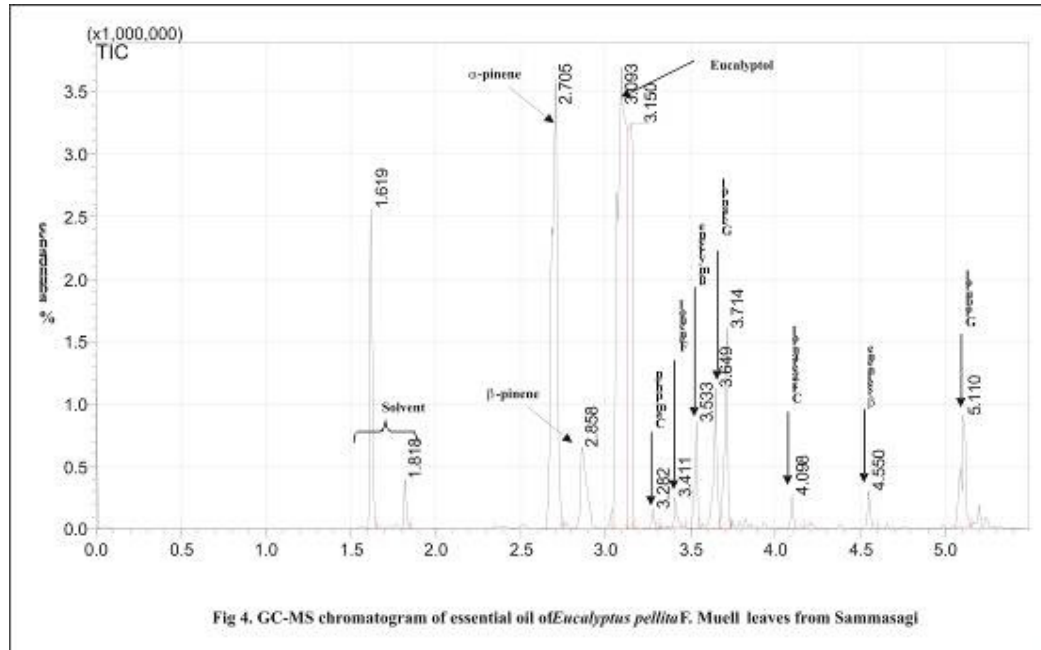


Fig 4. GC-MS chromatogram of essential oil of *Eucalyptus pellita* F. Muell leaves from Sammasagi

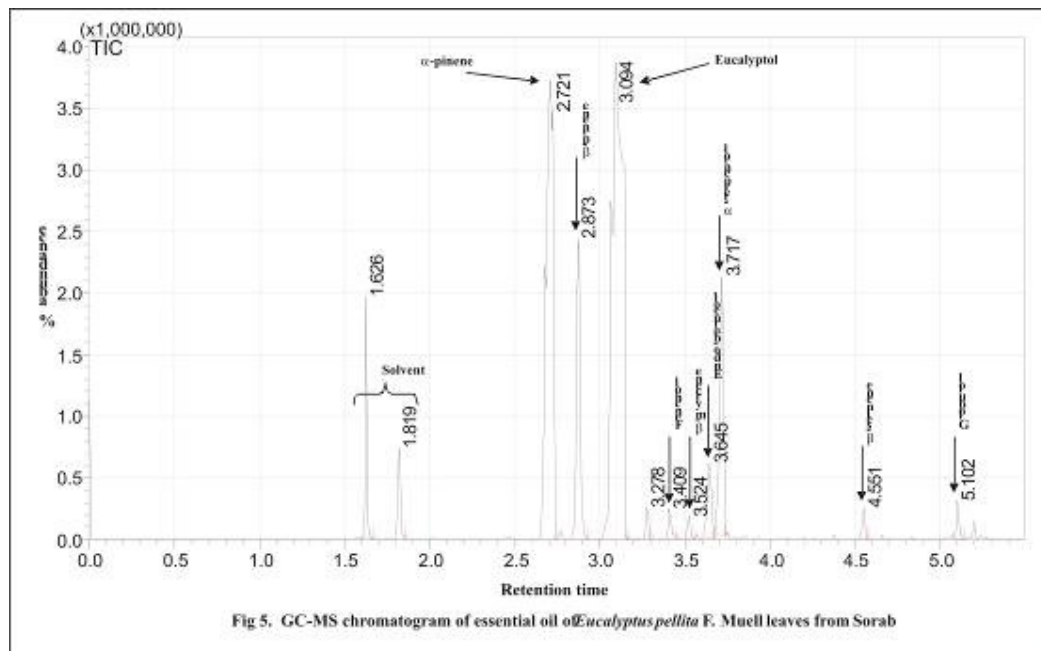


Fig 5. GC-MS chromatogram of essential oil of *Eucalyptus pellita* F. Muell leaves from Sorab

**Table 10. GC-MS report of essential oil of *Eucalyptus pellita* F. Muell leaves from Sagar**

Name	Molecular weight	% Area	Base peak	Retention Time
$\alpha$ -Pinene	136	17.43	93	2.650
$\beta$ -Pinene	136	1.25	93	2.833
Eucalyptol	154	71.68	43	3.025
Bi-Fenchol	154	1.24	92	3.500
Geraniol	154	2.05	69	3.583
$\alpha$ -Terpeniol	140	3.29	59	3.658
$\alpha$ -Selinene	204	0.94	41	4.533
Globulol	222	0.49	43	5.058

**Table 11. GC-MS report of essential oil of *Eucalyptus pellita* F. Muell leaves from Teerthahalli**

Name	Molecular weight	% Area	Base peak	Retention Time
$\alpha$ -Pinene	136	21.46	93	2.704
$\beta$ -Pinene	136	0.55	93	2.758
$\gamma$ -Terpinene	136	23.39	93	2.890
Eucalyptol	154	26.75	43	3.102
Fenchol	154	1.65	81	3.412
$\beta$ -Myrcene	136	0.94	41	3.528
Endo-borneol	154	6.15	95	3.657
$\alpha$ -Terpeniol	140	12.19	59	3.733
$\beta$ -Selinene	204	1.67	41	4.561
Globulol	222	1.56	43	5.110

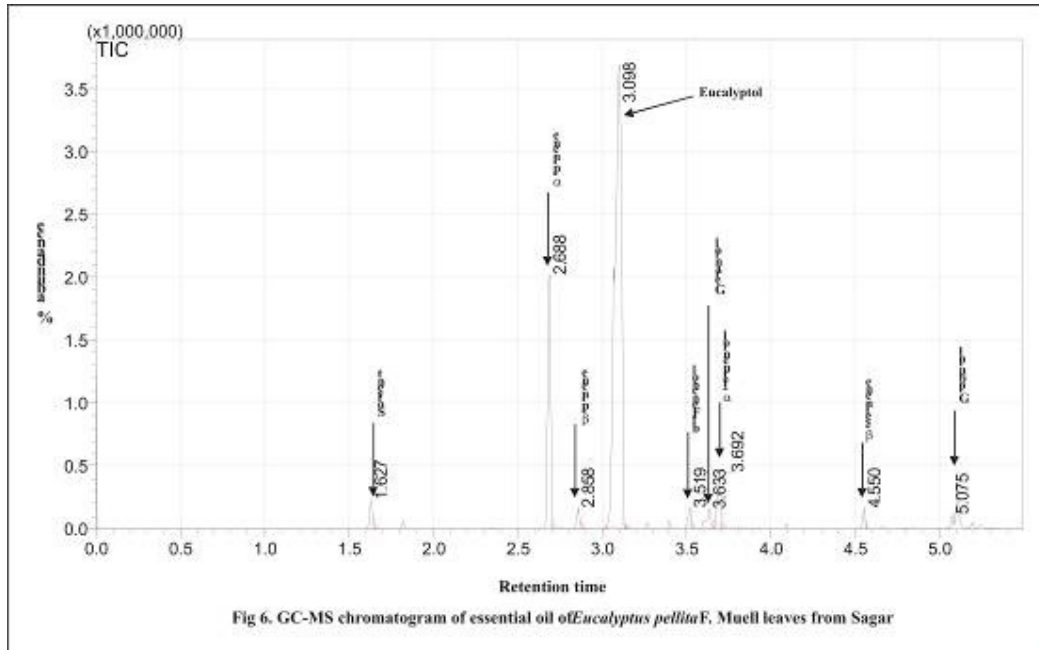


Fig 6. GC-MS chromatogram of essential oil of *Eucalyptus pellita* F. Muell leaves from Sagar

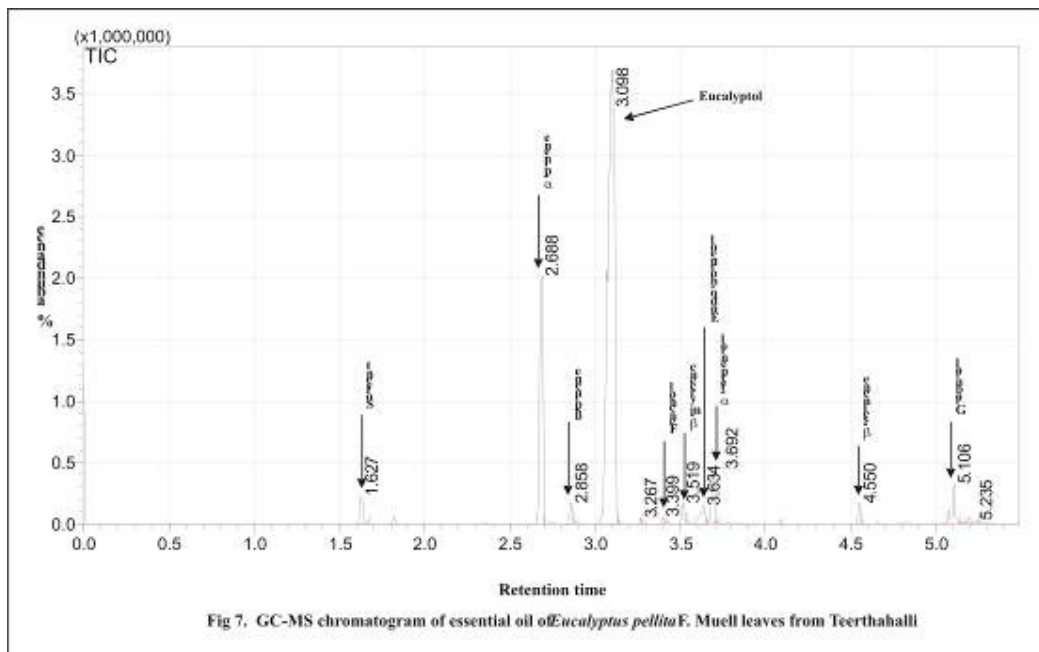


Fig 7. GC-MS chromatogram of essential oil of *Eucalyptus pellita* F. Muell leaves from Teerthahalli

