



Effect of Different Nutrient Sources on Growth Performance and Carbon Sequestration Potential of *Melia azedarach* and *Eucalyptus tereticornis* Plantations

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Abstract

The present study evaluates the impact of different nutrient sources including sewage sludge on the growth performance, productivity and carbon sequestration by *Melia azedarach* (dek) and *Eucalyptus tereticornis* (eucalyptus) plantations. The trees were planted at a spacing of 4×3 m i.e., 833 trees ha⁻¹ in randomized block design (RBD) in three replications with a net plot size of 4 plants plot⁻¹. The treatments viz. T1: recommended dose of nitrogen (N) and phosphorus (P) through inorganic fertilizers (urea and DAP), T2:100% N through farmyard manure (FYM), T3:100% N through sewage sludge, T4: 50% N through sewage sludge and T5:150% N through sewage sludge were applied. Growth measurements, including diameter at breast height (DBH) and height, were recorded annually and timber volume was estimated using species-specific regression equations. At six years of age, total biomass production, carbon stock and carbon dioxide (CO₂) assimilation potential were also quantified. Statistically significant variations were observed among treatments for both species across the years. In dek, DBH, height and timber volume were 10.7, 14.4 and 33.2% higher, respectively in T2 over T4 with recorded ranges of 17.17–19.01 cm, 16.71–19.12 m, and 188.8–251.4 m³ ha⁻¹, respectively. Similarly, in eucalyptus, T2 had 8.7, 6.7 and 34.8% higher DBH, height and volume, respectively over T4 with corresponding ranges of 18.87–20.50 cm, 23.02–24.56 m, and 182.6–246.1 m³ ha⁻¹, respectively. Consequently, T2 also resulted in the highest total biomass (270.6 and 242.8 Mg ha⁻¹), total carbon stock (123.5 and 110.8 Mg C ha⁻¹) and CO₂ assimilation potential (453.1 and 369.2 Mg CO₂ ha⁻¹) in dek and eucalyptus, respectively. The findings demonstrate that the growth and productivity of both species under T2 and T3 were statistically better compared to other treatments. Therefore, sewage sludge can be effectively utilized as an alternative organic nutrient source for enhancing the productivity and carbon sequestration potential of *Melia* and *Eucalyptus* plantations instead of inorganic fertilizers.

Key words: Biomass, Carbon-stock, Productivity, Sewage sludge, Tree volume

Introduction

India generates approximately 72,368 million litres per day (MLD) of sewage. The installed capacity of sewage treatment plants (STPs) is 31,841 MLD, which is about 43.9% of the total sewage generated. However, the operational capacity is 26,869 MLD and the actual utilized capacity is 20,235 MLD, thus only about 28% of the sewage is effectively treated (Anonymous, 2021). The need for affordable, sustainable and environmentally safe waste management alternatives is growing, particularly in rapidly urbanizing regions like India, where solid and liquid waste generation is outpacing treatment capacity. Among the by-products of wastewater treatment is sewage sludge, which contains a

substantial proportion of organic (50–70%) and inorganic (30–50%) matter. This sludge is rich in macronutrients, such as nitrogen (3.4–4.0%) and phosphorus (0.5–2.5%), along with essential micronutrients (Samolada and Zabaniotou, 2014). However, it also harbors toxic heavy metals, including Hg, Cd, Zn, Pb, Ni, Se, Cu and Cr, which pose a significant ecological and public health risk due to their potential to enter the food chain (Kacprzak *et al.*, 2017; Raheem *et al.*, 2018). The sewage sludge application in soils improves physical, chemical and biological soil properties, water-holding capacity, bulk density and the formation of stable organo-metallic complexes (Singh and Agrawal, 2008; Kominko *et al.*, 2017) thus, significantly enhancing plant growth and

productivity (Eid *et al.*, 2019; Guoqing *et al.*, 2019). Nevertheless, the ecotoxicological risks associated with heavy metal accumulation cannot be overlooked. Plants composed of macromolecules like carbohydrates, proteins, lipids and nucleic acids, contain functional groups that can interact with and bind to these heavy metals (Usman *et al.*, 2019). When these metals are absorbed by crops, they enter the trophic chain, potentially threatening human and animal health. While, perennial tree species extract, immobilize or degrade contaminants and their inherent physiological mechanisms can help to restore ecological balance through the stabilization or uptake of soil and water pollutants (Ahmadi *et al.*, 2020). Therefore, trees are more sustainable and lower-risk alternative, as their products are not typically consumed directly by humans (Madejon *et al.*, 2006; Picariello *et al.*, 2021).

