



PLANNING MALAYSIA:

Journal of the Malaysian Institute of Planners

VOLUME 24 ISSUE 3 (2026), Page 178 – 193

ASSESSING THE CARBON SEQUESTRATION POTENTIAL OF BAMBOO IN URBAN ROAD RESERVES: A NATURE-BASED SOLUTION FOR CLIMATE MITIGATION AND URBAN PLANNING

**Atikah Fukaihah Amir¹, Nurul Husna Abd Rahim², Foong Swee Yeok³,
Meor Abdullah Zaidi Meor Razali⁴**

^{1,2} Faculty of Built Environment,

UNIVERSITI TEKNOLOGI MARA PERAK BRANCH, SERI ISKANDAR
CAMPUS, 32610 SERI ISKANDAR, PERAK, MALAYSIA

³ School of Biological Sciences,

UNIVERSITI SAINS MALAYSIA, PULAU PINANG, MALAYSIA

⁴ MAJLIS BANDARAYA IPOH

Abstract

Urban road reserves represent underutilized linear green spaces with significant potential to support nature-based climate mitigation strategies in rapidly urbanizing environments. Despite their availability, these spaces remain largely overlooked in urban planning as functional carbon sink corridors. This study assesses the carbon sequestration potential of *Gigantochloa albociliata* (buluh madu) cultivated within urban road reserves, using Lebuhraya Meru Raya, Ipoh, Perak, Malaysia, as a case study. Field measurements were conducted using a LI-6400XT Portable Photosynthesis System to determine leaf-level photosynthetic assimilation rates under controlled photosynthetically active radiation (PAR) conditions, while canopy characteristics were quantified through Leaf Area Index (LAI) measurements and crown area estimation. A light response curve analysis was applied to derive a representative net carbon assimilation rate, which was subsequently extrapolated to estimate annual carbon sequestration potential. Results indicated a mean net assimilation rate of $6.0 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$, with an LAI of 2.08 and a mean crown area of 51.35 m^2 . Based on the modeled assumptions, a single bamboo clump was estimated to sequester approximately 121.26 kg of carbon annually, equivalent to 445.02 kg CO_2 . Extrapolation across a 7 km urban road reserve corridor suggests a theoretical sequestration potential of approximately 106.1 metric tonnes of carbon per year, or 389.4 metric tonnes of CO_2 equivalent, assuming full planting occupancy. While these estimates are derived from controlled physiological measurements and annualized assumptions rather than destructive biomass validation, the findings suggest the potential of bamboo as a nature-based planning intervention for climate mitigation, green infrastructure enhancement, and low-carbon urban development.

Keywords: Bamboo, Carbon Sequestration, Urban Road Reserves, Nature-Based Solutions, Climate Mitigation, Urban Planning

¹ Corresponding author. Email: atika250@uitm.edu.my

INTRODUCTION

The escalating urgency to address climate change has intensified the global pursuit of effective strategies to reduce greenhouse gas (GHG) emissions. Nature-based solutions have emerged as strategic components in climate mitigation efforts, particularly through natural carbon sequestration using fast-growing plant species. Among these, bamboo has gained prominence due to its rapid biomass accumulation, short rotation cycle, and high carbon sequestration potential. According to King, et. al (2021), certain bamboo species are capable of storing between 100 to 300 tons of carbon per hectare, depending on species and management conditions.

Gigantochloa albociliata, locally known as buluh madu, is a native Malaysian bamboo species noted for its swift growth, significant biomass yield, and strong regenerative ability (Abd. Razak, 2012). Beyond ecological applications, bamboo has also been explored in infrastructure and construction contexts due to its structural versatility and renewable material potential (Pitroda et al., 2016). It's ecological adaptability and structural characteristics make it highly suitable for incorporation into nature-based urban carbon management and sustainable land use practices (Piazza et al., 2007). Due to its minimal maintenance requirements and ability to thrive in tropical climates, it is increasingly recognised as a viable species for integration into nature-based carbon mitigation solutions (Yiping et al., 2010).

Urban and peri-urban environments especially roadside reserves represent underutilised green spaces with latent potential for biomass cultivation and carbon storage. These narrow, linear strips of land span significant areas across urban landscapes but are often overlooked in landscape and climate planning (Yasin et al., 2020). In the Malaysian context, the Low Carbon Cities Framework (LCCF) encourages sustainable urban development practices, yet the role of road reserves in national carbon offsetting and urban greening strategies remains largely unexplored.

