SAGO PALM 28: 1 – 4 (2020)

Methods for Estimating the Leaf Area of Sago Palms (*Metroxylon sagu* Rottb.)

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Abstract: In Sarawak, Malaysia, simple methods for estimating the leaf area of sago palms were examined using a total of eight leaves of the lower, middle, and upper three leaves for first and seventh year plants after trunk formation and the middle and upper two leaves for fourth year plant after trunk formation. Taking into account the positions of attachment from the lower to the upper of the eight leaves, the leaf area of half of the leaflets was actually measured, and this was doubled to obtain the measured leaf area (A). For each leaf, three methods of estimating leaf areas—(B) the longest-leaflet area × the number of leaflets, (C) the longest-leaflet length × the maximum width × the number of leaflets, and (D) the longest-leaflet SLA (specific leaf area) × leaflet weight per leaf—were applied, and the leaf areas were determined and compared with the measured leaf area (A). The average A/B, A/C, and A/D values of the eight leaves were 0.65, 0.54, and 1.03, respectively, and the coefficients of variation were as low as 3.7–8.7%. From these results, it seemed that the leaf area of the sago palm can be easily estimated by multiplying the values obtained with methods (B) to (D) mentioned above by the correction factors of 0.65, 0.54, and 1.03, respectively.

Keywords: Correction factor, Estimation method, Leaf area, Leaflet area, Leaflet characteristics, Sago palm

Introduction

The starch production of the sago palm is governed by its leaf area (Yamamoto et al., 2010; 2014), and the starch production per area is considered to be closely related to the leaf area index (LAI). Therefore, clarifying the relationships between the leaf area or LAI and starch yield is important for establishing cultivation management techniques such as planting density and sucker control on sago palm plantations. However, there have been few reports about the methods of estimating the leaf area of the sago palm (Flach and Schuiling, 1989; Nakamura et al., 2004; 2005; 2009), and the establishment of a simple method of estimating the leaf area of the sago palm is desired.

In this study, we investigated a simple method for estimating the leaf area of individual leaves after trunk formation in the sago palm.

Materials and Methods

This survey was conducted in a sago palm farmer's garden on Tebing Tinggi Island, Riau, Indonesia, in July 1999. Three sago palm plants (variety name unknown) with different ages (one, four, and seven years after trunk formation) were cut down with a chain saw, and the plant length (from the cut end of the trunk to the tip of the uppermost leaflet) and trunk length (from the cut end of the trunk to the node of the lowest living leaf) were measured. After cutting off all of the leaves from the trunk at the base of the leaf sheath, the leaves located in the lower, middle, and upper positions of the first and seventh year plants and in the middle and upper positions of the fourth year plant were selected for measuring the leaf and leaflet characteristics. The leaf numbers counted from the base were the third, fifth, and seventh leaves of the first year plant, the tenth and

Table 1. Leaf and leaflet characteristics of sago palms at different ages grown on Tebing Tinggi Island, Riau, Indonesia.

Plant age[1)]	Leaf position[2)]	Leaf length (m)	No. of leaflets	Total leaf area (m^2 $plant^{-1}$)	Leaflet length[3)] (cm)	Leaflet width[3)] (cm)	Leaflet weight[3)] (g)	Leaflet area[3)] (cm^2)
1	3	5.9	126	6.2	34.0 〜 124.6	1.1 〜 8.0	1.1 〜 29.4	44.1 〜 804.6
1	5	5.7	108	5.8	40.2 〜 123.0	1.7 〜 8.2	3.4 〜 31.0	59.4 〜 811.4
1	7	5.9	128	6.8	59.6 〜 134.6	0.5 〜 8.2	1.3 〜 29.7	30.5 〜 814.9
4	10	6.7	140	8.0	43.6 〜 132.7	1.5 〜 9.4	1.4 〜 34.4	55.3 〜 951.1
4	14	6.5	140	8.9	42.2 〜 129.4	0.9 〜 9.5	1.2 〜 36.7	35.4 〜 999.6
7	3	7.1	138	7.3	39.5 〜 129.9	2.0 〜 8.2	2.0 〜 34.0	53.9 〜 831.4
7	7	7.1	140	8.8	42.0 〜 141.6	0.5 〜 8.2	0.5 〜 37.7	22.9 〜 919.0
7	13	6.3	100	6.7	60.6 〜 141.0	1.9 〜 8.9	2.7 〜 40.2	77.4 〜 933.6

1) Years after trunk formation; 2) Leaf position from the base; 3) Measured minimum 〜 maximum value

fourteenth leaves of the fourth year plant, and the third, seventh, and thirteenth leaves of the seventh year plant. After measuring the leaf length (from the base of leaf sheath to the tip of the uppermost leaflet) of these leaves, the number of leaflets on the left and right sides were counted. Every consecutive ten leaflets from the base to top were collected alternately from the left and right side of each leaf, that is, half the number of leaflets, totaling 510, and the fresh weight was measured for each leaflet. A copy of each leaflet was then made. Then, after measuring the leaflet length and maximum leaflet width (hereinafter referred to as leaflet width), copies of leaflets were made by cutting paper following the shape of the leaflets, and their areas were measured by an automatic leaf area meter (AAM-7, Hayashi Denko Co.).

