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ARTICLE

Sago Forests for Food Security and Handling Climate Change in Indonesia

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ABSTRACT

A crucial impact of climate change is the disruption of the agricultural sector, posing a threat to food supply for the globally increasing population. In this context, prioritizing food security in each country becomes an important concern. This study aimed to explore biomass and C-Stock content of Sago forests for handling climate change and resilience. The methodology used comprised various steps including determining the type and the hydraulic conductivity of the soil, assessing biomass and C-Stock by cutting Sago at various growth stages, weighing the wet and dry weight of each fraction, calculating the Top-Root Ratio, and determining the starch yield. The results showed that there were four types of soil namely Hydric, District, and Fluvic Gleisol, as well as Oxic Cambisole. C-Stock was 26.99 tonnes per hectare with a Top-Root Ratio of 636%, implying that above-ground biomass (AGB) was six times more than below-ground biomass (BGB) and the presence of mineral soil. Sago dry starch product ranged from 490.3–571.8 kg per tree and the potential relatively varied due to differences in the structure and composition of forests, as well as habitat and environment. Although logging remained persistent on a very small scale, early signs of disturbances were observed in hydrological conditions and fluctuations in water levels or puddles in the soil profile. This implied that conversion of Sago forests to other uses for the expansion of grain crops on a large scale, would lead to the area experiencing drought.

Keywords: Soil Hydraulic Conduction; Above-Ground Biomass; Below-Ground Biomass; Climate Change; Food Security

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1. Introduction

Sago trees (*Metroxylon sago*, Rottb) are native plants widely distributed across several islands in Indonesia, including Maluku, Papua, West Papua, Kalimantan, Sulawesi, Sumatra, Java, and the Mentawai Islands. The area distribution and types of cultivation on each island differ slightly, with some being natural while others are semi-cultivated. The majority of areas in Papua and West Papua have not been managed or cultivated, thereby reducing overall productivity. Compared to food crops derived from grains such as rice, wheat, corn, and others, Sago trees offer better advantages due to high biomass content and resilience to climate change. Food crops produced from grains are generally vulnerable to climate change, which causes a decline in productivity when the impact becomes greater. According to Choya, Rosalia, and Mulyaningsih [1] various countries worldwide are facing climate change attributed to various factors including global warming, posing a threat to food production. Rainfall below or above normal conditions as well as extreme temperatures also pose a significant risk to the world food system. The concept of resilience is increasingly being proposed as a framework for finding solutions to these challenges. In this context, it is necessary to assess how resilience has been integrated into discussions regarding climate change and food security by both academics and practitioners [2].

Sago flour has the potential to replace or substitute wheat flour in various confectionery and other local food products. This substitution can increase the availability of additional food resources produced locally on underused land resources without or with less competition with other food crops, thereby contributing to food security [3]. In general, climate change has a negative impact on food security but the majority of previous literature focused on the complex mechanisms linking climate stressors, as well as the relationship with food production or productivity rather than food security. Therefore, it is necessary to investigate the extent to which current changes in food insecurity can be linked to climate change [4]. Several studies have been conducted on Sago in terms of production aspects related to food security. Neglected consumption of local food such as Sago and dependence on imported rice will endanger local food security on small islands in Maluku (eastern Indonesia). Although there is a government policy to reduce rice consumption and promote local food, various factors influencing preferences have not been identified.

According to Rampisela et al. [5], the main problem affecting food security in Indonesia is the limited land suitable for food crops despite the significant potential for high productivity. In this context, a transdisciplinary approach is needed to develop a local community-based Sago plant development model, such as the conversion of Sago land into ponds and plantations, and semi-forest cultivation. This will enable a triple helix collaboration between universities, industry, and government, action collaboration from stakeholders as well as support for several government regulations and local community activities. Clearing land for infrastructure development has threatened the ecosystem of Sago forests growing abundantly. In general, Sago grows in areas that are rarely explored by various human activities; hence, the conversion of land for development is also part of modernization. The negative impact includes a decline in people's interest in cultivating Sago as daily food. Sago, which was previously easy to obtain in forests, has now been cut down, making acquisition significantly difficult [6]. According to Dimara et al. [7], this plant is a promising alternative to ensure food safety due to the high carbohydrate content. Describing the potential of local Sago food to identify consumer preferences and improve local Sago food (papeda) can be achieved through collaboration with food technology scientists [8].

Istikowati et al. [9] analyzed the suitability of Sago plant waste, particularly fronds as raw material for pulp and paper based on the chemical content and anatomical characteristics, yielding α-cellulose and lignin content of 31.585% and 37.996% respectively. The leaf lignin content was relatively high but the α-cellulose content showed standard values for non-timber forest products. Moreover, the fiber derivatives were classified as class II signifying suitability for pulp and paper raw materials. Apart from Sago fronds, charcoal and Sago husk ash can also be used to overcome soil acidity due to pH, as well as high P fixation by Al and Fe [10]. Based on the latest research results, Sago palm can be converted into bio-energy resources such as biomass-biogas, biohydrogen, bioelectricity and also bioethanol [11]. In this way, Sago can increase economic value and provide incentives for conservation.

Lewantaur, Siahaya, and Gaspersz [12] analyzed Sago forest density using vegetation index transformation in Ambon Bay, Ambon City. Based on the results, three levels of Sago forest density were found in the study area, namely medium (13.3%), low (3.4%), and high (1.6%). Buchholz[13] identified several advantages of Sago compared to other staple crops commonly with edible starch yield ranging from 25 to 40 tons ha^{-1} per year, depending on environmental conditions. This figure is six times higher than rice, the most commonly produced staple crop in Indonesia. In addition, Sago can be planted in areas that are not suitable for other crops such as peatlands due to its high tolerance to poor environmental conditions. Peatland does not require draining to grow Sago compared to most other plants, offering a great opportunity to reduce carbon emissions from carbon-rich soil. Sago also offers two important health benefits compared to white rice, including numerous dietary fibers that aid the intestinal environment and reduce constipation as well as a significantly low glycemic index (GI). These benefits make the crop very suitable for diabetes patients and obesity sufferers.

Dam[14] stated that excessive intake of white rice can trigger the risk of type 2 diabetes, while Said et al.[15] studied the protein content in Sago dregs to increase the nutritional value as animal feed. Khairunnisa et al.[16] focused on improving the morphological characteristics and physicochemical properties of Sago biochar produced by carbonizing husk waste in an oxygen-free environment. Furthermore, Wulan[17] observed Sago culture in endemic peatlands by measuring the sustainability life cycle assessment of the cultivated plants. Sago trees cultivated on peatlands were included in the "sustainable" category when assessed based on aspects of social, economic, and environmental sustainability, while Wulandari, Hairiah and Prayogo[18] assessed Sago based on an agroforestry system in Sorong (Southwest Papua). According to Local Ecological Knowledge (LEK), the most suitable land for planting must be close to a water source and not affected by soil biota as well as fertilization. As stated by Modern Ecological Knowledge (MEK), starch formation is reduced in waterlogged land and remaining Sago dregs are very good for making compost or animal feed. There are numerous studies regarding Sago from various aspects, but information on the biomass aspect is limited, specifically using destructive samples. In general, biomass estimation can be performed using the wood volume, specific gravity, and Basal Area Factor (BAF) approach. However, biomass estimation by calculating the wet and dry weight directly for each segment of the Sago plant has not been performed. This study aimed to analyze Sago biomass and starch production for food security and handling climate change.

