International Journal of Bio-resource and Stress Management https://ojs.pphouse.org/index.php/IJBSM

Crossref

IJBSM January 2024, 15(1): 01-12

Article AR4981a

Review Article

Natural Resource Management

DOI: HTTPS://DOI.ORG/10.23910/1.2024.4981a

Growing Eucalypt Outside its Native Range: A Review on Suitability and Beneficial Role

Brajkishor Prajapati[1], S. Sarvade[2], Jaya Prajapati[3], Atul Kumar Shrivastava[4] and Mrigendra Singh[1]

[1]Dept. of Agronomy, Krishi Vigyan Kendra, Shahdol, M.P. (484 001), India
[2]Dept. of Forestry, College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, M.P. (482 004), India
[3]Dept. of Soil Science and Agricultural Chemistry, Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalayam Gwalior, M.P. (474 002), India
[4]College of Agriculture, Balagaht, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, M.P. (481 331), India

Open Access

Corresponding somanath553@gmail.com

0000-0002-6812-3766

ABSTRACT

Eucalypt is an industrial short rotation fast growing tree species (SRFGTs), having wide range regarding climatic and edaphic requirements in Indian subcontinent. *Eucalyptus camaeldulensis, E. globulus, E. grandis, E. tereticornis* and *E. citriodora* are the widely planted eucalyptus species for different purposes in the country. Oil extracted from *E. globulus* has medicinal value and used to inhibit the avian influenza virus H11N9, and has wide scope in cosmetics, perfume, food, beverages, phytotherapy and aromatherapy. Oil contain *p*-coumaric, gallic, gentisic, *p*-hydroxybenzoic, syringic and vanillic acids and catechol are the responsible for retarding seed germination growth and survival of *Parthenium*, *Solanum lycopersicum*, *Lactuca sativa* and *Agrostis stolonifera*. Burning of eucalypt leaves used as mosquito repellent and compound 1, 8 cineole of eucalypt oil damage and kills *Pediculus humanus capitis* and lice. Aqueous solutions extracted from different parts of eucalypt showed nematocidal properties. Maize, wheat, mustard, berseem, potato, lentil are agricultural crops widely grown under eucalypt based agroforestry systems. Wider spacing of eucalypt in block plantations or boundary plantation mostly adopted in the agroforestry systems. Eucalypt sequester carbon 6 – 43 Mg C ha^{-1} yr^{-1} under plantations and agroforestry systems. The species has potential to reclaim waterlogged sites and escalate soil health through improving soil physical, chemical and biological properties. In case of economic returns from eucalypt based agroforestry systems, it gives nearly 1.5 B:C ratio.

KEYWORDS: Agroforestry, carbon, eucalypt, insecticidal, nematocidal, oil, profitability soil

***Citation* (VANCOUVER):** Prajapati et al., Growing Eucalypt Outside its Native Range: A Review on Suitability and Beneficial Role. *International Journal of Bio-resource and Stress Management,* 2024; 15(1), 01-12. HTTPS://DOI.ORG/10.23910/1.2024.4981a.

Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

Conflict of interests: The authors have declared that no conflict of interest exists.

RECEIVED on 25th October 2023 RECEIVED in revised form on 19th December 2023 ACCEPTED in final form on 02nd January 2024 PUBLISHED on 23rd January 2024

1. INTRODUCTION

Eucalypt (safeda) is evergreen, fastest growing multipurpose species (MPTs), widely adopted in various climatic conditions. It belongs to the *Myrtaceae* family, with three genera such as *Eucalyptus*, *Corymbia* and *Angophora* comprising about 900 species (Pereira et al., 2014; Mengistu et al., 2020; Chebet et al., 2022). More than 700 known eucalypt species are native to Australia (Hooga et al., 2019) and few species are indigenous to Indonesia, the Philippines and New Guinea (Stanturf et al., 2013; Hayat et al., 2015). Blue gum, lemon-scented gum, rainbow gum, manna gum and red cap gum, salmon gum, silver dollar gum, scribbly gum, snow gum, spotted gum and red ironbark tree are the commonly known names used for different species of eucalypt. It is one of the most cultivated woody/timber tree species in the world next to *Pinus* and *Cunninghamia* (Raj et al., 2016; Mengistu et al., 2020). The word eucalypt comes from the Greek words "Eu" and "Kalypta" with the meaning "Well" and "Cover". Therefore, the name eucalypt refers to a small cap covering the closed flower (Bayle, 2019; Yimam and Hailu, 2022). It can be grown in tropics, sub-tropics and some temperate regions, representing 8% of all forest plantations (Gupta et al., 2015; Cook et al., 2016). Area of *Eucalyptus* trees is expanded from 0.7 mha during 1955 to more than 20.0 mha during 2018 in plantations of >100 countries around the world. Outside its native habitat, eucalypt first grown in Portugal, some four hundred years ago. Subsequently, it was widely distributed in Europe, Latin America, Asia and Africa. Among the world, prominent eucalypt growing countries are USA (California), Ecuador, Colombia, Chile, China, Spain, Israel, India, Ethiopia, Morocco, South Africa, Portugal, Brazil, Tasmania and Uganda (Vecchio et al., 2016; Yimam and Hailu, 2022). Eucalypt succeeded as a preferred species for agroforestry and farm forestry interventions throughout the India (Singh et al., 2015a; Singh et al., 2015b; Chaturvedi et al., 2017; Dhillon et al., 2018; Berry et al., 2021). Whereas, eucalypt species such as lemon scented gum (*E. citriodora* Syn. *Corymbia citriodora*), Tasmanian blue gum (*E. globulus*), blue mallee (*E. polybractea*), and River red gum (*E. camaldulensis*) consists of tall, magnificent and evergreen trees with fragrant foliage rich in oil glands (Sabo and Knezevic 2019; Prajapati et al., 2020) has multiple uses. The main goal of this review is to assess the major benefits of eucalypt under different climatic conditions.

2. HISTORICAL BACKGROUND

Tipu Sultan in 1790 introduced eucalypt in India at Nandi hills (Bangalore). He obtained seeds of about 16 eucalyptus species from Australia for plantation (Shyam Sundar, 1984). After that, eucalypt introduced in the Nilgiri hills, Tamil Nadu, in 1843 and later in 1856, *E. globulus* raised to meet the demands for firewood (Wilson, 1973). *E. tereticornis* known as Mysore gum, most widely planted in India. This *Eucalyptus hybrid* represents about half of the total plantion in many parts of India (Jacobs, 1981), and believed to be derived from one small stand of *E. tereticornis* the early introductions in Nandi hills (Pryor, 1966; Chaturvedi, 1976). *E. camaldulensis* is suitable species for Himachal Pradesh, Uttarakhand; *E. globulus* is for Kerala, Karnataka; *E. grandis* is for Kerala (high rainfall areas); *E. tereticornis* is for Madhya Pradesh, Uttar Pradesh, Punjab, Haryana, Bihar, Rajasthan, Gujarat, Maharashtra, Odisha, West Bengal, Andhra Pradesh, Karnataka, Himachal Pradesh and Tamil Nadu (Table 1). *E. tereticornis* is frost-tolerant and can withstand 1 to 15 frost incidences in cold season. *E. citriodora* is highly suitable for Hilly areas. Eucalypt is the most preferred species under agroforestry systems in Indian subcontinent due to short rotation and fast growth, high survival traits, suitability to all types of soils and tolerance to water logging, salinity and sodicity (Singh et al., 2014; Sarvade et al., 2017) and assured market, highly lucrative returns, ecological value and supportive Govt. policies, attracting farmers in a big way (Prasad et al., 2010; Joshi et al., 2013). In India, eucalypt comprised 71.60% of the total trees planted in farm forestry (Dhillon et al., 2018). Eucalypt is also suitable for saline or sodic soils, waterlogged area for draining excess water and reclaim degraded area due to soil erosion that results in loss of soil fertility (Sarvade et al., 2017). Eucalypt is useful in shelterbelts and wind breaks on large-scale farm, farmlands. *E. tereticornis* and *E. camaldulensis* may grow in the ravine areas. *E. grandis* and *E. tereticornis* can be planted in grasslands (Luna, 1996). *E. camaldulensis* can be planted in areas having saline and alkaline soils, sandy areas and soils deficient in nutrients experiencing very low rainfall. At present, the total planted area in India is around 8.0 mha and these plantations were mostly of seed origin (Aregowda et al., 2010). Eucalypt can grow in the soil having pH of 11.0, 9.2 and 8.8 in sandy, clay and loamy soils, respectively (Gupta et al., 1990). Most of the agroforestry systems raised in India lie in the plains and lower altitudes of the hilly area up to an elevation of about 1,000 m. Based on site quality, eucalypt ascertained that *E. hybrid* under agroforestry grow better in hot arid regions than hot semi-arid regions and hot sub-humid regions of Punjab (Luna et al., 2006).