Results and Discussion

The average total length and trunk length of the surveyed plants were: 8.9 m and 0.9 m, 10.6 m and 4.1 m, and 12.7 m and 5.3 m for the first, fourth, and seventh year plants, respectively. The numbers of expanded leaves were 10, 16, and 17, respectively. The leaf lengths, the numbers of leaflets, and the leaf areas determined by the leaf area meter for the eight leaves ranged from 5.7–7.1 m, 100–140, and 5.8–8.9 m^2, respectively, and no tendencies in these characteristics with differences in palm ages and leaf positions were observed (Table 1). Taking the lower leaf of the first year after trunk formation (the third leaf from the base) as an example, the positional differences of leaflet characteristics such as length, width, length × width, weight, and area determined by

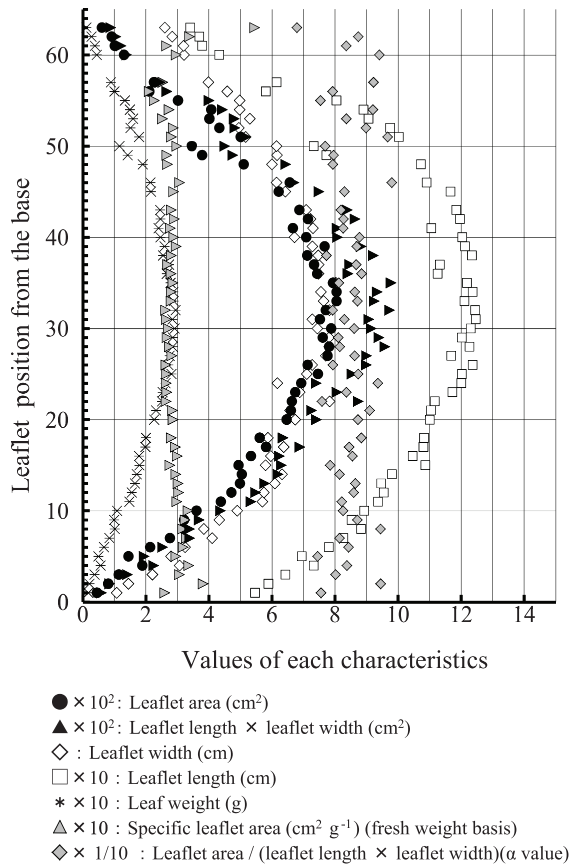

Fig 1. Leaflet characteristics at different positions on a leaf at the base of a first-year sago palm after trunk formation grown on Tebing Tinggi Island, Riau, Indonesia.

actual measurements are shown in Fig. 1. These values were all the largest for leaflets positioned near the center of the leaf, and they became smaller toward the top and the base. The values obtained by dividing the leaflet areas by the products of the leaflet length and width (hereinafter referred to as α value) were distributed in the range of 0.68–0.96 regardless of the leaflet positions, and most of the values were in the range of 0.75–0.90, with an average of 0.84 (Fig. 1). Nakamura et al. (2005) reported that the ratio of the

Table 2. Correlation coefficients *(rs)* among the leaflet characteristics of sago palms at different ages grown on Tebing Tinggi Island, Riau, Indonesia.

Characteristic	Length (L)	Width (W)	Weight	Area	SLA	L×W
Length (L)	—	0.851***	0.900***	0.907***	-0.477***	0.928***
Width (W)		—	0.915***	0.947***	-0.387***	0.966***
Weight			—	0.980***	-0.523***	0.948***
Area				—	-0.424***	0.975***
SLA					—	-0.379***
L×W						—

n = 510; SLA: specific leaf area; *** : significant at p<0.001

measured area to the product of the leaflet length and width of sago palm in Sarawak, Malaysia, was 0.74–0.78, which was close to the result of this study. The specific leaf areas (SLA: fresh weight base) of leaflets at the central position were slightly lower than those at the top and base positions, but most of the values showed 26.5–30.0 cm^2 g^{-1} (Fig. 1). Regarding the correlation coefficients among leaflet characteristics such as leaflet length, width, weight, area, and leaflet length × width, all showed a significant positive correlation with each other. In particular, the leaflet area was highly and positively correlated with the leaflet weight (r = 0.980, p<0.001) and the value of the leaflet length × width (r = 0.975, p<0.001) (Table 2). On the other hand, the leaflet area showed a significant negative correlation with the SLA, suggesting that the larger leaflets located at the center of leaves were thicker than those at the top and base positions (Fig. 1 and Table 2).

