

Leaf Characteristics and Shape of Sago Palm (*Metroxylon sagu* Rottb.) for Developing a Method of Estimating Leaf Area

Satoshi Nakamura, Youji Nitta* and Yusuke Goto**

(Miyagi Agricultural College, Sendai 982-0215, Japan; *School of Agric., Ibaraki Univ., Ami, Ibaraki 300-0393, Japan;

**Graduate School of Agric., Tohoku Univ., Sendai 981-8555, Japan)

Abstract : We aimed to determine the orientation for developing the method to estimate leaf area of sago palm (*Metroxylon sagu* Rottb.) by extracting characteristics that might be related to estimating leaf area from characteristics of leaves. Plants of around two years after trunk formation at a sago palm farm in Sarawak, Malaysia were used for the investigation. In a plant with eleven living leaves, the length of the unfolded leaf blade ranged from 6.0 to 7.2 m; the length of a petiole ranged from 1.8 to 3.1 m. The number of leaflets on the left side of a leaf viewing adaxial leaf surface with the tip upward was larger than that on the right side by 1-5 leaflets in all leaves. The lowest leaflet of a leaf was on the left side in all leaves. The relative position of the lowest leaflet on the rachis was related to the way a leaf was folded in a plant. The length, width and area of the right and the left leaflets were compared on the basis of their position on a rachis. They had approximately the same dimensions. This fact implied that those characteristics were almost symmetric with respect to the rachis; therefore, the position of a leaflet on a rachis was considered to be an important characteristic for analyzing leaf area. We drew a leaf diagram based on the measured data and examined a method of estimating leaf area using the leaf outline, but the method was not suitable. We decided to examine a method to integrate the leaflet areas for accurate estimation of the leaf area.

Key words : Leaf area, Leaf shape, Leaflet, Leaflet area, *Metroxylon sagu* Rottb., Sago palm.

Sago palm (*Metroxylon sagu* Rottb.) accumulates a large quantity of starch in its trunk. It is an important starch crop in Southeast Asia. It has been cultivated traditionally and utilized in the southern regions of Thailand, Malaysia, Indonesia and Papua New Guinea (Flach, 1977; Nagato and Shimoda, 1979; Nishikawa et al., 1979). It is the only starch crop to grow in peat soil with extremely low pH in tropical swamps. Sago palm proliferates by suckers emerged from the base of the plant. It is possible to develop a canopy that consists of trunks of various ages if suckers are properly controlled. In such a canopy, continuous cultivation can be achieved sustaining an adequate stand without planting suckers after harvesting.

Large-scale sago palm plantations are continuously expanded in Malaysia and Indonesia (Hassan, 2001; Jong, 2001). For continuous harvesting in these plantations, optimum plant density with proper sucker control needs to be sustained. It is necessary to know the leaf area of each plant and obtain the leaf area index (LAI) of a canopy to calculate and evaluate the optimum plant density. However, the current estimation method for leaf area, which uses the length,

width of the largest leaflet and the number of leaflets on one side of the rachis (Flach and Schuiling, 1989), is illogical and offers only low accuracy. Therefore, we need to develop a method of estimating leaf area simply and more accurately.

The sago palm leaf is a pinnate compound leaf with many leaflets (Fahn, 1990; Bell, 1998). It has 130-160 leaflets; the leaf length is around 8 m at the trunk formation stage (Yamamoto, 1998). A method of estimating leaf area can be established by scrutinizing areas of many leaves, but such an investigation will require much work and time in the case of the large sago palm leaves. Thus, we adopted a procedure to evolve a method of estimating leaf area by a detailed investigation of leaf morphology at various ages, from the beginning of unfolding to the onset of withering in selected plants. We prepared an estimation method logically based on that morphology and validated the method by inspecting many plants. To begin with, the objectives of this study were investigation of many characteristics of the leaf to form the basis of estimating the leaf area, extraction of characteristics related to leaf area, estimation from them, and

Received 17 July 2003. Accepted 8 December 2003. Corresponding author : S. Nakamura (s-nakamura@miyanou.ac.jp, fax +81-22-245-1534).