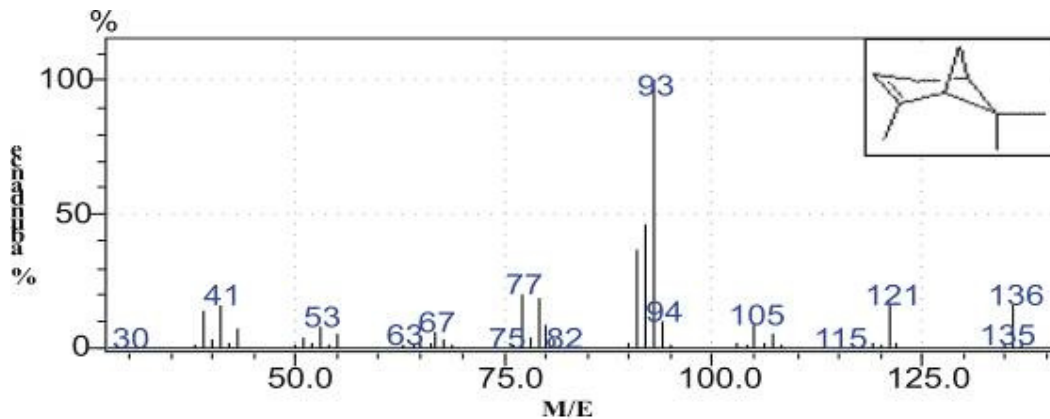


Fig. 8-A. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves -  $\alpha$ -Pinene

Fig 8-A The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves -  $\alpha$ -Pinene

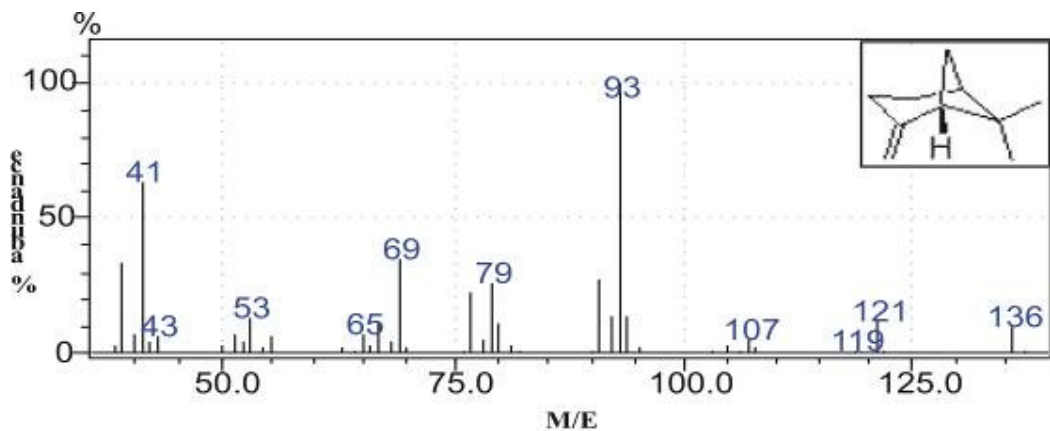


Fig. 8-B. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves -  $\beta$ -Pinene

Fig 8- B. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves -  $\beta$ -Pinene

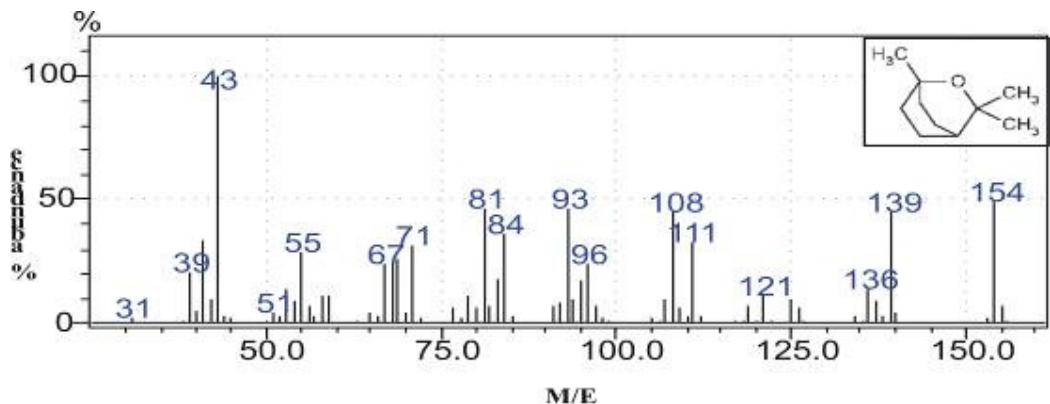
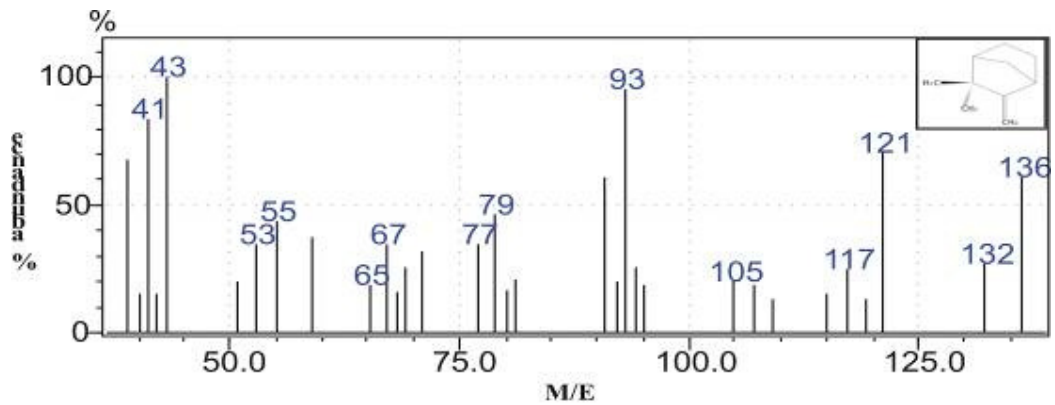
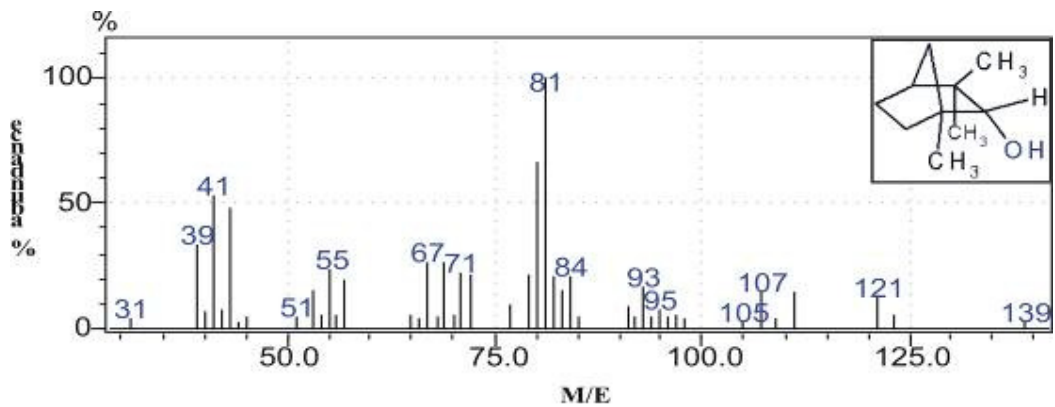


Fig. 8-C. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves - Eucalyptol

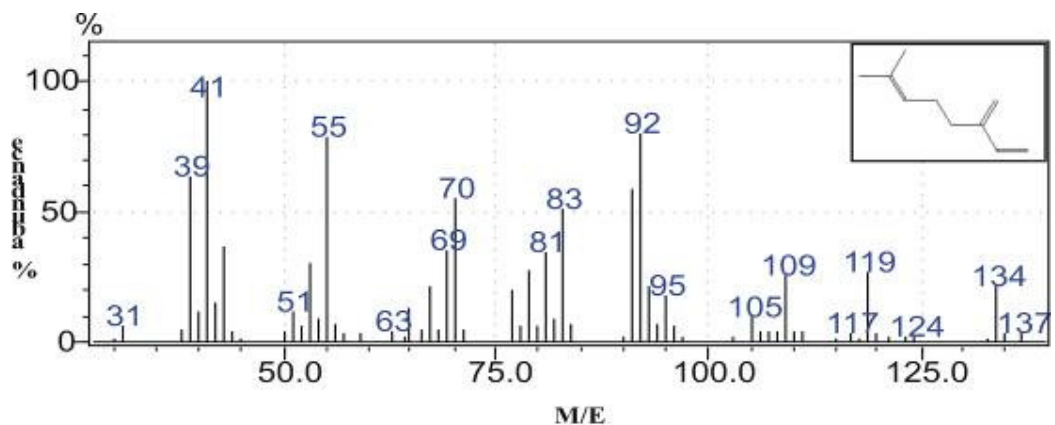
Fig 8 - C The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves - Eucalyptol



**Fig. 8-D. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves - Camphene**  
**Fig 8 - D. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves - Camphene**



**Fig. 8-E. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves - Fenchol**  
**Fig 8-E. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves - Fenchol**



**Fig. 8-F. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves -  $\beta$ -Myrcene**  
**Fig 8-F. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves -  $\beta$ -Myrcene**

