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ORIGINAL RESEARCH ARTICLE

Growth performance of *Eucalyptus camaldulensis* across two distinct sites in Sindhuli district of Nepal

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ABSTRACT

This study evaluated the site-specific growth performance of *Eucalyptus camaldulensis* plantations in Nepal's Sindhuli district, comparing -terraced agricultural land (Site 1) and flatland (Site 2) over nine years. The aim was to quantify differences in growth parameters and soil properties to perform sustainable plantation management. Diameter at breast height (DBH), height, basal area, volume, and above-ground total biomass (AGTB) were measured for 314 trees, alongside soil nutrients analysis (pH, organic carbon, N, P, K) from 43 plots. Statistical analyses (Welch's t-test, regression) were employed to assess site variations. Results revealed significantly ($p < 0.001$) superior growth in Site 2, with higher mean DBH (9.00 ± 2.61 cm vs. 6.95 ± 3.71 cm), height (7.88 ± 0.80 m vs. 7.01 ± 1.97 m), and AGTB (26.96 ± 17.11 kg vs. 20.48 ± 34.16 kg) compared to Site 1. Volume distribution also significantly ($p < 0.001$) favored at Site 2 across all diameter classes (e.g., >15 cm: 0.16 m^3 vs. 0.12 m^3). Soil pH was significantly lower in Site 2 (4.72 vs. 5.48, $p < 0.05$), likely due to *Eucalyptus* litter acidity, though other nutrients remained comparable. Regression confirmed DBH and height as robust predictors of volume ($R^2 = 0.955$). The findings highlighted the flatland topography as optimal for *E. camaldulensis* productivity, driven by favorable microclimatic and edaphic conditions. Therefore, this study recommends strategic site selection prioritizing flatlands and pH-adjusted soil management to enhance carbon sequestration and timber yields, offering actionable insights for agroforestry resilience in Nepal's mid-hills.

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INTRODUCTION

The genus *Eucalyptus* (family Myrtaceae), comprising over 700 species, is predominantly native to Australia, with some natural distributions extending to New Guinea, Indonesia, and the Philippines (Mengistu *et al*., 2022). Renowned for its rapid growth and adaptability, *Eucalyptus* has become one of the most widely planted tree genera globally, with over 22 million hectares under cultivation (Bekele, 2015) Its ecological and economic significance spans timber production, fuelwood, and environmental conservation, making it a cornerstone of agroforestry systems worldwide (Santoro *et al*., 2020). Among the *Eucalyptus* species, *Eucalyptus camaldulensis* (river red gum) stands out for its resilience and versatility. This evergreen species thrives in diverse climates, from arid regions to riverbanks with seasonal or perennial water availability (Brooker & Hopper, 2002). With a lifespan exceeding 500 years (Jacobs, 1955), *E. camaldulensis* is valued for its fast growth, straight trunks, and high crowns, making it an ideal candidate for reforestation and agroforestry initiatives (Aleksic Sabo & Knezevic, 2019). In Nepal, *E. camaldulensis* has been widely planted since 1960, particularly in the Terai and Mid-Hills, where it supports rural livelihoods through fuelwood, construction materials, and agroforestry (Ghimire *et al*., 2024). The calorific value of its dry fuelwood (4880 kcal/kg) and adaptability to marginal lands further underscore its utility as an energy source in fuelwood-dependent communities (Singh & Toky, 1995). Recent studies have also highlighted its potential for carbon sequestration, with plantations storing 80-120 Mg/ha over 15 years, contributing to climate change mitigation (Nawaz, 2017). Beyond its economic benefits, *Eucalyptus* plays a critical role in environmental conservation. It is often integrated with terraces and check dams to mitigate soil erosion and act as a windbreak (Teshome, 2009).