2. Materials and Methods

2.1. Study Site Location

The study was carried out in a 126.9 ha Sago forest area, Tulehu Village, Ambon Island as presented in **Figure 1**.

Figure 1. Study site in Ambon island.

Source: https://ibb.co.com/qd96MJY.

2.2. Observation of Soil Profile and Hydraulic Conductivity

Soil samples were taken near Sago trees using purposive sampling, with five excavation units each measuring 1 × 1 × 1 m. The distance between Sago trees was 75 m. Undisturbed soil samples were collected from Sago wetlands and weighed along with the sample ring. Subsequently, drying was carried out in the oven at 105 °C for 2 × 24 hours in the laboratory. The soil was removed from the sample ring, weighed, and the dry weight was calculated. The hydraulic conductivity of soil in a saturated state was assessed by making a hole measuring 1 × 1 × 1 meter, determining the groundwater level, and observing the condition of the soil texture during excavation. Water was removed from the hole, and initial measurements were made by recording the speed of water surface rise during refilling. Once the hole was prepared, the water was allowed to rise until equilibrium was reached. Measurements included hole diameter (2π), depth of water in the hole, and water surface height in the hole (H). The water contained in the hole was removed and the speed of change within a certain time was measured several times. Groundwater level rise was measured in three dimensions (maximum and minimum). The calculation of water availability in Sago fields is presented in **Figure 2**.

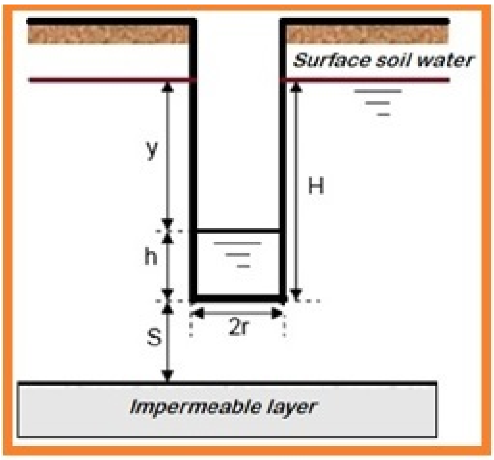


Figure 2. Water availability in Sago fields.

Source: (Kurnia, U.; Agus, F.; Adimihardja, A.; Dariah [19]).

Where:
H = height of the water level in the hole (soil profile);
2r = hole diameter (soil profile);
h = height of groundwater rise (after the hole is emptied) – 1/2H;
y = H – h;
S = distance from the bottom of the hole to waterproof layer (estimated by drilling).

2.3. Biomass and C-Stock Measurement Procedures

Sago biomass measurements were carried out by cutting down Sago trees and sorting each fraction starting from stems, leaves, flowers, fruits, and roots. Subsequently, the wet weight of each segment was measured at the study site and the dry weight in the laboratory. The design of Sago and soil sampling positions as well as wet and dry weight for each Sago tree segment are presented in **Figure 3**.

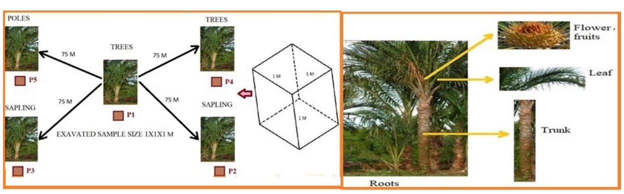


Figure 3. Sago and soil sampling layout as well as wet and dry weight for each Sago tree segment.

Source: Constructed by authors.

Procedures for implementation in the field are as follows:

Biomass and C-Stock calculations were carried out through destructive sampling for five Sago trees as samples. The distribution of sample tree fractions was determined to separate parts of tree biomass including stem, leaf, flower, and fruit. The sample tree fraction to be weighed was adjusted to the capacity of the available scales. Specifically, the stems were divided into several sections (sub-fractions of stems) by considering the shape, uniformity, and weight of the pieces. After the distribution of the sample tree fractions, the wet weight was weighed. All fractions were weighed in the field in a fresh state as follows:

- Stem: A sample of stem fraction reaching 250 g was collected by cross-cutting at least a quarter of the circumference from each section (stem sub-fraction). For root sections with a diameter >50 cm and weight exceeding the existing scale, volume measurements were carried out using the Brereton formula according to Indonesian National Standard (SNI) 7724:2011.
- Leaf test samples reaching at least 250 g were taken, while flowers and fruit were collected as a whole.
- Dry weight analysis in the laboratory

The dry weight for each Sago sample fraction was measured by drying in an oven at a temperature range of 70 °C–85 °C until a constant weight was reached. The weight of each fraction was measured with an analytical balance after drying in the oven.

The total dry weight and C-Stock were calculated using the formula:

$$Bkt = (Bks \times Bbt)/Bbs \quad (1)$$

where: Bkt or biomass is the total dry weight (kg); Bks is the dry weight of the test sample (g); Bbt is the total wet weight (kg); Bbs is the wet weight of the test sample (g).

$$C - Stock = 0.47 \ \ Biomass \quad (2)$$

Destructive sampling of Sago trees is considered more accurate than non-destructive sampling. In general, non-destructive samples are only estimates and have the potential for large bias in estimating Sago biomass content. The use of destructive sampling is very important for the accuracy of biomass and C-Stock estimates, especially for small forest areas. For very large forest areas, through the use of remote sensing technology and interpretation of satellite imagery, alternative non-destructive methods can be used.

After collecting soil and Sago samples for each fraction, forest mapping was carried out using drones. Data recording was carried out using a DJI Phantom 4 Pro type drone with a 20 MP resolution camera and the ability to fly for 30 minutes per battery. The drone deployment application used was based on iOS and Android, while the flight height for mapping was 150 m with a pixel resolution of 3.0 cm per pixel. Object-based image analysis (OBIA) was used to classify Sago and non-Sago forests, as well as identify various levels of growth at the study site including seedlings, saplings, poles, and trees.

3. Results

3.1. Several Activities at the Study Site

In general, this study involved several activities as shown in Figure 4, and it required careful works particularly in producing root samples for calculating biomass and underground C-stock as well as Top-Root Ratio (TRR). Several activities at the study site are presented in **Figure 4**.