Abbreviations : ebLn, the nth (counted from the top basipetally) emerged leaf; L, the left side of the rachis with the tip of the leaf upward and facing the front surface of the leaf; LAI, leaf area index; Ln, the nth (counted from the base acropetally) leaflet on the left side of the leaf; R, the right side of the rachis viewing the adaxial surface of the leaf with the tip upward; Rn, the nth (counted from the base acropetally) leaflet on the right side of the leaf; uLn, the nth (counted from the base acropetally) unemerged leaf.

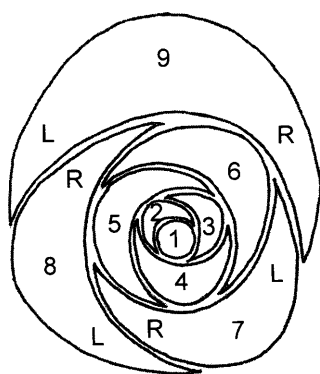


Fig. 1. Cross section illustration of the petiole viewed from above. Right (R) and left (L) were determined viewing the adaxial surface of the leaf (petiole) with the tip upward. 1, ebL1 (the spear leaf); 2-9, ebL2 - ebL9. ebLn represents the n th (counted from the top basipetally) emerged leaf.

determination of the orientation for development.

Materials and Methods

We studied a plant with eleven living leaves around two years after trunk formation at a sago palm farm in Sarawak, Malaysia. The plant had an average thickness of trunk and plant height of the plants of the same age at the farm. Another especially large plant just after trunk formation (with nine living leaves) was also investigated for comparison.

The youngest emerged leaf, namely the top leaf called a spear leaf (Jones, 1995) was named ebL1, and sequentially lower leaves ebL2, ebL3 and so on basipetally (Fig. 1). Unemerged leaves, e.g., the next leaf inside the spear leaf was named uL1; and sequentially higher leaves uL2, uL3, and so on.

We measured the lengths of leaf blade, rachis, petiole and the number of leaflets in each leaf (Fig. 2). The basal part of the petiole that extends from the trunk to the first leaflet is the leaf sheath (Jones, 1995), but the length of leaf sheath was included in

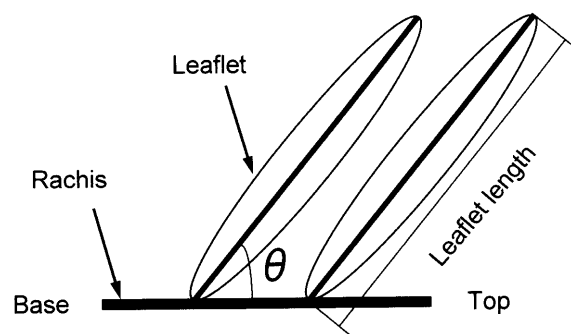


Fig. 3. Illustration of leaflets on the rachis. θ shows the angle between the leaflet and the rachis.

the length of petiole (Fig. 2). The right (R) and the left side (L) of the leaf were determined viewing the adaxial surface of the leaf with the tip upward. The lowest (basal) leaflet on the right side of the rachis was named R1, and sequentially higher leaflets, R2, R3 and so on. The leaflets on the left side of the rachis were also named L1, L2, L3, and so on in the same way.

The position of each leaflet on the rachis, the length (leaflet length), the maximum width (leaflet width) and the angle of a leaflet to the rachis (angle, θ) were measured as shown in Fig. 3. The leaflet area was measured with a portable leaf area meter (Laser Area Meter CI-203; CID, Inc.). The size of the leaflet that was lost or broken before measurement was presumed from that of the two adjacent leaflets on each side of the rachis.

