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Nipa (*Nypa fruticans* Wurmb) Sap Collection in Southern Thailand II. Biomass and Soil Properties

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Abstract

Nipa (*Nypa fruticans* Wurmb) frond biomass is the cruicial factor for sap/sugar production. An allometric equation was firstly formulated for estimating frond biomass from the length (L) and the diameter at breast height (DBH) of a frond. And subsequently the L-DBH relationship was applied for L estimation at five nipa farms. As a result, the allometric equation was expressed as Log DW = 0.85 x Log D^2L + 1.54 (r^2 = 0.94). The highest above-ground biomass was 83 t/ha, whereas the average biomass in other farms was 32 t/ha, which was almost the same as that in young oil palm plantation. The physical and chemical properties of soils in the nipa farms were analyzed using 80 soil samples to elucidate the factors determining nipa soil properties by principle component analysis (PCA). Consequently, organic matter, salt content and brackish water were considered to be the key factors determining nipa soil properties. Daily sap production (ml/day) (DSP) was well explained by frond biomass and above-ground biomass with the equations: DSP = 17.6 x frond biomass (kg) + 256.1 (r^2 = 0.48) and DSP = 11.4 x above-ground biomass (t/ha) + 263.4 (r^2 = 0.57), respectively. When soil properties are included, sap production is better explained, as shown by multivariate analysis followed by PCA with the equation, DSP = 609.7 – 92.9 x PC1 – 58.5 x PC2 (r^2 = 0.93). As PC1 and PC2 correspond to the organic matter factor and the salt content factor, sap production would be controlled by the nipa growth and the amount of Na in soil.

Keywords: allometric relationship, biomass, nipa, soil properties

1. Introduction

From the examination on the sap and sugar productivity of nipa (*Nypa fruticans* Wurmb), it was elucidated that nipa farming could be a promising practice in tropical coastal areas because it produces sap sustainably. The growth properties of the nipa fruit stalk, as well as the water status, were shown to affect sap production. Taking these into account, more detailed studies about other factors regulating nipa growth and sap production are required to draw more attention to the incorporation of nipa to an integrated coastal management.

Since sap is a product of photosynthesis, frond (leaf) biomass is likely related to sap production. Many biomass studies have been carried out on other palms such as coconut and oil palm (Henson & Chai, 1997; Fangren et al., 1999; Khalid et al., 1999; Thenkabail et al., 2004; Shuit et al., 2009; Morel et al., 2011), but there are scarcely any studies of nipa biomass. Tree/plant biomass has been measured by a destructive method involving the cutting off of an entire plant and weight measurement after partitioning. Moreover, above-ground biomass can be easily estimated by a method established by Corley et al. (1971) with some accuracy from allometric relationships between plant height and diameter. Allometric equations were formulated for oil palm (Aholoukpè et al., 2013) and coconut (Navarro et al., 2008; Brakas & Aune, 2011), but not yet for nipa. Hence, we firstly intended to establish an allometric equation for nipa biomass estimation in the area where we conducted sap monitoring.

Soil is an important component of the environment, functioning not only as a substrate but also as source of nutrients for plant growth. The distribution of mangrove species is affected by topography (Komiyama et al., 1996, Kitaya et al., 2002), and the growth of the mangrove species *Rhizophora apiculata* is regulated by up to 90.3% by soil conditions (Matsui et al., 2008). Moreover, soil properties affect palm growth in coconut

(Arachchi & Liyanage, 1997) and oil palm plantations (Auxtero & Shamshuddin, 1991; Khalid & Anderson, 2000). Soil conditions may thus have an impact on nipa growth and sap production; therefore, soil properties in a nipa stand is worth studying.

The objectives of this study were hence 1) to determine the biomass of nipa stands by formulating an allometric relationship, 2) to understand the soil properties of nipa stands, and 3) to examine the effects of biomass and soil properties on sap production.