However, despite its widespread adoption and apparent benefits, concern persists regarding Eucalyptus plantations long -term impact on ecosystem health, particularly soil fertility dynamics in different agro-ecological settings. The impact of *Eucalyptus* plantations on soil health is a subject of ongoing research. While some studies highlight their potential to enhance soil organic carbon (SOC) and nutrient availability, others caution against their use in nutrient-poor soils. For instance, Laclau *et al*. (2010) and Zhang *et al*. (2022) reported increases in SOC levels and nitrogen availability under Eucalyptus plantations compared to natural vegetation, attributing these changes to high leaf litter production. Similarly, Cortez & Madeira (1998) observed increased nitrogen availability in Australian plantations due to nitrogen-fixing bacteria in root nodules. However, Santos *et al*. (2017) noted that *Eucalyptus* can deplete soil nutrients in less fertile areas, emphasizing the need for site-specific management strategies. Despite the significant ecological and economic potential of *E. camaldulensis*, limited research has been conducted on its site-specific growth performance and soil nutrient interactions in Nepal. Previous studies have primarily focused on general growth patterns (Khanal, 1996; Gupta *et al*., 2019), but comprehensive analyses integrating growth metrics with soil nutrient dynamics are lacking. Also, conflicting results regarding the effects of *Eucalyptus* plantations on soil health (Zhang *et al*., 2022; Santos *et al*., 2017) highlight the need for localized studies to develop tailored management practices. This knowledge gap is particularly significant in Nepal's Sindhuli district, where *E. camaldulensis* is widely cultivated on both terraced agricultural land and flatlands without site-specific management strategies. Furthermore, no studies have systematically compared tree growth and soil health between these two contrasting terrains, leading to potential mismanagement practices such as improper spacing, inadequate thinning, and unsustainable nutrient cycling (Chaturvedi, 1989; Mengistu *et al*., 2022). This study addresses these gaps by providing the first comprehensive assessment of *E. camaldulensis* growth performance in two distinct sites in Sindhuli District, Nepal—terraced agricultural land and flatland—over a nine-year period. By analyzing growth parameters (diameter at breast height (DBH), height, biomass) and soil properties (pH, SOC, nitrogen, phosphorus, potassium), the research seeks to provide insights into how terrain-specific conditions influence plantation sustainability. The findings are expected to benefit local communities, government agencies, and private stakeholders by informing strategies for optimizing *Eucalyptus* plantations while enhancing soil fertility and ecosystem health. Furthermore, this research will contribute to the global understanding of *E. camaldulensis* as a valuable species for sustainable forestry, agroforestry, and climate resilience.

MATERIALS AND METHODS

Study area and site selection

This study was conducted in Kamalamai Municipality of Sindhuli District, located in the Churia and Mid-Hills regions of central Nepal (27°15'–24°78' N, 85°58'–86°76' E). The district, covering an area of 2491 km^2 is characterized by diverse topography, ranging from flatlands to terraced hills. The climate is subtropical, and the region has seen increasing interest in fast growing tree plantations, particularly *Eucalyptus camaldulensis*, due to its economic and ecological value. Two distinct sites within the municipality were selected for the study: Site 1, located in Ward 11, consists of terraced agriculture at an elevation of 650 m above sea level. This site contains the *E. camaldulensis* plantation area of 0.3 ha established in the year 2014. Site 2, situated in Ward 9, comprises of flatland at an elevation of 650 m above sea level, and spanning 0.4 ha with plantations established concurrently with Site 1 (Figure 1). Both plantations were established by local farmers without specific management guidelines, though a consistent planting spacing of 2.5 m × 2.5 m was observed in both sites. While no active management practices (e.g., fertilization, irrigation, or thinning) were applied during the study period, natural site conditions such as topography and soil characteristics varied between the terraced and flatland environments. By controlling for soil type, land use history, and management practices, the study isolates topography as the primary variable influencing growth performance.