Figure 4. Several activities at the study site.

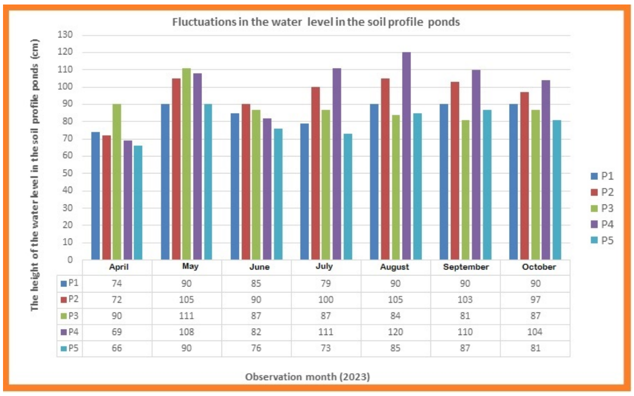
Source: Documentation in the field.

3.2. Soil Profile and Hydraulic Conductivity

Soil observations were carried out on five representative profiles in Sago fields with different flooding conditions including external characteristics consisting of coordinate points, slope steepness, altitude, and land use types, and internal characteristics such as soil color, texture, structure, pores, BO, and soil pH. Soil classification was conducted using the 2014 National Soil Classification System and equivalent to the 2014 USDA Soil Taxonomy classification system down to the USDA type or sub-group level. The collected soil samples were analyzed at the Soil Laboratory of the South Sulawesi Agricultural Technology Assessment Agency in Maros. Based on field observations and laboratory analysis results, four soil types were found and classified as presented in **Table 1**.

Hydrological conditions and fluctuations in water level height (inundation in soil profile):

The results of fluctuations in soil profile ponds and water content are presented in **Figures 5** and **6** below.



	April	May	June	July	August	September	October
P1	74	90	85	79	90	90	90
P2	72	105	90	100	105	103	97
P3	90	111	87	87	84	81	87
P4	69	108	82	111	120	110	104
P5	66	90	76	73	85	87	81

Figure 5. Fluctuations in the water level in the soil profile ponds.

Source: Processed field data.

The hydrological conditions at the various sample locations are as follows: P1 and P2 had moist soil conditions, while P3, P4, and P5 were slightly dry. Based on observations for 7 months (April–October 2023), the water level at P1 ranged from 74–90 cm. From August–October 2023 with high-intensity rainfall, the land was flooded at a height of 90 cm. Furthermore, P2 had a water level ranging from 72–105 cm, with the highest occurring in May and August 2023 (105 cm) without flooding. At location P3, the water level ranged from 80–111 cm, and the highest was observed in May 2023 (111 cm), with an average of <90 cm and without flooding. The P4 location had a water level ranging from 69–120 cm, with the highest occurring in August 2023 (120 cm). At location P4, the water level was >100 cm in May, July, August, and September 2023, while at P5, the water level ranged from 66–90 cm, with the highest occurring in May 2023 (90 cm), without flooding.

Table 1. Soil types of study site.

No	Soil Type	Location	Description
1.	Hydric Gleisol (*Typic Hydraquents*)	Coordinates 03°39′147″ S and 128°11′645″ E, altitude 24 m above sea level, slope 1% with Sago forests land use. Flood conditions for 3 months	The soil color was black (5 Y 2.5/1) in layer I, gray (5 Y 5/1) in layer II, and olive gray (5 Y 4/2) in layer III. Sandy loam soil texture in all layers. Soil acidity level was acidic (4.65–5.35), C-Organic content ranged from medium-high (2.71–5.15%), base saturation ranged from medium-high (42–68% and cation exchange capacity was between low–medium (12.51–17.83 me per 100 g).
2.	District Gleisol (*Typic Endoaquepts*)	Coordinates 03°39′147″ S and 128°11′645″ E, altitude 24 m above sea level, slope 1% with Sago forests land use. Flood conditions for 3 months	The soil color was dark gray (5 Y 3/1) in layer I, pale olive (5 Y 5/1) in layer II, and oliv (5 Y 5/6), while layer III had brownish yellow (10 YR 6/8) mottling color. Soil texture was sandy loam and acidity level was acidic (4.21–4.49), C-Organic content was very low–medium (0.51–3.63%), base saturation was low–medium (19–30% and cation exchange capacity was low (10.81–13.06 me per 100 g).
3.	Fluvik Gleisol (*Fluventic Endoaquepts*)	Coordinates 03°35′162″ S and 128°18′809″ E, altitude 22 m above sea level, slope 1% with Sago forests land use. Flood conditions for 6 months.	Soil color was very dark gray (5Y 3/2) in layer I, greenish gray (6/5 G) and brownish yellow (10YR 6/6) in layer II, bluish-gray (5/5 PB) and brownish yellow (10 YR 6/6) in layer III, light greenish gray (7/5 BG) and yellow (10 YR 8/8) in layer IV. Sandy loam soil texture. The soil acidity level was acidic (4.37–4.67), the C-Organic content was very low–medium (0.43–2.82%), the base saturation was moderate (38–49% and the cation exchange capacity was low (10.32–11.54 me per 100 g).
4.	Oxic cambisol (*Typic Dystropepts*)	Coordinates 03°39′147″ S and 128°11′645″ E, altitude 36 m above sea level, slope 40% with Sago forests land use. The condition of the puddle is never stagnant.	The soil color was yellowish brown (10YR 5/6) in layer I, brownish yellow (10YR 6/8) in layer II, and brown (10YR 4/3) in layer III. Sandy loam soil texture. Soil acidity level was acidic – slightly acidic (4.90–5.36), C-Organic content was very low – medium (0.93–2.57%), base saturation was very low – medium (13–51% and cation exchange capacity was low (12.22–15.87 me per 100 g).

Source: Processed field data.

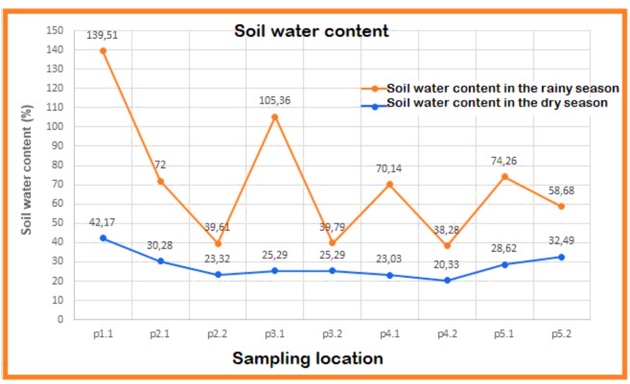


Figure 6. Soil water content in the rainy and dry season.

Source: Processed field data.