Despite various government initiatives promoting green infrastructure, empirical research on the carbon sequestration performance of bamboo in road reserve conditions is still limited. Existing carbon offset models often exclude or underestimate the contribution of these fragmented urban lands. There is thus a pressing need to quantify the carbon sink potential of bamboo in non-forest, roadside settings, particularly using species like *Gigantochloa albociliata*.

This research examines the capacity of *Gigantochloa albociliata* to enhance carbon sequestration initiatives in underutilised areas such as road reserves. The study specifically investigates the road reserve area along Lebuhraya Meru in Ipoh, Perak, as a test site to evaluate the species' carbon sequestration capacity through photosynthetic assimilation analysis.

Accordingly, this study has two objectives: (1) to assess the carbon sequestration potential of *Gigantochloa albociliata* for urban climate mitigation; and (2) to estimate a theoretical carbon sequestration contribution in the Lebu Meru road reserve. The findings aim to offer practical insights for incorporating bamboo into sustainable land management strategies, carbon offsetting initiatives, and comprehensive climate mitigation policies.

LITERATURE REVIEW

Bamboo as a Carbon Sequestration Resource and Nature-Based Climate Solution

Nature-based solutions (NBS) have gained increasing recognition as strategic approaches for addressing climate change, biodiversity loss, and urban sustainability challenges by working with natural systems to deliver environmental and societal benefits (Cohen-Shacham et al., 2016; Seddon et al., 2020). Within climate mitigation discourse, vegetation-based interventions remain among the most accessible NBS strategies due to their ability to remove atmospheric carbon dioxide through photosynthesis while simultaneously delivering ecosystem co-benefits such as urban cooling, biodiversity enhancement, and air quality improvement.

Among plant-based carbon mitigation options, bamboo has attracted growing attention due to its rapid growth rate, high biomass productivity, regenerative growth behaviour, and adaptability across a wide range of environmental conditions (Yiping et al., 2010; Song et al., 2011, Liese & Kohl, 2015). Unlike many woody species that require long maturation periods, bamboo can establish quickly and sustain repeated biomass regeneration without replanting, making it particularly relevant for climate mitigation and sustainable land management initiatives.

Previous studies have demonstrated bamboo's significant carbon sequestration potential in forestry, agroforestry, and managed plantation systems. Nath and Das (2011) reported substantial carbon storage in bamboo-based homegarden systems, while Marchi et al. (2023) highlighted bamboo's capacity to contribute to carbon offset strategies under managed plantation conditions. King et al. (2021) further emphasized bamboo's emerging relevance within voluntary carbon markets due to its rapid carbon uptake and commercial viability. In addition to carbon mitigation, bamboo has also gained attention for its broader ecological benefits, including erosion control, habitat support, land rehabilitation, and renewable material applications within low-carbon built environment strategies (Isukuru et al., 2023).

In Malaysia, *Gigantochloa albociliata* (buluh madu) presents strong potential due to its rapid growth, structural resilience, and suitability for tropical climatic conditions (Abd. Razak et al., 2012; Salleh et al., 2014). While bamboo's

ecological and economic advantages are increasingly acknowledged, empirical studies assessing its carbon sequestration potential within urban planning applications remain limited, particularly under constrained urban land conditions.

Urban Road Reserves as Underutilized Green Infrastructure Corridors

Urban planning increasingly recognizes green infrastructure as a multifunctional strategy capable of improving ecological performance, climate resilience, and public environmental quality within built environments (Tzoulas et al., 2007). Beyond conventional parks and open spaces, underutilized urban residual spaces are increasingly being reconsidered as opportunities for ecological intervention and environmental enhancement.

Road reserves represent one such category of overlooked urban land. These linear spaces are commonly maintained for infrastructure setbacks, utility corridors, visual buffering, and transportation safety requirements, yet their ecological contribution is often minimal. Due to their extensive distribution, public accessibility, and relatively low development opportunity cost, road reserves offer practical potential for integration into urban climate mitigation strategies.

Recent planning studies have explored the adaptive transformation of residual urban spaces into functional green infrastructure systems. Mohamed Anuar and Abdullah (2022) demonstrated how underutilized spaces beneath elevated urban highways can be repurposed through green infrastructure planning to improve ecological and social outcomes. Similarly, Krishnamoorthy et al. (2024) highlighted the role of nature-based solutions in revitalizing urban voids within the Malaysian context, emphasizing the importance of strategic planning interventions for resilient city development.