Results and Discussion

1. Leaf size

Fig. 4 shows the leaf length of the uL5 to ebL11 on a logarithmic scale. The increase in leaf length from uL5 to uL3 and from uL3 to uL1 showed two different exponential curves. The increase from uL1 to ebL1 appears to be gentle in the graph, but uL1 was 3.7 m and ebL1 6.8 m, indicating the rapid elongation at

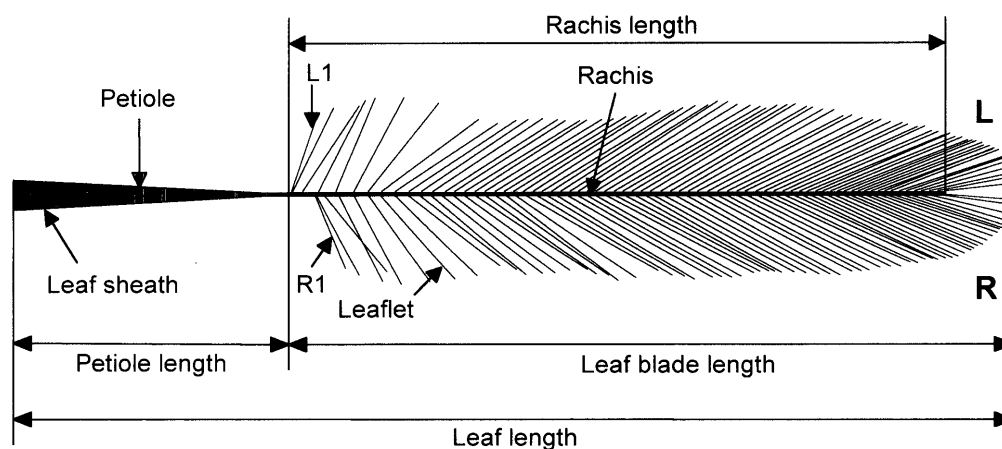


Fig. 2. Illustration of a sago palm leaf. Petiole length includes leaf sheath length. R1 and L1 are the first leaflets on the right side (R) and left side (L) of the leaf, respectively. The right and left of leaves were defined as shown in Fig. 1.

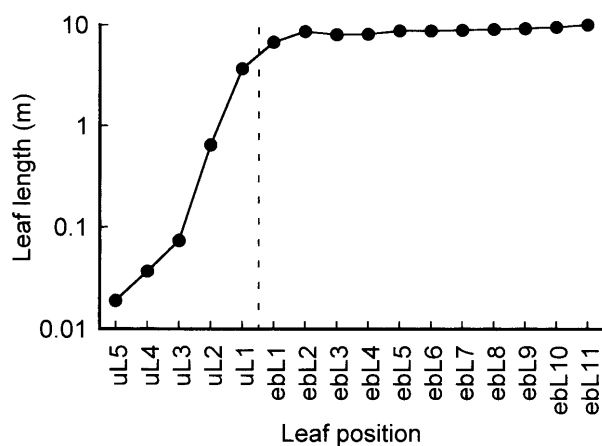


Fig. 4. Leaf length of uL5 to eBL11. eBLn represents the nth leaf as shown in Fig. 1. uLn represents the nth (counted from the base acropetally) unemerged leaf.

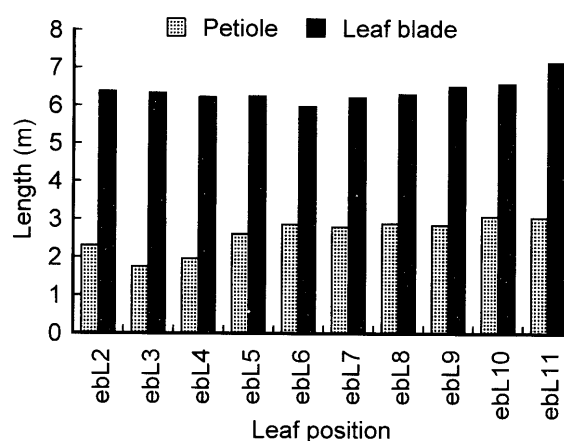


Fig. 5. Length of leaf blade and petiole of eBL2 to eBL11. eBLn represents the nth leaf as shown in Fig. 1.

