Research Title **Assessment of Aboveground Carbon Stock of Sago Palm (Metroxylon sagu Rottb.) under Natural Growth Conditions in Areas with Different Soil Quality: A Case Study of Khok Saba and Na Khao Sia Subdistricts, Nayong District, Trang Province, Thailand**

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Abstract

This study aimed to assess aboveground carbon sequestration in sago palm (Metroxylon sagu Rottb.) growing naturally in wetland areas with different soil properties, by comparing Khok Saba Subdistrict and Na Khao Sia Subdistrict, Nayong District, Trang Province. Field surveys were conducted in 20 plots per subdistrict, each measuring 5 × 20 m. Stem circumference at breast height (1.3 m) and tree height were measured to estimate aboveground biomass and carbon sequestration using allometric equations. Soil properties, including pH and macronutrient contents (N, P, and K), were also analyzed.

The results showed that Khok Saba Subdistrict contained 89 sago palms, which was higher than Na Khao Sia Subdistrict with 61 palms, resulting in greater total aboveground biomass (1,024.84 tons) and carbon sequestration (481.68 tons) compared to Na Khao Sia Subdistrict, which exhibited 799.62 tons of aboveground biomass and 375.72 tons of carbon sequestration. Although the average height of sago palms in Khok Saba Subdistrict (12.47 m) and Na Khao Sia Subdistrict (13.70 m), as well as the average stem circumference (1.44 and 1.48 m, respectively), were relatively similar, significant differences were observed in soil properties. Soils in Khok Saba Subdistrict had a pH of approximately 4 and high potassium levels, whereas soils in Na Khao Sia Subdistrict had a pH of approximately 8 and low potassium levels. Nitrogen and phosphorus levels in both areas were very low. These findings indicate that sago palm density, together with soil properties—particularly pH and potassium availability—are key factors influencing carbon sequestration potential in sago palm ecosystems.

Keywords: Sago palm, Carbon sequestration

Introduction

Climate change is a global issue primarily driven by the increasing concentration of greenhouse gases in the atmosphere, particularly carbon dioxide (CO_2), resulting from human activities such as fossil fuel combustion, land-use change, and terrestrial ecosystem degradation. The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) emphasizes that enhancing and maintaining carbon sinks in natural ecosystems is one of the key mechanisms for long-term climate change mitigation (IPCC, 2022).

Plants play a crucial role in the global carbon cycle by absorbing CO_2 through photosynthesis and storing carbon in both aboveground and belowground biomass. Therefore, carbon stock assessment has been widely used as an essential tool to evaluate the potential of ecosystems to mitigate greenhouse gas emissions and to provide baseline data for carbon accounting at local and national levels (Brown, 1997; IPCC, 2019). Estimating tree biomass using allometric equations is a well-established approach in ecological research, as it relies on measurements such as diameter or stem circumference at breast height, tree height, and wood density to accurately predict aboveground biomass without destructive sampling (Picard et al., 2012; Nam et al., 2016).

Tropical wetland ecosystems have a high potential for carbon sequestration due to the accumulation of organic matter in both plant biomass and soils. However, drainage and land-use conversion in wetlands can shift these ecosystems from carbon sinks to sources of greenhouse gas emissions. Consequently, identifying plant species suitable for utilization in wetland areas without disrupting carbon balance is of critical importance (IPCC, 2019).

Sago palm (Metroxylon sagu Rottb.) is a native palm species of Southeast Asia and a key component of wetland ecosystems. It thrives in waterlogged and highly moist soils and possesses a large stem capable of storing substantial amounts of starch and biomass. Previous studies have reported that sago palm plays a significant role in the carbon cycle of wetland ecosystems by sequestering carbon in both aboveground biomass and peat soils (Watanabe et al., 2018). Moreover, direct biomass-based assessments have demonstrated that sago palm exhibits a considerable carbon sequestration potential at the individual tree level (Azizah et al., 2023).