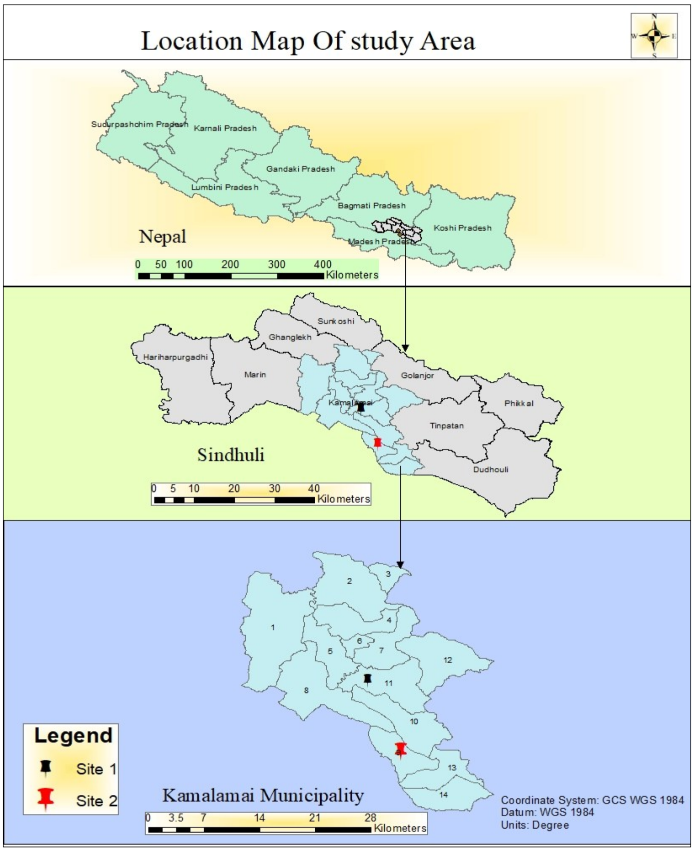

Figure 1. *Map showing the study area at Sindhuli, Nepal.*

Data collection

Tree measurements

A total of 314 trees were sampled across two plantation sites. Site 1, located on agricultural land with terraces, covered 0.3 ha and included 151 trees, while Site 2, situated on a flat area, spanned 0.4 ha and included 163 trees. Diameter at breast height (DBH, cm) and height (m) were measured for all 314 trees using digital calipers and a clinometer, respectively. Measurements were taken at 1.3 m above ground level to ensure standardization.

Soil sampling and analysis

Soil samples were collected from 43 plots (22 in Site 1 and 21 in Site 2) using a systematic random sampling technique, with plots spaced at 20 m intervals along transects to ensure spatial representativeness. In each plot, composite soil samples were taken from a 0–30 cm depth using a soil corer and shovel. The samples were air-dried, sieved (2 mm), and homogenized prior to analysis. Bulk density was determined by oven-drying samples at 105°C, while soil organic carbon (SOC) and organic matter were measured using the Walkley-Black method, with SOC derived from organic matter content. Phosphorus (P) levels were assessed using the modified Olsen's bicarbonate method, and potassium (K) concentrations were analyzed using the neutral ammonium acetate flame photometer method. Soil pH was measured with a glass electrode digital pH meter at a soil-to-water ratio of 1:2.5, and nitrogen (N) content was determined from organic matter using the Kjeldahl method. To ensure accuracy and precision of laboratory analyses, replicate samples and blanks were included as part of a rigorous quality control process.

Growth and biomass calculations

Volume, biomass, and carbon content were calculated using standardized forestry formulas and species specific allometric equations:

Volume estimation

Mean Volume (MV, m^3) = Sum of total volume / Total number of measured trees

Mean Annual Volume Increment (MAVI)=MV / Age of trees

Volume of tree was calculated using the allometric equation suggested by Sharma and Pukkala, (1990).

$$\ln(V) = a + b \times \ln(DBH) + c \times \ln(H)$$

where, 'ln' is natural logarithm with base 2.71828; 'V' is the volume of tree, 'DBH' is diameter of trees at breast height (cm), 'H' is height of trees, and 'a, b, c' are species specific coefficients.