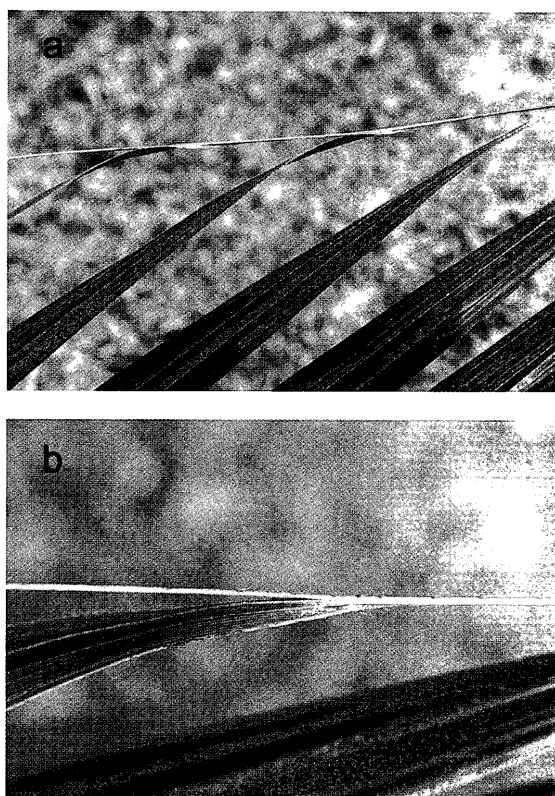


Fig. 6. The tips of leaflets in eBL2. Each leaflet tip was connected with the next leaflet tip. eBL2 represents the 2nd leaf from the top leaf (eBL1) as shown in Fig. 1.

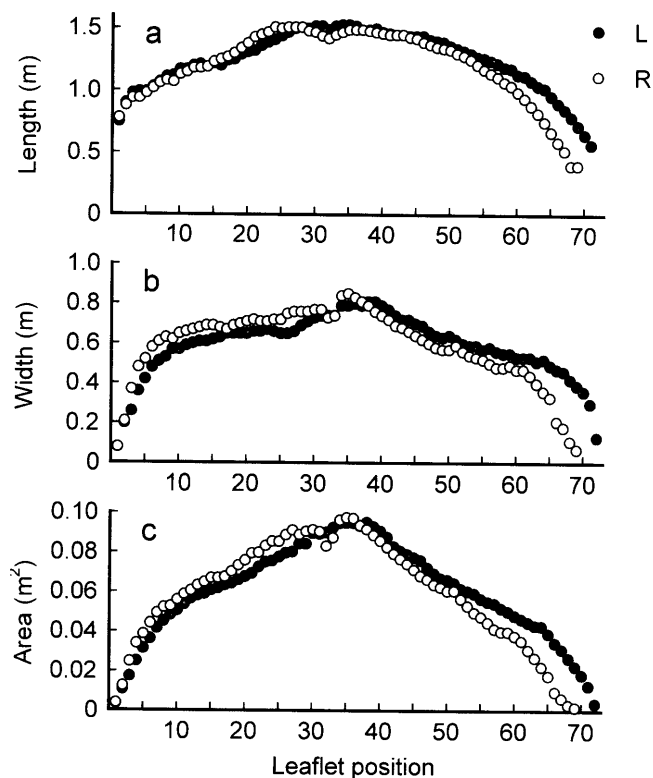


Fig. 7. Length (a), width (b) and area (c) of each leaflet in eBL3 plotted against the leaflet position. The lowest leaflets on the right and the left were named R1 and L1, respectively. The right side (R) and left side (L) of the leaf were defined as shown in Fig. 1.

Table 1. Number of leaflets in eBL2 to eBL11.

	eBL2*	eBL3	eBL4	eBL5	eBL6	eBL7	eBL8	eBL9	eBL10	eBL11
L	73	72	70	69	70	68	69	70	70	70
R	72	67	65	65	66	65	64	67	66	67
Total	145	139	135	134	136	133	133	137	136	137

*: eBLn represents the nth leaf as shown in Fig. 1. The left side (L) and right side (R) of the leaf were defined as shown in Fig. 1.

