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ESTIMATING CARBON SEQUESTRATION OF GIGANTOCHLOA ALBOCILIATA FOR CARBON FARMING STRATEGY

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ABSTRACT

This research explores the carbon sequestration potential of Gigantochloa albociliata (common name: buluh madu), positioning it as a viable option for both carbon farming and eco-friendly construction. Known for its rapid growth, extensive biomass accumulation, and structural durability, bamboo captures atmospheric CO2 efficiently, while also catering to the rising demand for sustainable construction materials. The study examines the economic viability and market interest in Gigantochloa albociliata, while also investigating its potential for carbon sequestration in underutilized spaces like road reserves. Through a combination of market analysis through narrative literature review, and experimental research, the study estimates the species' carbon storage capacity, providing the dual benefits of improving landscape aesthetics and mitigating greenhouse gas emissions. Findings suggest that integrating Gigantochloa albociliata into sustainable land use and carbon offset initiatives could play a pivotal role in climate mitigation, delivering carbon credits, and fostering ecological resilience and biodiversity. Overall, this research highlights the potential of bamboo as a resource for sustainable development, contributing to global climate goals and offering socio-economic benefits in construction and agriculture.

Keyword: *Bamboo Adaptation and Restoration, Carbon Farming, Carbon Sequestration, Sustainable Construction, Livelihood*

INTRODUCTION

The world community is increasingly focusing on natural carbon sequestration techniques as a way to reduce greenhouse gas emissions in response to the worsening effects of climate change (Khumukcham & Laishram, 2023). Bamboo, especially Gigantochloa albociliata, has drawn interest due to its great potential as an atmospheric carbon sink, quick growth, and enormous biomass output. Bamboo is ideally adapted for collecting carbon dioxide (CO_2) and is a prime option for incorporation into carbon farming practices and sustainable land management because of its rapid regeneration (Lobovikov et al., 2007; van der Lugt, Thanglong, & King, 2018). In particular, this study looks at Gigantochloa albociliata in relation to road reserves, which are frequently neglected spaces that provide special chances to improve the environment.

Bamboo, a sustainable construction material, is increasingly recognized for its environmental benefits and versatility. This study aims to evaluate the feasibility of using Gigantochloa albociliata for mitigating the CO2 in the atmosphere and as a sustainable material for construction, analyzing market trends, economic factors, and consumer preferences. The research aims to provide insights into Gigantochloa albociliata 's market viability, potential contribution to sustainable land use, and greenhouse gas reduction. The study aims to contribute valuable information for policy and practice on integrating bamboo into carbon offset schemes and sustainable development frameworks. Thus, the objectives of this research are (i.) To estimate the carbon sequestration of Gigantochloa albociliata for carbon farming and (ii) To quantify carbon farming of Gigantochloa albociliata in Lebuh Meru road reserve.

LITERATURE REVIEW

Carbon Sequestration and Ecological Benefits in Bamboo.

According to Nath & Das (2011), bamboo stands outperformed compared to typical plantations in terms of carbon sequestration. The study shows that smallholder farmers who cultivate bamboo boost the land's carbon sequestration capacity and produce a sellable crop. These findings suggest engaging smallholder farmers and rural communities in participatory systems that incorporate their existing knowledge with bamboo cultivation and management. Bamboo thrives on eroded and nutrient-poor soils, commonly found in degraded land. Deforestation and other anthropogenic activity can degrade soils, making them infertile and unsuitable for agricultural crops. According to Borrelli et al. (2020), soil degradation is expected to worsen as severe weather becomes more often due to climate change. The University of Las Villas in Santa Clara, Cuba conducted a study to assess the impact of bamboo production on damaged soil quality (Cairo et al. 2018). The study by Cairo et al. (2018) examined mineral nutrients, fungi, and bacteria at various soil depths in plots with and without bamboo stands. Bamboo and its biomass considerably improved the consistency, structure, and biological aspects of damaged soil (Cairo et al., 2018). Thus, it shows that bamboo can revitalize soils, trap the carbon in the soil, and provide an economically viable crop.

Bamboo is extensively distributed across Southeast Asia, Africa, and Latin America and serves as a prominent non-wood forest product and sustainable alternative to traditional timber. Its rapid growth and potential for climate change mitigation have made it increasingly attractive to ecologists (Khumukcham & Laishram, 2023; van der Lugt et al., 2018). In China, with a rich history of bamboo production, possesses one of the world's largest bamboo forest areas and has dedicated significant attention to bamboo forest management in recent decades. Research highlights bamboo's ecological contributions, including carbon sequestration, water and soil conservation, socio-economic benefits, and its role in climate change mitigation (Vogtländer, van der Velden, & van der Lugt, 2014; Md. Shawkat Islam et al., 2015).