3. EUCALYPT IN PHARMACEUTICAL INDUSTRIES

Oil extract from the different plant parts of the eucalypt shows potential use in pharmaceutical industries because of its medicinal property and as natural preservatives for food as it prevents the development of

Table 1. Suitability of eucalypt in different agro-climatic zones of India

Sl. No.	Species	Climatic zone	Altitude (m)	Annual rainfall (mm)	State
1.	*E. camaldulensis*	Tropical and sub-tropical	Up to 1,800	250-625	Himachal Pradesh and Uttarakhand
2.	*E. globulus*	Mild temperate to cool tropical climate	1,500 to 2,343	1,270 to 2,500 but without snowfall	Kerala and Karnataka (Annamalai and Palni Hills)
3.	*E. grandis*	Lower sub-tropical areas	800 to 1,500	2,000 to 4,000	Kerala (Plateau plains, high rainfall areas)
4.	*E. tereticornis*	Dry tropical to moist tropical areas	Up to 1,000	400 to 4,000	Punjab, Haryana, Uttar Pradesh, Rajasthan, Gujarat, Madhya Pradesh, Maharashtra, Bihar, Odisha, West Bengal, Andhra Pradesh, Karnataka and Tamil Nadu
5.	*E. citriodora*	Mild temperate areas	600 to 1,200	-	Hilly areas

the yeast (*Saccharomyces cerevisiae*) in fresh juices (Marzoug et al., 2011). Eucalypt oil contains an exponential amount of secondary metabolites such as 1,8- cineole, citronellal, citronellyl acetate, p-cymene, eucamalol, limonene, linalool, β- pinene, γ-terpinene, α-terpinol, alloocimene and aromadendrene (Nezhad et al., 2009) these possess anti-inflammatory, analgesic, antimicrobial, anticancer, antioxidant and insecticidal properties. Certain secondary metabolites contain anticancer cytochrome p40 inhibitors, which reveals the medicinal importance of eucalypt oil (Adnan, 2019). *E. globulus* is widely used species in cosmetics, perfume, food, beverages, cosmetics, phytotherapy and aromatherapy (Vecchio et al., 2016). The anti-microbial activity of eucalypt oil from *E. globulus* affects both gram-negative bacteria (*Salmonella enteritidis*, *Escherichia coli* and *Pseudomonas aeruginosa*) and gram-positive bacteria (*Staphylococcus aurans*, *Enterococcus faecium*, *Listeria monocytogenes* 4b and *Listeria monocytogenes* EGD-e) (Bachir and Benali 2012; Vecchio et al., 2016). Oil from *E. polybractea* shows potential inhibiting action against the avian influenza virus H11N9 in aerosol and vapour form (Asif et al., 2020). They reported 1,8-cineole is the active constituents of eucalypt oil, found to exhibit the muscle relaxation by decreasing the muscle contraction.

4. HERBICIDAL PROPERTIES

Allelopathy is associated with *Eucalyptus spp*. due to the presence of allelochemicals; several studies have demonstrated the release of phenol and volatile compounds in its foliage (Al-Naib and Al-Mousawi, 1976). *E. citriodora* and *E. tereticornis* oil applied in *Parthenium hysterophorus* plants in vapors form decrease their cellular respiration, chlorophyll content and increases water loss resulting in complete wilting (Kohli et al., 1998). The secondary metabolites such as tannins, phenolics and monoterpenes from various plant parts of eucalypt showed herbicidal properties (Vourc'h et al., 2002; Bailey et al., 2004; Foley and Moore, 2005). Eucalypt plant releases the volatile compounds from its foliage, which appear to have an inhibitory effect on the growth of under-storey vegetation, and this could lead to the development of natural herbicides (Golob et al., 2007). Eucalypt oil contain growth inhibitors such as p-coumaric, gallic, gentisic, p-hydroxybenzoic, syringic and vanillic acids and catechol (Figure 1) that are capable of reducing the growth and survival of *Parthenium* plant (Zhao-Hui et al., 2010). The volatile oils from leaves of *E. citriodora* tested on the noxious weed *Parthenium hysterophorus* in laboratory at Punjab (India) by Singh et al. (2005) and conveyed significant results as it retards seed germination and seedling height growth, lowered chlorophyll content and respiratory activity of *Parthenium* seeds with increasing concentration of eucalypt oils from 0.2 to 5.0 nl ml^{-1}. *Parthenium* seed germination was completely inhibited at 5.0 nl ml^{-1} eucalypt oils. Furthermore, sprayed with different concentrations of volatile oils on 4-week-old *Parthenium* plants, visible damage increased and chlorophyll content and respiratory activity decreased with increased concentration from 0 to 100-µl ml^{-1}, a week after spraying. Oil from *E. globulus* able to shows strong deleterious effects on the germination of *Amaranthus retroflexus* and *Portulaca oleracea* L. (Azizi and Fuji, 2006). Jawahar et al. (2013) reported eucalypt oil at higher concentrations significantly reduced the relative plant density. This might be due to presence of allelochemicals in eucalypt oil. In Punjab state of India, similar study conducted by Vishwakarma and Mittal (2014) and observed the content of carbohydrate and water-soluble proteins decreased in response to essential oil extracted from *E. tereticornis*. Allelochemicals disturb