Consequently, the present study was undertaken to assess the effects of sewage sludge application on the growth performance and productivity of two fast-growing and ecologically significant tree species, *Melia azedarach* (dek) and *Eucalyptus tereticornis*, under the agro-climatic conditions of Punjab, India. These species are widely recognized for their economic value and ecological adaptability and are increasingly used in agroforestry systems and afforestation programs. Dek is traditionally planted along farm boundaries but is now also cultivated in block plantations at spacings of 5×4 m or 7×3 m, often intercropped with agricultural crops (Saralch *et al.*, 2007; Singh *et al.*, 2016). Its moderately hard wood is highly valued for a range of applications, including wallboards, door panels, furniture, agricultural implements, matchsticks, paper pulp, flooring, and most notably, as a premium raw material for plywood suitable for both face and core veneers. *Eucalyptus* is a highly versatile and adaptable species that thrives under a wide range of soil and climatic conditions. It is commonly planted in block configurations at spacings of 4×2 m or 3×3 m, or along field boundaries at spacing of 2 m. The species is valued for its high biomass yield and wood, which is extensively used in furniture making, packaging (crates and boxes), pulpwood production and the plywood industry (Amer *et al.*, 2021). External nutrient

supplementation can significantly enhance plant growth, particularly in nutrient-deficient soils (Singh *et al.*, 2018; Singh *et al.*, 2023) while utilization of organic nutrient sources is crucial for sustainable land management practices and conservation efforts (Kumar *et al.*, 2025). In this context, the current study seeks to evaluate the growth performance of *dek* and *eucalyptus* under different nutrient regimes, including inorganic fertilizers, FYM and different levels of sewage sludge.

Materials and Methods

Climatic conditions and experimental details

The present investigation was carried out at the Research Farm of the Department of Forestry and Natural Resources, Punjab Agricultural University, Ludhiana, India ($30^{\circ}54'N$ and $75^{\circ}48'E$) from 2013 to 2019. The area falls within the central agroclimatic zone of Punjab. The climate of the region is typically semi-arid subtropical to tropical, characterized by a prolonged dry season from early October to June and a wet season from July to mid-September. The region also experiences hot, desiccating winds in the summer (May-June) and severe cold in winters, leading to intense evapo-transpirational loss. December and January are the coldest months. The trees were planted at a spacing of 4×3 m i.e., 833 trees ha^{-1} in randomized block design (RBD) in three replications with a plot size of 4 plants $plot^{-1}$. The non-experimental rows of plants of each species were also planted and maintained around each species. The treatments comprised of recommended N and P application through inorganic fertilizers i.e. urea and DAP, respectively (T1), 100% N from FYM (T2), 100% N from sludge (T3), 50% N from sludge (T4) and 150% N from sludge (T5). So, there were 15 experimental plots of each species. The 50% N level from sludge was taken to assess the influence of lower application of sludge on growth, being its influence also on soil physical properties. The remaining 50% of N was omitted to assess how the lower nutrient input from sludge alone influences the tree growth. This will help to understand the minimum effective dose and potential benefits or limitations of reduced sludge