The specific hydrological conditions that are most favorable for the growth of Sago trees are: in wet or flooded land, either permanent, or flooded during the rainy season. A good living environment includes muddy areas where the respiratory roots are not submerged, rich in minerals and organic materials, and groundwater is brown and reacts slightly acidic. The main difference with rice and corn plants is: they are planted on dry land and need to pay attention to the water requirements for plant growth. Rice needs sufficient water for its growth and development. Therefore, to create new rice fields, adequate irrigation facilities are needed.

3.3. Biomass, C-Stock of Sago and TRR

Above-ground biomass (AGB) for each Sago growth stage and the total is presented in **Table 2** and **Figure 7**. Based on the results, greater AGB was observed at the seedling (P1) to the tree level (P2, P1).

Below-ground biomass (BGB) for each Sago growth stage and the total is presented in **Table 3** and **Figure 8**. Based on the results, greater BGB was observed from the seedling (P1) to the tree level (P2, P1).

Table 2. AGB total.

No	*Carbon Pool*	AGB (g)				Biomass Total	
		Leaves	Leaf Stem	Leaf-Sheath	Stem	(g)	(kg)
1	P1	28,420	23,790	45,300	1,376,000	1,473,510	1,473.51
2	P2	13,440	12,214	11,660	1,017,000	1,054,314	1,054.31
3	P3	9,318	18,040	14,112	285,000	326,470	326.47
4	P4	26,760	29,400	27,244	326,000	409,404	409.40
5	P5	4,386	7,626	3,630	0	15,642	15.64
	Total	82,324	91,070	101,946	3,004,000	3,279,340	3,279.34

Source: Processed field data.

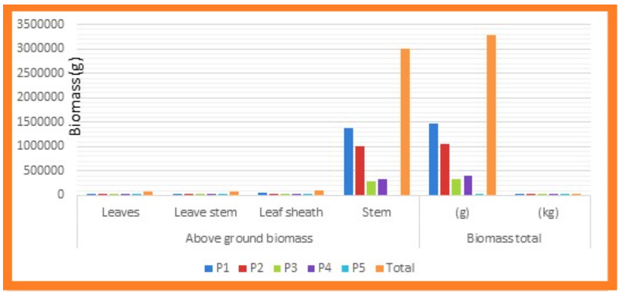


Figure 7. AGB total.

Source: Processed field data.

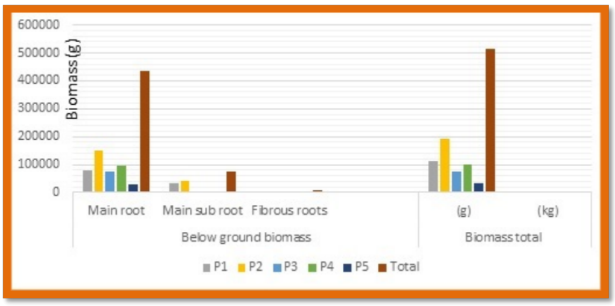


Figure 8. BGB total.

Source: Processed field data.

Based on the results, AGB was greater than BGB, with the comparison of both yielding a TRR of 6.36 times as presented in **Table 4**.

The C-Stock content at various growth stages is presented in **Table 5**.

3.4. Sago Production

Sago stem consists of a hard outer layer of skin, as well as an inner layer in the form of pith which contains fibers and starch [20]. The starch collected from Sago stems has the potential to address food security due to its consumption as a staple food for the population, specifically in Eastern Indonesia. The wet weight of flour from Sago trees is presented in **Table 6**.

3.5. Results of Mapping Sago Forests with Drones

At the study site, three types of Sago were found as shown in **Figure 9** including two with thorns: Sago tuni *(M. rumphii* Mart.), Sago ihur (*M. sylvestre* Mart.) as well as one without thorns, Sago molat (*M. Sagu* Rottb.). The dominant type was Sago tuni, while Sago ihur and Sago molat were unevenly mixed with Sago tuni.

Figure 9. Types of Sago found at the study location: (**a**) Sago tuni (M. rumphii Mart.), (**b**) Sago ihur (M. sylvestre Mart.), and (**c**) Sago molat (M. sagu Rottb).

Source: Documentation in the field.

A 126.9 ha Sago forests has been successfully mapped and the number of trees at various growth stages is presented in **Table 7** and **Figure 10**.

Figure 10. Conditions before and after classification of Sago growth levels.

Source: Results of processing Sago forest cover with drones.

Table 3. BGB total.

Carbon Pool	BGB (g)			Biomass Total	
	Main Root	**Main Sub Root**	**Fibrous Roots**	**(g)**	**(kg)**
P1	80,640	32,712	1,120	114,472	114.47
P2	149,760	41,859	2,808	194,427	194.43
P3	74,340	0	1,000	75,340	75.34
P4	97,560	0	1,194	98,754	98.75
P5	30,960	0	1,518	32,478	32.48
Total	433,260	74.571	7,640	515,471	515.47

Source: Processed field data.

Table 4. TRR (%) at each growth level.

Carbon Pool	AGB (kg)	BGB (kg)	TRR (%)	Description
P1	1,473.51	114.47	1,287	TRR of Sago at various growth stages from seedlings to trees increased from P5 to P1. At the seedling level (P5), the top biomass was only about half of the bottom. On the other hand, as the tree level (P1) increased, the upper biomass was around 13 times that of the lower biomass.
P2	1,054.31	194.43	542	
P3	326.47	75.34	433	
P4	409.40	98.75	415	
P5	15.64	32.48	48	
Total	3,279.34	515.47	636	The greater Sago forests biomass, the higher the CO_2 absorption.

Source: Processed field data.

4. Discussion

4.1. Types of Soil in Sago Forests

- Hydric Gleisol (Typic Hydraquents)

Gleisol soil is always saturated with water, at levels exceeding 100%. Profile P1 observations showed year-round flooding or consistent water saturation >100% and have never experienced dry periods. Consequently, the soil was included in the Hydric Gleisol type. In the taxonomic classification system, this type of soil belongs to the Entisol order because it cannot be included in other orders. The suborder is Aquents because the soil has an aquic humidity regime and is always saturated with water, while the group is Hydraquents due to the n value of >0.7. The soil also belongs to the Typic Hydraquents because it cannot be included in other subgroups.

- District Gleisol (Typic Endoaquepts)

District Gleisol (Typic Endoaquepts) is a Gleisol soil with a base saturation (KB) value of <50% at least in some parts of the horizon. The analysis results of soil samples in profiles P2, P4, and P5 found a base saturation value of <50%, with an average KB value of 23%, 19%, and 29% respectively. Therefore, the soil profiles of P2, P4, and P5 were included in the Gleisol District soil. This order is Inceptisol because the soil has a cambic horizon, while the suborder is Aquepts due to the aquic conditions. The soil also belongs to the Epiaquepts group because it cannot be included in the Aquepts Sub Order, while the subgroup is Typic Epiaquepts.