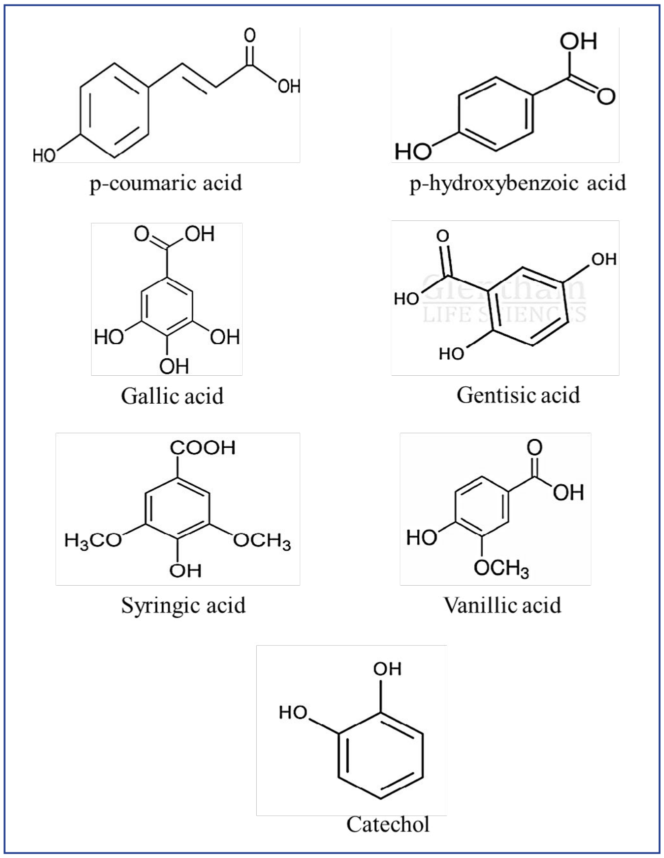

Figure 1: Plant growth inhibiting acids present in eucalypt essential oil

the metabolic activities like photosynthesis and respiration of the *Echinochloa crus – galli* L. seedlings and retards the growth. Possessing great weed-suppressing ability due to essential oils of *E. citridora* phytotoxicity on weed species such as *Portulaca oleracea*, *Lolium multiflorum*, *Amaranthus viridis* and *Echinochloa crusgalli* (Ibanez and Blazquez, 2018). Similarly, eucalypt species; *E. camaldulensis* and *E. globulus* have potential to reduce germination efficiency of *Solanum lycopersicum*, *Lactuca sativa* and *Agrostis stolonifera* seeds (Fikreyesus, 2011; Puig, 2018).

5. INSECTICIDAL/INSECT-REPELLENT PROPERTIES

Eucalypt oil used as an anti-feedant, particularly against biting insects (Trigg, 1996a,b; Trigg and Hill, 1996; Chou et al., 1997; Thorsell et al., 1998). Essential oil extracted from key eucalypt species tested against insect/pest species presented in Table 2. The eucalypt oil having at least 70% cineole content, the oil with 30% conc. prevent mosquito bite for 2 hr (Fradin and Day, 2002). Burning of leaves of *E. citriodora,* the cost effective method provides household protection against mosquitoes (Seyoum et al., 2003) in Africa. Essential oil extracted from *E. globulus* can used to control *Aedes aegypti* larvae at LC50 of 32.4 ppm (Lucia et al., 2007). Whereas, its compound, 1,8 cineole has potential to control of *Pediculus humanus* capitis and lice (Ceferino et al., 2006). Essential oil from the *E. cinerea* and/or 1,8-cineole used as fumigants or as synergistic of pyrethroid insecticides, an interesting alternative to control flies in human habitats, especially against resistant flies (Rossi and Palacios, 2015).

6. NEMATOCIDAL ACTIVITY

Essential oil obtained from *E. citriodera* and *E. hybrida* shows strong nematocidal properties even at the lower

Table 2: Insecticidal properties of eucalypt essential oil

Sl. No.	*Eucalyptus* spp.	Tested organism	Reference
1.	*E. camaldulensis*	Repels adult females of Culex pipiens	Erler et al. (2006)
2.	*E. camaldulensis*	Egg mortality in *Tribolium confusum* and *Ephestia kuehniella*	Tunc et al. (2000)
3.	*E. citriodora*	Toxicity against *Sitophilus zeamais*	Tinkeu et al. (2004)
4.	*E. globulus*	Repellent in action, reduced fecundity, decreased egg hatchability, increased neonate larval mortality and adversely influenced offspring emergence in *Acanthoscelides obtectus*	Papachristos and Stamopoulos, (2002; 2004)
5.	*E. globulus*	Kills pupae of *Musca domestica*	Halim and Morsy (2005)
6.	*E. globulus*	Toxic to Aedes aegypti larvae	Lucia et al. (2007
7.	*E. saligna*	Repellent activity against *Sitophilus zeamais* and *Tribolium confusum*	Tapondjou et al. (2005)
8.	*E. tereticornis*	Larvicidal, pupicidal and adulticidal activity towards *Anopheles stephensi*	Nathan (2007)
9.	*Eucalyptus* spp.	Rice weevil *Sitophilus oryzae*	Lee et al. (2001)
		Mushroom fly *Lycoriella mali*	Choi et al. (2006)

concentrations, such as 500 and 250 ppm (Pandey et al., 2000). Essential oil extracted from *E. camaldulensis*, *E. saligma*, *E. urophylla* cause mortality and hatching of second stage-juveniles (J2) of *Meloidogyne exigua* (Salgado et al., 2003). Aqueous solution obtained from different parts of eucalypt (leaves, stem, bark and fruit) has nematocidal properties and may use against *Meloidogyne javanica* root knot nematode in mung bean and chickpea crops. It also reduced egg hatching and cause mortality of juveniles with solution @ 5% (Dawar et al., 2007). Essential oil of *E. globulus* (rich in eucalyptol) and *E. citriodora* (rich in the aliphatic terpene aldehyde citronellal) significantly reduce nematode reproduction and root galling on tomato as applied at the rates greater than 50 µl kg^{-1} soil (Laquale et al., 2015). Essential oil of *E. camaldulensis*, with eucalyptol and α-pinene as the main components have already been tested and implicated in inhibiting egg hatchability, and causing mortality of second-stage juveniles (J2s) of *Meloidogyne incognita* (El-Baha et al., 2017).

7. EUCALYPT BASED AGROFORESTRY

Eucalypt is the most preferred species among the farmers for planting in agricultural fields, along the edges or bunds and appears to be well-incorporated and popular choice in agroforestry systems in India. It gradually gained momentum in all parts of India, especially in Punjab, Haryana, Western Uttar Pradesh, Gujarat, Tamil Nadu, North Bengal and Andhra Pradesh (Chaturvedi et al., 2017). Effect of boundary plantation of eucalypt on the yield of adjoining agriculture crops showed maximum yield reduction of 64.4, 58.4 and 42.6% in wheat, rice and potato crops, respectively near the tree line (Dhillon et al., 1979; 1982; Sarvade et al., 2014a; Sarvade et al., 2014b). The reduction in the agriculture crop yield is depends on the direction of tree line, its composition, spacing of trees, cropping season and type of agriculture crop cultivated. In Gujarat, eucalypt planted as windbreaks helped in increasing the atmospheric humidity and, thus, resulted in an increase in the yield of wheat and mustard by 23–24% (Kumar, 1984). Similar trend was available in Andhra Pradesh for groundnut, pigeon pea and pearl millet where an increase in yield to the order of 40–43%, 39-47 % and 23–64%, respectively. In another study on the effect of 8 year-old *E. hybrid* plantation in Dehradun on *kharif* maize crop found non-significant reduction in yield because of moisture availability (Dadwal and Narain, 1984). Kumar and Nandal (2004) evaluated the performance of five-test crops viz. wheat, beseem, potato, mustard and lentil 2.5 years old *E. tereticornis* (6×2 m^2) based agri-silviculture system. They studied that all the test crops sown in the interspaces of eucalypt reduced plant growth in terms of plant height, stem diameter, number of branches and yield attributes as compared to control. Kidanu et al. (2005) found the significant reduction in grain yield of mustard in the first 12 m from the tree (eucalypt) line of boundary plantation and the reduction in grain yield was 20 to 51% over control (sole crop). Kumar et al. (2013) reported that the yield of wheat and mustard was significantly less under eucalypt based agroforestry system as compared to sole crop (devoid of trees). Further, they studied that the parameters such as plants per running meter row length (161.7), spike length (7.7 cm), grains spike^{-1} (37.7) and test weight (26.7 g) were also significantly less under eucalypt based agroforestry than in sole cropping. The grain and straw/stover yields of both the crops under eucalypt decreased significantly as compared to sole cropping. The experiment conducted at Haryana (India) on farmer's field by Ahlawat et al. (2019) under different ages (1 year and 2 years old) of eucalypt based agroforestry system. Among the agricultural crops grown under eucalypt plantation, berseem and oat showed significantly higher yield under study during 2014–15 and 2015–16. However, yield of other agricultural crops (wheat and mustard) reduced remarkable in both the years under eucalypt based agroforestry system over control. The experiment conducted at Haryana (India) under eucalypt plantation (2.8 years old) by Kombra et al. (2020) observed that plant height, fresh and dry matter accumulation, grain and stover yield declined under eucalypt over control (sole mustard). Similarly, Bisht et al. (2022) who stated that eucalypt based agroforestry system in paired row planting (17×1×1 m^3) was found best for production of wheat followed by 6×1.5 m^2 and 3×3 m^2. Further, suggested that HD-2967 variety of wheat was found best as a shade tolerant followed by DPW-621-50 and WH-542 at Hisar (India).