Biomass estimation

Mean Biomass (MB, kg) = Sum of total biomass / Total number of measured trees Mean Annual Biomass Increment (MABI) = MB / Age of trees

Biomass was calculated using the formula suggested by Chave *et al.* (2005):

$$AGTB = 0.0509 \times \rho \, DBH^2 \times H$$

where, 'AGTB' is the above ground tree biomass (kg), 'ρ' is the wood density –specific gravity (g/cm^3), 'DBH' is diameter at breast height (DBH) (cm).

Carbon estimation

Mean Carbon (MC, kg) = Sum of total carbon / Total number of measured trees

Mean Annual Carbon Increment (MACI) = MC / Age of trees

Carbon content was derived by applying a conversion factor of 0.50 to biomass (MacDicken, 1997):

Carbon (kg) = 0.47 × Biomass (kg)

Statistical analysis

The statistical analysis was conducted using R software (version 4.3.0) and SPSS (version 28.0). Welch's t-test was performed to compare tree growth parameters—including DBH, height, basal area, volume, and biomass as well as soil properties between site 1 and site 2. This statistical test assessed whether there were significant differences in these variables between Site 1 (terraced agricultural land) and Site 2 (flat area). Additionally, a multiple linear regression analysis was performed to model the relationship between tree volume (dependent variable) and independent variables (height and DBH). P-values were examined to determine the statistical significance of each predictor variable, providing insights into the extent to which height and DBH contributed to variations in tree volume.

RESULTS AND DISCUSSION

Growth performance across sites

In this study, the growth performance of *Eucalyptus camaldulensis* varied significantly between Site 1 (terraced agricultural land) and Site 2 (flatland) (Table 1). At Site 1, the mean diameter at breast height (DBH) was 6.95 ± 3.71 cm, ranging from 2.07 to 21.02 cm. The mean height was 7.01 ± 1.97 m (range: 5–13.5 m), and the mean volume was 0.03 ± 0.04 m^3 (range: 0–0.23 m^3). Mean above-ground biomass (AGTB) was 20.48 ± 34.16 kg, with a wide range from 0.91 to 206.9 kg. The mean basal area was negligible (≈0 m^2), indicating limited stand density. In contrast, Site 2 demonstrated significantly superior growth across all parameters: mean DBH was 9.00 ± 2.61 cm, mean height was 7.88 ± 0.80 m, and mean AGTB was 26.96 ± 17.11 kg. Site 2 also had greater volume production in trees with DBH >15 cm (0.16 m^3 vs. 0.12 m^3 in Site 1, $p < 0.001$). These trends align with findings from (Tang *et al.*, 2023), who reported enhanced growth in lowland plantations due to better soil moisture retention and nutrient availability. Shrestha *et al.* (2022) similarly emphasized the role of topography in supporting deeper root penetration and stable microclimatic conditions—factors particularly important for the water-demanding Eucalyptus species. Growth variability was notably higher in Site 1 (range: 0.91-206.9 kg), as reflected in the standard deviations of DBH, height, and AGTB. The higher variability in growth parameters at Site 1 underscores the challenges of terraced systems, where heterogeneous microclimates and soil erosion can limit productivity (Shrestha *et al.*, 2022). These results underscore the influence of site-specific factors, including topography, soil structure, and microclimate, on tree growth performance. The findings emphasize the need for careful site selection to maximize plantation productivity.