From a climate perspective, roadside vegetation has also been associated with ecosystem services including air quality enhancement, thermal regulation, and carbon sequestration potential (Srouf et al., 2024). However, most existing studies focus on conventional tree planting, urban forestry, or broad landscape greening strategies, with limited attention given to bamboo as a linear roadside carbon sink intervention.

Research Gap

Although bamboo's carbon sequestration potential has been widely examined in forestry and plantation contexts, limited research has investigated its application within urban roadside environments, particularly using physiological carbon assimilation measurements to estimate sequestration potential under constrained urban conditions.

Within Malaysia, studies involving bamboo have predominantly focused on cultivation, productivity, and construction applications, while

empirical planning-oriented investigations remain scarce. Furthermore, despite increasing interest in nature-based urban interventions, road reserves remain underexplored as carbon sink corridors within local urban planning practice.

This study addresses these gaps by evaluating the carbon sequestration potential of *Gigantochloa albociliata* within an urban road reserve context using field-based physiological measurements and spatial extrapolation. By linking ecological performance with urban planning application, the study contributes empirical evidence to support the integration of bamboo planting as nature-based solutions into low carbon urban development strategies.

METHODOLOGY

Research Design

This study employed an experimental quantitative approach to assess the carbon sequestration potential of *Gigantochloa albociliata* (*buluh madu*) through field-based physiological measurements and spatial extrapolation. The study combined direct measurements of leaf-level photosynthetic carbon assimilation with canopy structural analysis to estimate theoretical annual carbon sequestration potential under modeled conditions.

Study Site

The study was conducted along the urban road reserve corridor of Lebuhraya Meru Raya, Ipoh, Perak, Malaysia, located between coordinates 4°40'26.5"N, 101°04'21.7"E and 4°39'51.2"N, 101°05'09.3"E. The selected site represents an underutilized linear urban green space with potential for integration into climate-responsive green infrastructure planning.

Lebuhraya Meru Raya was selected due to its strategic urban context, accessibility for field measurements, and availability of continuous roadside reserve areas suitable for hypothetical bamboo planting. The site is characterized by a semi-urban environment influenced by vehicular activity, open solar exposure, and fragmented vegetation, making it an appropriate setting for evaluating bamboo's applicability within urban roadside conditions. The study location and assessed road reserve corridor are illustrated in Figure 1.



Figure 1: Study area of Lebuhraya Meru Raya, Ipoh, Perak, showing the assessed road reserve corridor and potential bamboo planting zones.

Sampling Procedure

A stratified canopy sampling approach was adopted to capture physiological variability across the vertical structure of *Gigantochloa albociliata*. A total of 20 healthy, mature leaves were sampled from representative canopy strata comprising the upper ($n = 6$), middle ($n = 8$), and lower canopy levels ($n = 6$). This approach was adopted to account for differences in light exposure and photosynthetic performance within the canopy profile, consistent with established plant ecophysiology sampling practices (Ninimets, 2010). Access to elevated canopy sections was facilitated using a skylift to ensure representative sampling across all canopy layers.

Photosynthetic Carbon Assimilation Measurement

Leaf-level photosynthetic carbon assimilation was measured using a LI-6400XT Portable Photosynthesis System (LI-COR Biosciences, USA) under standard chamber carbon dioxide conditions. Measurements were conducted using a controlled light response curve protocol to assess photosynthetic performance across varying levels of photosynthetically active radiation (PAR). PAR levels were sequentially adjusted at 0, 200, 400, 600, 1000, 1500, 1800, and 2500 μmol

$\text{m}^{-2} \text{ s}^{-1}$ to evaluate the physiological response of *Gigantochloa albociliata* under different light intensities.

Net photosynthetic assimilation rates were recorded as $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ for each sampled leaf. A representative mean net assimilation value derived from the light response curve analysis was subsequently used for carbon sequestration estimation.

Because the study employed controlled chamber light manipulation, measurements were standardized independently of ambient time-of-day fluctuations. Environmental parameters including temperature, relative humidity, and ambient CO_2 concentration were monitored throughout the measurement process using the integrated LI-6400XT sensors.