8. CARBON SEQUESTRATION POTENTIAL

Eucalypt is fast growing short rotation tree species fixes the atmospheric carbon into biomass and sequestrate carbon at a faster rate as compared to other forestry species (Sarvade et al., 2019). Plantations of the eucalypt species grown in adverse climatic and edaphic conditions are the potential sites of carbon storage (Liew, 2009). Eucalypt has the highest capacity for total C flux (27.5 mt C yr^{-1}) in the plantation sites (Raizada et al., 2003). In comparison with the 4 economically important tree species, fast growing short rotation poplar sequestrate net annual carbon at the rates of 8 mg C ha^{-1} yr^{-1} and eucalypt plantation at 6 mg C ha^{-1} yr^{-1} followed by teak forests (2 mg C ha^{-1} per yr^{-1}) and slow growing long rotation sal forests (1 Mg C ha^{-1} yr^{-1}) (Kaul et al., 2010). In, *Eucalyptus hybrid* boundary plantation-based agroforestry system (wheat agri crop), total carbon of 8.53 t C ha^{-1} sequestrated and carbon sequestration rate was 0.88 53 t C ha^{-1} yr^{-1} (Yadava, 2010). According to Joshi et al. (2013), the rate of carbon sequestration in *Eucalyptus* *hybrid* of 8 years' plantation at the *Tarai* region of central Himalaya was 7.88 t C ha^{-1} yr^{-1}. Due to fast growth rate of short rotation plantations and their adaptability to the wide range of climatic and edaphic conditions, store carbon rapidly through producing higher biomass and contribute to reduced greenhouse gas emissions. In another study shown that, the *E. tereticornis* clones planted in water logging site of Haryana (strip planted) sequestrate total carbon of 15.5 t ha^{-1} after the age of 5 years 4 months (Ram et al., 2011). In case of agroforestry systems, the carbon sequestration was studied in Navsari, Gujarat by Panchal et al. (2017) and reported maximum above ground (34.05 t ha^{-1}), below ground (8.85 t ha^{-1}) and total (42.90 t ha^{-1}) carbon under eucalypt in agri-silvi-culture system (*Eucalyptus*+Spider lily) followed by Mango and Teak in agri-silvi-horticulture system (Mango+Teak+Brinjal) with 3.63, 1.37, 5.0 t ha^{-1} of aboveground, belowground and total carbon, respectively.

9. SOIL HEALTH

Eucalypt tree species or eucalyptus based agroforestry system enhances soil physical properties such as soil texture, porosity, water holding capacity and water-stable aggregates by adding organic matter through continuous degeneration of roots and decomposition of litter, modify the temperature by shading, reduces soil and water erosion from barren slope or land and increase chemical properties like CEC, organic carbon, pH and nutrient availability (Sarvade et al., 2014b). Eucalypt plantation also showed improvements in soil nutrient (N, P, K and organic matter) as compared to natural soil (Jan et al., 1996). In eucalypt, subsoil (30–105 cm) contained appreciable amount of Walkley and black carbon (60–62%, WBC) at 0–105 cm soil layer, signifying the importance of subsoil horizons for C storage. This may be ascribed to relatively higher resistance C to oxidation in lower soil layers, indicating the turnover time of C was higher in sub-surface horizons (Gaudinski et al., 2000). Study conducted by Mishra et al. (2003) on sodic wastelands in relation to age and depth and found that the highest organic carbon content (12.8 g kg^{-1}) at 0–10 cm depth under 9 year *E. tereticornis* plantation and soil pH is decreased (8.02) due to the litter decomposition and root exudates, and/or products. Increase in the available P (28 mg kg^{-1}) and K (284 mg kg^{-1}) at 0–10 cm depth under 9 year *E. tereticornis* plantation was directly related to the quality of organic matter. The increase in the available K may be due to the release of K from K-bearing minerals after recovery and, in part, to the recycling of K due to the decomposition of litter. The micro-pores, water-holding capacity of the soil increased and the soil bulk density reduced with the age of *E. tereticornis* plantation (Table 3). Eucalypt plantation can ameliorate salinity and sodicity of soil by improving soil EC, pH and SAR (Nasim et al., 2007). Decrease in soil pH (8.65) was observed in eucalyptus-based systems compared to sole crops (8.81) after 5 years of plantation compared to initial year in Karnal, India. Whereas, decrease in soil EC from 0.45 dSm^{-1} under eucalypt based systems to 0.32 dSm^{-1} in sole crop, and organic carbon (0.37%), Nitrogen (86 kg ha^{-1}), Phosphorus (18.5 kg ha^{-1}), Potassium (259 kg ha^{-1}) in eucalypt based systems increased as compared to sole crop (Ghosh et al., 2014). Similarly, Kumar et al. (2018) conducted study to investigate short-term changes in eucalyptus (*E. tereticornis*) based agroforestry (6-year-old) and mono-cropped (2-years) sugarcane-sugarcane (*Saccharum officinarum*) system for soil physico-chemical properties in the semi-arid region of north-west India. The soil under eucalyptus-based agroforestry system has 17

Table 3: Improvement in chemical and physical properties of *Eucalyptus tereticornis* plantations on sodic wastelands in Sultanpur district, India

Depth (cm)	pH				Organic carbon (g kg^{-1})				Avail. P (mg kg^{-1})				Avail. K (mg kg^{-1})			
	C	3 Yr	6 Yr	9 Yr	C	3 Yr	6 Yr	9 Yr	C	3 Yr	6 Yr	9 Yr	C	3 Yr	6 Yr	9 Yr
0-10	10.1	9.82	9.11	8.02	2.0	3.2	5.5	12.8	9.00	17.1	23.6	28.0	115	160	195	284
10-30	10.4	10.17	9.74	8.29	1.6	2.2	3.3	6.6	9.75	15.3	20.5	24.5	109	142	182	241
30-60	10.5	10.5	10.3	8.43	0.9	1.2	1.4	2.3	10.62	12.1	13.8	25.7	104	123	126	214
60-90	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 3: Continue...