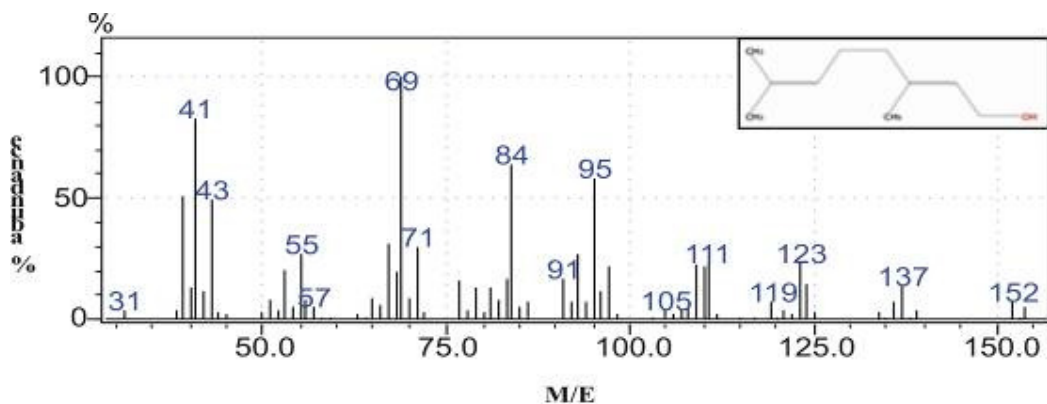


Fig. 8-G. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves - Geraniol

Fig 8-G. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves - Geraniol

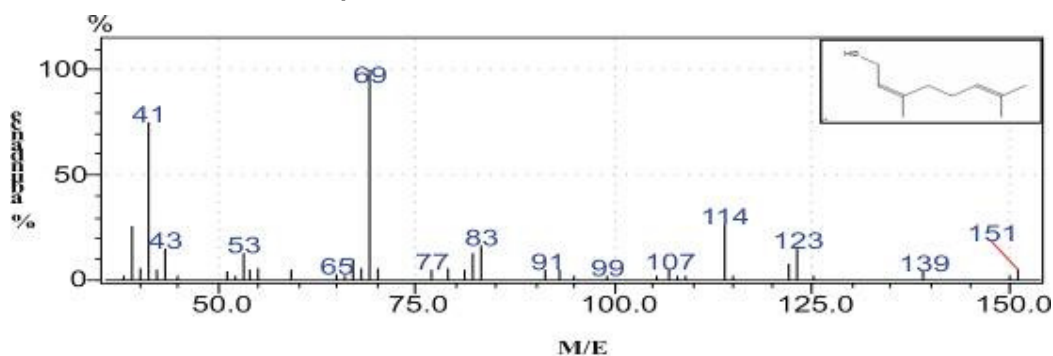


Fig. 8-H. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves - cis-Geraniol

Fig 8-H. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pelli*

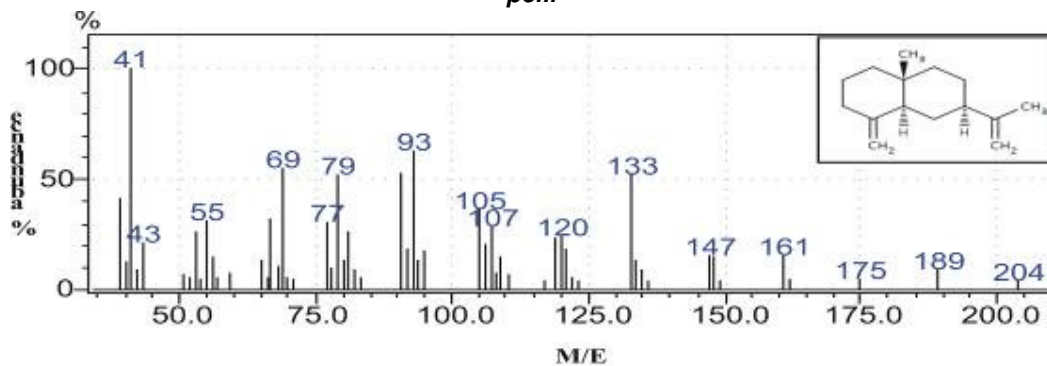


Fig. 8-I. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves - beta-Selinene

Fig 8-I The Mass Spectra of chemical components in the essential oil of *Eucalyptus pelita* F. Muell leaves - beta-Selinene

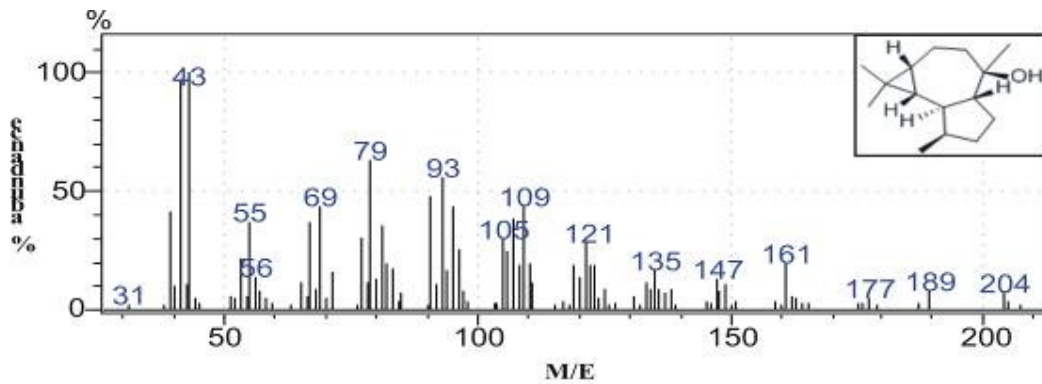


Fig. 8-J. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves - Globulol

Fig 8-j. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves - Globulol

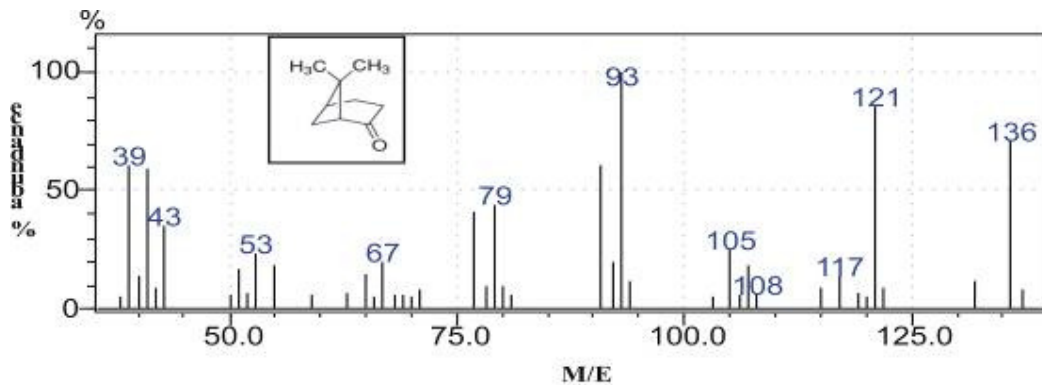


Fig. 8-K. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves - trans-Pinocarveol

Fig 8-K. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves - trans-Pinocarveol

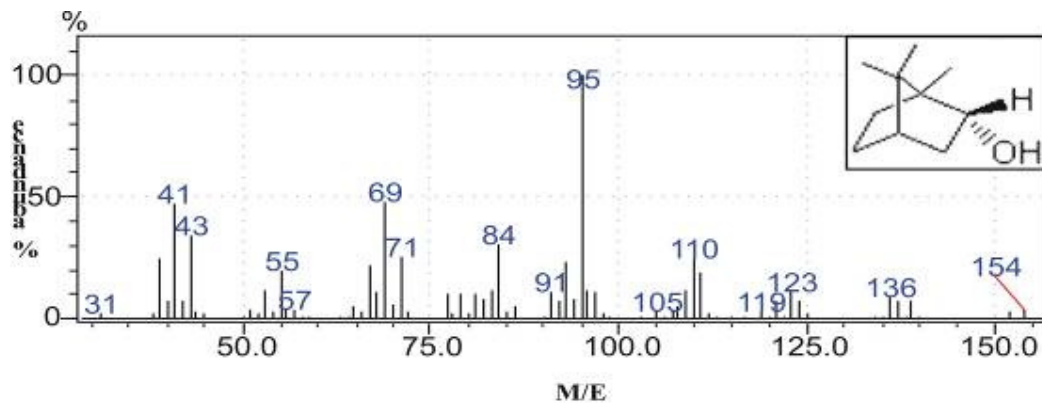


Fig. 8-L. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves - endo-Borneol

Fig 8-L. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves - endo-Borneol

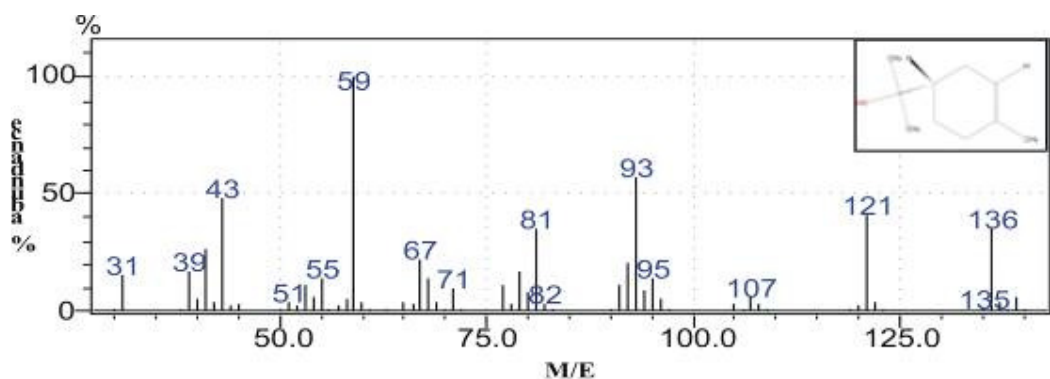


Fig. 8-M. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves -  $\alpha$ -Terpineneol

Fig 8-M. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves -  $\alpha$ -Terpineneol

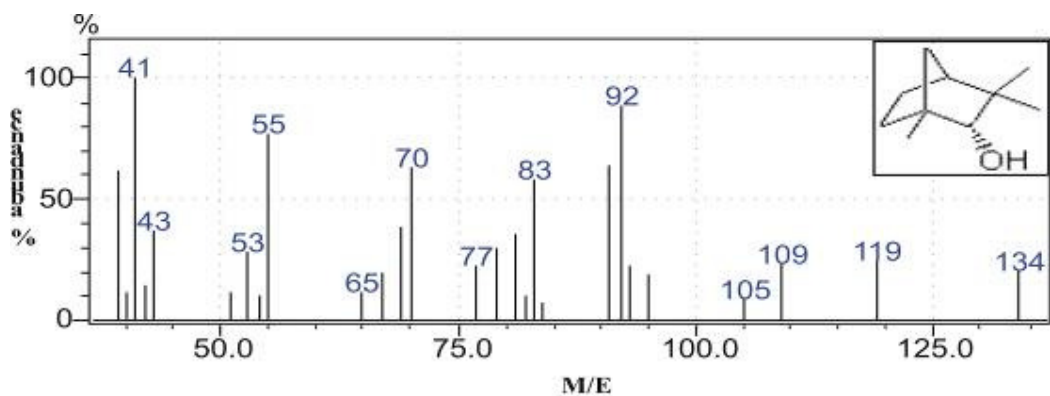


Fig. 8-N. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves - bi-Fenchol

Fig 8-N. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves - bi-Fenchol

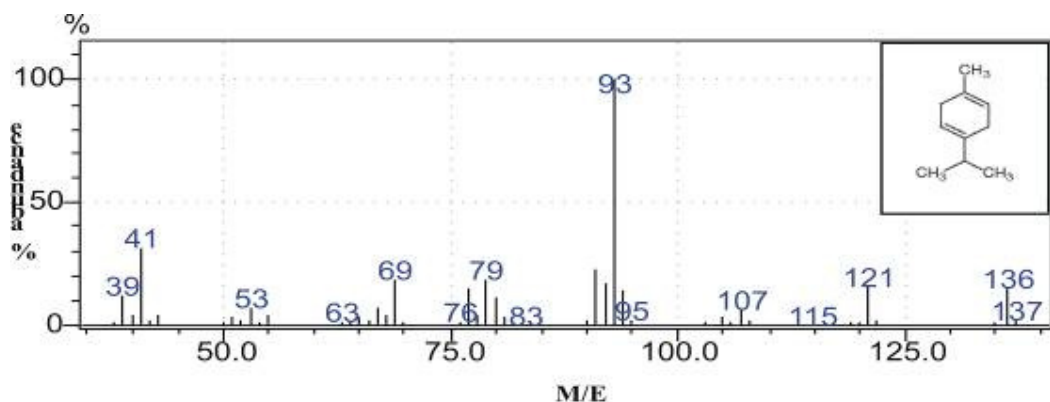


Fig. 8-O. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves -  $\gamma$ -Terpinene