Table 1. Concentration of nutrients and heavy metals in FYM and sewage sludge

Elements	FYM	Sewage sludge
Nitrogen (%)	1.0	1.5
Phosphorus (%)	0.29	0.19
Potassium (%)	1.65	1.76
Calcium (%)	1.91	2.23
Magnesium (%)	0.61	0.68
Sulphur (%)	0.24	0.93
Fe (mg kg ⁻¹)	6259	9457
Mn (mg kg ⁻¹)	165	196
Cu (mg kg ⁻¹)	18.3	86.1
Zn (mg kg ⁻¹)	98.1	364
Ni (mg kg ⁻¹)	12.8	22.3
Cd (mg kg ⁻¹)	0.52	5.4
Bo (mg kg ⁻¹)	18.0	22.3
Cr (mg kg ⁻¹)	13.5	35.2
Pb (mg kg ⁻¹)	10.3	46.2

application. The 150% N level from sludge was kept to evaluate the toxic effect of higher application of sludge. The quantity of FYM and sewage sludge required for each treatment was determined on the basis of N content in these sources (Table 1). Sewage sludge was taken from a sewage treatment plant located at village Bhatian, Ludhiana. Fertilizers, FYM and sewage sludge were mixed properly in the soil around plants every year (Table 2). Irrigation and weeding in the plantation were done as and when required.

Measurement of growth parameters

Girth at breast height (GBH) of trees (cm) was measured each year in the month of January by measuring tape at 1.37 m from ground level and converted to diameter at breast height (DBH) using the formula $DBH = GBH/\pi$. Height of trees (m) was recorded from base of the tree to growing tip with the help of Ravi's Multimeter. Timber volume was estimated from these parameters

every year by the following regression equations:

$$\text{Timber volume for dek (m}^3 \text{ tree}^{-1}\text{)} = -0.0056342806 + 0.0000513229 * (D^2H), \text{ (Gill } et al., 2025) \quad (1)$$

$$\text{Timber volume for eucalyptus (m}^3 \text{ tree}^{-1}\text{)} = -0.00321 + 0.32098 * (D^2H), \text{ (Dhanda and Singh, 1990)} \quad (2)$$

Where, D is the DBH, and H is the height of the trees. Timber volume (m³ ha⁻¹) was calculated by assuming 10% mortality of trees i.e. on the basis of 750 trees ha⁻¹.

Assessment of biomass, carbon stock and CO₂ assimilation potential

Dek: Stem biomass (SB) of dek was calculated by multiplying volume (V) into species specific gravity (0.491) (Anonymous, 2023)

$$SB = V \times 0.491 \quad (3)$$

Above ground Biomass (AGB) was estimated by applying the biomass expansion factor (BEF) of 1.74, specific to dek (Newaj *et al.*, 2014; Anonymous, 2023)

$$AGB = \text{Stem Biomass} \times \text{BEF} \quad (4)$$

Eucalyptus: Above ground biomass of eucalyptus was calculated by the following allometric equation published by Central Soil Salinity Research Institute (Kumar *et al.*, 2020)

$$Y = -12.8528 + 3.7309x - 1.4085y \quad (5)$$

Where, Y = biomass (kg), x = girth (cm) and y = height of the tree (m)

Below ground biomass (BGB) of both species: The below ground biomass (BGB) was calculated by multiplying AGB by a factor of 0.26 as IPCC default factor for root: shoot ratio.

$$BGB = AGB \times 0.26 \quad (6)$$

Table 2. Application of different sources of nutrients to tree plantations during different years

Treatments	1 st year	2 nd year	3 rd year	4 th year	5 th year	6 th year
T ₁ (N: P ₂ O ₅ from Urea and DAP, g plant ⁻¹)	50:30	85:50	120:75	155:100	190:125	225:150
T ₂ (100% N from FYM, kg plant ⁻¹)	5	8.5	12	15.5	19	22.5
T ₃ (100% N from Sludge, kg plant ⁻¹)	3.3	5.6	8	10.5	13	15.5
T ₄ (50% N from Sludge, kg plant ⁻¹)	1.6	2.8	4	5.2	6.5	7.8
T ₅ (150% N from Sludge, kg plant ⁻¹)	4.8	8.4	11.8	15.6	19.2	23.3

Carbon stock estimation: The carbon content of the biomass was calculated using carbon fraction coefficients from literature. The carbon content in AGB and BGB was determined by multiplying the biomass by carbon fractions of 0.45 and 0.48, respectively (Newaj *et al.*, 2014; Kumar *et al.*, 2019).