2. Methods

2.1 Study Site and Frond Measurement

Biomass and soil studies were conducted in the same place where sap/sugar monitoring was conducted, Pak Phanang Basin in Nakorn Si Thammarat Province in southern Thailand (Part I; Figure 1). For this study, other farms were also studied in addition to those studied for sap/sugar monitoring.

A monitoring plot of 20 m x 20 m was established within a nipa plantation for measuring frond biomass at five nipa farms including three farms studied for sap/sugar production (Part I; Table 1). All individual fronds within the plot were tagged, counted, and numbered randomly for measuring frond diameter at breast height (DBH) and frond length (L) (Figure 1). For four farms, a crown projection diagram was prepared to display the locations of fronds growing or held together (which is called as cluster, Part I; Figure 10).

2.2 Estimates of Above-Ground Biomass of Nipa Stands From Allometric Equation

2.2.1 Allometric Equation Formulation

Ten fronds in Kovit's farm were selected from the various sizes of small to large lengths for formulating allometric equation. Immediately after cutting off whole fronds of nipa, their fresh weight, L, and DBH were measured. Subsequently, their rachis and leaves were separated (Figure 1). They were brought back to the laboratory for complete drying at 120 °C for 48 hours in the oven. Allometric equation for estimating biomass on dry weight basis (DW) were formulated from the measured biophysical properties of fronds, namely, DBH and L.

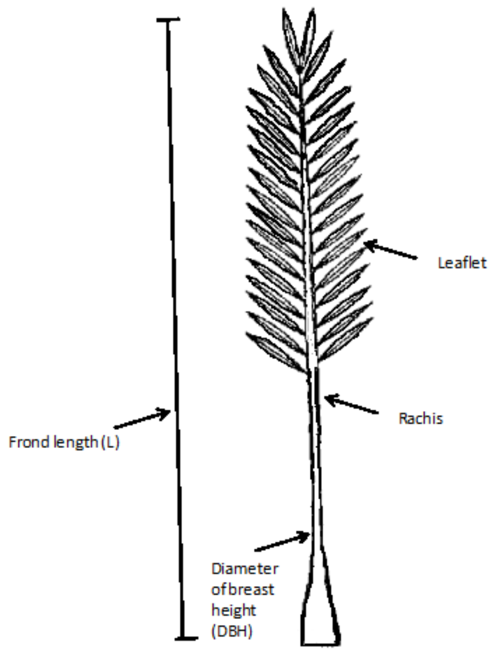

Figure 1. Diagram of nipa frond. Frond is divided into two parts, the leaf and rachis. For biomass measurement, DBH and L are measured

The diameter of a rachis differs depending on the part of the rachis measured (Figure 1); thus, the diameter was measured at four different heights: at the base and at 100 cm, 130 cm, and 160 cm above the ground in Bunchoy's farm. The values obtained were compared to determine the part of the rachis whose diameter correlates most with the L of fronds.

2.2.2 Above-Ground Biomass Measurement of Nipa Stands

To calculate above-biomass using an allometric equation, the DBH and L of all fronds were measured within the plots prepared for frond measurement either at the end of August or in September for three years, 2010, 2011 and 2013.

Regarding DBH and L in the allometric equation, DBH is easy to measure in a farm, but L measurement is rather time-consuming because fronds are mostly inclined and their Ls sometimes exceed 10 m. Thereby, the relationship between DBH and L was obtained to derive L from DBH. Because frond shape varies with time and space, the relationship between these variables was examined for each farm.

The biomass of fronds surrounding a fruit stalk being tapped for sap was estimated using the allometric equation formulated in this study to examine the relationship between frond biomass and sap production. At three farms, 2 or 3 fruit stalks were selected for monitoring sap production from 16 to 53 days. For each fruit stalk, the DBH and L of all the surrounding fronds, which are either 4 or 5, were measured for biomass estimation.