Bamboo is extremely valuable by environment and socially, especially as a carbon sink in the long run. China's history and vast area of bamboo forest give it uniqueness in expanding the areas and industries of bamboo. Such government and public initiatives promote productivity and sustainable management, positioning bamboo among top strategies for determining and mitigating climate changes (Nath et al., 2015; SongXinzhang et al., 2011). This ongoing development raises China's status as an exemplar for many developing countries, and it could inspire the growth of bamboo plantations for carbon storage capacity across Southeast Asia, Africa, and Latin America (Fu et al., 2019).

Gigantochloa albociliata, commonly known as "Madu", is an affordable substitute for wood in a variety of structural applications. Hence, its strength and then thick walled culms make it appropriate for scaffolding, fences, floors, staircases, and lightweight roofing. Its straightness and load bearing capability make it suitable for developing countries. Apart from constructions, Gigantochloa albociliata is used in handicraft, furniture making, and agricultural implements. This offers a material to construct environmentally conscious buildings with high biomass production in a short period and by durable growth. As the demand for sustainable and renewable materials is higher, the bamboo industry is likely to experience a compound annual growth rate (CAGR) of 5-7%. The increased focus on green building around the globe is expected to complement the sustainable development of the bamboo sector as well as carbon farming at a compound annual growth rate (CAGR) of 5-7%.

Gigantochloa albociliata's Contributions to Ecosystems and Carbon Sequestration

The southeast Asian region has this highly biomass producing and very fast- growing bamboo species, Gigantochloa albociliata, which is known as carbon sequestering. It is now proved the ability to mitigate climate change effects in the agroforestry system just by carbon storage in dense culms, root systems in research findings. It indicates that in plantation-placed infrastructures, soil quality enhancement, the stabilization of altered land conditions, and rising biodiversity are its essential values (Chung et al., 2021; Iswanto et al., 2023).

Aside from its environmental benefits, Gigantochloa albociliata is recognized for its structural strength, making it appropriate for construction materials such as flooring, trusses, and joists. Because of its high calorific content and rapid regeneration, the species is rapidly being investigated for bioenergy. Its adaptation to marginal terrain demonstrates its value in road reserve plantings, which improves carbon farming tactics (Nugroho & Maulana, 2020).

The economic potential of Gigantochloa albociliata stems from its dual position as a carbon sink and a renewable building material. According to market data, there is an increasing demand for bamboo in building and carbon credits as part of global sustainability programs. As carbon offset programs gain traction, this species may make considerable contributions to climate mitigation and rural economy (Sohel et al., 2015; Nath & Das, 2015).

RESEARCH METHODOLOGY

This study uses experimental research with a quantitative methodology to investigate the potential market demand for *Gigantochloa albociliata*. Lebuh Meru Raya, Ipoh are choosen as the site sample location, many considerations were made. A road reserve is considered one of the open sites characterized by low flow where Gigantochloa albociliata is sequestering carbon. They form areas that are less utilized but biologically significant. The site is highly important since it is influenced by various environmental conditions such as exposure to vehicle emissions and those of urban impacts for assessing the effectiveness of bamboo in reducing carbon dioxide emissions in semiurban areas. Lebuh Meru Raya, Ipoh gives access that enables easy observation, data collection, and maintenance of recognized experimental setups, assuring the exactness and reliability of the results of the studies. The experimental research will estimate the carbon sequestration potential of Gigantochloa albociliata by collecting data from a controlled cultivation site, measuring phoyosynthesis assimilation rate, and analyzing carbon content for research objective 1, to estimate the carbon sequestration of Gigantochloa albociliata for carbon farming. Statistical analysis will determine the carbon sequestration rates, providing empirical support for its role in carbon farming strategies. Quantifying the quantity of carbon sequestered by bamboo in road reserves is the main goal of this approach. Bamboo has a great ability to store carbon and grows quickly, making it able to absorb large amounts of CO2 from the atmosphere. The amount of carbon sequestered over time can be accurately estimated by measuring its biomass and carbon content.

The study focuses on Gigantochloa albociliata because it has high biomass productivity, is of economic value in Malaysia, and is available. It produces 6–13 Mg ha^{-1} $year^{-1}$ of biomass carbon, which is comparable or even higher than other species in similar environments (Hein & van der Meer, 2012). Gigantochloa albociliata grows fast and has more biomass compared to other types, increasing its economic value and making it highly suitable for carbon sequestration. Its establishment in the fabric of culture and economics of Malaysia makes this a strong case study for sustainable land use and carbon farming.