Canopy Structure Measurement

Canopy structural characteristics were quantified using Leaf Area Index (LAI) analysis to estimate effective photosynthetic surface area. LAI measurements were conducted using a HM-G10 Plant Canopy Analyzer, based on comparative light interception measurements above and beneath the bamboo canopy. Multiple readings were collected surrounding the representative bamboo clump to improve measurement consistency and reduce localized variability. The crown area of the bamboo clump was calculated using the measured mean crown radius according to:

$$CA = \pi r^2$$

where:

CA = crown area (m^2)

r = mean crown radius (m)

The resulting crown area and LAI values were subsequently integrated into the carbon sequestration estimation model.

Carbon Sequestration Estimation

The theoretical annual carbon sequestration potential of *Gigantochloa albociliata* was estimated by integrating measured photosynthetic assimilation rates with canopy structural parameters. This extrapolation approach is consistent with established principles for estimating carbon uptake from photosynthetic productivity measurements (Clark et al., 2001). Annual carbon uptake was estimated using:

$$\text{Annual carbon uptake} = A_n \times CA \times LAI \times T$$

where:

A_n = mean net photosynthetic assimilation rate ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$)

CA = crown area (m^2)

LAI = leaf area index

T = annual active photosynthetic duration (seconds)

A 12-hour average daily photoperiod was assumed based on typical equatorial daylight conditions and extrapolated over 365 days to estimate annual carbon sequestration potential. The resulting annual CO_2 uptake values were converted from micromoles to moles and subsequently converted into elemental carbon using the molecular conversion ratio:

$$C = \text{CO}_2 \times (12/44)$$

Equivalent carbon dioxide values (CO_2e) were calculated using the standard conversion factor:

$$\text{CO}_2\text{e} = C \times (44/12)$$

As destructive biomass sampling was not permitted at the study site, the analysis was based on physiological carbon assimilation measurements and modeled annual extrapolation rather than direct biomass validation.

Spatial Extrapolation

To estimate corridor-scale carbon sequestration potential, a theoretical planting model was applied to the 7 km Lebu Meru Raya road reserve corridor. Based on the measured mature canopy diameter of approximately 8 m per bamboo clump, a full planting occupancy assumption was applied at 8-meter linear intervals, yielding an estimated 875 potential bamboo clumps.

This extrapolation represents a theoretical maximum planting scenario intended to illustrate planning-scale carbon uptake potential rather than a final implementation layout, as practical constraints such as infrastructure setbacks, access requirements, and utility corridors may reduce actual planting capacity.

RESULTS AND DISCUSSION

Photosynthetic Response of *Gigantochloa albociliata*

Photosynthetic assimilation measurements were obtained from 20 mature leaves ($n = 20$) sampled from a representative *Gigantochloa albociliata* clump under controlled photosynthetically active radiation (PAR) conditions using the LI6400XT portable photosynthesis system. The mean net photosynthetic assimilation rates and associated variability statistics are presented in Table 1.

Table 1: Net photosynthetic assimilation rates of *Gigantochloa albociliata* under controlled photosynthetically active radiation (PAR) conditions (n = 20 leaves).

PAR ($\mu\text{mol photons m}^{-2} \text{ s}^{-1}$)	Mean Net Assimilation ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$)	Standard Error (SE)	Standard Deviation (SD)
0	-4.1	1.72	7.7
200	3.3	1.37	6.11
400	8.2	1.3	5.81
600	9.4	2.06	9.21
1000	10.8	1.65	7.39
1500	13.7	1.50	6.69
1800	12.9	1.68	7.50
2500	12.4	1.91	8.55

Under dark conditions (PAR = 0 $\mu\text{mol photons m}^{-2} \text{ s}^{-1}$), net assimilation was negative, indicating respiratory carbon loss in the absence of illumination. Once light was introduced, positive carbon assimilation was observed, with mean net assimilation increasing progressively from 3.3 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ at 200 $\mu\text{mol photons m}^{-2} \text{ s}^{-1}$ to a maximum observed mean of 13.7 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ at 1500 $\mu\text{mol photons m}^{-2} \text{ s}^{-1}$.

Beyond this level, assimilation values remained relatively stable, with only slight reductions at higher PAR levels, suggesting saturation of photosynthetic response under the tested measurement conditions.

The light response curve (Figure 2) demonstrates a non-linear relationship between PAR and net photosynthetic assimilation. A quadratic trendline provided a strong empirical fit to the observed mean response pattern ($R^2 = 0.937$), supporting the suitability of the averaged response data for subsequent carbon sequestration estimation.