2.3 Soil Sampling and Analysis

In 2010, we collected 16 soil samples from each of the five farms. A total of 80 samples were analyzed for moisture content, pH, EC, exchangeable Mg, Ca, K, and Na contents, and total C and N contents. Moisture content was calculated by heating at 105 °C for 48 hours using a 100 cc volumetric cylinder. Samplings for moisture content were conducted within 30 min after water receded from the site. pH and EC were measured after shaking fresh soil samples for 1 hour at a soil-to-water ratio of 1:10 using a BeckmanΦ72 and a CyberScan Con300, respectively. Total C and N contents were determined by the dry combustion method (NC-analyzer, 1000; Sumigraph, Shimadzu, Kyoto, Japan) and the C-to-N ratio was calculated. Dry soil samples were prepared by shaking them with 1 N ammonia acetate then measured for exchangeable Ca, Mg, Na, and K contents by the atomic absorption method (Shimadzu A-6000, Kyoto, Japan).

2.4 Statistical Analysis

For analytical results of the 80 soil samples, descriptive statistics, the mean, maximum, and minimum values, and the coefficient of variation of each soil property were calculated. Correlation analysis was also conducted for all datasets. Principal component analysis (PCA) of the soil properties was conducted to summarize data and investigate the relationships among the properties (Kosaki & Juo, 1989). Using the mean values of soil analysis, above-ground biomass and mean daily sap production at the five farms, correlation analysis and multivariate analysis were conducted. Statistical analysis was conducted using the software JMP 8.0.2 version for Windows (SAS Inc., 2009).

3. Results

3.1 Number of Fronds and DBH

The average number of fronds within a plot of 20 m x 20 m was 542, that is, 13,550 fronds/ha (Table 1). The numbers of fronds were almost the same in three years in Kovit, Sompong, and Bunchay's farms, but fluctuated yearly in Yong Yot's farm. Farmers conduct thinning of fronds as a conventional practice; thus, the number of fronds always change. Moreover, management practices vary among farms, resulting in differences in frond number.

The number of clusters was the lowest (n=29; 725 clusters/ha) in Kovit's farm, whereas Sompong's farm had 42 (1,050 clusters/ha) and Yong Yot's farm had 40 (1,000 clusters/ha) (Figure 2). Although Kovit's farm had the lowest number of clusters, the number of fronds was not markedly different from those in the other farms, which means that a cluster in Kovit's farm was larger than those in the other farms. A larger cluster in Kovit's farm corresponds to a larger frond DBH (6.8 cm) than in the other farms (mean DBH; 4.6 cm). In contrast, Kan's farm had a highest number of fronds but the smallest DBH among the farms.

Table 1. Number of fronds, DBH and biomass

Farm owner			2010	2011	2012	Average in 3 years
Kovit						
	Total No. of fronds*		514	554	547	538
	DBH (cm)**		6.75	6.82	6.74	6.77
		Stdv	1.63	1.55	1.56	
	DW (t/ha)***		64.3	83.8	72.5	73.5
Sompong						
	Total No. of fronds		480	561	432	491
	DBH (cm)		4.55	4.59	4.26	4.47
		Stdv	0.66	0.76	0.86	
	DW (t/ha)		24.3	30.2	27.6	27.4
Yong Yot						
	Total No. of fronds		397	625	489	504
	DBH (cm)		4.82	4.90	4.77	4.83
		Stdv	1.19	1.10	1.30	
	DW (t/ha)		27.4	40.1	35.8	34.4
Bunchoy						
	Total No. of fronds		519	516	521	519
	DBH (cm)		4.60	4.61	4.50	4.57
		Stdv	0.77	0.80	0.81	
	DW (t/ha)		27	30.3	32.1	29.8
Kan						
	Total No. of fronds			611	703	657
	DBH (cm)			3.99	4.15	4.07
		Stdv		0.71	1.48	
	DW (t/ha)			21.1	40.8	31.0
Average	Total No. of fronds				542	542
in 5 farms	DBH (cm)				4.94	4.94
	DW (t/ha)				39.2	39.2

fronds* - number in 20 m x 20 m block; DBH* - diamter at breast height; DW*** - Above ground biomass in dry weight.