$$\text{Carbon stock AGB} = \text{AGB} \times 0.45 \quad (7)$$

$$\text{Carbon stock BGB} = \text{BGB} \times 0.48 \quad (8)$$

Total carbon stock was calculated by addition of carbon stock present in AGB and BGB

CO₂ assimilation potential: The total carbon stock was converted into carbon dioxide equivalents (CO₂) using the molecular weight ratio of CO₂ to carbon (44/12 or 3.67) (IPCC, 2006).

$$\text{CO}_2 = \text{Total Carbon} \times 44/12 \quad (9)$$

Soil, FYM and sludge analysis

Soil samples were collected from the surface depth (0-15 cm) at the time of initiation of the study. The samples were ground to pass through a 2 mm sieve after air drying. Soil organic carbon content in the samples was determined by Walkley and Black method, available nitrogen by potassium permanganate method (Subbiah and Asija, 1956), available phosphorus by Olsen method and available potassium by ammonium acetate method (Jackson, 1973). The soil had loamy sand texture, alkaline pH (7.89), normal EC (0.29 dS m⁻¹), low OC (0.32%) low available N (125.2 kg ha⁻¹), medium available P (13.3 kg ha⁻¹) and sufficient available K (176 kg ha⁻¹) at the time of initiation of study. The concentration of N in FYM and sewage sludge was determined by Kjeldahl method (Jackson, 1973). The other nutrients and heavy metals in FYM and sewage sludge were determined by digestion of the sample with 10-15 ml of diacid mixture (HNO₃ and HClO₄ in 3:1 ratio). The readings were taken on Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES) after making the volume of the extract. All the nutrients and heavy metals except P were higher in sewage sludge than FYM (Table 1).

Statistical analysis

Statistical analysis was done by using ANOVA technique in randomized block design (RBD). The

differences among treatments were compared by critical difference (CD) test at 5% level of significance (Panse and Sukhatme, 1985). All statistical analyses were performed using CPCS-1 statistical software of PAU, Ludhiana.

Results and Discussion

Growth, productivity and carbon sequestration by dek

The DBH and height of *dek* varied significantly across treatments over the six-year study period (Figure 1). As the trees aged from one to six years, DBH increased from 6.07 to 17.23 cm in T1, 5.93 to 19.01 cm in T2, 6.37 to 18.49 cm in T3, 4.73 to 17.17 cm in T4, and 4.80 to 17.33 cm in T5. At the age of six, the highest DBH was recorded in T2 (19.01 cm), which was statistically at par with T3 (18.49 cm) and T5 (18.33 cm), while the lowest DBH was observed in T4 (17.17 cm). Over the period, height increased from 7.60 to 17.38 m in T1, 7.43 to 18.86 m in T2, 7.43 to 19.12 m in T3, 6.33 to 17.46 m in T4, and 6.27 to 16.71 m in T5. The tallest trees were recorded in T3 (19.12 m), statistically at par with T2 (18.86 m), while the shortest were observed in T5 (16.71 m) after six years (Figure 1).

Tree volume (productivity) was calculated using DBH and height with the help of a regression equation, which varied significantly among treatments (Table 3). After six years, volume was significantly higher in T2 (251.4 m³ ha⁻¹) followed by T3 (240.9 m³ ha⁻¹) compared to other treatments. The enhanced growth and productivity observed in these treatments are attributed to the application of 100% nitrogen through FYM and sewage sludge and improvement in soil physical properties and supply of other nutrients by these organic manures. In contrast, growth parameters and volume were considerably less under T4, which received only 50% nitrogen from sludge, may be due to insufficient nutrient availability. Application of FYM or sewage sludge not only supplies essential nutrients (Table 1) but also enhances soil physical and microbial properties, such as water-holding capacity and bulk density, which further support plant growth (Xue and Huang, 2013; Rani *et al.*, 2021; Singh *et al.*, 2023). Notably, the application