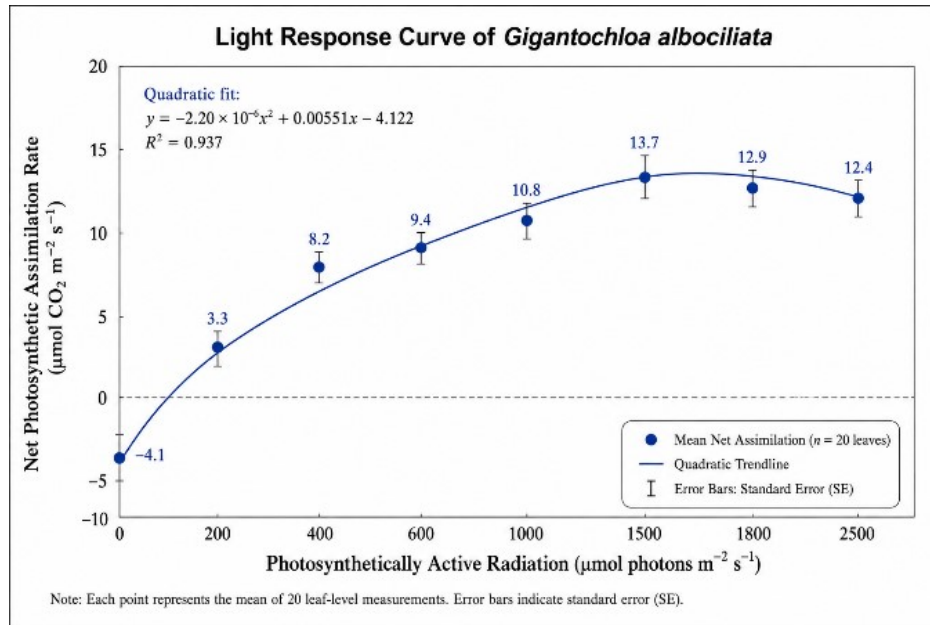


Figure 2: Light response curve of *Gigantochloa albociliata* showing mean net photosynthetic assimilation under controlled PAR conditions (n = 20; error bars represent SE).

Variability across PAR levels likely reflects physiological heterogeneity among sampled leaves from different canopy positions, together with measurement variability commonly associated with field-based physiological observations. Nevertheless, the overall response pattern remained sufficiently consistent for estimating representative carbon sequestration potential. For subsequent carbon sequestration calculations, a representative mean net assimilation value of $6.0 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ was adopted based on the averaged light response dataset.

Canopy Structural Characteristics

The structural characteristics of the representative *Gigantochloa albociliata* clump were assessed using crown area measurement and Leaf Area Index (LAI) analysis. The measured mean crown radius was 4.043 m, corresponding to a crown area of 51.35 m^2 , while the recorded LAI value was 2.08. The measured canopy structural parameters are summarized in Table 2

Table 2: Canopy structural characteristics of the representative *Gigantochloa albociliata* clump used for carbon sequestration estimation.

Parameter	Value
Mean crown radius (m)	4.043
Estimated crown area (m ²)	51.35
Leaf Area Index (LAI)	2.08
Effective photosynthetic leaf area (Crown Area × LAI) (m ²)	106.81

These structural characteristics indicate substantial canopy coverage and effective photosynthetically active surface area. By integrating crown area with LAI, the effective leaf surface area contributing to carbon assimilation was estimated at approximately 106.81 m².

Estimated Carbon Sequestration Potential of *Gigantochloa albociliata*

The annual carbon sequestration potential of a single clump of *Gigantochloa albociliata* was estimated by integrating the representative mean net photosynthetic assimilation rate with measured canopy structural parameters. Using a mean assimilation rate of 6.0 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$, crown area of 51.35 m², and LAI of 2.08, the effective photosynthetic surface area was estimated at 106.81 m². Assuming a 12-hour average daily photoperiod under tropical equatorial conditions over 365 days, the total annual uptake was estimated at approximately 10,104.68 mol CO₂ per clump.

Following molecular conversion to elemental carbon using the standard 12/44 carbon-to-CO₂ ratio, the estimated annual sequestration potential of a single bamboo clump was 121.26 kg C year⁻¹, equivalent to approximately 445.02 kg CO₂ year⁻¹. The detailed annual carbon sequestration estimation is summarized in Table 3.