Depth (cm)	Porosity (%)				WHC				BD (g kg^{-1})			
	C	3 Yr	6 Yr	9 Yr	C	3 Yr	6 Yr	9 Yr	C	3 Yr	6 Yr	9 Yr
0-10	41.2	44.9	47.5	50.9	43.3	45.7	48.2	52.9	1.66	1.39	1.27	1.01
10-30	41.4	45.2	47.6	52.8	44.8	46.6	47.9	52.2	1.59	1.39	1.27	1.01
30-60	42.2	44.2	45.0	47.5	44.6	45.6	47.6	49.1	1.66	1.48	1.38	1.01
60-90	35.4	37.7	38.4	44.2	44.3	45.1	47.0	48.1	1.72	1.56	1.45	1.07

and 77% higher values of available N and P, 100% higher DTPA extractable Zn and Cu and 38% greater Mn than mono-cropped sugarcane. Furthermore, eucalyptus-based agroforestry system contained 22 and 13% higher total organic carbon stock; and 15 and 23% greater microbial biomass C (MBC) concentration in soils sampled in March and September 2013, respectively compared with mono-cropped sugarcane in averaged depth of 105 cm soil layer.

10. ECONOMICS OF EUCALYPT BASED AGROFORESTRY

Eucalypt plantations on agricultural farms proved to be highly economical giving an internal rate of return of 35% to 38% without intercropping and 85% with intercropping (Dogra, 1984). Luna (1996) stated that eucalypt planting in combination with agricultural crops at 6.0×1.0 m^2 spacing with 8-year rotation gave the highest net present value and benefit cost ratio at 12% rate of interest in Haryana, Punjab and Uttar Pradesh. The profitability of various spacing's of eucalypt based agroforestry system ranges from ₹ 54808 ha^{-1} yr^{-1} for sole eucalypt to ₹ 72690 ha^{-1} yr^{-1} for paired row spacing's (Prasad et al., 2010). They also reported that higher internal rate of return in modified tree geometries ranges from 56–88%, where as sole eucalypt woodlot (28%) for eucalypt based agroforestry system in Andhra Pradesh (India). Similarly, Agarwal et al. (2017) analyses various crops (Rice, cotton and wheat) and trees (Subabul, eucalypt and *Casuarina*) in Gujarat and Maharashtra and compared their overall investment, overall sales, market price, net profits, etc. They reported that all these parameters in eucalypt were higher than other species. The net return from the plantation of eucalypt is ₹ 43860 per acre per year with total expenditure of ₹ 25,400, which is the largest of all other species such as Subabul (₹ 34833), *Casuarina* (₹ 28833), Cotton (₹ 33860), Rice (₹ 24360), Wheat (₹ 19000) with total expenditure of ₹ 12500, 14500, 28140, 10640, 8500, respectively. The experiment conducted at Hisar, Haryana (India) on sandy-loam soil by (Dhillon et al., 2018) reported that 17×1×1 m^3 spacing of eucalypt registered the highest NPV @ 12% discounting of ₹ 185336 followed by spacing of 6×1.5 m^2 (₹ 140975). The B:C ratio of these agroforestry system was recorded maximum in wider spacing (17×1×1 m^3) and ranging from 1.57 and followed by 1.44 (6×1.5 m^2), 1.25 (sole eucalypt) and 1.2 (sole agricultural crops). Similarly, among all the agricultural crops (mustard, wheat, berseem and oat) grown under eucalypt plantation, the maximum net return was found in oat crop (₹ 26,535 and ₹ 14,580 ha^{-1}), which was closely followed by berseem with the net returns (₹ 8693 and ₹ 7086 ha^{-1}) during 2014–15 and 2015–16, respectively (Ahlawat et al., 2019).

11. CONCLUSION

Eucalypt is widely adopted by farming communities received high importance because of its multifaceted uses. Secondary metabolites of the oil have use in pharmaceutical industries, allelochemicals in the different plant parts may be used for weed control. Essential oil extracted from eucalypt has potential to control insect and nematode attack in agriculture crops. The species can grow in degraded lands, widely planted on the boundary of agriculture fields under agroforestry, also in block plantations to meet out the industrial demand. Continuous adding organic matter it improves soil health.

12. ACKNOWLEDGEMENT

Authors and co-authors of the manuscript are thankful to the Programme Coordinator, Krishi Vigyan Kendra, Shahdol (MP), Head, Department of Forestry, Jabalpur (MP) and Dean, College of Agriculture, Balaghat (MP), JNKVV Jabalpur (MP), India for providing facilities to prepare this manuscript.

13. REFERENCES

Adnan, M., 2019. Bioactive potential of essential oil extracted from the leaves of *Eucalyptus globulus* (Myrtaceae). Journal of Pharmacognosy and Phytochemistry 8(1), 213–216.

Agarwal, N.K., Shukla, O.P., Narkhede, S.L., Chauhan, S.K.S., 2017. Promotion of short rotation agro and farm forestry system in Gujarat and Maharashtra by JK paper limited unit-CPM. Indian Forester 143(9), 737–744.

Ahlawat, K.S., Daneva, V., Sirohi, C., Dalal, V., 2019. Production Potential of Agricultural Crops under Eucalyptus tereticornis based agri-silvi-culture system in Semi-Arid Region of Haryana. International Journal of Current Microbiology and Applied Sciences 8(06), 2725–2731.

Al-Naib, F.A.G., Al-Mousawi, A.H., 1976. Allelopathic effects of *Eucalyptus microtheca*: identification and characterization on the phenolic compounds in *Eucalyptus microtheca*. Kuwait Journal of Science 3, 83–87.

Aregowda, J., Prabhu, S.T., Patil, R.S., 2010. Evaluation of botanicals and synthetic insecticides against Eucalyptus gall wasp, *Leptocybe invasa* (Eulophidae: Hymenoptera). Karnataka Journal of Agricultural Sciences 23(1), 200–202.

Asif, M., Saleem, M., Saadullah, M., Yaseen, H.S., Al Zarzour, R., 2020. COVID-19 and therapy with essential oils having antiviral, anti-inflammatory, and immunomodulatory properties. Inflammo