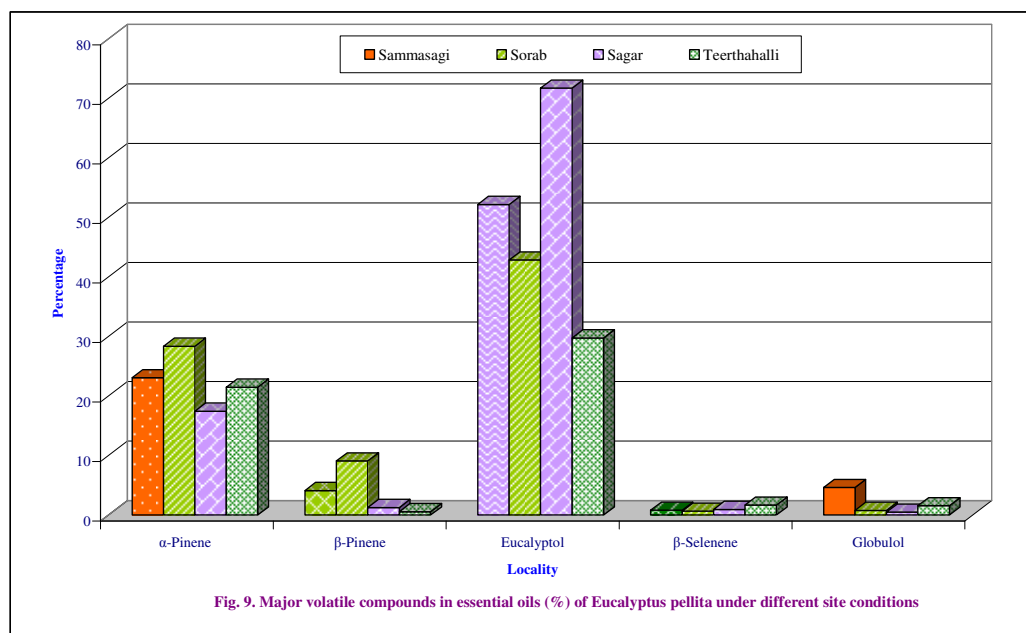
Fig 8-O. The Mass Spectra of chemical components in the essential oil of *Eucalyptus pellita* F. Muell leaves -  $\gamma$ -Terpinene

**Table 12. Percentage content of volatile compounds in essential oil of the leaves from examined *Eucalyptus pellita* F. Muell from agro-climatic zone 9 of Karnataka**

Figures	Compounds	Sammasagi	Sorab	Sagar	Teerthahalli
A	$\alpha$ -Pinene	23.05	28.33	17.43	21.46
B	$\beta$ -Pinene	4.09	9.07	1.25	0.55
C	Eucalyptol	52.15	42.84	71.68	29.75
D	Camphene	0.5	-	-	-
E	Fenchol	0.98	0.68	-	1.65
F	$\beta$ -Myrcene	2.29	0.5	-	0.94
G	Geraniol	2.93	-	2.05	-
H	<i>cis</i> -Geraniol	0.65	-	-	-
I	$\beta$ -Selinene	0.78	0.62	0.94	1.67
J	Globulol	4.62	0.77	0.49	1.56
K	<i>trans</i> - Pinocarviol	-	0.79	-	-
L	endo-Borneol	-	2.59	-	6.15
M	$\alpha$ -Terpeniol	-	7.84	3.29	12.19
N	bi-fenchol	-	-	1.24	-
O	$\gamma$ -Terpinene	-	-	-	23.39

GC, identification based on retention times of authentic compounds on DB-5 fused silica column;

MS, tentatively identified on the basis of computer matching of the mass spectra of peaks with the NIST/NBS and Wiley libraries.



**Fig. 9. Major volatile compounds in essential oils (%) of Eucalyptus pellita under different site conditions**

In Sagar area, 8 chemical components were obtained from the leaf oil *E. pellita*, of which the eucalyptol (71.68%) had highest percentage, followed by  $\alpha$ -pinene (17.43%),  $\alpha$ -terpeniol (3.29%), geraniol (2.05%),  $\beta$ -pinene (1.25%), bi-fenchol (1.24%),  $\beta$ -selinene (0.94%), and lowest was globulol (0.49%) (Table 10).

In Teerthahalli area, 10 chemical components were obtained from the leaf oil of *E. pellita*, of which the eucalyptol (26.75%) had highest percentage, followed by  $\gamma$ -terpinene (23.39%),  $\alpha$ -pinene (21.46%),  $\alpha$ -terpeniol (12.19%), endo-borneol (6.15%),  $\beta$ -selinene (1.67%), fenchol (1.65%), globulol (1.56%),  $\beta$ -myrcene (0.94%) and lowest was  $\beta$ -pinene (0.55%) (Table 11).

The results from all the four places with respect to the composition of *Eucalyptus pellita* oil varied except in some major components viz.  $\alpha$ -pinene,  $\beta$ -pinene,  $\beta$ -selinene, globulol and eucalyptol (1, 8-Cineol). Eucalyptol (Fig.8-C) showed high percentage in all the site conditions followed by  $\alpha$ -pinene (Fig. 8-A). However, the *cis*-geraniol (Fig. 8-H), *trans*-pinocarviol (Fig. 8-K) and  $\gamma$ -terpinene (Fig.8-O) were new components found in Sammasagi, Sorab and Teerthahalli plantations, respectively (Table 12).

## 5. DISCUSSION

The present extent of planted forest world wide probably exceeds 250 million hectares, corresponding to 6.6 per cent of the forest area. Planting in both tropical and temperate regions is leading to a significant net increase in plantations each year. It is predicted that a greater proportion of industrial wood will soon be tapped from the plantations than from the exploitation of natural forest. Hence, plantation forestry appears to become a major, perhaps dominant form of forest development in the future (Obe, 1999). *Eucalyptus pellita* F. Muell is one of the best known and popular pulp wood species introduced on a large scale across the world. It is imperative to understand the growth and productivity in relation to varied site conditions under which it is being grown.

The *Eucalyptus pellita* has been extensively raised on private farmlands and industrial private lands in Agro-climatic Zone-9 (Hilly Zone) of Karnataka state. The zone is highly variable with respect to climatic, topographic and edaphic conditions (Gaonkar, 1991). Despite the importance *Eucalyptus pellita* as a major plantation species, studies focusing on the effect of different site conditions on its growth, productivity and oil quantity and quality are surprisingly very scanty. The knowledge of species-site interaction will be highly useful in selecting sites for future plantations in order to increase the production per unit area. The plantation raised by Harihara Polyfibers industry in farmers land in the Agro-climatic Zone-9 offered great opportunity to study the response of *E. pellita* F. Muell to site conditions. Climate and topography of Ninth zone vary greatly in rainfall, number of rainy days and altitude. The results obtained in the present investigation are discussed hereunder.

### 5.1 Growth and productivity performance of *Eucalyptus pellita*

Several climatic factors like moisture, rainfall, number of rainy days, temperature, wind, etc. effect the vegetation. Among the climatic factors, rainfall and number of rainy days are most important. In the present study, the analysis of variance showed significant effect of site condition on various growth and productivity parameters such as DBH, total height, bole height, crown diameter, basal area and total volume. The growth and productivity parameter examined such as DBH (13.44 cm), crown diameter (2.27 cm), basal area (35.35 m<sup>2</sup>/ha), total volume (360 m<sup>3</sup>/ha) (Table 4) at different site conditions were found superior under very high rainfall area (Teerthahalli) plantation than rest of the sites. The Teerthahalli site was characterized by higher mean annual rainfall (3000 – 3500 mm) and more number of rainy days (125) (Table 1) and adequate moisture availability. This might have enhanced the growth of trees in the initial years and accelerated it at the subsequent litter fall leading to improved soil properties (Table 5). Most of the climatic and edaphic factors exhibited positive and significant correlations with almost all the growth and productivity parameters, except bulk density, particle density and pH which showed negative association with them. This may be due to increase in organic carbon content of the soil which decreases the bulk density and pH of the soil (Table 5). It is evident from the present investigation that the abundance of moisture coupled with rich nutrient status of their soils enhanced the growth and productivity of the species under the very high rainfall area (3000-3500). The poor growth attributes were observed in plantation grown under low rainfall areas (500-1000 mm) and number of rainy days (75) (Table 1). It may be noted here that soil properties were found to be poor under low rainfall area plantation as compared to rest of the sites.

The plantation under moderate rainfall (Sagar area) exhibited next superiority with respect to various growth and productivity parameters viz., bole height (12.71 m), total height (14.80 m), except DBH (9.2 cm) and basal area (17.7 m<sup>2</sup>) (Table 4). The region because of its high mean annual rainfall 2000 to 2500 mm and number of rainy days have probably supported the rich growth of the plantation in the initial years and thus accelerated its growth, productivity and subsequent litter fall, thereby enriching the soil properties (Table 5). The growth and productivity attributes exhibited positive and significant association with most of the climatic and edaphic factors, except electrical conductivity and particle density which showed negative association. This may be due to increase in nitrogen and phosphorus content of soil and pH. The availability of abundant moisture coupled with rich soil nutrients might have enhanced the growth (except DBH) and productivity under Sagar (high rainfall area) plantations. However, the DBH and basal area were comparable with other three sites. This may be attributed to the low temperature and high humidity of the site.

The plantation grown under low (Sammasagi) and high (Sagar) rainfall areas were next in the rank of productivity parameters to the plantation under moderate rainfall (Sorab) (Table 1).