Research Procedure

The deliberate selection of representative bamboo leaves (six from the top, eight from the centre, and six from the bottom) for study Objective 1, which focuses on experimental study to measure the species' capacity to sequester carbon, is made possible by purposive sampling that be taken from 7:00 A.M. to 6:00 P.M. to measure daily carbon sink. This systematically selects leaves of the plant ensuring increased accuracy in the measurement of carbon sequestration. Sampling criteria include collecting a minimum of 20 healthy leaves to reflect all possible physiological states of Gigantochloa albociliata (refer Figure 1.1). This systematic selection minimizes sampling bias by including various growth stages and conditions of the plant in the analysis. Easy access to bamboo clumps is one of the reason for the site choice since it allows a complete sampling, free from external disturbance (Benton et al., 2014; Nath et al., 2009). In this case, the researchers use a skylift for easy access towards leaves sampling (refer Figure 1.2, 1.3). The researchers use a Portable Photosynthesis System model LI- 6400XT (refer Figure 1.4, 1.5). This instrument calculates photosynthesis based on variations in CO2 and H2O between pre-chamber and in-chamber conditions. This field-portable equipment offers in-situ laboratory quality measurements (Amir, 2014).

By site selection and accurate sampling criteria, this study aspires to yield the carbon sequestration capacity of *Gigantochloa albociliata*.

Figure 1.1: Different parts of the sampling level including top, middle and bottom.

Figure 1.2: Skylift used to measure data from sampling at middle.

Figure 1.3: Skylift used to measure data from sampling at middle.

Figure 2.4: Portable Photosynthesis System model LI-6400XT

Figure 1.5: Setup that need to be done before data can be obtained.

Lastly, to achieve research objective 2, the researcher will use a mathematical equation to quantify carbon farming of *Gigantochloa albociliata* in the Lebuh Meru road reserved. The equation as below:

Net Primary Production (NPP) = Gross Primary Production (GPP) – Respiration (R) . (1)

Carbon Storage of *Gigantochloa albociliata* in one clump = Photosynthesis Assimilation Rate μ mol/m²/s CO2 x Crown Area m2 x LAI x 365 days x 12 hours daylight x 60 minutes x 60 second) x (12gC/44gCO2) (2)

Equation (1) is to obtained Net Primary Production of photosynthesis assimilation rate, and this value are related to Equation (2), to obtained the weight of carbon storage of *Gigantochloa albociliata* in one clump. The researchers will estimate the area of road reserved for carbon farming strategy.

ANALYSIS AND FINDINGS

Research objective 1 (To estimate the carbon sequestration of Gigantochloa albociliata for carbon farming) data analysis.

Based on the data collection, samples 1 to 20 were analyzed for photosynthetically active radiation (PAR) levels from 0 to 2500 µmol m^{-2} s^{-1} and the photosynthesis rates were recorded. The last column represents the average rate for each PAR level.

i.Data of 20 leaves sample from *Gigantochloa albociliata* (refer Table 1) and graph (Figure 2).

Table 1. Photosynthesis Data Collection

NO.	PAR	Photosynthesis																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0	-3.0	-3.9	-4.6	-3.5	-4.6	-1.7	-2.8	-2.5	-3.7	-2.9	-5.74	-19.2	-23.5	-5.4	-7.4	-3.2	-1.9	-23.68	-6.49	-6.19
2	200	0.6	2.8	5.7	7.8	7.0	0.5	0.3	12.0	-1.3	0.5	-1.14	4.2	6.7	7.8	4.9	1.9	7.4	-16.37	-6.77	2.38
3	400	4.3	7.4	7.7	14.0	9.2	3.4	5.9	18.7	-0.4	3.8	11.73	6.3	6.8	13.1	0.2	6.2	7.2	11.36	23.53	3.26
4	600	6.3	9.3	6.7	16.4	11.6	5.4	4.5	21.7	2.3	9.4	16.34	38.0	15.1	16.3	-7.1	12.5	11.8	7.93	1.37	11.04
5	1000	9.7	11.8	4.8	19.5	10.7	6.2	13.3	27.4	4.6	11.9	16.15	10.2	16.9	16.5	-2.4	15.3	-4.6	3.21	9.94	15.01
6	1500	11.4	12.8	6.4	20.6	12.6	6.3	12.6	29.2	5.9	12.6	23.7	9.8	11.2	13.7	3.9	16.6	9.2	15.68	14.45	24.44
7	1800	12.5	13.2	7.7	20.7	14.1	6.1	14.0	31.0	6.9	12.7	0.24	13.4	14.1	22.4	3.6	7.3	7.7	18.56	10.37	20.72
8	2500	13.9	13.4	11.8	21.9	15.8	5.0	19.6	33.5	7.3	13.6	15.99	17.5	0.3	18.8	-2.3	14.2	3.3	9.42	17.05	-2.22