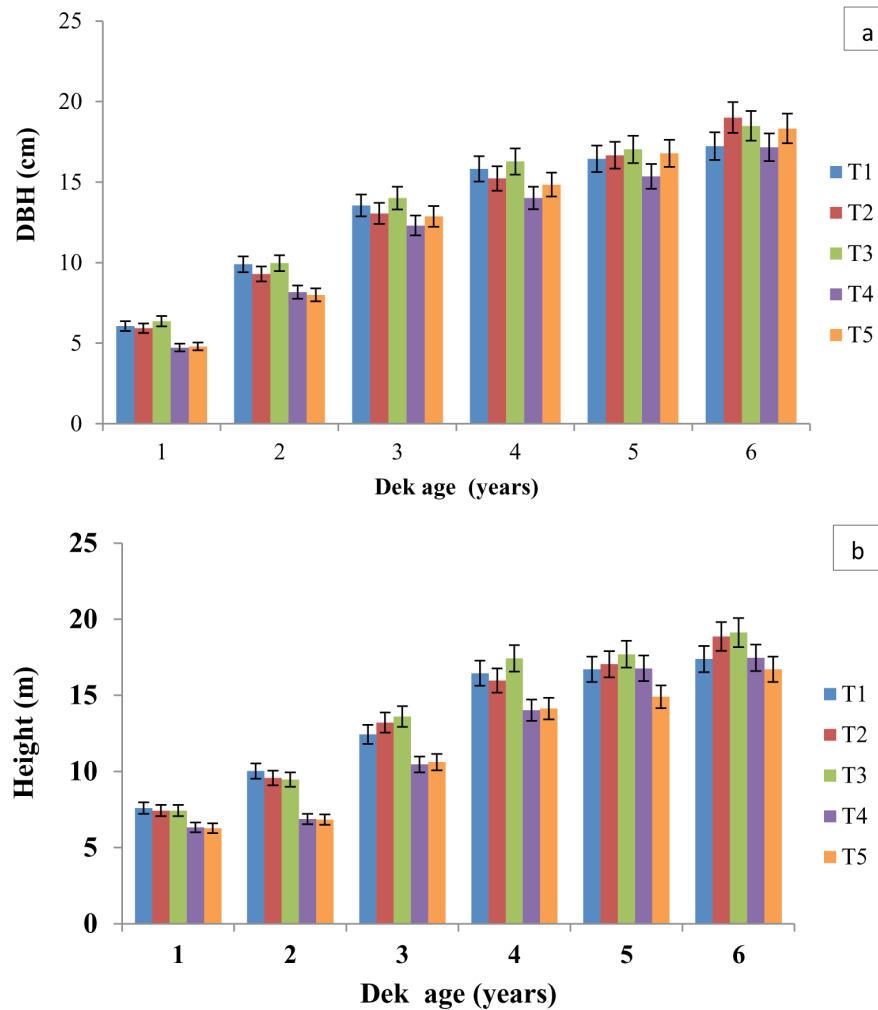


Fig. 1 Diameter at breast height (a) and Height (b) of dek under various nutrient sources during different years. The error bars are standard error of means. Treatments T1 to T5 as in Table 2.

Table 3. Volume of dek under various nutrient sources during different years

Treatments	Volume (m ³ ha ⁻¹) during different years					
	1	2	3	4	5	6
T1	6.28	32.6	81.4	150.2	165.3	189.3
T2	5.58	26.8	80.3	134.7	173.3	251.4
T3	7.08	31.1	96.0	168.9	188.3	240.9
T4	1.09	13.0	55.2	99.2	144.1	188.8
T5	1.19	12.2	61.8	112.5	153.4	206.3
SE $\pm$ m	0.29	1.37	1.55	1.91	2.30	2.55
CD (P=0.05)	0.95	4.55	5.03	6.38	7.65	8.53

Treatments T1 to T5 as in Table 2.

of 150% nitrogen through sludge did not result in additional growth over the 100% level. The lack of additional growth at 150% N compared to 100% N may be attributed to fulfillment of N requirement of plants where the excess nitrogen

does not boost growth and may even harm the plants. Higher application of sewage sludge may also be toxic to plants. High nitrogen levels from sewage sludge can increase soil salinity or toxicity, which impairs water and nutrient uptake, enzyme

Table 4. Estimation of biomass and C assimilation in 6 year-old *dek* plantation in five treatments by an allometric equation