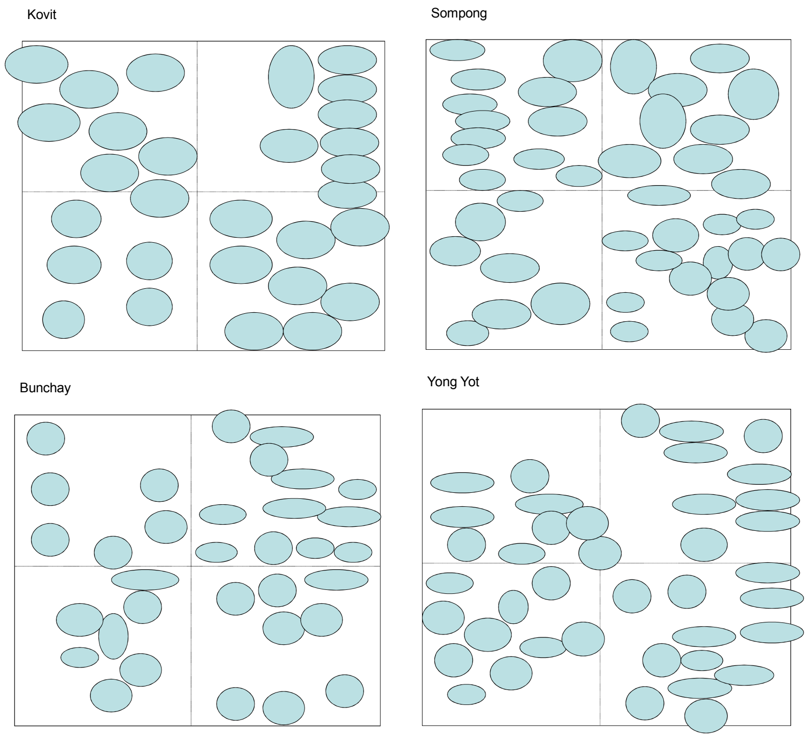

Figure 2. Crown projection diagram of nipa fronds in four farms. A circle indicates a cluster of fronds

Figure 3 shows the proportion of tagged fronds in three different years. Fronds tagged in 2010 aged at least more than 3 years were nearly 30% out of all fronds in Kovit's farm. However, the tagged fronds were only 5% in Kan's farm. However, young fronds tagged in 2012 were only 40% in Kovit's farm, whereas nearly 50% in Sompong, Yong Yot, and Kan's farms were young fronds.

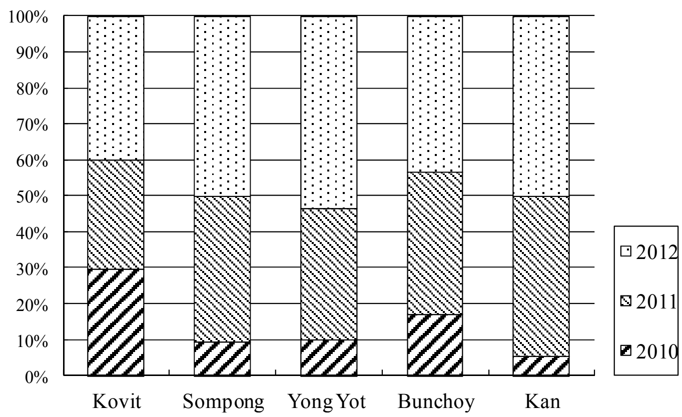

Figure 3. Number of fronds measured in 20 m x 20 m block for three consecutive years, 2010, 2011 and 2012

3.2 Allometric Equation Formulation

The diameters at four different heights [Base, 100 cm, 130 cm (DBH), and 150 cm] were measured to determine the part of the rachis whose diameter correlates the most with L. The diameters at the base and 160 cm above the ground did not correlate well with L, showing $r^2 = 0.001$, $r^2 = 0.29$, respectively, but DBH showed the highest correlation with L ($r^2 = 0.58$) (Figure 4). Hence, we adopted DBH for biomass estimation in this study.