Pharmacology, 1–9.
Azizi, M., Fuji, Y., 2006. Allelopathic effect of some medicinal plant substances on seed germination of *Amaranthus retroflexus* and *Portulaca oleraceae*. Acta Horticulturae 699, 61–67.
Bachir, R.G., Benali, M., 2012. Antibacterial activity of the essential oils from the leaves of *Eucalyptus globulus* against *Escherichia coli* and *Staphylococcus aureus*. Asian Pacific Journal of Tropical Biomedicine 2(9), 739–742.
Bailey, J.K., Schweitzer, J.A., Rehill, B.J., Lindroth, R.L., Martinsen, G.D., Whitham, T.G., 2004. Beavers as molecular geneticists: a genetic basis to the foraging of an ecosystem engineer. Ecology 85(3), 603–608.
Bayle, G.K., 2019. Ecological and social impacts of eucalyptus tree plantation on the environment. Journal of Biodiversity Conservation and Bioresource Management 5(1), 93–104.
Berry, N., Dilraj, I.T.K., Dubey, S., Rai, N., 2021. Agroforestry system adopted by farmers of Hoshangabad district of Madhya Pradesh. The Pharma Innovation Journal 10(10), 72–79.
Bisht, V., Purwar, S., Kumar, D., Kumar, B., Upadhayay, V., 2022. Effect of different spacings of eucalyptus plantation on biomass production of wheat cultivars in Northern India. The Pharma Innovation Journal 11(1), 135–139.
Ceferino, T.A., Julio, Z., Mougabure, C.G., Fernando, B., Eduardo, Z., Maria, I.P., 2006. Fumigant and repellent properties of essential oils and component compounds against permethrin-resistant *Pediculus humanus* capitis (Anoplura: Pediculidae) from Argentina. Journal of Medical Entomology 43, 889–895.
Chaturvedi, A.N., 1976. Eucalyptus in India. Indian Forester 102(1), 57–63.
Chaturvedi, O.P., Handa, A.K., Uthappa, A.R., Sridhar, K.B., Kumar, N., Chavan, S.B., Rizvi, J., 2017. Promising agroforestry tree species in India. Jhansi, India, Central Agroforestry Research Institute; New Delhi, India, 190p.
Chebet, D., Musila, F.M., Kituyi, S.N., Muthike, G.M., Kaigongi, M.M., 2022. Molecular phylogeny of selected kenyan eucalyptus species inferred from MatK, rbcL and TrnL-F genes and their suitability for power transmission poles. Diversity 14, 563.
Choi, W.S., Park, B.S., Lee, Y.H., Jang, D.Y., Yoon, H.Y., Lee, S.E., 2006. Fumigant toxicities of essential oils and monoterpenes against *Lycoriella mali* adults. Crop Protection 25, 398–401.
Chou, J.T., Rossignol, P.A., Ayres, J.W., 1997. Evaluation of commercial insect repellents on human skin against *Aedes aegypti* (Diptera: Culicidae). Journal of Medical Entomology 34, 624–630.
Cook, R.L., Binkley, D., Stape, J.L., 2016. Eucalyptus plantation effects on soil carbon after 20 years and three rotations in brazil. Forest Ecology and Management 359, 92–98.
Dadwal, K.S., Narain, P., 1984. Root effects of the boundary trees on the rabi crops can be reduced by trenching. Soil Conservation Newletter 3(2), 15–16.
Dawar, S., Younus, S.M., Javed Z.M., 2007. Use of *Eucalyptus* spp in the control of *Meloidogyne javanica* root knot nematode. Pakistan Journal of Botany 39(6), 2209–2214.
Dhillon, R.S., Chavan, S.B., Bangarwa, K.S., Bharadwaj, K.K., Kumari, S., Sirohi, C., 2018. *Eucalyptus*-based agroforestry system under Semi-Arid condition in North-Western India: an economic analysis. Indian Journal of Ecology 45(3), 470–474.
Dhillon, G.S., Singh, S., Dhillon, M.S., Atwal, A.S., 1982. Developing agri-silvi-cultural practices: studies on the shading effect of *Eucalyptus* on the yield of adjoining crops. Indian Journal of Ecology 9(2), 228–236.
Dhillon, G.S., Grewal, S.S., Atwal, A.S., 1979. Developing agri-silvi-cultural practices: effect of farm trees (*Eucalyptus*) on the adjoining crops (India). Indian Journal of Ecology 6(2), 88–97.
Dogra, A.S., 1984. Farm and agroforestry in south-western Punjab. *In*: Mathur, R.S., Gogate, M.G. (Eds.), Agroforestry in India. FRI, Dehradun, 157–177.
El-Baha, A.M., El-Sherbiny, A.A., Salem, M.Z.M., Shaarawy, N., Mohamed, N.H., 2017. Toxicity of essential oils extracted from *Corymbia citriodora* and *Eucalyptus camaldulensis* leaves against *Meloidogyne incognita* under laboratory conditions. Pakistan Journal of Nematology 35, 93–104.
Erler, F., Ulug, I., Yalcinkaya, B., 2006. Repellent activity of five essential oils against *Culex pipiens*. Fitoterapia 77, 491–494.
Fikreyesus, S., Kebebew, Z., Nebiyu, A., Zeleke, N., Bogale, S., 2011. Allelopathic effects of *Eucalyptus camaldulensis* Dehnh on germination and growth of tomato. American-Eurasian Journal of Agricultural & Environmental 11, 600–608.
Foley, W.J., Moore, B.D., 2005. Plant secondary metabolites and vertebrate herbivores–from physiological regulation to ecosystem function. Current Opinion in Plant Biology 8(4), 430-435.
Fradin, M.S., Day, J.F., 2002. Comparative efficacy of insect repellents against mosquito bites. New England Journal of Medicine 347, 13–18.
Gaudinski, J.B., Trumbore, S.E., Davidson, E.A., Zheng, S., 2000. Soil carbon cycling in a temperate forest: radiocarbon based estimates of residence

times, sequestration rates and partitioning of fluxes. Biogeochemistry 51, 33–69.

Ghosh, P.K., Kumar, S., Singh, G., 2014. Agronomic practices for agroforestry systems in India. Indian Journal of Agronomy 59(4), 497–510.

Golob, P., Nishimura, H., Satohi, A., 2007. *Eucalyptus* (medicinal and aromatic plants - industrial profiles). *Eucalyptus* in insect and plant pest control. 1st Edn. Taylor & Francis, USA 464p.

Gupta, B., Sarvade, S., Mahmoud, A., 2015. Effects of selective tree species on phytosociology and production of understorey vegetation in mid-Himalayan region of Himachal Pradesh. Range Management and Agroforestry 36(2), 156–163.

Gupta, G.N., Prasad, K.G., Mohan, S., Subramaniam, V., Manovachkam, P., 1990. Effect of alkalinity on survive and growth of tree seeding. Journal of the Indian Society of Soil Science 36, 537–542.

Halim, A.A.S., Morsy, T.A., 2005. The insecticidal activity of *Eucalyptus globulus* oil on the development of *Musca domestica* third stage larvae. Journal of the Egyptian Society of Parasitology 35(2), 631–636.

Hayat, U., Jilani, M.I., Rehman, R., Nadeem, F., 2015. A Review on Eucalyptus globulus: A New Perspective in Therapeutics. International Journal of Chemical and Biochemical Sciences 8, 85–91.

Hoogar, R., Malakannava, S., Sujatha, H.T., 2019. Impact of eucalyptus plantations on ground water and soil ecosystem in dry regions. Journal of Pharmacognosy and Phytochemistry 8(4), 2929–2933.

Ibanez, M.D., Blazquez, M.A., 2018. Phytotoxicity of essential oils on selected weeds: potential hazard on food crops. Plants 7, 79–94.

Jan, M.N., Dimri, B.M., Gupta, M.K., 1996. Soil nutrient changes under different ages of Eucalyptus monocultures. Indian Forester 122, 55–60.

Jawahar, S., Deepika, A.V.L., Kalaiyarasan, C., Suseendran, K., 2013. Herbicidal efficacy of eucalyptus oil on parthenium (*Parthenium hysterophorus* L.) control. Life Sciences Leaflets 3, 79–88.

Jacobs, M.R., 1981. Eucalypts for planting. FAO Forestry Series No. 11. Rome, FAO. 667p.

Joshi, N.R., Tewari, A., Singh, V., 2013. Biomass and carbon accumulation potential towards climate change mitigation by young plantations of *Dalbergia sissoo* Roxb. and *Eucalyptus hybrid* in *Terai* Central Himalaya, India. American Journal of Research Communication 1(4), 261–274.

Kaul, M., Mohren, G.M.J., Dadhwal, V.K., 2010. Carbon storage and sequestration potential of selected tree species in India. Mitigation and Adaptation Strategies for Global Change 15, 489–510.

Kidanu, S., Mamo, T., Stoosnijder, L., 2005. Biomass production of *Eucalyptus* boundary and their effect on crop productivity on Ethiopian highland Vertisols. Agroforestry Systems 63, 281–290.