- Gleisol Fluvik (Fluventic Endoaquepts)

Gleisol Fluvik (Fluventic Endoaquepts) is a Gleisol soil with layered characteristics due to different deposition or irregular levels of organic matter in the cross-section. P3 soil samples contain irregular organic matter in the soil profile with C-organic content of 2.82%, 0.43%, and 2.05% in layers I, II, and III respectively. This characteristic shows the irregular level of organic matter in the soil, leading to the classification as Gleisol Fluvik. The soil was included in the Inceptisol Order because it has a cambic horizon, while the assigned suborder was Aquepts due to aquic conditions of the horizon. The soil was further included in the Epiaquepts group because it cannot be included in another group of the Aquepts Sub Order. The subgroup is Fluvaquentic Epiaquepts Sub Group because it has a C-organic content >0.2% and an irregular decrease in C-organic levels.

- Oxic Cambisole (Typic Dystropepts)

Oxic Cambisol (Typic Dystropepts) is a Cambisol soil with a cambic B horizon without showing hydromorphic properties at a depth of 50 cm from the surface. The cambic

Table 5. C-Stock at various growth levels.

Carbon Pool	AGB (kg)	BGB (kg)	Biomass Total (kg)	C-Stock on Study Site (kg)	Description
P1	1,473.51	114.47	1,587.98	746.35	As with biomass, C-Stock also increases from seedling level (P5) to tree level (P2 and P1).
P2	1,054.31	194.43	1,248.74	586.91	
P3	326.47	75.34	401.81	188.85	
P4	409.40	98.75	508.15	238.83	
P5	15.64	32.48	48.12	22.62	
Total	3,279.34	515.47	3,794.81	1,783.56	

Source: Processed field data.

Table 6. Wet weight of Sago flour.

No.	Sago Tree P1				Sago Tree P2				Description
	Stem Length (cm)	Sago Bark (pieces)	Bark Weight (kg)	Wet Weight of Flour (kg)	Stem Length (cm)	Sago Bark (Pieces)	Bark Weight (kg)	Wet Weight of Flour (kg)	
1.	67	14	13	70	60	12	11	59	Sago tree P1:
2.	64	13	12	62	64	15	14	60	total height 10.6 m,
3.	71	10	11	71	55	12	9	60	diameter 47.53 cm.
4.	71	13	14	73	60	15	12	65	Sago tree P2:
5.	73	17	15	85	60	15	13	56	total height 11.4 m,
6.	69	15	18	69	64	16	18	59	diameter 43.15 cm.
7.	62	13	14	63	61	15	14	68	
8.	70	15	16	75	62	17	12	70	
9.	73	16	18	86	63	17	13	86	
10.	74	18	14	73	60	15	13	55	
11.	72	11	10	71	60	13	17	51	
12.	71	13	15	74	60	13	18	52	
13.	68	15	13	54	60	16	15	52	
14.	65	13	12	51	62	15	16	52	
15.	-	-	-	-	58	15	15	83	
Total	970	196	195	977	909	221	210	928	

Source: Processed field data.

B horizon has experienced weathering and clay accumulation but is not yet very obvious. Based on the results, soil sample P6 did not show significant clay accumulation, and at a depth of 50 cm from the surface, no hydromorphic properties were found. In the P6 soil example, the CEC value was <24 cmol in layers I–III leading to the inclusion in the Oxic Cambisol soil type. The soil belongs to the Inceptisol Order due to the presence of a cambic horizon and is included in the Udepts Suborder because it has a hill moisture regime. The assigned group was Dystrudepts due to the KB value <50%, while the subgroup was Typic Dystrudepts.

Gleisol and Kambisol soil types are usually found in Sago forest land. According to Nusawakan, Kunu and Luhukay [21], Sago forest land in Rumahkay Village, Seram Island also has Alluvial, Regosol, and Litosol soil types which are generally spread over slightly concave-flat areas. In hilly areas, various types of Kambisol and Podzolic soil also exist in locations with coral, including Renzina and Mollisol. Based on the 2014 Soil Taxonomic Classification System, the various soil units are included in the orders Entisol, Inceptisol, Mollisol, Alfisol, and Ultisol.

4.2. Hydrological Conditions and Water Level Fluctuations (Puddles in Soil Profile)

Based on **Figures 5** and **6**, the hydrological conditions and water level fluctuations can be explained as follows:

The results showed that Sago forest land varied in hydrological conditions in the rainy and dry seasons. The groundwater level follows the depth of the soil profile. Location P1 was inundated during periods of heavy rainfall with a water level of 90 cm, while locations P2–P5 were not flooded. This condition suggests that P1 has a growing habitat experiencing water immersion during the rainy season. Moreover, P1 was flooded for a while, around one to two weeks or a maximum of 1 month according to the intensity of rainfall. At locations P2–P5, there was an increase in the water level but no flooding occurred. When rainfall does not occur for a particular period, the habitat starts to dry out. In this regard, Sago land at the study site was concluded to have a flooded habitat type (location P1) depending on the presence or absence of rainwater. Based on the length of inundation during the rainy season (≤3 months) at the time of the first observation, there was no rainfall. However, in the second observation, there was rain before and after the observation. From April to October 2023, each land profile tends

Table 7. Sago classification at each growth level.

No.	Classification of Sago	Height (m)	Sum (Individual)	Description
1.	Seedling	0–4	100	Classification can be done due to the use of drones with high spatial resolution
2.	Sapling	5–9	818	
3.	Poles	10–14	3,332	
4.	Trees	>14	3,709	
	Total		925,041	

Source: Processed field data.

to have different water levels at varying heights depending on rain events.

Locations P1, P2, P3, P4, and P5 have high water levels, specifically in May, July, August, and September, illustrating the hydrological conditions of inundation lasting 3–6 months, with height (MH) > 10 cm. The result was categorized in the good hydrology class with a limiting factor of groundwater depth <100 cm. The slope of the land was flat to concave (slope 0–2%) with temporary stagnant hydrological conditions causing the soil to be brown at the top and grayish brown at the bottom approaching groundwater. Water plays an important role in the growth of Sago plants, functioning as a source of nutrients and a solvent. Excessive water conditions, such as in swampy areas, are not useful for growth due to the tendency towards poor soil aeration for plant roots.

Undisturbed soil samples were taken in two different seasons, namely during the dry and rainy seasons. The results show that the difference in water content was relatively large between the dry and rainy seasons. In the dry season, soil water content tends to be lower (<50%) than the bulk weight of the soil at all observation locations. Furthermore, in the rainy season, the highest water content was found in P1, 139%, and in the dry season, a decrease was observed to 42.17%. The lowest water content in the rainy and dry seasons was found at locations P4.1 and P4.2, with values of 70.14% and 23.03% respectively. This causes the soil conditions in the rainy season to become more humid compared to the dry.