Source: Data and Author's Calculation

Data outlier (were highlighted in yellow) recorded at PAR = 0, sample 12 had a low photosynthesis rate of -19.2, sample 13 was at -23.5, while sample 18 at -23.68 which is contrast from others. At PAR = 200, sample 18 had a abnormal rate of -16.37, which is very different from other samples. At PAR = 600, sample 12 shows the highest rate of 38.0, much higher than the trend. Sample 19 at PAR = 1800 showed a value of 25.38 that was clearly higher than other samples. These anomalies have probably been due to measurement-related factors, including the physiological condition of the leaves (e.g., wilting, heterogenous chlorophyll) or environmental factors like wind that would interfere with the gas exchange process.

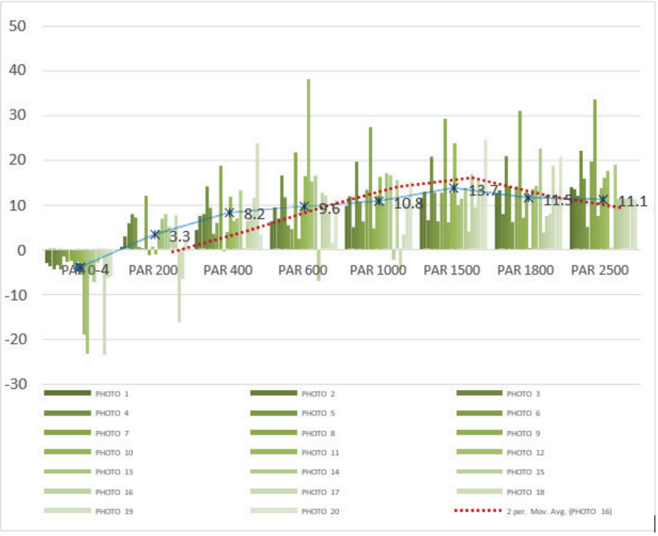

Figure 2. Photosynthesis Trend from PAR 0 until PAR 2500

Source: Author's Calculation

The average rate is obtained from every data gain except the outlier data. -4.0 at PAR = 0, indicating negligible or negative photosynthetic activity, as expected under no light conditions. At PAR = 200, the rises to 3.3, showing the beginning of photosynthetic activity at low light levels while at PAR = 400 the average rate increases further to 8.2, reflecting an increase in photosynthesis with improved light availability. At PAR = 600: rate of average is 9.6 shows optimum light levels for photosynthesis. At PAR = 1000: it increase to 10.8 demonstrates saturation in photosynthetic efficiency. The peak average rate of 13.7 reflects maximum photosynthetic activity at PAR = 1500. There is a slight drop in the average rate at PAR = 1800, to 11.5, likely due to light saturation or photoinhibition. At PAR = 2500 rate drops even further to 11.1, indicating light stress or photoinhibition at higher PAR values. Blue labelling are the average mapped at the graph. A

ii.Crown Area (B) dan Leaf Area Index (C) were obtained by using reference from Laporan Awal Kajian Prospek Terhadap Pembangunan Karbon Sifar Bersih bagi Bangunan Buluh di Perak (Amir, A. F 2024).

Table 2. Crown Area and Leaf Area Index Reference

Bamboo and Location	Average Photosynthesis Assimilation Rate (μ mol/m²/s CO_2) (A)	Crown Area (m2) (B)	LAI (Leaf Area Index) (C)	Carbon sequestration of 1 bamboo clump per year (μ mol CO_2) (D = A x B x C x 365 hari x 12 jam matahari siang x 60 minute x 60 saat)	Carbon sequestration of 1 bamboo clump per year (mol CO_2) (E = D / 10-6)	**Carbon sequestration of 1 bamboo clump per year (C kg) (F = E x (12g / 44g)**
Buluh Madu at Meru	6.0	51.35	2.10	10234768870	10234.77	**2791.30**

Source: Data from Laporan Awal Kajian Prospek Terhadap Pembangunan Karbon Sifar Bersih bagi Bangunan Buluh di Perak (Amir, A. F 2024). and Author's Calculation

In the case of the Gigantochloa albociliata experiment, GPP is given as total carbon fixed through photosynthesis = 6.0 μmol/m²/s CO_2 (equivalent to assimilation rate A), which includes the plant's total carbon uptake. The R process, representing the carbon cost of maintenance in plants, was set to –4 μmol/m²/s CO_2. This proves that respiration reduces the carbon budget of the plant, which may be caused by some physiological or environmental conditions.