The plantation under moderate rainfall areas (Sorab) exhibited low superiority over other sites but was high with respect to various growth and productivity parameters *viz.*, bole height (9.8 m), total height (13.35 m) but low in DBH (10.3 cm), basal area (19.7 m<sup>2</sup>/ha) and volume (183.5 m<sup>3</sup>/ha) (Table 4). The region because of its moderate mean annual rainfall 1500 to 2000 mm and number of rainy days (Table 1) might have supported the rich growth of the plantation in the initial years leading to acceleration of its growth. The low productivity or poor performance observed in this region may be attributed to its less deep soil properties nitrogen, potassium, phosphorus, electrical conductivity and pH which may be due to poor fertility build up and competition for nutrients by the seedlings because of its profuse natural regeneration in these sites (Table 5).

The plantation under low rainfall areas (Sammasagi) occupied second place with respect to various growth and productivity parameters *viz.*, DBH (10.9 cm), basal area (23.55 m<sup>2</sup>/ha) and total volume (200.5 m<sup>3</sup>/ha) (Table 4). The region because of the growth and productivity attributes exhibited positive and significant association with most of the climatic and edaphic factors, except in bulk density, particle density, pH and phosphorus which showed negative association. This may be due to increase in nitrogen and phosphorus content of the soil (Table 5). The availability of abundant moisture coupled with rich soil nutrients might have enhanced the growth (except DBH) and productivity under Sagar region (high rainfall area) plantations. However, the DBH, basal area, total volume of the tree were comparable with the other three sites which may be attributed to the high temperature and low humidity of the site.

The similar results reported by Harwood *et al.* (1997) reveal that in New Guinea provenances of *Eucalyptus pellita* were good performers relative to other *Eucalyptus* species in certain lowland tropical environments, in both seasonally dry and year-round-humid climates and on soils of relatively low to high fertility. Although they can tolerate a dry season of up to 5–6 months and annual rainfall of only 1200 mm (Pegg and Wang, 1994 and Pinyopusarerk *et al.*, 1996), under these conditions their advantage over Queensland provenances of *E. pellita* appears to be minor. The superiority of the New Guinea over the Queensland provenances appears clearest on lowland tropical sites with high annual rainfall (over 1600 mm) and a short (4 months or less) dry season. Dickinson and Sun, (1995) reported that *E. urophylla* and *E. pellita* grown on a lowland site with higher rainfall and grown on more fertile *i.e.*, kraznozem soil, survival and health of both the species was excellent. *E. urophylla* slightly outgrew *E. pellita* in this trial, although its stem form had inferior growth and was much faster than that on the infertile, poorly textured Cardwell soil. The Keru provenance of *E. pellita* attained a mean DBH of 15.7 cm at 39 months of age. *E. grandis* and *E. tereticornis* showed a standing volume of 88.5 and 205 m<sup>3</sup> per ha at the age of 4 and 10 years, respectively in Asarori area of Deharadun (Dwivedi, 1993).

## 5.2 Influence of *Eucalyptus pellita* on soil properties

*Eucalyptus pellita* exerts great influence on both the soil physical and chemical properties. The species shed good amount of litter material on to the soil resulting in enrichment of the soil properties.

### 5.2.1 Soil physical properties

The soils under plantations exhibited lower Bulk density as compared to their respective control sites. The reduction in Bulk density was high under Teerthahalli plantations (1.27 g/ml) and low in Sammasagi and Sagar plantations (1.34 g/ml) (Table 5). Moreover, the plantations under high rainfall area (Teerthahalli) showed higher reduction in the bulk density as compared to the low and moderate rainfall area (Sammasagi and Sagar). The reduction in bulk density may be attributed to higher production of litter material and its incorporation into the soil as humus over their respective controls as observed by Prathiban and Rai (1994). They reported that the soil physical properties such as bulk density, particle density and water holding capacity were distinctly improved under plantation of *Eucalyptus tereticornis*, as compared to rest of the species and their respective control sites.

The particle density was low under all the plantations as compared to their respective control sites. The reduction in particle density was high under Sorab plantation (2.28 g/ml) and low in Teerthahalli plantation (2.37 g/ml) (Table 5). The results clearly reveal that the plantation with medium rainfall had low particle density and the plantation with high rainfall had slightly increased particle density because there was no significant difference between those areas. The reduction in the particle density may be attributed to the addition of litter material and subsequent decomposition resulting in the production of higher organic carbon content in plantation as compared to their respective control sites (Prathiban and Rai, 1994).

### 5.2.2 Soil chemical properties

Soil fertility is determined by the presence or absence of plant nutrients *i.e.* macro and micronutrients. For obtaining high yield and quality, nitrogen, phosphorus and potash are supplied to the soil through commercial fertilizers. Nitrogen plays an important role in utilization of carbohydrates, phosphorus in energy transformation and potash in the activation of enzymes, osmotic regulation and protein synthesis (Samuel, 1985). Nutrients taken up by the plants are used for their growth and development activities and their concentration at root surface plays a key role in meeting these requirements (Wild and Jones, 1988). It may be noted here that the improvement in the chemical properties of soil under all the plantations was better as compared to their respective control sites (Table 5).

The soil pH was found to be reduced under all the plantations as compared to their respective control sites. It may be observed from Table 5 that the soil pH was 5.1 in Teerthahalli plantation, 5.44 at Sammasagi, 5.74 at Sorab and 6.1 in Sagar plantation. The reduction in pH noticed under plantations may be attributed to higher organic matter content and high microbial activities resulting in the production of high amount of organic acids, which in turn might have lowered the pH of the soil under the plantations as compared to their respective controls. These results are in conformity with the findings of Animon *et al.* (1999) who reported that soil pH under *E. tereticornis* ranged between 5.0 and 5.7 with depth. Syed *et al.* (2006) in Eucalyptus and Singh and Totey (1985) reported maximum increase in cation exchange capacity, exchangeable cations and organic matter in the soil under miscellaneous plantation flowers by Teak and Eucalyptus in Bhata soil of Raipur (MP).

The soils in the eucalyptus plantation with the oblong conical canopy were more subjected to the action of the environmental factors leading to enhanced leaching of bases which might have led to relatively higher acidity of soils in eucalyptus plantations observed in this investigation (Mary and Sankaran, 1991).

The soil under the plantations showed higher electrical conductivity than their corresponding control sites, except Sagar site. The increase in electrical conductivity was higher under Teerthahalli plantation (0.39 dS/m) followed by Sammasagi (0.37 dS/m) and Sorab (0.36 dS/m) and Sagar plantation (0.31 dS/m) (Table 5). Among these four sites there was no significant difference. Syed *et al.* (2006) reported that soil electrical conductivity of the soil samples in Eucalyptus plantations varied from 0.08 to 0.35 dS per m. This indicates that there was no contribution of the litter in increasing the cations in the soil under plantation significantly as compared to control sites.

The higher nitrogen content was observed under plantations (140-173 kg/ha) than their respective control sites (126- 168 kg/ha). The increase in nitrogen content was high under Sammasagi plantation (173 kg/ha) and low under the plantations of Sagar (140 kg/ha) and Teerthahalli (140 kg/ha) (Table 5). Stewart and Vander (1988) reported that soils at Kalhari and Miombo sites were strongly acidic and infertile nitrogen, mineral nitrogen and available phosphorus in the surface 10 cm under Miombo were more than double the values measured under Eucalyptus and the total nitrogen was significantly higher at the depth of 20-30 cm.

The higher phosphorus content was observed under plantations (18.88 - 25.32 kg/ha) than their respective control sites (10.10 - 12.60 kg/ha). The plantations under Teerthahalli had higher phosphorus content (25.32 kg/ha), whereas phosphorus content at Sammasgi it was low (18.88 kg/ha) (Table 5). Similar results have been observed by Animon *et al.* (1999) in *Eucalyptus tereticornis* and Syed *et al.* (2006) in Eucalyptus species.

In the present study, the plantations exhibited higher potassium content (88.0 – 333.6 kg/ha) than their respective control sites (84.0 – 264.0 kg/ha), except Sagar site. The potassium content was highest under the plantations in Sammasgi (333.60 kg/ha) and lowest under the plantations in Sagar (88.00 kg/ha) (Table 5). The observations on higher nitrogen, phosphorus and potash content of the soils under plantations may be attributed to the addition of organic matter in the form of litter fall under plantations as compared to their respective control sites. The significant differences between the plantation sites may be due to the climatic factors and edaphic factors *etc.* It may also be due to the leaching effect in high rainfall areas for low potassium. Stewart and Vander (1988) reported that exchangeable potassium and magnesium were higher under Eucalyptus plantation. The observations of Animon *et al.* (1999) in *Eucalyptus tereticornis*, Syed *et al.* (2006) in Eucalyptus species and Guo *et al.* (2002) in *E. tereticornis* lend support to the findings of the present investigation.

Organic carbon was found to be on the higher side under plantations than their respective control sites. The plantation under Teerthahalli recorded organic carbon content of 0.91 per cent and Sagar plantations recorded the lowest value of 0.80 per cent (Table 5). In general, the organic carbon content of the soil reflects the differences in quantity of leaf litter fall and the rate of its decomposition. This may be attributed to addition and incorporation of organic matter in to the soil. Vadiraj and Rudrappa (1990) reported decrease in pH, increase in organic carbon status of soil under five year plantation of *Casurina equisetifolia*, *Eucalyptus cameldulensis*, *Tamarindus indica* and *Mangifera indica* at Hoskote near Bengaluru. Similar results have been observed by Swami and Proctor (1997) in Eucalyptus, Teak and Acacia.

Chavan *et al.* (1995) reported that forest tree species such as *Tectona grandis*, *Terminalia tomentosa*, *Pongamia pinnata*, *Gmelina arboria*, *Eucalyptus*, *Acacia ariculiformis* and *Casurina equisetifolia* grown on lateritic soil showed significant increase in organic carbon, available nitrogen, potassium and phosphorus in the surface layer under plantations than their respective control sites.

### 5.3 Leaf biomass of *Eucalyptus pellita*

The four regions of Hilly zone studied in this investigation showed variation in the leaf biomass. Among these regions, Teerthahalli (13,115 kg/ha), showed highest leaf biomass followed by Sagar (10,355 kg/ha), Sorab (5,962 kg/ha) and lowest in Sammasagi (5,685 kg/ha) (Table 7 and Fig. 3a). The yield from Eucalyptus varied from 5.685 to 13.115 tonnes per ha in all the sites. These results may be attributed to the differential mean annual rainfall of the particular site. The plantation in Teerthahalli had higher leaf yield per hectare because of higher rainfall of the site and it was characterized by higher mean annual rainfall of 3000 to 3500 mm and more number of rainy days (125) and adequate moisture availability (Table 1). It might have enhanced the growth and high yield of foliage. The climatic factors, edaphic factors and addition and incorporation of organic matter and high microbial activities in the soil resulting in the production of high amount of leaves might have produced higher biomass.