Table 3: Annual carbon sequestration estimation for a representative clump of *Gigantochloa albociliata* based on physiological carbon assimilation measurements and modeled annual extrapolation.

Parameter	Value
Representative mean net photosynthetic assimilation rate ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$)	6.0
Effective photosynthetic leaf area (m ²)	106.81
Estimated carbon uptake per second ($\mu\text{mol CO}_2 \text{ s}^{-1}$)	640.86
Daily active photosynthetic duration (hours day ⁻¹)	12
Annual active photosynthetic duration (seconds year ⁻¹)	15,768,000
Estimated annual CO ₂ uptake (mol CO ₂ year ⁻¹)	10,104.68
Estimated annual carbon sequestration (kg C year ⁻¹)	121.26
Equivalent annual CO ₂ sequestration (kg CO ₂ year ⁻¹)	445.02

As destructive biomass validation was not permitted at the study site, these estimates represent theoretical carbon sequestration potential derived from

physiological carbon assimilation measurements and modeled annual extrapolation rather than direct biomass accumulation measurements.

Corridor-Scale Carbon Sequestration Potential for Urban Planning

To estimate planning-scale implications, a theoretical spatial extrapolation was applied to the 7 km Lebuhraya Meru Raya road reserve corridor. Based on the measured mature canopy diameter of approximately 8 m per bamboo clump, a full planting occupancy assumption yielded an estimated 875 potential bamboo clumps along the corridor.

Under this theoretical planting scenario, the total annual carbon sequestration potential was estimated at approximately 106.1 metric tonnes of carbon per year, equivalent to 389.4 metric tonnes of CO₂ annually (Table 4). This demonstrates the potential role of bamboo-integrated road reserves as supplementary urban carbon sink corridors within broader low-carbon urban planning strategies. However, actual implementation capacity may be lower due to infrastructure setbacks, access requirements, utility corridors, and maintenance considerations.

Table 4: Theoretical corridor-scale carbon sequestration potential for bamboo planting along the 7 km Lebuhraya Meru Raya road reserve.

Parameter	Value
Total road reserve corridor length (m)	7,000
Assumed mature canopy diameter per bamboo clump (m)	8
Estimated maximum theoretical bamboo clumps	875
Annual carbon sequestration per bamboo clump (kg C year ⁻¹)	121.26
Total annual carbon sequestration potential (kg C year ⁻¹)	106,102.50
Total annual carbon sequestration potential (metric tonnes C year ⁻¹)	106.10
Equivalent annual CO ₂ sequestration (metric tonnes CO ₂ year ⁻¹)	389.40

The findings indicate that *Gigantochloa albociliata* demonstrates promising physiological carbon assimilation characteristics under controlled light conditions, with photosynthetic performance increasing progressively with increasing PAR before reaching saturation at higher light intensities. This response pattern is consistent with the non-linear photosynthetic behavior commonly observed in rapidly growing plant species, where carbon assimilation increases with light availability until reaching physiological saturation (Yiping et al., 2010; Song et al., 2011). The relatively broad variability observed across sampled leaves likely reflects natural physiological heterogeneity associated with vertical canopy stratification, as measurements were intentionally obtained from lower, middle, and upper canopy positions with differing light exposure conditions.

The estimated annual sequestration potential of approximately 121.26 kg C per bamboo clump suggests that *Gigantochloa albociliata* may contribute

meaningfully to localized carbon mitigation when strategically integrated into urban green infrastructure systems. While direct comparisons should be interpreted cautiously due to methodological differences, these findings align with broader literature identifying bamboo as a productive carbon-absorbing vegetation type due to its rapid growth, regenerative biomass dynamics, and efficient photosynthetic performance (Nath & Das, 2011; King et al., 2021). Bamboo may offer a complementary vegetation option for constrained urban corridors due to its rapid establishment and dense canopy structure.

From an urban planning perspective, the corridor-scale extrapolation demonstrates the conceptual feasibility of utilizing road reserves as supplementary carbon sink corridors within broader low-carbon urban development strategies. Urban road reserves are often maintained primarily for infrastructure clearance, visual buffering, or transport-related setbacks, yet many remain underutilized from an ecological perspective. The integration of bamboo within such spaces could potentially contribute to climate-responsive planning objectives while simultaneously supporting urban greening, microclimate improvement, and visual landscape enhancement. This is consistent with previous planning research emphasizing the multifunctional potential of underutilized urban residual spaces and roadside vegetation within nature-based urban interventions (Tzoulas et al., 2007; Srour et al., 2024; Yasin et al., 2020).