Despite evidence supporting the carbon sequestration potential of sago palm, most existing studies have focused on specific locations and lack comparative analyses across areas with differing environmental conditions, which may influence sago palm growth and carbon storage capacity. Furthermore, previous research has rarely examined the direct relationship between carbon sequestration in sago palm biomass and soil quality in wetland environments, particularly soil nutrients such as nitrogen (N), phosphorus (P), and potassium (K), as well as soil pH. In addition, the sago palms examined in this study are naturally growing individuals rather than plantation-grown trees of uniform age, resulting in variability in age and size that reflects real ecosystem conditions.

Therefore, this study emphasizes the analysis of the relationship between carbon sequestration in sago palm biomass and soil quality, rather than using tree age as the primary variable, in order to better represent carbon sequestration potential under natural ecosystem conditions. A comparative assessment of carbon sequestration in sago palms across two distinct wetland areas is thus essential for understanding the influence of soil quality on carbon storage potential. The findings of this study will not only contribute to filling knowledge gaps regarding carbon dynamics in sago palm ecosystems but also provide scientific evidence to support sustainable wetland management and climate change mitigation policies at both local and national levels.

Research Question

Is carbon sequestration in the biomass of naturally growing sago palms associated with soil quality in wetland ecosystems

Research Hypothesis

Differences in soil quality between study areas result in significant differences in aboveground biomass carbon sequestration of sago palms.

Materials and Methods

1. Assessment of Carbon Sequestration in Sago Palm

1.1 Materials and Equipment

1.Tree circumference measuring tape

2.Clinometer

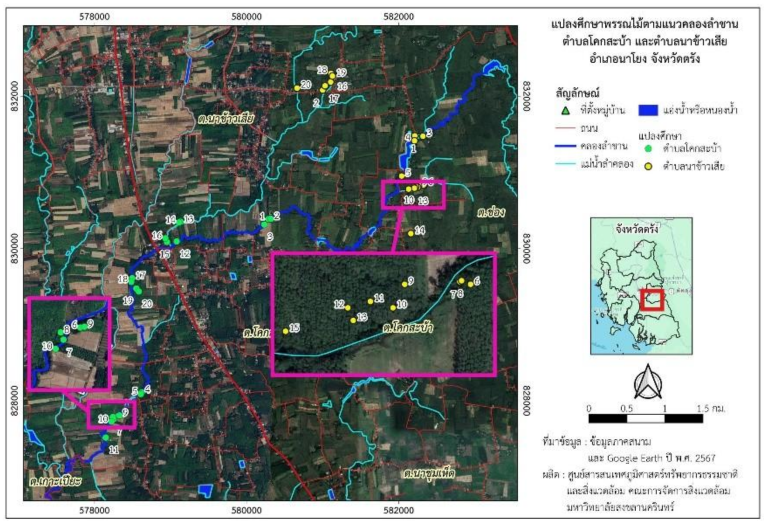
3.Measuring tape

4.Data recording materials

5.Global Positioning System (GPS)

1.2 Research Methods

1.The study sites were identified in Kok Saba Subdistrict and Na Muen Sri Subdistrict. In each subdistrict, 20 sampling plots were established, resulting in a total of 40 plots. Each plot measured 5 × 20 meters.



2.Sago palms within Kok Saba Subdistrict and Na Khao Sia Subdistrict were surveyed. Only sago palms with developed woody tissue and a minimum height of 1.5 m were selected. The stem circumference was measured at 1.3 m above ground level using a measuring tape. Tree height was determined using a clinometer based on trigonometric principles.