The L-DBH relationship was obtained for all the farms as follows:

Kovit: Log L = 0.63 x log DBH + 2.40 (n = 55, $r^2 = 0.42$);
Sompong: Log L = 0.83 x log DBH + 2.19 (n = 483, $r^2 = 0.77$);
Yong Yot: Log L = 0.71 x log DBH + 2.26 (n = 56, $r^2 = 0.56$); and
Bunchoy: Log L = 1.23 x log DBH + 1.95 (n = 190, $r^2 = 0.77$).

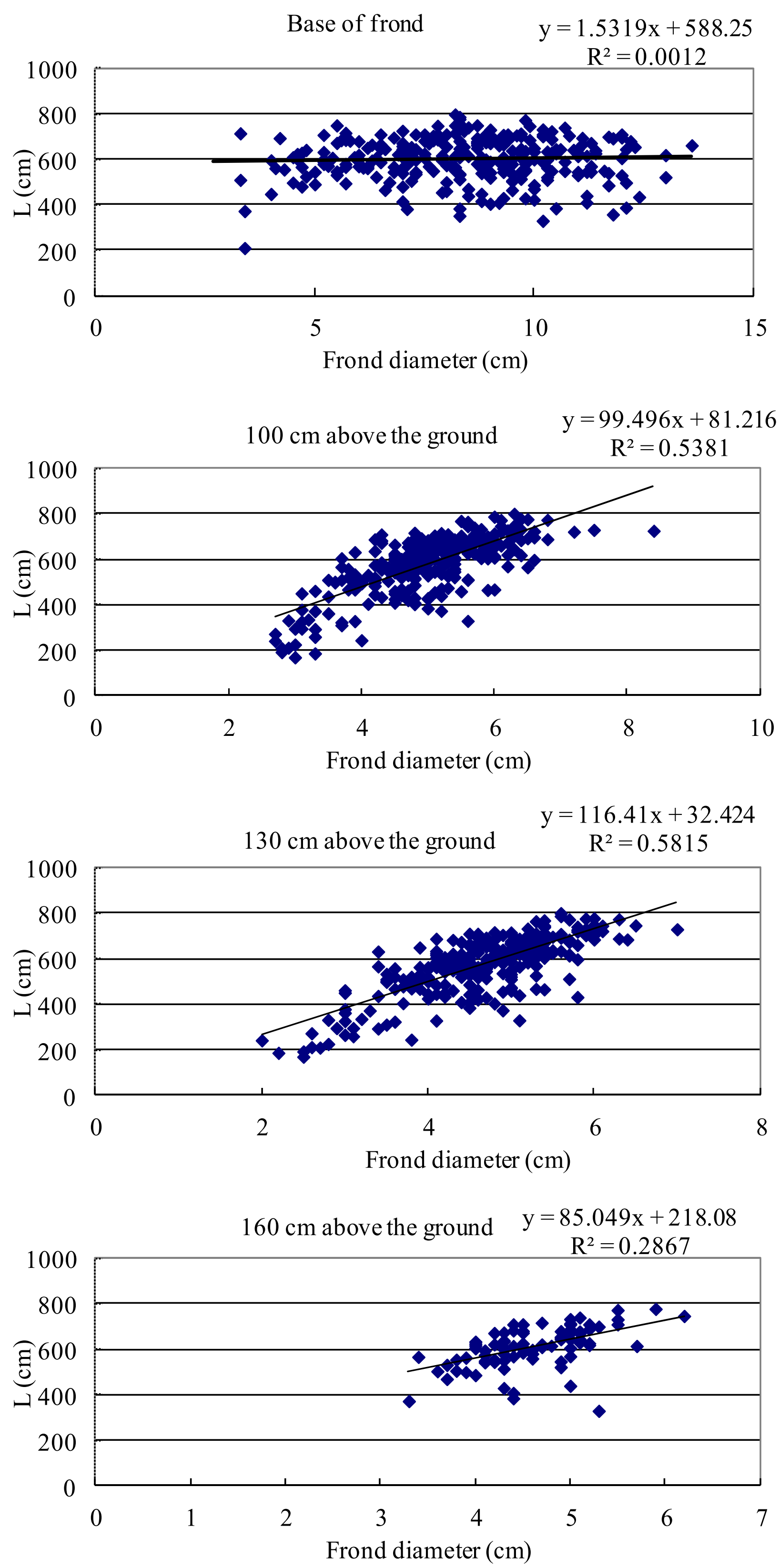

Figure 4. Relationships between frond diameter measured at different heights and L.

Since L affects biomass estimation, we used the equation corresponding to each farm for calculating biomass in each farm.