However, the findings should be interpreted within several methodological limitations. First, the physiological measurements were derived from a single representative bamboo clump, which limits broader generalizability across species populations and site conditions. Second, the annual sequestration estimates were derived from modeled extrapolation based on controlled photosynthetic measurements, assuming a constant 12-hour active photoperiod throughout the year. In reality, carbon uptake is influenced by environmental fluctuations, including cloud cover, seasonal rainfall variability, plant age, maintenance conditions, and physiological stress responses, which were not explicitly measured in this study.

Additionally, destructive biomass validation or allometric verification was not permitted at the study site, meaning the estimates represent theoretical carbon sequestration potential rather than directly measured long-term biomass carbon storage. The corridor-scale projection also assumes full planting occupancy at regular 8-meter intervals, which represents a maximum conceptual planning scenario rather than a final implementation design. Practical deployment would likely require adjustments to accommodate utility infrastructure, traffic visibility requirements, pedestrian access, drainage systems, and long-term maintenance considerations.

Despite these limitations, this study contributes localized empirical evidence to the limited Malaysian literature examining bamboo-based carbon

sequestration within urban planning applications. By linking physiological carbon assessment with spatial planning extrapolation, the study offers a practical foundation for future investigations involving multi-site validation, biomass-based carbon accounting, species comparisons, and implementation-orientated planning frameworks for bamboo-integrated urban green infrastructure.

CONCLUSION

This study assessed the carbon sequestration potential of *Gigantochloa albociliata* within an urban road reserve context using field-based physiological carbon assimilation measurements and canopy structural analysis. The findings suggest that bamboo exhibits promising photosynthetic carbon uptake characteristics under controlled PAR conditions, with an estimated theoretical annual sequestration potential of approximately 121.26 kg C per bamboo clump, equivalent to 445.02 kg CO₂ year⁻¹.

When extrapolated to the 7 km Lebuhraya Meru Raya road reserve corridor under a maximum theoretical planting scenario, the estimated sequestration potential reached approximately 106.1 metric tonnes of carbon annually, equivalent to 389.4 metric tonnes of CO₂. These findings suggest that underutilized urban road reserves may offer practical opportunities for integrating bamboo-based nature-based solutions within broader low-carbon urban planning strategies.

Beyond carbon mitigation, bamboo integration may provide additional co-benefits including urban greening enhancement, microclimate improvement, visual landscape value, and ecological enrichment within constrained urban spaces. As road reserves are widely distributed and publicly managed, their strategic ecological activation presents a potentially scalable planning intervention.

Nevertheless, the study should be interpreted within its methodological limitations, particularly the reliance on physiological extrapolation from a single representative bamboo clump and the absence of biomass-based carbon validation. Future research should therefore expand toward multi-site assessment, species comparison, long-term monitoring, and implementation-orientated planning evaluation to strengthen the practical application of bamboo within urban green infrastructure systems.

Overall, the study contributes localized empirical evidence supporting the exploration of bamboo as a nature-based climate mitigation strategy and offers a preliminary planning framework for rethinking underutilized road reserves as functional urban carbon sink corridors.

ACKNOWLEDGEMENT

The researcher would like to express sincere gratitude to the Majlis Bandaraya Ipoh for their invaluable support throughout the project, especially for approving the use of technical equipment and on-site support facilities. This research is funded by a Contract Research Grant No. 20240722006 under the MBI consultation project titled “Kajian Prospek Terhadap Pembangunan Karbon Sifar Bersih Bagi Bangunan Buluh di Perak 2024–2025.”