$$\text{Net Primary Production (NPP)} = \text{Gross Primary Production (GPP)} - \text{Respiration (R)} \ . \ (1)$$

Substituting the values,

$$NPP = 6.0 - (-4) = 10.0 \mu mol/m2/sCO2$$

This value shows a high net gain in carbon fixation, which means that photosynthesis considerably exceeds respiratory losses, suggesting the plant may have strong growth. The figure provides an analysis: GPP, 6.0 μmol/m²/s; respiration, -4 μmol/m²/s; and NPP, 10.0 μmol/m²/s, representing the carbon dynamics for *Gigantochloa albociliata* under experimental conditions— demonstrating the potential this species has in producing biomass under peculiar conditions.

Based on Table 2 above, crown area is 51.35 m2 dan leaf area index is 2.10. Using the formula given, carbon sequestration of *Gigantochloa albociliata* for one clump per year are 2791.30 Ckg.

Research objective 2 : To quantify carbon farming of Gigantochloa albociliata in Lebuh Meru Raya's road reserve.

Using the calculation in previous method,

i. Carbon sequestration of Gigantochloa albociliata for one clump per year are 2791.30 Ckg.

ii. So, the carbon sequestered for 25 clump at 100m road reserve per year are 69782.5 Ckg (refer Figure 1.6).

Figure 3.6. Amount of bamboo clump in 100 meter of road reserve at Lebuh Meru Raya, Ipoh

By using Meru Raya as site selection, there are around 7 km zone for urban agriculture with Gigantochloa albociliata. Green and developed spaces bounded by a red boundary, just right for growing bamboo in the city. As one of fast- growing plant proper for urban agriculture, attaining its stature under a variety of conditions, hence helping in sequestering carbon. High productivity and high rate of carbon fixation will further increase its value for ecosystems. Urban agriculture brings environmental benefits, social interaction, economic opportunity, and amenity values. The plant's access to major roads and infrastructure supports scalability and success, aligning with sustainability, biodiversity, and community development goals.

Total amount of the carbon that can be sequestered by Gigantochloa albociliata in perimeter of 7km road reserve per year are 48,847750 Ckg equal to 179,271,242.5 kg (179,271 metric tons) of CO_2 carbon footprint, comparable to the annual emissions of approximately 38,937 vehicles in an urban area.

Figure 4.7. Potentional Road Reserve that are Suggested to Propose Gigantochloa Albociliata as Urban Farming

DISCUSSION AND CONCLUSION

The research on road reserves, particularly the Lebuh Meru Raya in Ipoh, for carbon sequestration potential integrates Gigantochloa albociliata, a bamboo with high biomass productivity, into semi-urban carbon farming strategies. It also details a step-by-step methodology of how to measure carbon using purposive leaf sampling supported with advanced tools like the LI-6400XT Portable Photosynthesis System. This study utilizes mathematical models to estimate Net Primary Production (NPP) and carbon storage per clump of bamboo. It investigates the role that bamboo might play in the mitigation of CO_2 and as a substitute sustainable material for construction. The study has focused on Malaysia, since Gigantochloa albociliata has cultural and economic importance in that country. The research points out road reserves as sources of challenges in vehicle emissions and urban stress. The methodology uses time-specific leaf sampling to account for diurnal photosynthesis variations, ensuring precise daily carbon assimilation measurements. The objective of the research is to quantify carbon farming potential in road reserves and provide policy and sustainable development recommendations for integrating bamboo into carbon offset and land management strategies.

Bamboo is a Fast-growing Plant with Great Potential as a Carbon Sink because of its rapid growth and adaptability. Its carbon sequestration along road reserves enhances sustainability and aesthetics, helping mitigate climate change. The carbon sequestration rates of bamboo depend on factors like temperature, rainfall, and soil type. To boost bamboo's carbon storage in farming initiatives, environmental factors must be considered. Bamboos in road reserves reduce soil erosion, increase biodiversity, and generate carbon credits.

In short, these plants of bamboo in road reserves hold a new way to land use and climate change regulation through effective carbon sequestration. Further research and development of policies will be needed to make the most of bamboo's role in carbon farming and sustainable land management. Bamboos are carbon sequesters, but not all species and areas. There needs to be more research on different soil types and climates. Long-term studies will be required to show the true carbon sequestration potential of bamboo, as the rate of absorption changes with age. Further research is merited to test the financial viability of bamboo in road reserves and non-invasive species.

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