Kohli, R.K., Batish, D.R., Singh, H.P., 1998. Eucalypt oils for the control of parthenium (*Parthenium hysterophorus* L.). Crop Protection 17(2), 119–122.

Kombra, S., Ahlawat, K.S., Sirohi, C., Dalal, V., Kumar, S., Poonia, P., Yadav, S., Khaiper, M., 2022. Performance of mustard as intercrop in *Eucalyptus tereticornis* based cropping system in semi-arid ecosystem of India. Biological Forum-An International Journal 14(2), 143–148.

Kumar, P., Mishra, A.K., Chaudhari, S.K., Basak, N., Rai, P., Singh, K., Singh, R., Pandey, C.B., Sharma, D.K., 2018. Carbon pools and nutrient dynamics under *Eucalyptus*-based agroforestry system in semi-arid region of North-west India. Journal of the Indian Society of Soil Science 66(2), 188–199.

Kumar, R., Sood, S., Kasana, R.C., Pathania, V.L., Singh, B., Singh, R.D., 2013. Effect of plant spacing and organic mulch on growth, yield and quality of natural sweetener plant Stevia and soil fertility in western Himalayas. International Journal of Plant Production 8(3), 1735–1741.

Kumar, A., Nandal, D.P.S., 2004. Performance of winter crops under *Eucalyptus tereticornis* based agroforestry systems. Indian Journal of Agroforestry 6(2), 97–98.

Kumar, D., 1984. Place of *Eucalyptus* in Indian agroforestry systems. *In*: Proceedings Sharma,J.K., Nair, C.T.S., Kedharnath, S., Kondos, S. (Eds.), National Seminar on Eucalypts in Indian Forestry: Past, Present and Future, Peechi, 30–31 January 1984. *Eucalypts* in India: Past present and future:Peechi, KFRI. pp. 257–260.

Laquale, S., Candido, V., Avato, P., Argentieri, M.P., D'Addabbo, T., 2015. Essential oils as soil bio-fumigants for the control of the root-knot nematode Meloidogyne incognita on tomato. Annals of Applied Biology 167, 217–224.

Lee, B.H., Choi, W.S., Lee, S.E., Park, B.S., 2001. Fumigant toxicity of essential oils and their constituent compounds towards the rice weevil, *Sitophilus oryzae* (L.). Crop Protection 20, 317–320.

Liew, J.J., 2009. Carbon sequestration of *Eucalyptus polybractea* and D_2 as an indicator of below ground biomass. Honour's Dissertation, School of Environmental Systems Engineering, The University of Western Australia, Crawley, Perth, Australia, 2009.

Lucia, A., Audino, P.G., Seccacini, E., Licastro, S., Zerba, E., Masuh, H., 2007. Larvicidal effect of *Eucalyptus grandis* essential oil and turpentine and their major components on *Aedes aegypti* larvae. Journal of the American Mosquito Control Association 23, 299–303.

Luna, R.K., Rawat, V.R.S., Singh, B., Chandra, A., 2006. Site suitability of *Eucalyptus* under agroforestry system in different agro-climatic zones of Punjab. *In*: National seminar on trees outside forests: potential for socio-economic and ecological development, Chandigarh, 25-26 April 2006. Proceedings.

Luna, R.K., 1996. Plantation trees. International Book Distributors, Dehradun, Uttaranchal, 975p.

Marzoug, H.N.B., Romdhane, M., Lebrihi, A., Mathieu, F., Couderc, F., Abderraba, M., Khouja, M.L., Bouajila, J., 2011. *Eucalyptus oleosa* essential oils: chemical composition and antimicrobial and antioxidant activities of the oils from different plant parts (stems, leaves, flowers and fruits). Molecules 16(2), 1695–1709.

Mengistu, B., Amayu, F., Bekele, W., Dibaba, Z., 2020. Effects of Eucalyptus species plantations and crop land on selected soil properties. Geology, Ecology and Landscapes 6(4), 277–285.

Mishra, A., Sharma, S.D., Khan, G.H., 2003. Improvement in physical and chemical properties of sodic soil by 3, 6 and 9 years old plantation of *Eucalyptus tereticornis* Bio-rejuvenation of sodic soil. Forest Ecology and Management 184, 115–124.

Nasim, M., Qureshi, R.H., Saqib, M., Aziz, T., Nawaz, S., Akhtar, J., Anwar-ul-Haq, M., 2007. Properties of salt affected soil under *Eucalyptus camaldulensis* plantation in field conditions. Pakistan Journal of Agriculture Science 44, 401–414.

Nathan, S.S., 2007. The use of *Eucalyptus tereticornis* Sm. (Myrtaceae) oil (leaf extract) as a natural larvicidal agent against the malaria vector *Anopheles stephensi* Liston (Diptera: Culicidae). Bioresource Technology 98, 1856–1860.

Nezhad, F.M., Zeigham, H., Mota, A., Sattari, M., Yadegar, A., 2009. Antibacterial activity of *Eucalyptus* extracts on methicillin resistance *Staphylococcus aureus*. Research Journal of Biological Sciences 4(8), 905–908.

Panchal, J.S., Thakur, N.S., Jha, S.K., Kumar, V., 2017. Productivity and carbon sequestration under prevalent agroforestry systems in Navsari District, Gujarat, India. International Journal of Current Microbiology and Applied Science*s* 6(9), 3405–3422.

Pandey, R., Kalra, A., Tandon, S., Mehrotra, N., Singh, H.N., Kumar, S., 2000. Essential oils as potent sources of nematicidal compounds. Journal of Phytopathology 148, 501–502.

Papachristos, D.P., Stamopoulos, D.C., 2004. Toxicity of vapours of three essential oils to the immature stages of *Acanthoscelides obtectus* (Say) (Coleoptera: Bruchidae). Journal of Stored Products Research 40, 517–525.

Papachristos, D.P., Stamopoulos, D.C., 2002. Repellent, toxic and reproduction inhibitory effects of essential oil vapours on *Acanthoscelides obtectus* (Say) (Coleoptera: Bruchidae). Journal of Stored Products Research 38, 117–128.

Pereira, V., Dias, C., Vasconcelos, M.C., Rosa, E., Saavedra, M.J., 2014. Antibacterial activity and synergistic effects between *Eucalyptus globulus* leaf residues (essential oils and extracts) and antibiotics against several isolates of respiratory tract infections (*Pseudomonas aeruginosa*). Industrial Crops and Products 52, 1–7.

Prajapati, N., Sharma, R., Singh, H., 2020. Unravelling the bioherbicidal potential of eucalyptus species aqueous leaf extract and leaf oil on germination and initial growth performance of weed *Parthenium hysterophorus*. International Journal of Current Microbiology and Applied Sciences 9(09), 3028–3040.

Prasad, J.V.N.S., Korwar, G.R., Rao, K.V., Mandal, U.K., Rao, C.A.R., Rao, G.R., Ramakrishna, Y.S., Venkateswarlu, B., Rao, S.N., Kulkarni, H.D., Rao, M.R., 2010. Tree row spacing affected agronomic and economic performance of *Eucalyptus*-based agroforestry in Andhra Pradesh, Southern India. Agroforestry System 78, 253–267.

Pryor, L.D., 1966. A report on past performance and some current aspects of the cultivation of quick-growing species (mainly *Eucalyptus*) in India. Indian Forester 92(10), 615–622.

Puig, C.G., Reigosa, M.J., Valentao, P., Andrade, P.B., Pedrol, N., 2018. Unravelling the bioherbicide potential of *Eucalyptus globulus* Labill: biochemistry and effects of its aqueous extract. PLoS One 13, e0192872.