Volume distribution by diameter class

The mean volume of *Eucalyptus camaldulensis* trees was analyzed across four diameter classes: <5 cm, 5–10 cm, 10–15 cm, and >15 cm. The results revealed that Site 2 consistently exhibited higher mean volumes across all diameter classes compared to Site 1. For trees with a diameter of <5 cm, the mean volume was 0.00625 m^3 in Site 1 and 0.0075 m^3 in Site 2. For the 5–10 cm class, the mean volume increased to 0.01962 m^3 in Site 1 and 0.02504 m^3 in Site 2. In the 10–15 cm class, the mean volume rose to 0.04794 m^3 in Site 1 and 0.05467 m^3 in Site 2. The most pronounced difference was observed in the >15 cm class, where Site 2 had a mean volume of 0.16365 m^3 compared to 0.11967 m^3 in Site 1 (Table 2). These differences were statistically significant across all diameter classes (p<0.05 to 0.001), reinforcing the finding that Site 2 supports better growth conditions across all tree size categories. These results further emphasize the value of site selection in maximizing volume production and timber yield. This aligns with findings from Brazil (Tang *et al.*, 2023), where Eucalyptus plantations in flat areas generated 30% more volume than those on slopes. The uniform growth in Site 2, reflected in narrower confidence intervals, likely stems from stable soil conditions and reduced competition for resources (Laclau *et al.*, 2010). For Nepal's mid hills, prioritizing flatlands could enhance both short-term productivity and long-term carbon sequestration, aligning with sustainable agroforestry practices.

Statistical analysis of growth parameters

A Welch two sample t-test confirmed highly significant differences between the sites for diameter at breast height (DBH) (t = -8.8747, p<2.2e-16), tree height (t = -7.73, p-value <5.112e-13), and basal area (p-value <1.628e-14). Boxplots (Figures 2-3) visually reinforced these findings, with Site 2 consistently showing higher median values and tighter interquartile ranges, indicating more uniform growth. Volume differences, though having similar means, showed significantly different distributions (P<5.386e-16), suggesting variation in tree form and structure influenced by environmental conditions. Similarly, biomass and carbon content were significantly greater in Site 2, with mean carbon values of 11.98 kg versus 6.13 kg in Site 1 (p<0.001), affirming site conditions influence carbon sequestration potential. These findings align with studies in India, where flat lands Eucalyptus plantations sequestered 15% more carbon than sloped sites over a decade (Kiran *et al.*, 2023), and in Ethiopia, where gentle slopes (<5%) improved by 18% compared to terrace systems (Alemayehu & Melka, 2022). The superior growth in Site 2 can be attributed to several factors: flat terrain, which facilitates deeper root growth and better access to soil nutrients and moisture; a microclimate characterized by higher temperatures and more stable moisture levels; and the deposition of fertile soil from upper terraces, which may have enhanced nutrient availability. These results are consistent with (Srivastav, 2022), who emphasized that *Eucalyptus* plantations thrive in waterlogged and saline conditions but may not be suitable for fertile agricultural lands. Similar findings have been reported in Brazil, where *Eucalyptus* growth was significantly higher in lowland areas with better water retention than upland sites (Tang *et al.*, 2023). Altogether, these results highlight that site selection and microclimatic conditions are critical determinants of *Eucalyptus* growth performance globally.

Table 1. Growth parameters of *E. camaldulensis* across sites.

Variable	Site 1 (n=151)	Site 2 (n=163)	P-value
DBH (cm)	6.95 ± 3.71 (SE = 0.30)	9.00 ± 2.61 (SE = 0.20)	< 0.001***
Height (m)	7.01 ± 1.97 (SE = 0.16)	7.88 ± 0.80 (SE = 0.06)	< 0.001
Basal Area (m^2)	0 ± 0.01 (SE ≈ 0)	0.01 ± 0 (SE ≈ 0)	< 0.001
Volume (m^3)	0.03 ± 0.04 (SE = 0.003)	0.03 ± 0.02 (SE = 0.002)	< 0.001
AGTB (kg)	20.48 ± 34.16 (SE = 2.78)	26.96 ± 17.11 (SE = 1.34)	< 0.001

*Standard Error (SE) is calculated as SD / √n, where SD is the standard deviation and n is the sample size. P-values indicate the significance of differences between Site 1 and Site 2 for each variable. A p-value < 0.001 suggests a highly significant difference, implying that the observed differences are extremely unlikely to have occurred by random chance.