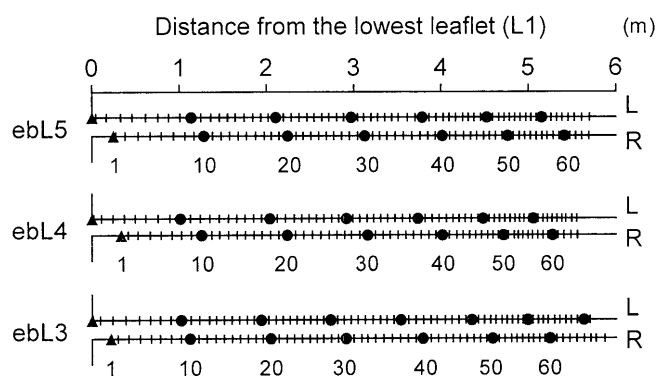


Fig. 8. Comparison of the positions of the right (R) and left (L) leaflets with the same leaflet number on the rachis. $\blacktriangle$ shows the position of R1 and L1. $\bullet$ shows the leaflet position of every 10th designated leaflet. Figures represent the leaflet position. ebLn represents the n th leaf as shown in Fig. 1.

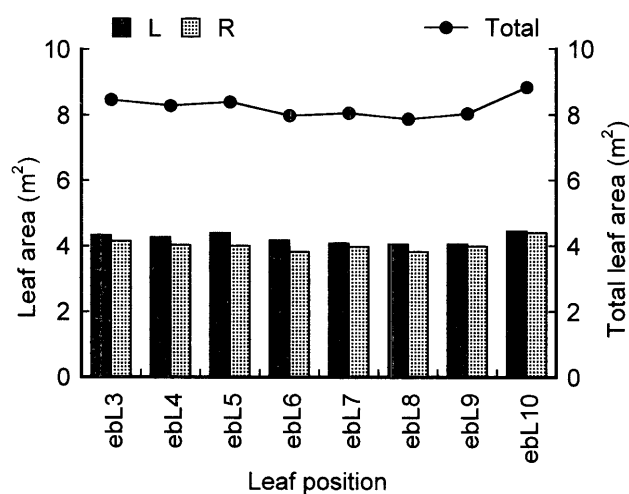


Fig. 10. Leaf area on the right side (R) and left side (L), and total area of each leaf. ebLn represents the n th leaf as shown in Fig. 1.

this stage. ebL2 that was in the process of expanding leaflets seemed to have finished elongation.

Fig. 5 shows the length of leaf blades and petioles of ebL2 to ebL11. The length of each leaf blade ranged from 6.0 m (ebL6) to 7.2 m (ebL11); the length of each petiole ranged from 1.8 m (ebL3) to 3.1 m (ebL10). The petiole length was shortest in ebL3, and had a tendency to be shorter in upper leaves. At the time of investigation, the trunk was about 1.7 m in height. There may be a relationship between trunk formation and the length of petiole, but more data are required to identify this relationship.

Table 1 shows the numbers of leaflets in ebL2 to ebL11. The number of left leaflets was larger than that of right leaflets in all leaves, the difference ranged from one to five leaflets.

The largest leaf in another large plant was the ebL2. It was 12.4 m in length, 7.8 m in leaf blade, and had 69 and 66 leaflets on the left and right side, respectively