REFERENCES

- Abd. Razak, O., Salleh, M., Rosdi, K., & Hashim, M. N. (2012). Harvesting evaluation of *Gigantochloa albociliata* (Buluh Madu) on shoot productivity. In *Transactions of the Malaysian Society of Plant Physiology* (Vol. 20). Forest Research Institute Malaysia (FRIM).
<https://www.cabidigitallibrary.org/doi/pdf/10.5555/20173097504>
- Clark, D. A., Brown, S., Kicklighter, D. W., Chambers, J. Q., Thomlinson, J. R., & Ni, J. (2001). Measuring net primary production in forests: Concepts and field methods. *Ecological Applications*, 11(2), 356–370. [https://doi.org/10.1890/1051-0761\(2001\)011\[0356:MNPPIF\]2.0.CO;2](https://doi.org/10.1890/1051-0761(2001)011[0356:MNPPIF]2.0.CO;2)
- Isukuru, E. J., Ogunkeyede, A. O., Adebayo, A. A., & Uruejoma, M. F. (2023). Potentials of bamboo and its ecological benefits in Nigeria. *Advances in Bamboo Science*, 4, 100032. <https://doi.org/10.1016/j.bamboo.2023.100032>
- King, C., van der Lugt, P., Thang Long, T., & Yanxia, L. (2021). *Integration of bamboo forestry into carbon markets*. https://pure.tudelft.nl/ws/files/90321914/Mar_2021_Integration_of_Bamboo_For_etry_into_Carbon_Markets_2.pdf
- Krishnamoorthy, K., Mohd Adnan, Y., & Md Yassin, A. (2024). Urban voids: Nature-based solutions (NBS) to revitalize Kuala Lumpur. *Planning Malaysia*, 22(32). <https://doi.org/10.21837/pm.v22i32.1517>
- Liese, W., & Kohl, M. (2015). *Bamboo: The plant and its uses*. Springer. <https://doi.org/10.1007/978-3-319-14133-6>
- Marchi, M., Marchettini, N., Neri, E., Esposito, G., Niccolucci, V., Pulselli, F. M., Lajo, M., Rissone, E., & Pulselli, R. M. (2023). Carbon footprint offset of a managed bamboo plantation in temperate regions. *Sustainable Production and Consumption*, 40, 220–235. <https://doi.org/10.1016/j.spc.2023.05.025>
- Mohamed Anuar, M. I. N., & Abdullah, S. A. (2022). The benefits of green infrastructure planning in addressing lost spaces underneath elevated urban highways. *Planning Malaysia*, 20(23). <https://doi.org/10.21837/pm.v20i23.1165>
- Nath, A. J., & Das, A. K. (2011). Carbon storage and sequestration in bamboo-based smallholder homegardens of Barak Valley, Assam. *Current Science*, 100(2), 229–233. <https://www.jstor.org/stable/24073051>
- Niinemets, Ü. (2010). A review of light interception in plant stands from leaf to canopy in different plant functional types and climates. *Ecological Research*, 25(4), 693–714. <https://doi.org/10.1007/s11284-010-0712-4>

- Piazza, M., Lobovikov, M., Paudel, S., Ren, H., & Wu, J. (2007). *World bamboo resources: A thematic study prepared in the framework of the Global Forest Resources Assessment 2005*. <https://doi.org/10.13140/RG.2.1.1042.3764>
- Pitroda, J., Pankhaniya, H., Pachani, U., Agravat, S., & Parmar, P. (2016). A critical review on innovative utilization of bamboo in rural road construction. *International Journal of Constructive Research in Civil Engineering*, 2(4), 27–32. <https://doi.org/10.20431/2454-8693.0204004>
- Salleh, M., Abd Razak, O., & Azhan Shah, I. (2014). Viability of *Gigantochloa albociliata* (Buluh Madu) plantation for shoot production in Peninsular Malaysia. *Transactions of the Malaysian Society of Plant Physiology*, 22, 6. <https://www.cabidigitallibrary.org/doi/pdf/10.5555/20173097648>
- Song, X., Zhou, G., Jiang, H., Yu, S., Fu, J., & Li, W. (2011). Carbon sequestration by Chinese bamboo forests and their ecological benefits: Assessment of potential, problems, and future directions. *Environmental Reviews*, 19, 418–428. <https://doi.org/10.1139/a11-015>
- Srour, N., Thiffault, E., & Boucher, J.-F. (2024). Exploring the potential of roadside plantation for carbon sequestration using simulation in Southern Quebec, Canada. *Forests*, 15(2), 264. <https://doi.org/10.3390/f15020264>
- Yasin, I., Widaryanto, L. H., & Sutrisno, W. (2020). The technique of green belt bamboo constructions for highway noise effect reductions. *Journal of Physics: Conference Series*, 1456, 012006. <https://doi.org/10.1088/1742-6596/1456/1/012006>
- Yiping, L., Yanxia, L., Buckingham, K., Henley, G., & Guomo, Z. (2010). *Bamboo and climate change mitigation* (INBAR Technical Report No. 32). International Bamboo and Rattan Organisation (INBAR).

Received: 5th December 2025. Accepted: 6th February 2026