From ten fronds, the allometric equation for nipa was determined for the rachis, leaf, and whole frond (rachis + leaf). The coefficient (r^2) of the equation for the leaf was low but those for the rachis and whole frond were high, 0.94 (Figure 5). Consequently, the following equation was used for biomass calculation.

$$\text{Log DW} = 0.85 \times \text{Log } D^2L + 1.54 \; (r^2 = 0.94) \quad (1)$$

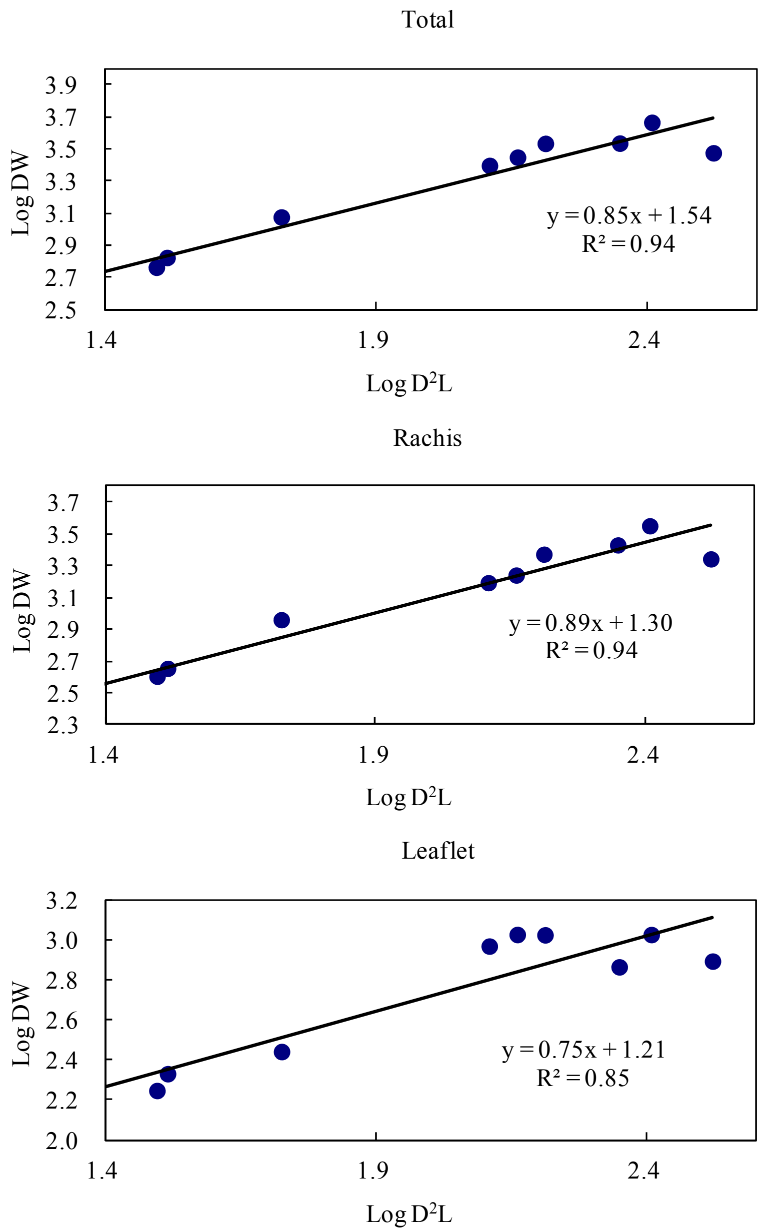

Figure 5. Allometric relationship formulated for rachis, leaf and whole frond (rachis + leaf)