The soil profile at the study site had fairly good to fairly poor drainage conditions, characterized by seasonal flooding. In the rainy season, poor drainage conditions were hampered by high groundwater levels, resulting in the soil pore space being completely filled with water (location P1). The sandy soil texture affects the drainage and aeration conditions of the soil, thereby creating a good growing place for Sago.

The large fluctuations in groundwater levels during the rainy and dry seasons cause Sago forests to have different responses to rising groundwater levels. Plants that grow with groundwater covering 50% and 80% of the Sago root area showed a higher morphological growth rate compared to normal groundwater conditions (field capacity). Sago forests that grow with high groundwater levels have greater trends in leaf growth, plant height, and roots. According to Nelsi, O., Arsyad, U., Bachtiar, B., Rampisela [22], soil texture with a high clay content (>60%) causes the soil to be sensitive to compaction. Thus, it has an impact on slowing the infiltration rate, and this condition is influenced by the density of the canopy of the Sago plant, and the properties of the soil and groundwater level.

Based on the chemical properties of the soil, the fertility status was classified as low although several nutrient elements showed moderate to high content. However, due to the low CEC and KB, the fertility status was considered low. In general, the soil pH was acidic and the nutrients were relatively low. Sago forests have the potential for aluminum (Al) poisoning, referring to excess Al and acidic pH conditions which affect morphological growth while also causing a decrease in Ca and Mg content. In slightly dry locations, P2–P6 had low–medium CEC. Cation Exchange Capacity is a chemical property closely related to soil fertility. Low–medium CEC in slightly dry and wet locations provides limited nutrients. This means that the nutrients are in a colloid adsorption complex, preventing leaching by water. Furthermore, potassium, sodium, and calcium were classified as low in locations P2–P6. In the slightly wet location, P1 had moderate sodium and potassium elements; calcium was classified as low, while magnesium was relatively high. Slightly wet locations with flooded soil conditions can accelerate the decomposition of solid compounds from these elements. The large amounts of NH4+, Fe2+, and Mn2+ ions released during flooding can move large amounts of calcium, magnesium, and potassium from the exchange sites into the soil solution. Although only five Sago trees were cut down, this action led to disturbances in hydraulic conditions, specifically water level fluctuations on a small scale. Large-scale conversion of Sago forests will lead to a massive release of water, causing a deficit in the surrounding area. According to a previous report, harvesting Sago trees will reduce biomass or C-Sock due to a decrease in the number of palm trees [23].

The conservation of Sago forests is necessary to achieve food security and address climate change. The government has issued Law of the Republic of Indonesia no. 41 of 2009 concerning the Protection of Sustainable Food Agricultural Land with the financing aspect governed by Regulation No. 30 of 2012. The objectives include ensuring the availability of food agricultural land in a sustainable manner; realizing independence, resilience, and food sovereignty; protecting farmers' food agricultural land ownership; maintaining ecological balance; and realizing agricultural revitalization. Nationally, this regulation supports food security, creating conditions for an adequate food supply for households, both in quantity and quality, safe, equitable, and affordable. However, the focus is primarily limited to a few commodities such as rice, corn, and soybeans, and does not include Sago.

In this regard, the majority of Eastern Indonesians are gradually shifting to consuming rice and have become less concerned about Sago forests managed for generations. According to Tolok [6] the people of South Papua are currently no longer interested in Sago as a result of globalization. Globalization has encouraged people to switch from Sago to other food products. The impact is that the community is very lacking in producing Sago in their region and this is a threat to local Sago wisdom. Sago forests are resilient to climate change, play a big role in food security, and offer various health benefits compared to rice. Therefore, for sub-national food procurement, the Indonesian Government needs to include Sago in sustainable food agriculture.

4.3. Biomass, C-Stock of Sago and TRR

Based on **Table 2**, AGB was 3,279.34 kg, with almost 92% being dominated by the stem fraction. Therefore, the role of vegetation in addressing climate change is largely determined by the size of biomass. **Table 3** showed that BGB was 515,471 kg with almost 84% being dominated by the main root fraction. In mineral soil, AGB is often greater than BGB, while in organic such as peatlands, BGB is >AGB. The shape of the Sago plant is similar to that of oil palm, and according to Sinuraya [24], the weight (total) of oil palm plant roots is greater in peat soil (shallow, medium, and deep) compared to mineral soil (alluvial), in primary, secondary, and tertiary roots. This shows that the weight of oil palm roots or BGB in peatland is greater than in mineral soil. The Top-Root Ratio for mineral soil was more than 100% while that of organic soil was less than 100%. In addition, C-Stock, as shown in Table 5 was 1,783.56 kg for five sample trees (P1–P5). Based on the results of Sago forests mapping at the study site (**Table 7**) and details of C-Stock for each growth level, the seedling (P5) had 100 stems; hence, C-Stock was calculated as 100 × 22.62 kg = 2,262 kg. The sapling (P3) had 818 stems with C-Stock calculated as 818 × 188.85 kg = 154,479 kg, while polishing (P4) had 3,332 stems; hence, C-Stock was calculated as 3,332 × 238.83 kg = 795,782 kg. Furthermore, trees (P1, P2) had 3,709 stems with C-Stock calculated as 3,709 × (746.35 + 586.91)/2 kg = 2,472,531 kg. The results showed that the 126.9 ha Sago forests contained a total C-Stock of 3,425 tons or 26.99 tons per hectare. As a comparison, Rahayu and Pambudi [25] stated that the C-Stock of Sago forests in Papua Province was 28.2 tons ha^{-1}, while Azizah and Rianawati [26] reported 67.5 tons ha^{-1} in South Kalimantan. The variation in results is presumably due to differences in the structure and composition of Sago forests, habitat, and environment.

Basically, roots play a major role in the uptake of nutrients, water, agricultural production, and tolerance to stress. The "root: shoot" trait ratio is very complex compared to other partial problems. The ratio can be used to assess the overall health of the plant, the physiological level of the complex, and the health of the analyzed genotype. The growth rate of roots and shoots during the vegetation growth period will adapt to environmental conditions as well as the "genetic program" of plant growth and development. In the case of a high ratio value, more nutrients are absorbed from the soil, facilitating increased AGB and resistance to stress such as low levels of nutrients in the soil and drought conditions [27]. The amount of C-Stock below the surface was significantly larger than above. In addition, the deeper the peat, the greater the carbon content as also reported in Pematang Gadung Peat Swamp and Lesan River Protection Forest, Kalimantan [28]. Qi et al. [29] state that the composition of C-Stock in peatlands is greater below the surface than above and vice versa for dry land or mineral soil above the surface compared to below the surface. In relation to climate change, the TRR of Sago forests on mineral soil is always flooded (wetland) and on organic soil (peatland) focuses on the size of the total biomass with greater biomass, leading to higher CO_2 absorption. According to Jong[30], Sago grows better on mineral soil than peat, specifically peat above 3 m high, and with a certain level of drainage.