3.The collected data were used to calculate aboveground biomass and carbon sequestration of sago palms as follows:

3.1 Calculation of Aboveground Biomass Aboveground biomass was calculated using the following equation:

$$Bap = v * BJ * BEF$$

where:

Bap = aboveground biomass (kg)

V = stem volume (m^3)

BJ = wood density (kg/m^3); wood density of sago palm ranges from 0.33–0.41 g/cm^3 (Ekawati, cited in Azizah et al., 2023). In this study, a value of 0.41 g/cm^3 was used

BEF = biomass expansion factor; BEF = 1.33 (Novita, 2010, cited in Azizah et al., 2023)

3.2 Calculation of Carbon Sequestration

Carbon stock in sago palm biomass was calculated using the following equation:

$$Cb = B * \%C\ organic$$

where:

Cb = carbon stock in biomass (tons)

B = total biomass (tons)

%C organic = organic carbon fraction (0.47)

2. Soil Property Analysis in the Study Area

2.1 Materials and Equipment

1.Test tubes

2.Soil test kit for NPK and pH analysis (HI3895 Quick Soil Test Kit)

3.Glass stirring rods

4.Beakers

2.2 Research Procedures

1.pH determination: Approximately half a teaspoon of soil was placed into a test tube, and distilled water was added up to the lower volume mark (2.5 mL) using the volume guide. One packet of HI3895 pH-0 reagent was added, the tube was capped, and gently shaken for 30 seconds. The mixture was allowed to stand for 5 minutes, after which the color was compared with the pH color chart to determine the pH value.

2.Preparation of soil extract solution: Soil extract was prepared by mixing 1.5 measuring cups of soil with 8 measuring cups of distilled water. The mixture was gently stirred or shaken for at least 1 minute, then left to stand until the soil particles settled.

3.Nitrogen (NO_2) analysis: Using a pipette, 2.5 mL of the clear supernatant from the soil extract was transferred into a clean test tube. One packet of HI3895N-0 reagent was added, the tube was capped, and shaken for approximately 30 seconds to dissolve the reagent. After standing for 30 seconds, the resulting pink color was compared with the nitrogen color chart.

4.Phosphorus (P_2O_3) analysis: A volume of 2.5 mL of the clear soil extract was pipetted into a clean test tube. One packet of HI3895P-0 reagent was added, and the tube was capped and shaken for about 30 seconds until fully dissolved. The resulting blue color was compared with the phosphorus color chart to determine phosphorus concentration.

5.Potassium (K_2O) analysis: Using a pipette, 0.5 mL of the clear soil extract was transferred into a clean test tube. Distilled water was added up to the lower volume mark (2.5 mL). One packet of HI3895K-0 potassium reagent was added, the tube was capped, and shaken gently for 30 seconds until dissolved. A blue coloration developed, and the turbidity was compared with the K_2O reading chart to determine potassium concentration.

Result

1. Carbon Sequestration in Sago Palms

The results of carbon sequestration assessment in sago palms from the two study areas revealed differences in the number of sampled trees. Khok Saba Subdistrict had a greater number of sago palms than Na Khao Sia Subdistrict. The average tree height and average stem circumference were relatively similar between the two areas, although Na Khao Sia showed slightly higher mean values for both parameters.

However, when tree structural data were used to calculate aboveground biomass and total carbon storage, Khok Saba Subdistrict exhibited higher total aboveground biomass and carbon sequestration than Na Khao Sia Subdistrict. This result indicates that tree density plays a significant role in determining the carbon sequestration potential of the area, rather than individual tree size alone. The results are presented in Table 1

Table 1 Results of carbon storage in sago palm

Study area	Number of sago palms	Mean height (m/tree)	Mean stem circumference (m/tree)	Aboveground biomass (ton)	Carbon storage (ton)
Khok Saba Subdistrict	89	12.47	1.44	1024.84	481.68
Na Khao Sia Subdistrict	61	13.70	1.48	799.62	375.72

2. Soil Properties in the Study Areas

The analysis of soil properties revealed clear differences between the two study areas, particularly in terms of soil pH. Soils in Khok Saba Subdistrict were classified as acidic, whereas soils in Na Khao Sia Subdistrict were alkaline.