Raizada, A., Parandiyal, A.K., Ghosh, B.N., 2003. Estimation of carbon flux through litter fall in forest plantation of India. Indian Forester 129(7), 881–894.

Raj, A., Jhariya, M.K., Bargali, S.S., 2016. Bund based agroforestry using eucalyptus species: a review. Current Agriculture Research Journal 4(2), 148–158.

Ram, J., Dagar, J.C., Lal, K., Singh, G., Toky, V., Tanwar, V.S., Dar, S.R., Chauhan, M.K., 2011. Bio-drainage to combat waterlogging, increase farm productivity and sequester carbon in canal command areas of Northwest India. Current Science 100(11), 1673–1680.

Rossi, Y.E., Palacios, S.M., 2015. Insecticidal toxicity of *Eucalyptus cinerea* essential oil and 1,8-cineole against *Musca domestica* and possible uses according to the metabolic response of flies. Industrial Crops and Products 63, 133–137.

Sabo, V.A., Knezevic, P., 2019. Antimicrobial activity of

Eucalyptus camaldulensis Dehn. plant extracts and essential oils: a review. Industrial Crops & Products 132, 413–429.

Salgado, S.L.M., Campos, V.P., Cardos, M.D.G., Salgado, A.P.S., 2003. Hatching and mortality of second-stage juveniles of *Meloidogyne exigua* in essential plant oils. Nematologia Brasileira 27, 17–22.

Sarvade, S., Mishra, H.S., Kaushal, R., Chaturvedi, S., Tewari, S., Jadhav, T.A., 2014a. Performance of wheat (*Triticum aestivum*) crop under different spacing of trees and fertility levels. African Journal of Agricultural Research 9(9), 866–873.

Sarvade, S., Mishra, H.S., Kaushal, R., Chaturvedi, S., Tewari, S., 2014b. Wheat (*Triticum aestivum* L.) yield and soil properties as influenced by different agri-silviculture systems of Terai Region, Northern India. International Journal of Bio-resource and Stress Management 5(3), 350–355.

Sarvade, S., Gautam, D.S., Kathal, D., Tiwari, P., 2017. Waterlogged wasteland treatment through agro–forestry: A review. Journal of Applied and Natural Science 9(1), 44–50.

Sarvade, S., Mishra, H.S., Kaushal, R., Chaturvedi, S., Singh, R., Lal, C., Attri, V., 2019. Carbon sequestration potential of fast growing short rotation tree species based agroforestry systems in Terai Region of Central Himalaya. *In*: Dev, I., Asha, R., Naresh, K., Ramesh, S., Dhiraj, K., Uthappa, A.R., Handa, A.K., Chaturvedi, O.P. (Eds), Agroforestry for climate resilence and rural livelihood. Scientific Publishers. Jodhpur (Rajasthan), 153–165.

Seyoum, A., Killeen, G.F., Kabiru, E.W., Knols, B.G.J., Hassanali, A., 2003. Field efficacy of thermally expelled or live potted repellent plants against African malaria vectors in western Kenya. Tropical Medicine and International Health 8, 1005–1011.

Shyam Sundar, S., 1984. Some aspects of *Eucalyptus hybrid*. *In*: Workshop on *Eucalyptus* plantation, Bangalore, June 1984. Papers and proceedings. Bangalore, Indian Statistical Institute.

Singh, M., Gupta, B., Das, S.K., Avasthe, R.K., Sarvade, S., 2015a. Assessment of economic viability of different agroforestry systems in Giri Catchment, Himachal Pradesh. Economic Affairs 60(3), 557–561.

Singh, M., Gupta, B., Sarvade, S., Awasthe, R.K., 2015b. Biomass and carbon sequestration potential in different agroforestry systems in Giri catchment of North Western Indian Himalayas. Indian Journal of Agroforestry 17(2), 42–48.

Singh, S.K., Verma, C., Sharma, D.K., 2014. Plant height model for *Eucalyptus* plantations for biodrainage use. International Journal of Research in Engineering and Technology 3(6), 250–259.

Singh, H.P., Batish, D.R., Setia, N., Kohli, R.K., 2005. Herbicidal activity of volatile oils from *Eucalyptus citriodora* against *Parthenium hysterophorus*. Annals of Applied Biology 146, 89–94.

Stanturf, J.A., Vance, E.D., Fox, T.R., Kirst, M., 2013. *Eucalyptus* beyond its native range: environmental issues in exotic bioenergy plantations. international journal of forestry research. Article ID 463030. Available [Online] http://dx.doi.org/10.1155/2013/463030.

Tapondjou, A.L., Adler, C., Fontem, D.A., Bouda, H., Reichmuth, C., 2005. Bioactivities of cymol and essential oils of *Cupressus sempervirens* and *Eucalyptus saligna* against *Sitophilus zeamais* Motschulsky and *Tribolium confusum* du Val. Journal of Stored Products Research 41, 91–102.

Thorsell, W., Mikiver, A., Malander, I., Tunon, H., 1998. Efficacy of plant extracts and oils as mosquito repellents. Phytomedicine 5, 311–323.

Tinkeu, L., Goudoum, S.N., Ngassoum, A., Mapongmetsem, M.B., Kouninki, P.M., Hance, T., 2004. Persistence of the insecticidal activity of five essential oils on the maize weevil *Sitophilus zeamais* (Motsch.) (Coleoptera: Curculionidae). Communications in Agricultural and Applied Biological Sciences 69, 145–147.

Trigg, J.K., 1996a. Evaluation of eucalyptus-based repellent against Anopheles spp. in Tanzania. Journal of the American Mosquito Control Association 12, 243–246.

Trigg, J.K., 1996b. Evaluation of eucalyptus-based repellent against *Culicoides impunctatus* (Diptera: Ceratopogonidae) in Scotland. Journal of the American Mosquito Control Association 12, 329–330.

Trigg, J.K., Hill, N., 1996. Laboratory evaluation of a eucalyptus-based repellent against four biting arthropods. Phytotherapy Research 10, 313–316.

Tunc, I., Berger, B.M., Erler, F., Dag, F., 2000. Ovicidal activity of essential oils from five plants against two stored-product insects. Journal of Stored Products Research 36, 161–168.

Vecchio, M.G., Loganes, C., Minto, C., 2016. Beneficial and healthy properties of *Eucalyptus* plants: A great potential use. The Open Agriculture Journal 10(1), 52–57.

Vishwakarma, G.S., Mittal, S., 2014. Bioherbicidal potential of essential oil from leaves of *Eucalyptus tereticornis* against *Echinochloa crus - galli* L. Journal of Biopesticides 7, 47–53.

Vourch, G., Russell, J., Martin, J.L., 2002. Linking deer browsing and terpene production among genetic identities in *Chamaecyparis nootkatensis* and *Thuja plicata* (Cupressaceae). Journal of Heredity 93,

370–376.
Wilson, J., 1973. The need for a rational utilisation of the montane temperate forests of South India. Indian Forester 99(12), 707–716.
Yadava, A.K., 2010. Carbon sequestration: underexploited environmental benefits of *Tarai* agroforestry systems. Report and Opinion. Indian Forester 136(2), 234–244.
Yimam, M.M., Hailu, L., 2022. Effects of eucalyptus plantation on environment and water resource. International Journal of Advanced Research in Biological Sciences 9(5), 156–163.
Zhao-Hui, L., Wang, Q., Ruan, X., Pan, C., Jiang, D., 2010. Phenolics and plant allelopathy. Mole 15, 8933–8952.