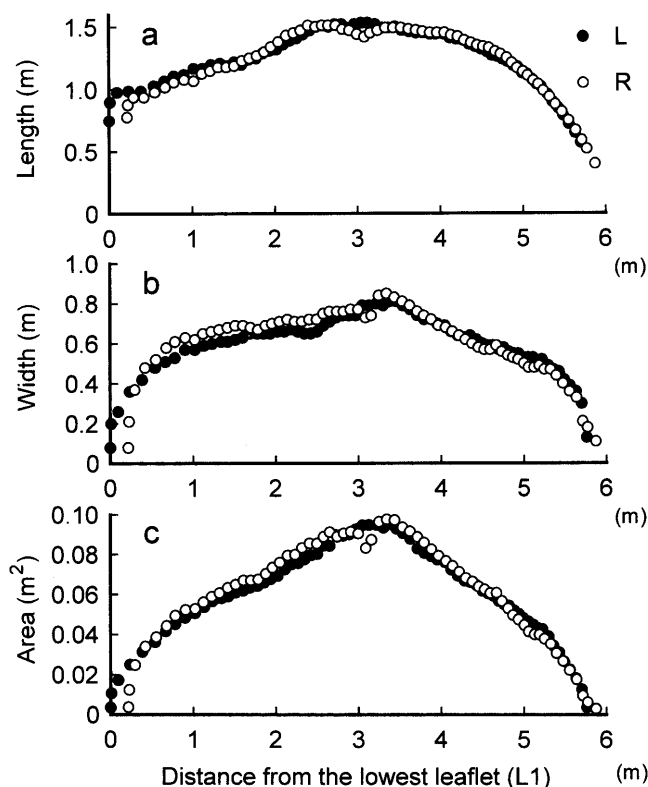


Fig. 9. Length (a), width (b) and area (c) of leaflets in ebL3 plotted against the distance from the lowest leaflet (L1). The right side (R) and left side (L) of the leaf were defined as shown in Fig. 1.

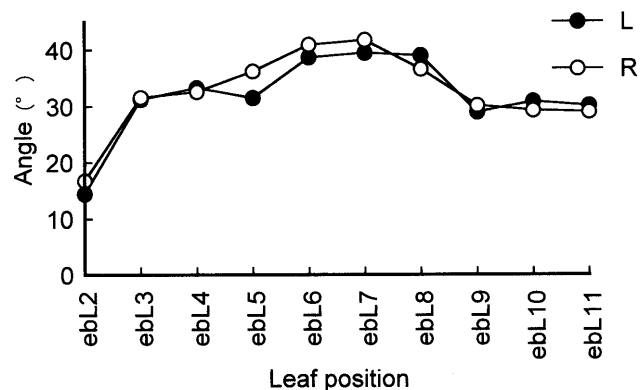


Fig. 11. Average angles between leaflets and the rachis excluding 10 leaflets at the top and the base of the leaf. ebLn represents the n th leaf as shown in Fig. 1. Angles were measured as shown in Fig. 3. The right side (R) and left side (L) of the leaf were defined as shown in Fig. 1.

(Nakamura et al., 2000).

2. Characteristics of leaflets

Fig. 6 shows the features of the tips of the leaflets in ebL2. In the leaf that had just expanded, the tip of the leaflet was thin and filiform. It was connected to the next ones at the edge of the leaf. This part breaks when the leaf unfolds becoming threadlike and drops off, or is torn apart. Some remnants will be left on the