Regarding soil nutrient status, both study areas exhibited very low levels of nitrogen and phosphorus, or only trace amounts were detected. In contrast, potassium levels varied markedly between the two areas. Soils from Khok Saba Subdistrict contained high potassium concentrations, while those from Na Khao Sia Subdistrict showed low potassium levels. Detailed soil property data for each study area are presented in Table 2.

Table 2 Soil properties of the study areas

Study area	pH	Nitrogen (N)	Phosphorus (P)	Potassium (K)
Khok Saba Subdistrict	4	trace	trace	high
Na Khao Sia Subdistrict	8	trace	trace	low

Conclusion and Discussion

The results of this study on aboveground biomass and carbon storage of sago palm (Metroxylon sagu Rottb.) in the two study areas indicate that sites with a higher number of sago palms were able to store a greater total amount of carbon, despite the absence of significant differences in average tree height and mean stem circumference between the areas. This finding suggests that the carbon sequestration potential of plant ecosystems is primarily determined by total biomass per unit area, rather than by the structural characteristics of individual trees. This result is consistent with the concept proposed by Brown (1997) and aligns with the IPCC (2022), which emphasizes that increasing the density of perennial vegetation can effectively enhance terrestrial carbon stocks.

Considering soil-related factors, the soil properties of the two study areas differed notably in terms of soil pH and macronutrient availability, which may influence the growth and biomass accumulation of sago palms. Brady and Weil (2017) explained that soil pH affects nutrient availability and biological processes in soils, thereby influencing plant productivity and biomass formation. In addition, Vitousek and Howarth (1991) highlighted that soil fertility, particularly nitrogen and phosphorus availability, is a key factor controlling plant biomass production in terrestrial ecosystems.

The present study found that nitrogen and phosphorus levels in soils from both study areas were very low or detected only in trace amounts. This result is consistent with the concept of resource limitation, which suggests that deficiencies in essential nutrients can constrain biomass accumulation and carbon sequestration, even under conditions where water availability is not limiting. Furthermore, differences in soil potassium levels between the study areas may affect photosynthetic efficiency and carbohydrate translocation within sago palms, as described by Mengel and Kirkby (2001).

In conclusion, this study demonstrates that sago palm density in combination with soil properties, particularly soil pH and macronutrient availability, plays a crucial role in determining aboveground biomass and carbon sequestration in the study areas. These findings highlight the potential of sago palm ecosystems as significant carbon sinks in wetlands and tropical agricultural landscapes and support the importance of nature-based solutions emphasized by the IPCC (2022) in addressing climate change.

Recommendations

1.Future studies should assess belowground biomass and soil carbon stocks in conjunction with aboveground biomass in order to provide a more comprehensive understanding of the carbon sequestration potential of sago palm ecosystems. In addition, the effects of sago palm age, plant population structure, and long-term changes in soil properties should be investigated to more accurately explain the dynamics of carbon accumulation in sago palm ecosystems.

2.Conservation and management of sago palm areas should be promoted in ways that maintain or appropriately increase sago palm density, as increasing the number of trees per unit area contributes to greater aboveground biomass and enhanced carbon sequestration capacity. Furthermore, soil management practices, particularly the improvement of soil macronutrient status, should be emphasized to support sago palm growth and to enhance long-term carbon accumulation potential.

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Globe Data Entry

Soil pH	
Measured Date:	2026-01-13
Organization Name:	Sawat Rattanapimuk
Site ID:	409468
Site Name:	Khok Saba
Country Name:	Thailand
Country Code:	THA
Latitude:	7.50921
Longitude:	99.71691
Elevation:	24.4m
Collected On:	2026-01-13T00:00:00
pH:	4
Horizon Top Depth:	0 cm
Horizon Bottom Depth:	10 cm
Horizon Number:	1
Reference Depth Level5cm:	true
Reference Depth Level10cm:	true
Ph Method:	meter
Comments:	