Next, in order to examine the methods of estimating the leaf area of individual leaves, the estimated leaf areas obtained by multiplying the leaf areas (measured values) of the longest leaflets or the values of the longest-leaflet length × width of each collected leaf by the number of leaflets per leaf, and those obtained by multiplying the SLAs of the longest leaflets by the leaflet weights per leaf of each collected leaf are shown in Table 3. The leaf areas obtained by multiplying the measured longest-leaflet areas by the numbers of leaflets per leaf ranged from 8.8–14.0 m^2, and they were 28–39% (35% on average) higher than those of the measured leaf areas. In addition, the leaf areas obtained by multiplying the values of the longest-leaflet length × width by the numbers of leaflets per leaf ranged from 10.5–17.4 m^2, and they were 40–54% (46% on average) higher than those of the measured leaf area. On the other hand, the leaf areas obtained by multiplying the SLAs of the longest leaflets by the leaflet weights per leaf of each collected leaf ranged from 5.9–8.5 m^2, and they were almost equal to the measured leaf areas from -2–+8% (-3% on average). This might be because the SLAs of the

Table 3. The ratios of leaf areas calculated by using longest-leaflet characteristics and number of leaflets to the actual measured leas area.

Plant age[1)]	Leaf position[2)]	Measured leaf area (m^2) (A)	Long. L. A[3)]. x No. Ls[4)] (m^2) (B)	A/B	Long. L. L x W[5)] x No. Ls (m^2) (C)	A/C	Long. L. SLA[6)]. x L. W.[7)] (m^2) (D)	A/D
1	3	6.2	10.1	0.61	11.8	0.53	5.89	1.05
1	5	5.8	8.8	0.67	10.5	0.56	5.92	0.99
1	7	6.8	10.4	0.65	13.0	0.52	6.93	0.99
4	10	8.0	13.0	0.62	17.4	0.46	8.08	1.00
4	14	8.9	14.0	0.64	15.3	0.58	8.53	1.05
7	3	7.3	11.6	0.63	14.9	0.49	6.79	1.08
7	7	8.8	13.0	0.67	15.9	0.55	8.22	1.07
7	13	6.7	9.3	0.72	11.1	0.60	6.38	1.05
Average		7.4	11.3	0.65	13.7	0.54	7.09	1.03
CV (%)		15.26	17.00	5.43	18.23	8.71	14.86	3.67

1) Years after trunk formation; 2) leaf position from the base; 3) longest-leaflet area; 4) number of leaflets per leaf; 5) longest-leaflet length x width; 6) specific leaf area of the longest leaflet; 7) total leaflet weight per leaf

longest leaflets located at the center of the leaves were lower than those of the leaflets located at the top and base positions (Fig. 1). The coefficient variations of the ratios of the estimated leaf areas of the eight leaves to the measured leaf areas surveyed were all low, ranging from 3.7–8.7% (Table 3), and it was considered that the leaf area of each individual leaf could be easily estimated by these methods by multiplying the correction factors.

From these results, it was considered possible to estimate the leaf area of a single leaf by multiplying the actually measured leaflet area or the length × width of the longest leaflet and the number of leaflets per leaf by the correction factors, 0.65 and 0.54, respectively. In addition, it was also considered possible to estimate the leaf area of individual leaves by measuring the leaflet area and weight of the longest leaflet and calculating the SLA and multiplying the value obtained by the leaflet weight per leaf and the correction factor, 1.03. Of these three methods, it was estimated that the method with the longest-leaflet SLA and the total leaflet weight per leaf had the smallest variation in the coefficient, and its accuracy was highest.

Flach and Schuiling (1989) estimated the leaf area of a sago palm by multiplying the product of the length and width of the longest leaflet by the number of leaflets and a correction factor of 0.5. Although they did not show the basis for the value of the correction factor, 0.5, it was presumed to be slightly lower than that estimated by the current research, 0.54. On the other hand, Nakamura et al. (2009) proposed a method of estimating the leaf area of sago palm (S) from the length of the rachis (a), and the sum of the heights of the rectangles converted from the leaflet areas on the left and right sides at a/2 (c) and a/4 (b) from the rachis base; $S = ab\pi/8 + ac/2$. However, this method is fairly laborious and complicated, as compared to the estimate methods of the current study.

In the future, it is necessary to examine the validity of the methods clarified in the current study for different varieties and sago palms grown under different growing and soil environments.

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