Treatments	Stem	Dry Biomass (Mg ha ⁻¹)			C-stock (Mg C ha ⁻¹)			CO ₂ assimilation (Mg ha ⁻¹)		
	Biomass	AGB	BGB	Total	AGB	BGB	Total	AGB	BGB	Total
T1	92.9	161.7	42.04	203.8	72.8	20.2	93.0	267.1	74.1	341.2
T2	123.4	214.8	55.84	270.6	96.7	26.8	123.5	354.7	98.4	453.1
T3	118.3	205.8	53.51	259.3	92.6	25.7	118.3	339.9	94.3	434.2
T4	92.7	161.3	41.93	203.2	72.6	20.1	92.7	266.4	73.9	340.3
T5	101.3	176.3	45.82	222.1	79.3	22.0	101.3	291.1	80.7	371.8
SE ± m	0.9	0.9	0.68	2.7	0.8	0.5	1.8	5.8	0.8	7.3
CD (P=0.05)	3.0	3.1	2.25	9.0	2.7	1.5	6.1	19.3	2.6	24.0

AGB: Above ground biomass, BGB: Below ground biomass

Treatments T1 to T5 as in Table 2

activity and root function, ultimately limiting growth (Singh and Agrawal, 2008). The findings align with earlier studies showing improved productivity in fast-growing, short-rotation species under integrated nutrient management across different agro-ecological zones (Yin *et al.*, 2009; Henderson and Jose, 2010; Singh *et al.*, 2022). Singh *et al.* (2023) reported significant improvements in poplar growth and yield with continuous fertilizer application throughout the rotation period. Verma and Sharma (2010) observed significant improvements in apple tree growth, yield and fruit quality with FYM application at 100 kg per tree.

Biomass production, carbon stock and CO₂ assimilation by *dek* was significantly influenced under five different treatments (Table 4). Among all treatments, T2 demonstrated the highest overall performance, with a total dry biomass of 270.6 Mg ha⁻¹, comprising 214.8 Mg ha⁻¹ of above-ground biomass and 55.84 Mg ha⁻¹ of below-ground biomass. This resulted in a total carbon stock of 123.5 Mg C ha⁻¹ and a CO₂ assimilation of 453.1 Mg CO₂ ha⁻¹, the highest among all treatments. In contrast, T1 and T4 had the lowest biomass and carbon accumulation, with total biomass around 203 Mg ha⁻¹, total carbon stock approximately 93 Mg C ha⁻¹, and CO₂ assimilation near 340 Mg ha⁻¹. The T3 showed statistically at par results with T2 in growth and biomass parameters. Bai *et al.* (2022) observed that sewage sludge significantly improved soil nutrient status and aboveground biomass in Mongolian pine (*Pinus sylvestris*), while reducing soil bulk density and increasing organic carbon, total nitrogen,

phosphorus and mineral nitrogen ultimately enhancing carbon and nitrogen stocks.

Growth, productivity and carbon sequestration by eucalyptus

The statistically significant variations were recorded in all the growth and productivity parameters across treatments over the six-year study period. As the trees matured, DBH increased from 8.13 to 18.87 cm in T1, 8.30 to 20.50 cm in T2, 7.97 to 20.13 cm in T3, 7.03 to 18.27 cm in T4, and 6.20 to 19.20 cm in T5 (Figure 2). After six years, the highest DBH was recorded in T2 (20.50 cm), followed closely by T3 (20.13 cm), while the lowest was observed in T4 (18.27 cm). Similarly, plant height varied significantly among treatments (Figure 2). Height increased from 9.30 to 23.47 m in T1, 9.33 to 24.56 m in T2, 9.47 to 24.36 m in T3, 9.03 to 23.02 m in T4, and 8.30 to 23.68 m in T5. After six years, T2 and T3 again recorded the tallest trees at 24.56 m and 24.36 m, respectively, while T4 had the lowest height (23.02 m).