4.4. Sago Production

Sago forests thriving in moist or watery soil conditions have a tall tree canopy characterized by regularly arranged fruit formed from the midrib with finned leaves. Sago tree is considered mature after reaching 8 to 17 m although others can reach a height of 30 m depending on the type and conditions of growth. On average, the lifespan may reach up to 80 years until becoming extinct. Sago trees are more productive when cut down for processing, at an average age of 15–30 years.

Samples P1 and P2 were processed by residents at the home industry level (**Table 6**). Specifically, Sago tree P1 had a total height of 10.6 m, a diameter of 47.53 cm, yielded 977 kg of wet starch, and 571.8 kg of dry starch. Sago tree P2 had total height of 11.4 m, diameter of 43.15 cm, as well as yielded 928 kg of wet starch and 490.3 kg of dry starch, or a yield of 53%. Although trees in P2 (11.4 m) were taller than P1 (10.6 m), the trunk diameter of P1 Sago was greater than P2. Sago stems processed at P1 (970 cm) were longer than P2 (909 cm). Also, the dry starch product at P1 (571.8 kg) was higher than P2 (490.3 kg). This implied that greater starch production was not due to the height but the diameter of the trunk. Furthermore, assumptions about the size of Sago processing yield are mostly determined by the processing method. The starch production per tree was greater compared to the results reported by Nusawakan, Kunu and Luhukay[21] in West Seram where dry starch production only ranged from 300–375 kg/tree but the yield of dried Sago starch processing was greater, reaching 64.22%. According to Ali, Harun and Ibrahim[31], the long soaking treatment for Sago fiber during processing had a significant effect on increasing the yield. A study conducted in Riau (Western Indonesia) showed that the yield of Sago starch was approximately 50.57%.

4.5. Mapping Sago Forests with Drones

Sago forests mapping was carried out with a drone height of 150 m and very high spatial resolution (resolution: 3.0 cm per pixel), followed by OBIA for precise classification of Sago and non-Sago forests. Due to the high spatial resolution, it is possible to identify Sago at various growth stages. This is because the use of high resolution supports accurate identification of tree canopy from above. In contrast, low-resolution satellite images such as Landsat, Aster, Sentinel, and SPOT cannot distinguish tree types based on the shape and image of the canopy. More specifically, drones are particularly well-suited for identifying tree types in small forests. As stated by Onishi and Ise[32], tree species can be identified with high accuracy using aerial and hyperspectral sensors, but these techniques are expensive, limiting the application by small-scale forest managers. Therefore, a machine vision system was developed for identifying and mapping trees using Red-Green-Blue (RGB) images taken by drones and convolutional neural networks (CNN). Through this system, seven tree classes have been successfully classified, with an accuracy exceeding 90%. Drones or unmanned aerial vehicles (UAVs) are aircraft that have great potential for carrying out large-scale activities and detailed surveys of natural resources. These aircraft are adept at producing high-resolution maps, as well as accurate models and telemetry data. The application of drones is increasingly widespread, ranging from filmmaking and video shooting in the film industry to specialized tasks including firefighting for tall buildings, as well as sophisticated military equipment for a country's national defense and security[33].

5. Conclusions

In conclusion, the soil types at Sago forests in Tuleh Village, Ambon Island comprised Hydric, District, and Fluvic Gleisol as well as Oxic Cambisol. Disturbances occurred in hydrological conditions and fluctuations in water level or puddles were observed in the soil profile on a small scale. Therefore, the conversion of Sago forests to other uses for the expansion of grain crops including rice, corn, and soybeans on a large scale, would cause drought in the area. Conservation of Sago forests is necessary due to their resilience to climate change and significant role in food security. Even though Sago trees produce higher biomass and are more resistant to climate change, they are not widely adopted as a staple crop throughout Indonesia due to differences between national policies and regional policies.

Furthermore, the consumption of Sago starch was found to be relatively healthier compared to rice. Sago forests contain C-Stock of 26.99 tons ha^{-1} and the greater the content, the higher the impact on climate change due to significant CO_2 absorption capacity. The TRR achieved was 636%, showing AGB was six times more than BGB, and the presence of mineral soil. Dry starch product ranged from 490.3–571.8 kg per tree, and the potential varied due to differences in the structure and composition of Sago forests, as well as habitat and environment. Mapping of Sago forests was carried out using drones with high spatial resolution which facilitated accurate classification of Sago and non-Sago forests as well as identifying types of trees at each level of growth. Consequently, Sago forests need to be conserved due to their significant role in food security and handling climate change.

Author Contributions

Writing—review and editing, writing original draft, methodology, investigation, formal analysis, data curation, conceptualization, G.M.; writing—review & editing, supervision, methodology, investigation, formal analysis, conceptualization, R.O.; supervision, conceptualization, funding acquisition, M.L.; supervision, methodology, investigation, formal analysis, J.W.H.

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Data Availability Statement

Data will be made available on request.

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Conflicts of Interest

The authors declare that there are no known competing financial interests or personal relationships capable of influencing the work reported in this paper.

References

[1] Choya, A., Tia, R., Tri, M., 2022. Climate change impact on food security: A review. Journal of Environment and Sustainability. 6(3), 227–238.

[2] Pinto, A.D., Islam, M., Katic, P., 2023. Food security under a changing climate: Exploring the integration of resilience in research and practice. Palgrave Macmillan: New York, NY, USA. pp. 1–207.

[3] Konuma, H., 2014. Studies on the characteristics of sago starch in relation to growth environment of sago palm (*Metroxylon sagu* Rottb.) and its value addition to wheat flour as a food starch ingredient Hiroyuki Konuma [Ph.D. Thesis]. University of Tsukuba: Tsukuba, Japan. pp. 1–61.

[4] Dasgupta, S., Robinson, E.J.Z., 2022. Attributing changes in food insecurity to a changing climate. Scientific Reports. 12(4709), 1–11. DOI: https://doi.org/10.1038/s41598-022-08696-x

[5] Rampisela, D.A., Sjahril, R., Lias, S.A., et al., 2018. Transdisciplinary research on local community based sago forest development model for food security and marginal land utilization in the coastal area. Proceedings of the 1st International Conference on Food Security and Sustainable Agriculture in The Tropics (IC-FSSAT); 24–25 October 2017; Sulawesi Selatan, Indonesia. pp. 1–7.

[6] Tolok, K.B.B., 2023. Globalization and castration of the sagu local wisdom of the South Papua community. Jumpa. XI(2), 148–158. (in Indonesian)

[7] Dimara, P.A., Purwanto, R.H., Auri, A., et al., 2023. Production potential of sago forests in different habitat types in Sentani watershed, Papua, Indonesia. Biodiversitas. 24(7), 3924–3931.