The observations of Ravat *et al.* (2008) are worth mentioning here. They observed that the biomass yield from Eucalyptus varied from 39.4 to 738.98 kg per tree and from 77.29 to 223.46 tonnes per ha in all the sites. Productivity varied from 2.57 tonnes per ha per year (at 32 years) to 9.31 tonnes per ha per year (at 24 years). The contribution of individual tree components to total biomass varied as leaf (1.41 to 4.29%), twig (2.92 to 6.31%), branch (10.95 to 19.98%), bark (6.65 to 10.69%), root (15.29 to 20.61%), and bole (42.86 to 56.33%). The per cent contribution of all the tree components in all the sites were in order of bole followed by root, branch, bark, twig and leaf.

There were strong effects of soil fertility on volume of the tree and leaf biomass, as measured by soil total nitrogen content, particularly in the higher rainfall zone (>800 mm). It may be noted that increase in total nitrogen content from 0.1 to 0.4 per cent increased tree volume from 60 to 150 m<sup>3</sup> per ha in the low evaporation zone and from 40 to 120 m<sup>3</sup> per ha in the high evaporation zone. These responses did not occur in the 600-800 mm rainfall zone. Total nitrogen content may be associated with a range of other soil attributes, such as texture, which influences nutrient and water supply and hence growth. They further observed that there will be a strong response in existing plantations to nitrogen fertilization, where soil total nitrogen contents are low and there is an adequate moisture supply (Harper *et al.* 2000).

Similar findings on biomass were reported by Madgwick *et al.* (2003) in *Eucalyptus species*, Dogra and Sharma (2009) in *Eucalyptus hybrid*, *E. camuldulensis*, *Acacia albida* and *Acacia auriculiformis*. Similar observations were also reported by Kaufmann (1977), Bachelard (1986), Myers and Landsberg (1989), Larcher (1995), Khan *et al.* (1996) and Nilsen and Orcutt (1996) in *E. grandis*.

#### 5.4 Yield and composition of oil from the leaves of *Eucalyptus pellita*

The essential oil content of the leaf samples of *Eucalyptus pellita* from Agro-climatic Zone-9 (Hilly Zone) of Karnataka state showed significant variations in the oil potential as well as in the chemical composition of essential oils. The amount of essential oil was obtained by hydro distillation using a Clevenger-type apparatus. All the extracted essential oils from all the *E. pellita* plants under study oils were of pale yellow to yellow coloured mobile liquids having camphor like smell predominantly of 1, 8-cineole (Table 6). Grieve (1992) also reported similar colour and smell characteristics of *Eucalyptus polybractea* oil. It may be recalled here that the highest oil yield was obtained with fresh leaves of *E. pellita* F. Muell from Sorab sample (0.44%), while the lowest was from Teerthahalli site (0.26%). The odour of oils from Sorab and Sagar was characteristic perfume, while it was perfume for oils from Sammasagi and Teerthahalli. Oil colour was found to be pale yellow to yellow that of Sammasagi and Sorab was yellow, while it was pale yellow for oils from Sagar and Teerthahalli.

The oil yield in any given situation is determined by the rate at which foliage biomass accumulates between successive harvests and the concentration of oil in the leaves. On the other hand, biomass production in oil plantations is strongly influenced by the climatic and edaphic features of a given planting site and the quality of establishment of plantings (Whiffin, 1982 and Wildy *et al.*, 2000). The bioactivity of the essential oil depends upon the type and nature of the constituents and their individual concentrations (Brooker and Kleinig, 2006) and which are highly determined by the genotype (Barton *et al.*, 1991). However, the environment may also influence the oil yields. Leaf oil yield further varies markedly between seasons and in relation to site-specific edaphic factors including season, location, climate, soil type, leaf age, fertility regime, the method used for drying the plant material and the method of oil extraction (Doran and Bell, 1994).

The four regions of Hilly zone showed different oil yields (0.26- 0.44%). Among these regions, Sorab, showed highest oil percentage in *Eucalyptus pellita* leaves followed by Sagar, Sammasagi and lowest in Teerthahalli (Table 6 and Fig. 7). Zafar *et al.* (2003) also reported higher results regarding oil potential of different *Eucalyptus* species (0.58 - 1.47%) from Faisalabad (Pakistan). Wildy *et al.* (2000) investigated four promising *Eucalyptus* species from Western Australia at six locations and reported 0.01 - 13.0 per cent oil production. They attributed these observations to different agro-climates and soil composition.

It may be inferred from the present study that *E. pellita* is a potential source of essential oil with ability to grow in diverse type of climatic conditions. Looking at its potential it may be further characterized for inclusion in various cosmetics, medicinal and pharmacological attributes.

Abd EL Mageed *et al.* (2011) reported that 2.5 ml was the highest value of oil yield obtained with the dry leaves of *Eucalyptus camuldulensis*, while the lowest value of 1.4 ml from *E. resinifera*. Oil odour of *E. citrodora* and *E. gomphocephala* was characteristic perfume, while it was perfume for *E. camuldulensis* and *E. resinifera*. Oil colour was found to be pale yellow to yellow. They observed that the production of essential oil depended on the site conditions and the yield of the species. The oil yield also depended on the geographical location, climatic factors, age (maturity of plants), parts of the plant *etc.*

The oil yield was reported to vary from report to report for *E. citriodora*. Ermias *et al.* (2000) stated 1 per cent oil yield, whereas Getnet (2004) reported 4 per cent oil yield in *E. citriodora*. Similar findings were reported by Abdolhamid *et al.* (2009) in air-dried leaves and flowers of the *E. camaldulensis* plant which were subjected to hydro distillation using a Clevenger-type apparatus and yellowish oils were obtained, yields of which were 0.43 and 0.58 per cent, respectively.

Haq *et al.* (2007) reported highest (1.33%) and lowest (0.29%) oil content in the leaves of *Eucalyptus crebra* collected from Shekhupura and Bahawalnagar, respectively. The soil of district Shekhupura and Lahore was found to be very fertile for essential oil production from *E. crebra* leaves. Grbovic *et al.* (2010) reported similar findings. Dethier *et al.* (1994), Chalchat *et al.* (2001) and Dang *et al.* (2001) reported that the amount of essential oil obtained by hydro distillation from the dried leaves varied from 0.63 to 1.59 per cent and compared well with available literature. They observed that only plants collected from the specific locations had satisfactory oil yield, whereas the other plants had rather poor oil yield.

The highest essential oil was extracted in the lowest altitude from *Thymus praecox* (2.73%), while it was the other way round at the highest altitude (1.98%). The highest thymol rate (69.08%) was ensured in the highest altitude. There were significant differences among populations for rates of essential oil with thymol and carvacrol content. However, rate of essential oil and its components depends upon many factors. Edaphic, climatic and genetic factors were reported to bring in chemical and compositional variations in essential oil of different plant species (Tkachev *et al.*, 2006; Mirjalili *et al.*, 2007; Lyra *et al.*, 2008; Echeverrigaray *et al.*, 2009; Hazzit and Baaliouamer, 2009 and Toncer *et al.*, 2010). Baser (2002) emphasized importance of harvesting period and time on essential oil rate in *M. communis*. Farah *et al.* (2006) reported that there could be differences in rates of essential oils among populations in *Myrtus communis*. In the present study, altitude was found to significantly influence 1, 8-cineole content and large individual differences were found in 1, 8-cineole content of *E. pellita*. At higher altitude, highest 1, 8-cineole content was found in *E. pellita* leaves. Similar findings were reported by Doran and Bell (1994) and Da Silva *et al.* (2006).

Sangwan *et al.* (2001) reported that leaf oil yield increased in the wet period following a dry season and then fell with approaching the next dry season. The greatest accumulation of recently mature leaf biomass with high oil yield values was expected to occur in the canopy when light, temperature and water were not limiting the growth (List *et al.*, 1995) which coincided with the summer time in their study area. It may be seen from the literature (Elaiissi *et al.*, 2007) that yields of oil from *Eucalyptus oleosa* from the center of Tunisia were richer in the essential oil than that of south with a difference of 2.25 per cent. The yield variability in the total essential oil of *E. oleosa* species growing in Tunisia was attributed to the soil conditions and ecological, climatic conditions, age of plant and the season of the harvest.

The GC-MS chromatogram of the essential oils is displayed in Figs. 4 to 7. The components of the volatile oils were determined by comparing their retention time with the retention time of standard compounds. Concentration of the detected or identified compounds was determined by the GC-MS QP2010S software considering the peak area or peak height. The presence of several overlapping peaks shows the complexity of the mixture. Seven to 15 compounds were detected in essential oils, of which 4 to 5 were well identified as the major compounds in *Eucalyptus pellita* F. Muell leaf oil (Tables 8 to 11) (Figs. 4 to 7 and 8-A to O). The major components were  $\alpha$ -pinene (17.43-28.33%),  $\beta$ -pinene (0.55-9.07%),  $\beta$ -selinene (0.62- 1.67%), Globulol (0.77- 4.62%) and Eucalyptol (1, 8-cineole) (26.79-71.68%). (Table 12) (Figs. 9 and 8-A to O). In addition, there were some other differences and similarity between oil compositions of *E. pellita* leaf oil. Similar variations in chemical composition in essential oil have been reported by previous workers in India, Pakistan and also across the world (Sheih, 1996; Bignell *et al.*, 1997; Oyedeji *et al.*, 2000; Pegula *et al.*, 2000; Tsiri *et al.*, 2003 and Zafar *et al.*, 2003).

It may be noted here that there are no reports on the chemical composition of essential oils of *E. pellita*. It is, therefore, for the first time that the analysis of leaf essential oil of *E. pellita* grown in Agro-climatic zone-9 of Karnataka is being reported through this investigation.

Results obtained from the qualitative and quantitative analysis of the oils of *E. pellita* F. Muell have been shown in Table 10. The eucalyptol, 1,8-cineole was high in Sagar area plantation (71.68%) (Fig. 8-C). On the basis of the results obtained, it may be inferred that the oil of *E. pellita* from the Sagar area was rich in 1, 8-cineole content. Among the four regions, Sagar region was the best place to grow the *E. pellita*. This oil may be used for medicinal purpose and as a substitute for the imported material. *E. pellita* with 0.39 per cent oil and 71.68 per cent of 1, 8-cineole content is suggested as its good source for medicinal use.

According to the European Pharmacopoeia, it has the most desirable specifications, *i.e.* not less than 70 per cent 1, 8-cineole content.

It is evident from results (Tables 8 to 11 and Figs. 4 to 7) that the chemical composition of essential oils varied in the leaves collected from different areas. The results reveal small differences in the composition of their oils with respect to data in the literature. These differences may be attributed to the geographical and climatic factors.