The volume of *Eucalyptus* plantations, calculated using regression equations based on DBH and height, also demonstrated statistically significant differences among treatments (Table 5). At the end of six years, T2 achieved the highest productivity at 246.1 m³ ha⁻¹, followed by T3 at 235.6 m³ ha⁻¹. These results indicate that the application of 100% nitrogen through FYM or sewage sludge were effective in productivity increase. The productivity of eucalyptus with 50% N application through sludge was the lowest after 6 years of growth which may be due to lower

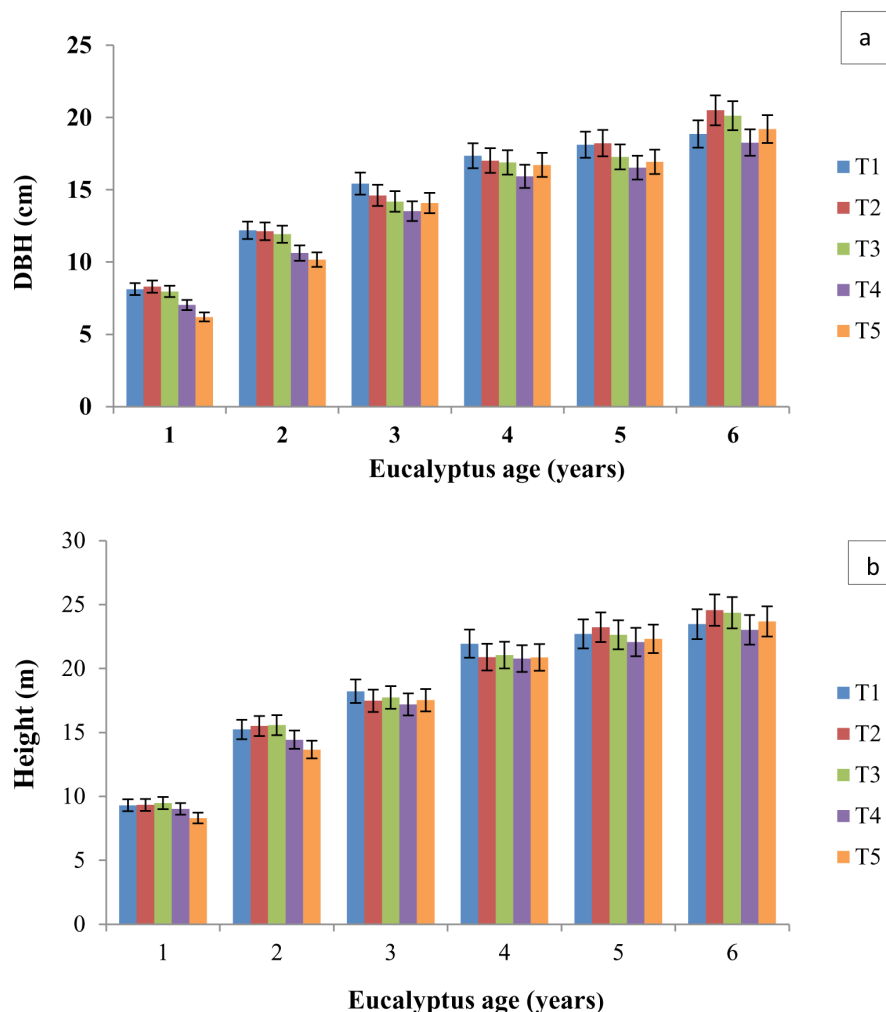


Fig. 2 Diameter at breast height (a) and Height (b) of eucalyptus under various nutrient sources during different years. The error bars are standard error of means.

Treatments T1 to T5 as in Table 2.

Table 5. Volume of eucalyptus under various nutrient sources during different years

Treatments	Volume ($\text{m}^3 \text{ha}^{-1}$) during different years					
	1	2	3	4	5	6
T1	12.39	52.2	102.0	156.8	177.0	198.8
T2	13.07	52.5	87.4	143.3	183.4	246.1
T3	12.07	50.9	83.5	142.2	160.1	235.2
T4	8.34	36.8	73.2	124.5	142.8	182.6
T5	5.27	31.6	81.2	138.0	151.6	207.7
SE $\pm$ m	0.34	1.86	1.89	2.54	3.08	3.56
CD (P=0.05)	1.17	6.11	6.36	8.43	10.11	11.82

Treatments T1 to T5 as in Table 2.