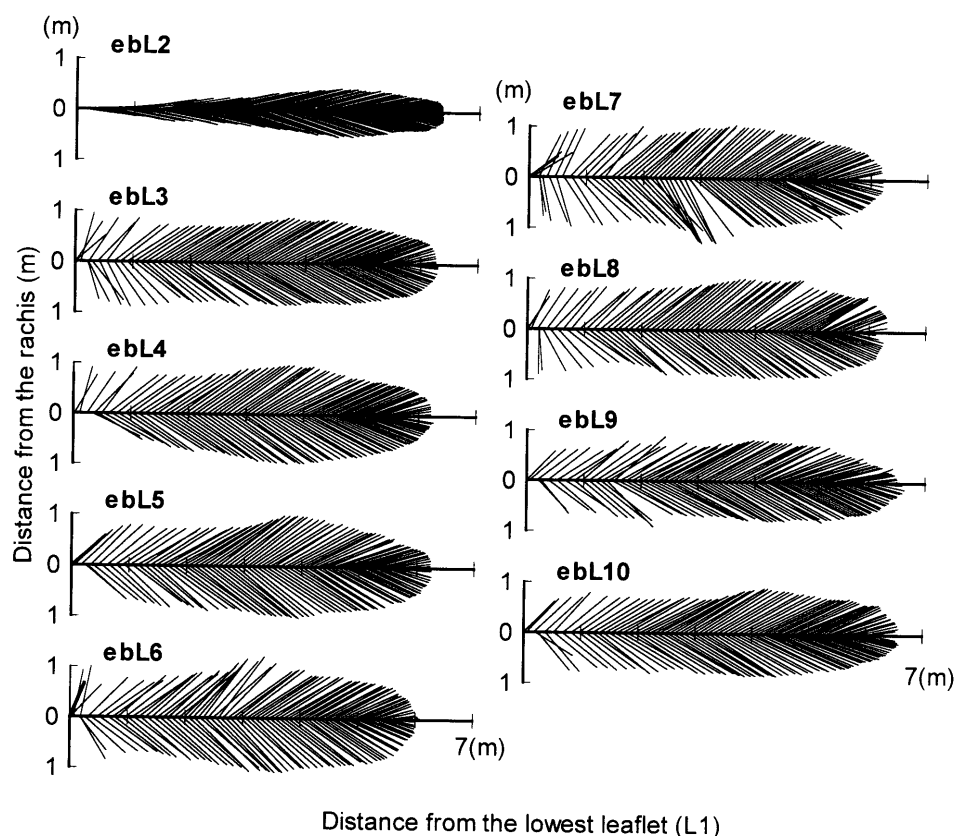


Fig. 12. Diagram of the leaf shape of ebL2 to ebL10. Each leaflet is shown by a segment. ebLn represents the *n*th leaf as shown in Fig. 1.

tip of the leaflet. This part, like a needle left on the tip of a leaflet, varies in length. In addition, this part does not affect the leaf area. Therefore, the thin and spinous part at the tip of a leaflet was not included in the leaflet length.

Fig. 7 shows the length, width and area of each leaflet in ebL3. This leaf had no loss or damage of leaflets; all the leaflets were measured completely. All dimensions were the largest in the leaflets near the middle positions. On the left side of the leaf, the maximum length was observed at L34 and L35 (153 cm), and the maximum width and area in L38 (8.1 cm width, 924 cm² area). On the right side, the maximum length was recorded in R24 through R28 (151 cm), and the maximum width and area in R35 (8.5 cm width, 946 cm² area). All dimensions were larger on the left side than on the right side at apical leaflet positions.

Positions of the right and left leaflets on the rachis were compared in Fig. 8. The position of the first left leaflet (L1) was always lower than that of the first right leaflet (R1) on the rachis. In order to elucidate this point, the way a leaf was folded in this plant was examined. We found that leaves were attached in a counterclockwise direction when viewed from the top of the plant. In addition, the left side of a leaf was located at the outer right side of the leaf just above itself (the leaf inside itself) (Fig. 1). In other words,

the left side of a leaf was located at the outer side of the next leaf, and the right side of a leaf was at the inner side of the previous leaf. From this relationship between the way a leaf was folded and the position of the lowest leaflet, the logical conclusion is that the lowest leaflet was outside of the next leaf in this plant with leaves attached in a counterclockwise direction. Ten other plants at the sago palm farm were observed for confirming this relationship. They showed essentially the same pattern as this plant. Namely, it was clear that the lowest leaflet was on the left side of a leaf in a plant with leaves attached in a counterclockwise direction, while it was on the right side of a leaf in a plant with leaves attached in a clockwise direction.

When the positions of the right and left leaflets were compared at the same leaflet position, the left leaflets were almost always lower than the right leaflets (Fig. 8). The distance between the adjacent two leaflets on the rachis tended to be wider at lower positions of the rachis, and narrower at higher positions.

In Fig. 9, the length, width, and area of each leaflet in ebL3 were plotted against the distance between the lowest leaflet and each leaflet on the rachis. Comparison between left and right leaflets on the basis of attaching position on the rachis proved that these characteristics were almost symmetric with respect to the rachis. Therefore, the attachment position of a leaflet on the rachis was inferred to be an important

characteristic for leaf area analysis.

Fig. 10 shows the leaf area of ebL3 to ebL10 calculated by integration of the areas of each leaflet. The largest leaf area was 8.57 m² of ebL10, the smallest was 7.64 m² of ebL8. The left side of the leaf was always larger than the right side in all leaves. One of the possible reasons for the difference between the leaf areas of left and right sides is the number of leaflets because it was larger on the left side than on the right side as mentioned in Table 1. In another large plant investigated (with the leaf area of 12.1 m²), also the left side of a leaf had a larger number of leaflets and larger leaf area than the right side.