It may be concluded from the present study that *E. pellita* is a potential source of essential oil and it can grow in diverse climatic conditions. It should be further characterized for various commodities of cosmetics, medicinal and pharmacological attributes. The study on essential oil of the *E. pellita* F. Muell has shown that there is potential for commercial exploitation of medicinal Eucalyptus oil in India for both the domestic and export markets. Much will depend on how this species perform in different regions of the country.

This study indicates that climatic and edaphic conditions exercise appreciable effect on proportional yields of the desirable compound 1,8-cineole. However, variations between species and sites in terms of total oil yield tended to dominate over those relating to variations in balance of specific oil constituents. It may be noted that the production of total oil by sapling or coppice leaf biomass varied more than 10-fold between species and sites. Nevertheless, a small, but highly reproducible, negative correlation was evident between proportion of oil as cineole versus other relatively major compounds,  $\alpha$ -pinene,  $\beta$ -pinene,  $\beta$ -selinene, terpinen-4-ol and  $\alpha$ -terpineol. It may be inferred that there may be other, not yet identified, effects which influence balance between constituents when species are grown at different locations. All the above-mentioned oil constituents are closely related structurally and stem from the same monoterpene based branch in the biosynthetic pathway for oil synthesis in Eucalyptus leaves (Dewick, 1997) providing evidence that minor climatic or edaphic differences between locations might influence efficiency or inhibition of enzymes responsible for specific inter-conversions. (Fig. 10)

The yield of essential oil and the content of 1, 8-cineole are within the values reported in the literature (Li and madden, 1995) and the percentage contents of the main constituents are similar to those given in the literature. However, some constituents such as  $\beta$ -sabinene, linalool, isolekene, ledene, epi-globulol, and cubenol have no literature data (Silvestre *et al.*, 1997 and Lassak *et al.*, 1998). This possibly may be due to differences in their chemical constituents as trees grown in different regions exhibited differences in their constituents. In the present study too, the chemical composition of *E. pellita* oil varied from location to location (Table 6).

## 5.5 Economic return from leaf oil of *Eucalyptus pellita*

Although about 300 species of Eucalyptus have been shown to contain volatile oils in their leaves, only a few are important as far as commercial production of essential oils is concerned. The oils of these species are classified in trade in three broad types according to their composition and main end-use: Medicinal (Cineole-rich), Perfumery (citronellal-rich) and Industrial (rich in phellandrene and piperitone). The distinction is not hard and fast and all the three types of oils, for example, could be used in perfumery.

The local market price of Eucalyptus oil is Rs.1900 per litre and the per hectare value is given here according to their oil yields *viz.*, Sagar recorded as highest (Rs. 78,299/ha) followed by Teerthahalli (Rs.64,790/ha), Sorab (Rs.49,856/ha) and Sammasagi (Rs.35,644/ha) (Fig. 3-c).

Yearly world production of all the types of Eucalyptus oils is estimated to be 5,000 tonnes, of which about 63 per cent is medicinal oil, 33 per cent is perfumery oil, and only 4 per cent is industrial oil. Current market prices for world Eucalyptus oils range between Rs.769 and 6103 per kg. Indian prices vary for 60 per cent oil from Rs. 380 per kg and for 80 per cent oil from Rs.450 (Anon, 2010).

The planting of Eucalyptus trees in India has been expanding rapidly from state owned plantations to community woodlots and household compounds. Moreover, growing Eucalyptus at a farm level has become very popular among some farmers. In some cases, it has partially or completely replaced annual crops (Anon, 1988). The planting rate is increasing due to the high demand for Eucalyptus wood.

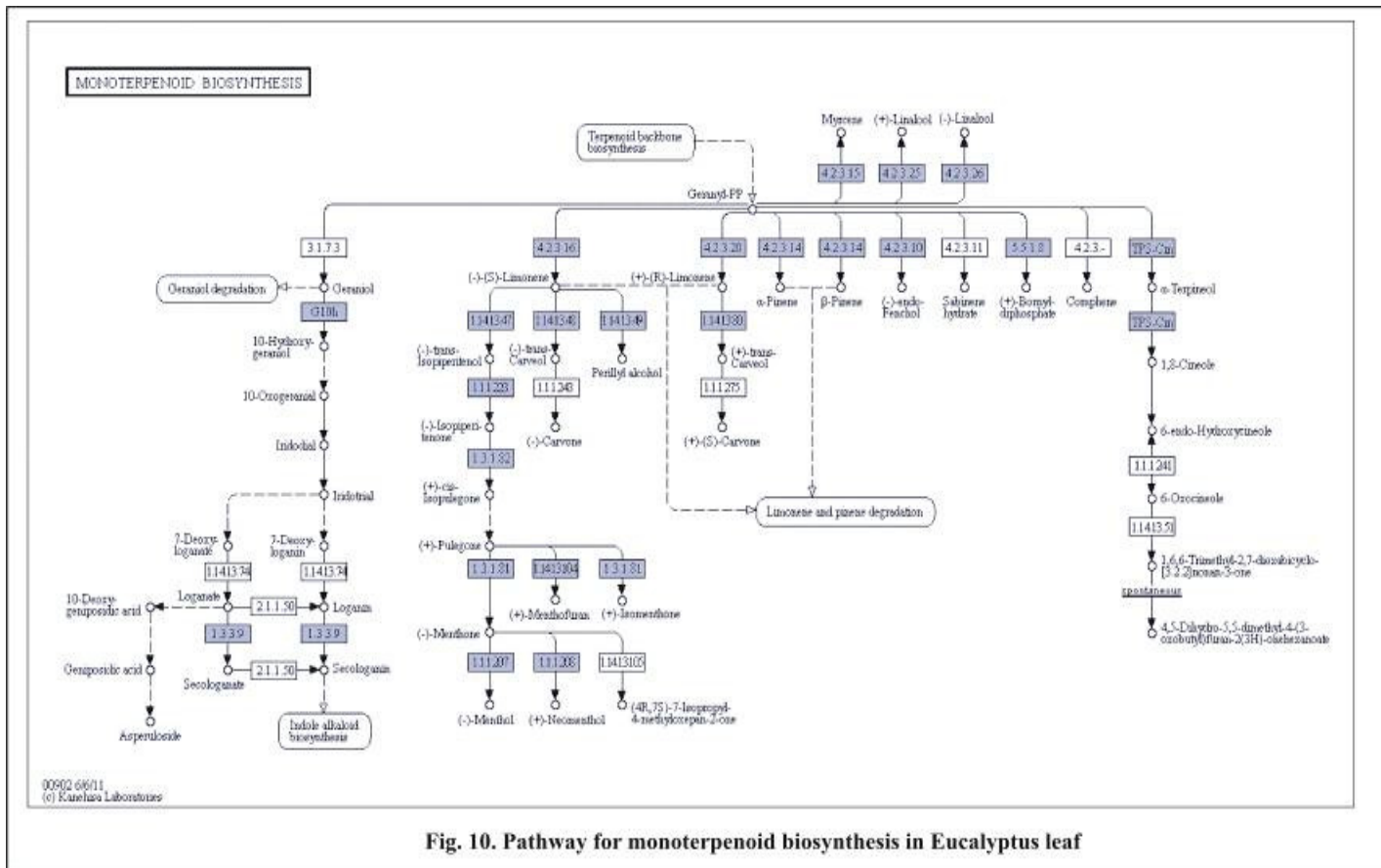


Fig. 10. Pathway for monoterpene biosynthesis in Eucalyptus leaf

Fig 10. Pathway for monoterpene biosynthesis in Encalyptus leaf

The use of Eucalyptus leaves as traditional medicine has been a long custom especially in the rural parts of India. It is also observed that Eucalyptus trees are grown in, around mourning places to refresh the air and to repel insects.

Similar applications of Eucalyptus leaves in flavour and fragrances, as condiment or spice, in medicines, as antimicrobial or insecticidal agents and to protect stored products is found in many parts of the world (Bakkali *et al.*, 2008). Among the number of species available in the country, *E. globules* and *E. citriodora* are promoted for essential oil production, at least on pilot scales. The dominant production system in India is traditional coppice system in which the wood part is used as fuel and the leaf part is usually extracted for essential oil.

One of the main advantages of using Eucalypts species for essential oil production is its ability to respond effectively to coppicing, which is central to the economic production of oil. Despite the available potential of Eucalyptus species to contribute towards the country's economy in essential oil sector, the present oil yield is considerably small and the major end users are small-scale detergent producers. Moreover, information on essential oil production in general and on yield influencing factors in particular is highly deficient (Anon 1995). To that end, this study helps in understanding the influence of abiotic factors like rainfall, temperature and soil properties on herbage and essential oil yield and oil quality of *E. pellita* F. Muell in Agro-climatic Zone-9 of Karnataka.

### Future line of work

1. *Eucalyptus pellita* F. Muell is a potential source of essential oil and it can grow in diverse type of climatic conditions. Work on characterization of its oil in various commodities like cosmetics, medicinal and pharmacological attributes is scanty which may be taken up in near future.
2. The study on essential oil of Eucalyptus species has shown that there is potentiality for commercial exploitation of medicinal Eucalyptus oil in India for both the domestic and export markets. Much will depend on how this species perform in different regions of the country. It may be standardized in future.
3. If intended to use *E. pellita* in the production of essential oils, further investigation may be undertaken for improving the efficiency of distillation process/units which is improved through design either to reduce energy consumption or to increase oil yield and by determining the most appropriate age at harvesting and harvesting time for better use efficiency.
4. Looking at the potential of *E. pellita* in the present study, establishment of plantations of high yielding species/provenance in different Agro-climatic Zones of Karnataka and India may be explored.