supply of nutrients than other treatments. Many research workers have observed higher productivity of tree species with application of nutrients (Gill *et al.*, 2007; Henderson and Jose, 2010; Singh and Singh, 2016; Singh *et al.*, 2022). Singh *et al.* (2018) observed a significant increase

in growth and productivity of clonal eucalyptus with application of fertilizers throughout the growing period of trees. Singh *et al.* (1991) observed the effect of FYM on *E. tereticornis* and reported that all mulched and fertilized treatments gave better growth than control seedlings, with

Table 6. Estimation of biomass and C assimilation in 6 year-old eucalyptus plantation in five treatments by an allometric equation

Treatment	Dry Biomass (Mg ha ⁻¹)			C-stock (Mg C ha ⁻¹)			CO ₂ assimilation (Mg ha ⁻¹)		
	AGB	BGB	Total	AGB	BGB	Total	AGB	BGB	Total
T1	175.2	45.5	220.7	78.8	21.9	100.7	262.7	72.9	335.6
T2	192.7	50.1	242.8	86.7	24.1	110.8	289.1	80.2	369.2
T3	188.7	49.1	237.7	84.9	23.5	108.4	283.0	78.5	361.5
T4	168.8	43.9	212.6	75.9	21.1	97.0	253.1	70.2	323.3
T5	178.7	46.5	225.2	80.4	22.3	102.7	268.1	74.3	342.4
SE ± m	3.2	0.7	3.8	1.4	0.2	1.5	2.3	0.9	6.2
CD (P=0.05)	10.7	2.2	12.6	4.5	0.7	4.9	7.6	3.0	20.4

AGB: Above ground biomass, BGB: Below ground biomass
Treatments T1 to T5 as in Table 2

FYM better than fertilizer applications. Abreu-Junior *et al.* (2017) used sewage sludge as a replacement of N and P fertilizers for eucalyptus plantations. The results showed that from 8 to 44 months after planting, the sludge application (with or without N and P) yielded a statistically larger wood volume compared to application of N and P fertilizers only and concluded that sewage sludge could represent an excellent unconventional N and P fertilizer source for wood production on unfertile soils.

The results revealed that treatment T2 (100% nitrogen from FYM) had the highest total biomass (242.8 Mg ha⁻¹), total carbon stock (110.8 Mg C ha⁻¹), and total CO₂ assimilation (369.2 Mg ha⁻¹), indicating its superior performance in promoting tree growth and carbon accumulation (Table 6). These results were statistically at par with treatment T3. Similar findings were reported in eucalyptus plantations by Kumar *et al.* (2019) and Kumar *et al.* (2020), highlighting the role of organic inputs in enhancing biomass production. Biomass yield in plantation systems is influenced by several key factors, including the choice of planting material, planting density, site characteristics, tree age and most importantly, management practices (Goswami *et al.*, 2014). A strong positive correlation between tree diameter, basal area, and carbon sequestration potential has also been observed, emphasizing the importance of tree growth parameters in ecosystem carbon dynamics (Sahoo *et al.*, 2021). The use of organic amendments not only improves soil structure and microbial activity but also ensures sustained nutrient availability, all of which contribute to

higher biomass production (Kumar *et al.*, 2019). Moreover, treated sewage sludge has been recognized as a valuable nutrient source, particularly in degraded or nutrient-deficient soils, due to its high organic matter content and richness in essential macro-nutrients (Samolada and Zabanioutou, 2014).

Conclusion

It may be concluded that among the treatments involving recommended nitrogen and phosphorus application through inorganic fertilizers *viz.* urea and DAP (T1), 100% N from FYM (T2), 100% N from sewage sludge (T3), 50% N from sewage sludge (T4) and 150% N from sewage sludge (T5), the growth, productivity and carbon sequestration by dek and eucalyptus after six years were statistically at par in T2 and T3 treatments. This indicates that sewage sludge can serve as a viable, sustainable and effective alternative to inorganic fertilizers or FYM for these tree species. However, it is important to assess the uptake of heavy metals by these tree species and their accumulation in the soil to fully understand the long-term effects of sewage sludge application on soil health.

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