Table 2. The mean volume (m^3) of *E. camaldulensis* by diameter class across sites.

Diameter Class (cm)	Site 1 (m^3) [95% CI]	Site 2 (m^3) [95% CI]	p-value
<5 cm	0.00625 [0.0051–0.0074]	0.0075 [0.0062–0.0086]	< 0.05*
5–10 cm	0.01962 [0.0173–0.0221]	0.02504 [0.0228–0.0273]	< 0.01**
10–15 cm	0.04794 [0.0435–0.0528]	0.05467 [0.0509–0.0584]	< 0.01**
>15 cm	0.11967 [0.1081–0.1314]	0.16365 [0.1502–0.1771]	< 0.001***

*Significance levels: *** p< 0.001 (highly significant), ** p < 0.01(significant), * p < 0.05 (significant).

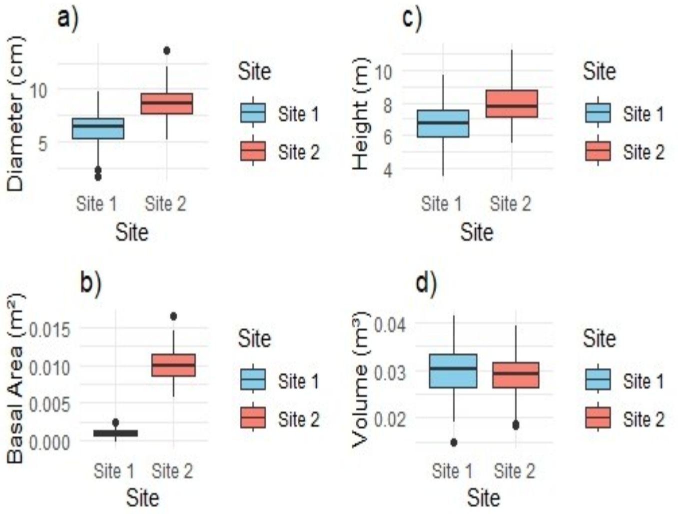

Figure 2. *Boxplots comparing diameter (cm), basal area (m^2), height, and volume(m^3) of E. camaldulensis trees between Site 1 and Site 2.*

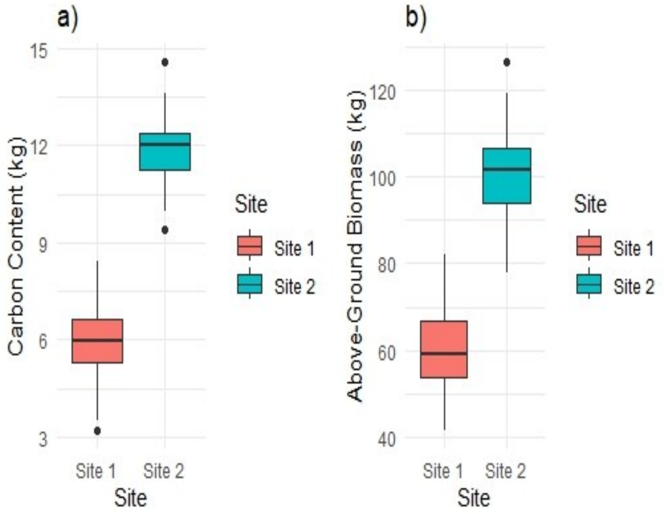

Figure 3. *Boxplots comparing carbon and biomass of E. camaldulensis trees between Site 1 and Site 2.*

Table 3. Regression analysis of volume predictors.