3.3 Above-Ground Biomass Measurement

Table 1 shows the above-ground biomasses obtained using Equation (1). The highest total biomass of 83.8 t/ha was observed in Kovit's farm whose value was especially high comparing to other farms. Biomass changed yearly because of the natural growth of fronds and thinning practiced by farmers.

For the fronds surrounding a fruit stalk with on-going sap collection, biomass was measured using Equation (1). Accordingly, the biomasses of fronds surrounding the fruit stalk were as follows: YY6, 25.3 kg; YY8, 14.5 kg for Yong Yot's farm; Kan8, 5.7 kg; Kan9, 12.3 kg for Kan's farm; and Kasem6, 5.4 kg; Kasem8, 9.1 kg; Kasem6, 5.2 kg for Kasem's farm (Table 2).

Table 2. Biomasses of the fronds surrounding fruit stalks

	Kasem			Kan		Yong Yot	
	Palm 6	Palm 7	Palm 8	Palm 8	Palm 9	Palm 6	Palm 8
Mean daily sap producion (ml)	301.7	520.8	280.4	291.2	729.4	654.7	378.6
Number of fronds	5.0	5.0	5.0	4.0	5.0	4.0	4.0
Biomass (DW kg)	5.3	9.1	5.2	5.7	12.3	25.3	14.5
Days of sap collection	23	23	23	16	17	54	28

3.4 Descriptive Statistics of Measured Soil Properties

Table 3 shows the descriptive statistics of soil properties measured in 80 samples. The coefficient of variance suggests that EC and CN showed a higher variability than the other soil properties, whereas pH showed a low variability. pH showed a statistically significant negative relationship with Total C and Total N and a positive relationship with exchangeable Mg (p <0.01) in the correlation matrix of measured soil properties (Table 4).

Table 3. Descriptive statistics of measured soil properties

	Mean	Minimum	Maximum	CV (%)
Moisture	39.6	14.6	57.3	24.5
pH	5.9	3.52	7.11	18.4
EC (mS/m)	115.0	0	1760	189.8
Exchangeable Mg (cmol kg^{-1})	88.4	32.5	176.4	29.9
Exchangeable Ca (cmol kg^{-1})	68.6	23.7	108.3	23.5
Exchangeable Na (cmol kg^{-1})	141.4	8.7	451.9	76.8
Exchangeable K (cmol kg^{-1})	17.2	8	27.3	23.6
Total C (%)	4.0	0.49	15.7	53.3
Total N (%)	0.32	0.11	0.72	35.2
C to N ratio	12.1	2.9	15.7	180.2

Table 4. Correlation matrix of soil properties

	pH	EC	Total C	Total N	CN	Ex. Ca	Ex. Mg	Ex. K	Ex. Na
Moisture	-0.38*	0.19	0.20	0.23**	0.07	-0.21	-0.01	0.38*	0.37*
pH		0.17	-0.52*	-0.55*	-0.33*	0.11	0.65*	0.21	0.30*
EC			0.02	-0.02	0.12	-0.06	0.27**	0.20	0.23**
Total C				0.89*	0.74*	0.26**	-0.25**	-0.09	-0.13
Total N					0.42*	0.21	-0.28**	-0.07	-0.13
C to N ratio						0.24**	-0.07	-0.08	-0.05
Exchangeable Ca							0.31*	0.16	-0.12
Exchangeable Mg								0.55*	0.68*
Exchangeable K									0.63*

* and ** indicate 1% and 5% levels of significance, respectively.