## 6. SUMMARY AND CONCLUSIONS

An attempt was made through the present study to analyze the influence of different site conditions on the growth, productivity, leaf yield, leaf oils and chemical composition of oil of *Eucalyptus pellita* F. Muell during 2010-11 at four sites. Uttar Kannada and Shimoga districts, which form parts of central Western Ghats is known for extensively established plantations of *E. pellita* grown mainly on degraded, open, bare and derelict lands. Being Hilly Zone it provides a wide variation in climatic, topographic and edaphic factors. The present study was aimed at (1) assessing the growth and productivity of *E. pellita* in different site conditions, (2) determining the influence of *E. pellita* on soil properties as compared to the control sites and (3) studying quantity and quality of *E. pellita* leaf oil under different site conditions. The salient futures of study are as follows:

1. All the sites were classified by taking in to account the rainfall and altitude. In the present study, four year aged plantations each under four conditions were evaluated for various growth and productivity parameters and quality and quantity of leaf oil.
2. The analysis of variance showed significant effect of site conditions on various growths and productivity parameters such as DBH, total height, bole height, crown diameter, basal area and total volume of the *E. pellita*.
3. The performance of *E. pellita* at the age of four years (harvesting stage) for its various growth and productivity attributes viz., diameter at breast height (cm), total height (m), bole height (m), crown diameter (m), basal area (m<sup>2</sup>) and total volume (m<sup>3</sup>) was studied.
4. Teerthahalli plantations showed superiority in growth (DBH 23.44 cm) and also good performance in productivity viz., basal area (35.35 m<sup>2</sup>/ha) and total volume (360 m<sup>3</sup>/ha) as compared to other experimental sites.
5. The soil under plantations exhibited better physical and chemical properties as compared to their respective control sites. The soil properties such as bulk density (g/ml), particle density (g/ml), pH, electric conductivity (ds/m), nitrogen (kg/ha), phosphorus (kg/ha), potassium (kg/ha) and organic carbon (%) were studied.
6. The highest leaf oil yield under different site conditions of *E. pellita* was obtained with fresh leaves of *E. pellita* from Sorab (0.44%), while the lowest values (0.26%) were from Teerthahalli area.
7. Oil color was found to be pale yellow to yellow. Color of oil from Sammasagi and Sorab was yellow, while it was pale yellow for Sagar and Teerthahalli.
8. The leaf yield from *E. pellita* varied from 5.685 (Sammasagi) to 13.115 (Teerthahalli) tonnes per hectare in all the sites. The Sagar (41.25 lit/ha) region had highest leaf oil as compared to other sites.
9. The local market price of oil was found to be Rs.1900 per litre and per hectare value was obtained according to their oil yields. Sagar recorded as highest value of Rs. 78,299 per ha as compared to other sites.
10. The Eucalyptol leaf oil content was highest in Sagar (71.68%) as compared to other sites.
11. Among the experimental sites, Sagar showed superiority in total height (14.80 m), bole height (12.71 m), leaf biomass (10,355 kg/ha), oil yield (41.5 lit/ha), 1,8-Cineol (71.68%) and also income from oil was Rs.78,299 per hectare.
12. At the Sagar site, eight chemical components were determined from *E. pellita* leaf oil, of which the Eucalyptol (71.68%) was the highest, followed by  $\alpha$ -Pinene (17.43%),  $\alpha$ -terpeniol (3.29%), Geraniol (2.05%),  $\beta$ -Pinene (1.25%), bi-Fenchol (1.24%),  $\beta$ -Selinene (0.94%) and Globulol (0.49%).
13. It was concluded from the present study that *E. pellita* has the potential to capture Medicinal (Cineole-rich), Perfumery (citronellal-rich) and Industrial (rich in phellandrine and piperitone) sectors.
14. Future line of work has been suggested.

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**Appendix I. Data sheet for enumeration of *Eucalyptus pellita* plantations**

Date:

Place:

Spacing:

Site conditions:

Climatic factors		Topographic factors				Edaphic factors			
						Physical properties		Chemical properties	
Rain fall		Altitude		Latitude	Bulk density		pH		
								EC	
Number of rainy days								N	
								P	
					Particle density		K		
							Organic carbon		

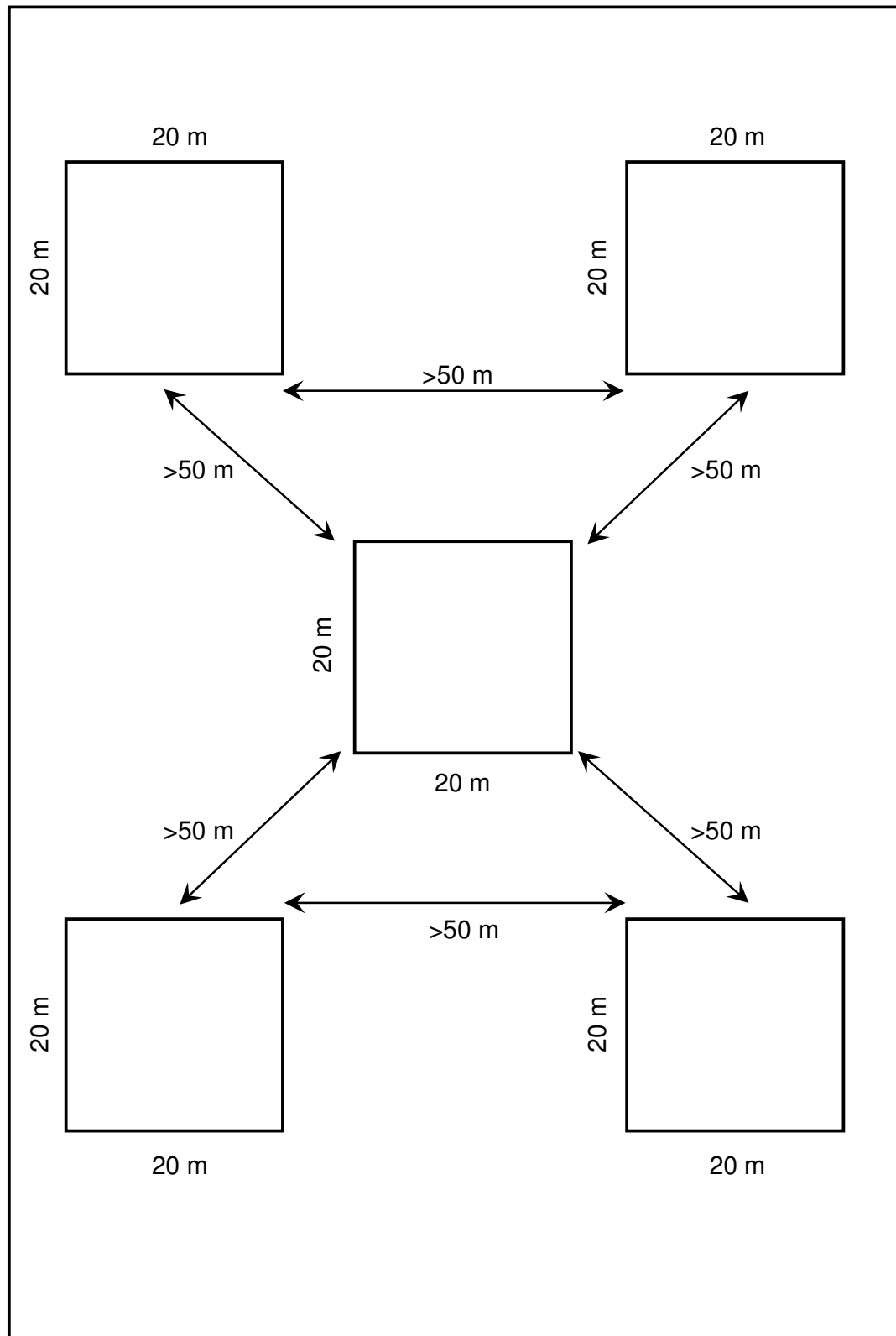
**Appendix II. Measurements of trees (20 m x 20 m Quadrat)**

<b>Sl. No.</b>	<b>DBH (cm)</b>	<b>Total height (m)</b>	<b>Bole height (m)</b>	<b>Crown diameter (m)</b>	<b>Basal area (m<sup>2</sup>)</b>	<b>Total volume (m<sup>3</sup>)</b>
1						
2						
3						
4						
5						

**Appendix III. Extraction of oil**

<b>Sl. No.</b>	<b>Treatments and replication</b>	<b>Weight of leaf sample(gm)</b>	<b>Time</b>	<b>Oil yield (ml)</b>	<b>Oil yield (%)</b>
1	T <sub>1</sub> R <sub>1</sub>				
2	T <sub>1</sub> R <sub>2</sub>				
3	T <sub>1</sub> R <sub>3</sub>				
4	T <sub>1</sub> R <sub>4</sub>				
5	T <sub>1</sub> R <sub>5</sub>				
6	T <sub>2</sub> R <sub>1</sub>				
7	T <sub>2</sub> R <sub>2</sub>				
8	T <sub>2</sub> R <sub>3</sub>				
9	T <sub>2</sub> R <sub>4</sub>				
10	T <sub>2</sub> R <sub>5</sub>				
11	T <sub>3</sub> R <sub>1</sub>				
12	T <sub>3</sub> R <sub>2</sub>				
13	T <sub>3</sub> R <sub>3</sub>				
14	T <sub>3</sub> R <sub>4</sub>				
15	T <sub>3</sub> R <sub>5</sub>				
16	T <sub>4</sub> R <sub>1</sub>				
17	T <sub>4</sub> R <sub>2</sub>				
18	T <sub>4</sub> R <sub>3</sub>				
19	T <sub>4</sub> R <sub>4</sub>				
20	T <sub>4</sub> R <sub>5</sub>				

Appendix IV. Layout of *Eucalyptus pellita* plantations



# STUDIES ON OIL CONTENT AND ITS QUALITY OF *Eucalyptus pellita* IN AGRO-CLIMATIC ZONE-9 OF KARNATAKA

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2011

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## ABSTRACT

A study was conducted in the established 4 year old *Eucalyptus pellita* F. Muell plantations in four sites of Agro-climatic Zone-9 of Karnataka in 2010-11 which comes under two districts Shimoga and Uttar Kannada which known for extensively established plantations of *E. pellita*. Being Hilly Zone it provides a wide variation in climatic, topographic and edaphic factors. The present study was aimed at assessing the growth and productivity, soil properties and quantity and quality of leaf oil under different site conditions. All the sites were classified based on the rainfall and altitude. The analysis of variance showed significant effect of site conditions on various growth and productivity parameters, Teerthahalli plantations showed superiority in growth (DBH 23.44 cm) and also good performance in productivity viz., basal area (35.35 m<sup>2</sup>/ha) and total volume (360 m<sup>3</sup>/ha) as compared to other experimental sites. The soil under plantations exhibited better physical and chemical properties as compared to their respective control sites. The highest leaf oil yield was from Sorab (0.44%). The colour of oil from Sammasagi and Sorab was yellow, while it was pale yellow for Sagar and Teerthahalli. The leaf yield varied from 5.685 (Sammasagi) to 13.115 t/ha (Teerthahalli) in all the sites. The Sagar site had highest leaf oil (41.25 lit/ha) as compared to other sites. Sagar recorded highest value of Rs.78,299/ha as compared to other sites. The Eucalyptol leaf oil content was highest in Sagar (71.68%) as compared to other sites. Among the experimental sites, Sagar site showed superiority in total height (14.80 m), bole height (12.71 m), leaf biomass (10,355 kg/ha), oil yield (41.5 lit/ha), 1,8-Cineol (71.68%). At the Sagar site, eight chemical components were determined from *E. pellita* leaf oil, which contained Eucalyptol (71.68%),  $\alpha$ -Pinene (17.43%),  $\alpha$ -terpeniol (3.29%), Geraniol (2.05%),  $\beta$ -Pinene (1.25%), bi-Fenchol (1.24%),  $\beta$ -Selinene (0.94%) and Globulol (0.49%).