[8] Girsang, W., 2017. Sago food product development for food security in small islands, Maluku, Indonesia. International Journal of Scientific & Engineering Research. 8(5), 703–712.

[9] Istikowati, W.T., Sunardi, Sutiya, B., et al., 2023. Chemical content and anatomical characteristics of sago (*Metroxylon sagu* Rottb.) frond from South Kalimantan, Indonesia. Indonesian Journal of Forestry Research. 10(2), 185–194.

[10] Johan, P.D., Ahmed, O.H., Maru, A., et al., 2021. Optimisation of charcoal and sago (*metroxylon sagu*) bark ash to improve phosphorus availability in acidic soils. Agronomy. 11(1803), 1–28. DOI: https://doi.org/10.3390/agronomy11091803

[11] Fetriyuna, F., Letsoin, M.A., Jati, I., et al., 2024. Potential of underutilized sago for bioenergy uses. International Journal on Advanced Science Engineering Information Technology. 14(1), 144–150. DOI: https://doi.org/10.18517/ijaseit.14.1.19202

[12] Lewantaur, K.E., Siahaya, W.A., Gazpersz, E.J., 2022. Sago forest density analysis using vegetation index transformation (case study in Tawiri Village, Teluk Ambon District). Agrologia. 11(1), 21–33.

[13] Buchholz, G., 2021. Policy Brief Sago Palm: A Sustainable Solution for Food Security and Peat Conservation in Indonesia.

[14] Dam, R.M.V., 2020. A global perspective on white rice consumption and risk of type 2 diabetes. Diabetes Care. 43(11), 2625–2627.

[15] Said, S.D., Pontas, K., Thaib, A., et al., 2022. Increasing crude protein content of sago dregs through solid state fermentation process. Journal of Applied Technology. 9(1), 1–6.

[16] Mohamad Fathi1, N.K., Abd Aziz Abdullah, S.M., Mohamad Bukhori, M.F., et al., 2021. PHYSICOCHEMICAL PROPERTIES OF SAGO BARK BIOCHAR AND ITS POTENTIAL AS PLANT GROWTH MEDIA (Sifat Fizikokimia Bio-Arang Sisa Kulit Sagu Dan Potensinya Sebagai Media Pertumbuhan). Malaysian Journal of Analatycal Sciences. 25(4), 622–636.

[17] Wulan, S., 2018. Sago as an environmentally sustainable food. Journal of Environmental Science and Sustainable Development. 1(1), 63–73. Available from: https://www.researchgate.net/publication/335560658_SAGO_AS_AN_ENVIRONMENTALLY_SUSTAINABLE_FOOD_RESOURCE_IN_THE_CLIMATE_CHANGE_ERA (cited on 14 May 2024).

[18] Wulandari, D.K., Hairiah, K., Prayogo, C., 2023. Land management and soil quality in sago-based agroforestry system: A study on Mooi tribe's ecological knowledge (Sorong, Southwest Papua) and modern ecological knowledge (MEK). Journal of Applied Agricultural Science and Technology. 7(4), 469–483.

[19] Kurnia, U., Agus, F., Adimihardja, A., et al., 2006. Physical properties of soil and methods of analysis. Balai Besar Litbang Sumberdaya Lahan Pertanian: Jakarta, Indonesia. pp. 1–278. Available from: https://repository.pertanian.go.id/server/api/core/bitstreams/0801f424-c383-4ab9-b887-f95baa010d5e/content (cited on 14 May 2024.) (in Indonesian)

[20] Suripatty, B.A., Poedjirahajoe, E., Pudyatmoko, S., et al., 2016. Growth of sagu (Metroxylon Sp) in the natural forests of Papua. Jurnal Hutan Pulau-Pulau Kecil. 1(2), 151–159. (in Indonesian)

[21] Nusawakan, M., Pieter, J.K., Marcus, L., 2017. Sago land condition in Rumahkay Village, Amalatu District, Seram Regency, West of Maluku Province. Budidaya Pertanian. 13(2), 84–93.

[22] Nelsi, O., Arsyad, U., Bachtiar, B., et al., 2021. Soil properties and infiltration rate in sago palm (metroxylon sago) forest in rongkong watershed South Sulawesi. Earth and Environmental Science. 807 (032053), 1–11.

[23] Peng, E.K., 2018. Biomass carbon stock change from major crops cultivated on agricultural land in Sarawak. International Journal of Civil Engineering and Technology. 9(11), 728–736.

[24] Zulkasta, S., 2010. Study of the distribution of roots of oil palm plants (Elaeis guineensis Jacq.) on peatlands in PT plantations. Jaya Palm Oil Day, Labuhan Batu Regency. [Master's Thesis]. Universitas Sumatera Utara: Medan, Indonesia. pp. 1–3. Available from: http://repositori.usu.ac.id/handle/123456789/40530 (cited on 14 May 2024.) (in Indonesian)

[25] Rahayu, S., Pambudi, S., 2017. Tree diversity and carbon stock in various land cover systems of Jayapura, Jayawijaya and Merauke Districts, Papua Province. Bogor.

[26] Azizah, F., Kissinger, Rianawati, F., 2023. Estimation of stored carbon of sago plant (Metroxylon sago Rottb) in Sungai Tabuk District. Jurnal Sylva Scienteae. 06(2), 235–239.

[27] Bláha, L., 2019. Importance of root-shoot ratio for crops production. Journal of Agronomy and Agri Science. 2(012), 1–6.

[28] Irawan, U.S., Purwanto, E., 2020. Measuring and Estimating Carbon Stocks in Peat and Mineral Forest Ecosystems, Case Study in Pematang Gadung Peat Swamp Forest and Sungai Lesan Protected Forest, Kalimantan.

[29] Qi, Y., Wei, W., Chen, C., et al., 2019. Plant root-shoot biomass allocation over diverse biomes: A global synthesis. Global Ecology and Conservation. 18(18), e00606. DOI: https://doi.org/10.1016/j.gecco.2019.e00606

[30] Jong, F.S., 2006. Technical recommendations for the establishment of a commercial sago palm (*Metroxylon sagu* Rottb.) plantation. Japanese Journal of Tropical Agriculture. 50(5), 224–228.

[31] Ali, A., Harun, N., Ibrahim, A., et al., 2014. Quality and rendement of sago starch produced through the process of soaking and stirring sago pilt. Prosiding Seminar dan Lokakarya Nasional FKPT-TPI 2014 MUTU. 96–102. (in Indonesian)

[32] Onishi, M., Ise, T., 2021. Scientific reports explainable identification and mapping of trees using UAV RGB image and deep learning. Scientific Reports. 11, 903. DOI: https://doi.org/10.1038/s41598-020-79653-9

[33] Alen Timisela, A.W., Mardiatmoko, G., 2024. The use of UAV in mapping and inventorying mangrove forest for handling climate change. Journal of Ecology and Natural Resources. 8(1), 1–11.