Variable/Metric	Estimate (β) / Value	Std. Error	t value	p-value
Intercept	-0.03755	0.001162	-32.31	< 0.0001***
Height (m)	0.003063	0.0001712	17.9	< 0.00049 ***
Diameter at Breast Height (cm)	0.005381	8.533E-05	63.05	< 0.0003 ***
Residual Standard Error	0.0037	N/A	N/A	N/A
R^2 (Coefficient of Determination)	0.9554	N/A	N/A	N/A
Adjusted R^2	0.9551	N/A	N/A	N/A
F-Statistic	3204	N/A	N/A	< 0.00025

Significance levels: *** p < 0.001, ** p < 0.01, * p < 0.05.

Table 4. Soil nutrients comparison.

Soil nutrient	t-Value	df	p-Value	95% Confidence Interval	Mean (Site 1)	Mean (Site 2)
pH	4.4574	6.722	0.0033**	[0.357, 1.178]	5.487	4.72
Potassium (kg/ha)	1.8976	6.075	0.1059	[-89.371, 715.231]	462.89	149.96
SOC (%)	0.5433	11.11	0.5977	[-0.423, 0.701]	1.853	1.714
Phosphorus (ppm)	1.1502	6.47	0.2908	[-0.168, 0.476]	0.318	0.164
Nitrogen (%)	1.397	8.364	0.1984	[-0.008, 0.033]	0.07	0.058

*Significance levels: *** p < 0.001, ** p < 0.01, * p < 0.05.

Volume relationships with volume, height and diameter

A multiple linear regression analysis revealed strong positive relationships between tree volume (m^3) and both height (m) and diameter at breast height (DBH, cm) (Table 3). For each 1-m increase in tree height, the volume increased by 0.0031 m^3 (β = 0.003063, p < 0.00049). Similarly, for each 1 cm increase in DBH, volume increased by 0.0054 m^3 (β = 0.005381, p < 0.0003). The model had a high coefficient of determination (R^2 = 0.9554), indicating that 95.54% of the variability in tree volume can be explained by these two variables. In this study, both height and DBH are strong predictors of tree volume, with DBH having a slightly larger effect. One possible reason is that Eucalyptus tends to prioritize radial growth (DBH) under resource-limited conditions to stabilize against wind throw, as seen in drought-prone or moisture-stressed regions (Martins *et al*., 2020). These findings are consistent with those reported by Titshall *et al.* (2013) in South Africa, where DBH explains 89% of volume variability in *E. grandis*. In contrast, Hutapea *et al.* (2023) found height to be a stronger predictor in fertilized plantations, suggesting nutrient availability alters growth priorities. The high R^2 value underscores the effectiveness of the model in capturing the relationship between tree dimensions and volume. These results are particularly valuable for forest management, as accurate volume estimation is critical for carbon stock assessments, timber yield predictions, and sustainable resource planning. Monitoring tree height and DBH can provide reliable insights into growth performance and support informed decision-making in plantation management.

Soil nutrient comparison

The analysis of soil nutrients revealed significant differences in pH levels between Site 1 and Site 2, with Site 2 being significantly more acidic ($p < 0.05$) (Table 4). This difference is likely attributed to the influence of Eucalyptus litter, which releases organic acids through decomposition and root exudates, gradually lowering soil pH over time. In contrast, other soil properties, including potassium (K_2O), soil organic carbon (SOC), phosphorus (P), and nitrogen (N), showed no statistically significant variations between the two sites, indicating relatively similar nutrient levels. The primary distinction between the sites was soil pH, with Site 2 exhibiting higher acidity. While nutrient concentrations were comparable, the lower pH in Site 2 may affect nutrient availability and uptake, potentially influencing tree growth. These findings highlight the importance of monitoring soil pH in *Eucalyptus* plantations, as it plays a critical role in nutrient dynamics and overall soil health. Ensuring optimal pH levels through appropriate management practices, such as liming or organic amendments, can enhance nutrient availability and support sustainable plantation growth. This approach has proven effective in Indonesian Eucalyptus plantations, where lime applications (2-4 tons/ha) mitigated acidity, boosting yield by 12% (Mariño Macana *et al*., 2022). Additionally, intercropping with nitrogen fixing species like *Leucaena leucocephala* improved overall soil structure and nutrient retention in Kenya trials (Muthuri *et al*., 2023). These findings align with recent research emphasizing the need for sustainable diversification. Bellink & Verburg (2023) demonstrated that monoculture Eucalyptus plantations are at risk without crop rotation, while Rahman *et al*. (2024) reported a 19% increase in SOC when rotating Eucalyptus with rice in Bangladesh. Adapting such a practice could sustain Site 2's productivity while countering acidification.