Fig. 11 shows the average angles of leaflets, excluding ten leaflets each at the top and the base. In ebL2 that had just expanded, the angle was small (L : 14.5°, R : 16.8°), but the angle of ebL3 that was well expanded was large (L : 31.2°, R : 31.6°). The largest angle was seen in ebL7, 39.4° on the left and 41.7° on the right leaflets. On the other hand, the leaflets of the lower leaves ebL9 through ebL11 had angles around 30°, which were smaller than in ebL7. Thus, the leaflet angle was larger in leaves at middle positions among the expanded ten leaves. There is the possibility that the angle for each leaf to be unfolded in a plant might have affected it.

3. Leaf shape

Fig. 12 shows a diagram of the leaf shape of each leaf (ebL2 to ebL10) based on the measured data. In this figure leaflets are shown by segments. ebL2 was in the process of expanding, but ebL3 had almost finished expanding. The correct leaf area cannot be obtained using the outline of a leaf drawn by connecting the leaflet tips because the leaflet angles were out of order at some positions : for instance, at the left side of ebL6 and the right side of ebL7. Moreover, the correct area cannot be calculated from photos taken with a camera because overlapping of some leaflets. Consequently, we concluded that we needed to examine a method of estimating leaf area by integrating leaflet areas, not from the apparent leaf shape as a whole, in order to estimate the leaf area with high accuracy. Omori et al., (2000) suggested that the leaflet area could be estimated using a coefficient (α value). A simple method of estimating leaflet area is to be reported in

the near future.

Acknowledgements

We greatly appreciate Mr. Smith and his family in Mukah, Malaysia for their kind assistance. We also thank the Japan Society for the Promotion of Science for support in 1999 and 2001.

References

- Bell, A.D. 1998. Plant form : an illustrated guide to flowering plant morphology. Leaf morphology : palms. Oxford University Press Inc., New York. 92.
- Fahn, A. 1990. Plant anatomy -4th ed. Butterworth-Heinemann Ltd., Great Britain. 223.
- Flach, M. 1977. Yield potential of the sago palm and its realization. In M.A. Tankooling ed., Sago '76 : Papers of the 1st International Sago Symposium, Kuala Lumpur. 157-177.
- Flach, M. and Schuiling, D.L. 1989. Revival of an ancient starch crop : a review of the agronomy of the sago palm. *Agroforestry Systems* 7 : 259-281.
- Hassan, F.H. 2001. Agronomic practice in cultivating the sago palm, *Metroxylon sagu* Rottb.—the Sarawak experience. In K. Kainuma, M. Okazaki, Y. Toyoda and J. E. Cecil eds., *New Frontiers of Sago Palm Studies*. Universal Academy Press Inc., Tokyo. 3-7.
- Jones, D.L. 1995. Palms. Smithsonian Institution Press, Washington, D.C. 1-410.
- Jong, F.S. 2001. Commercial sago palm cultivation on deep peat in Riau, Indonesia. *SAGO PALM* 9 : 16-20.
- Nagato, I. and Shimoda, H. 1979. The present state of sago production and its future. *Jpn. J. Trop. Agr.* 23 : 160-168*.
- Nakamura, S., Goto, Y. and Nitta, Y. 2000. Morphology of leaf and leaf area in sago palm (*Metroxylon sagu* Rottb.). *SAGO PALM* 8 : 21-23*.
- Nishikawa, G., Oda, K. and Suganuma, H. 1979. Botanical description of sago palm. *Jpn. J. Trop. Agr.* 23 : 130-136*.
- Omori, K., Yamamoto, Y. and Jong, F.S. 2000. Relationships between leaflet weight, length or width and leaflet area in Sago palm (*Metroxylon sagu* Rottob.). *Jpn. J. Trop. Agr.* 44 (extra issue 1) : 15-16*.
- Yamanoto, Y. 1998. Sago palm. In Association for International Cooperation of Agriculture and Forestry ed., *Sago Palm*. Association for International Cooperation of Agriculture and Forestry, Tokyo. 1-109**.

* In Japanese.

** Translated from Japanese by the present authors.