Practical implications for forest management and carbon sequestration

The findings of this study have significant practical implications for forest management and carbon sequestration. The superior growth performance of *E. camaldulensis* in flatland areas with favorable microclimatic conditions suggests that site selection is critical for maximizing productivity. Notably, growth was 30-40% higher on flatlands compared to terraced systems, attributed to improved soil moisture retention and nutrient availability (Gupta *et al*., 2019). Additionally, the positive correlation between soil potassium levels and tree growth underscores the importance of nutrient management, particularly in acidic soils. These insights can guide the development of tailored management practices, such as liming and potassium fertilization, to enhance soil fertility and tree growth. Furthermore, sustainable practices such as intercropping with nitrogen-fixing species like *Leucaena leucocephala* and crop rotations can increase soil nitrogen and boost soil organic carbon, thus mitigating the degradation risks associated with monoculture. *Eucalyptus* plantations, when managed sustainably, can serve as effective carbon sinks, contributing to climate change mitigation efforts. For instance, studies in India have shown that well-managed *Eucalyptus* plantations can sequester up to 25–30 tons of carbon per hectare annually (Chavan *et al*., 2023). By integrating these findings into forest management strategies, stakeholders can enhance the ecological and economic benefits of Eucalyptus plantations while promoting soil health and ecosystem resilience. Integrating these evidence based strategies into national frameworks– such as Nepal's Forestry Sector Strategy (2022-2032) can support climate smart forestry. This study contributes to the broader understanding of *E. camaldulensis* as a valuable species for sustainable forestry and climate resilience. Ultimately, it positions *E. camalduelensis* as a key stone species for sustainable agroforestry, offering scalable solutions for climate adaptation and soil rehabilitation in Nepal and other similar agro-ecological zones.

Conclusion

This study demonstrates that the site characteristics significantly influence the growth performance of *Eucalyptus camaldulensis*, with Site 2 consistently outperformed Site 1 in key growth metrics such as diameter at breast height (DBH), height, volume, and above-ground biomass, likely due to more favorable agro-climatic conditions, including higher soil moisture, stable temperatures, and fertile soil deposition. Soil analysis indicated that Site 2 had significantly lower pH levels, attributed to the allelopathic effects of *Eucalyptus*, which may influence nutrient availability despite similar nutrient levels between the sites. These findings underscore the importance of site selection (prioritizing flatlands) and soil management to enhance growth and biomass production of *Eucalyptus*. Practical recommendations include addressing soil acidification through liming, maintaining adequate potassium levels, and leveraging *Eucalyptus* for carbon sequestration. Future research should be focused on long-term soil-plant interactions, impact of management practices on ecosystem sustainability, biodiversity effects, and climate resilience. This study provides valuable insights for sustainable forest management, emphasizing the potential of *E. camaldulensis* in carbon sequestration, ecosystem conservation, and economic productivity enhancement, while highlighting the need for tailored strategies to balance ecological and economic benefits.

DECLARATIONS

Authors Contribution

Cconceptualization: S.L., R.B., and Y.B.; Methodology: S.L. and R.B.; Formal analysis and investigation: S.L. and R.B.; Original draft, review and edit: S.L., R.B., and Y.B.; Data visualization: R.B. and Y.B.; Overall supervision: Y.B. All authors have reviewed and approved the final version of the manuscript for publication.

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