Principle component analysis (PCA) identified three components (PC1-3) with eigenvalues, or the variances of components, greater than 1.0. Three components accounted for 71.8% of the total variance (Table 5). On the basis of the component loadings without rotation, the first component showed high loadings for pH, Total C, Total N and exchangeable Ca content. Similarly, the second component showed high loadings for exchangeable Na and K contents, the third component for exchangeable Mg and moisture contents. Such variations of the soil properties are summarized into three factors, which were independent of each other. Considering the properties of each of the components, PC1, PC2 and PC3 are the components that could be related to organic matter, brackish water and frond residue, respectively.

Table 5. component loadings, eigenvalues and % of total variance explained by the first three components

	Component		
	PC1	PC2	PC3
Moisture	-0.06	0.37	-0.54
pH	0.44	-0.05	0.31
EC	0.11	0.27	-0.07
Total C	-0.44	0.33	0.16
Total N	-0.42	0.28	0.06
C to N ratio	-0.31	0.30	0.24
Exchangeable Mg	-0.04	0.18	0.64
Exchangeable Ca	0.40	0.33	0.28
Exchangeable Na	0.26	0.44	-0.08
Exchangeable K	0.31	0.43	-0.17
Eigenvalue	3.29	2.34	1.55
% of total variance*	32.9	56.3	71.8

*Calculated as cumulatives value.

3.5 Relationship Between Biomass and Sap Production

Figure 6 shows the relationship between the biomass of a frond surrounding a fruit stalk with on-going sap collection and mean daily sap production (DSP). It shows that the higher the frond biomass, the more sap is produced. The relationship is expressed as

$$\text{Mean sap production (ml/day)} = 17.6 \times \text{frond biomass (kg)} + 256.1 \ (r^2 = 0.48) \quad (2)$$

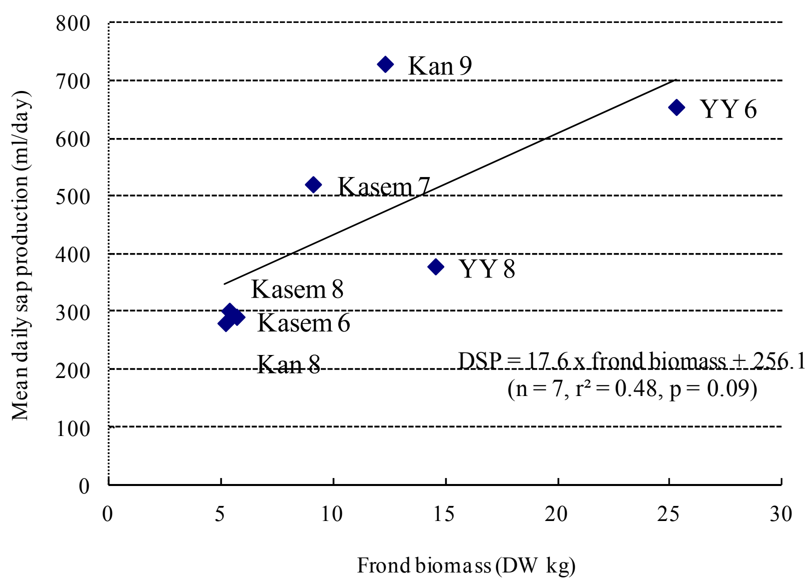

Figure 6. Relationship between frond biomass (kg) and mean daily sap production (ml/day)

A relationship was found between above-ground biomass and mean daily sap production (DSP) in five farms (Figure 7). Using the sap monitoring results reported in part I of this study and the measured above-ground biomasses obtained in this study, mean sap production can be expressed by above-ground biomass as

$$\text{Mean sap production (ml/day)} = 11.4 \times \text{above-ground biomass (t/ha)} \ (r^2 = 0.57) \quad (3)$$

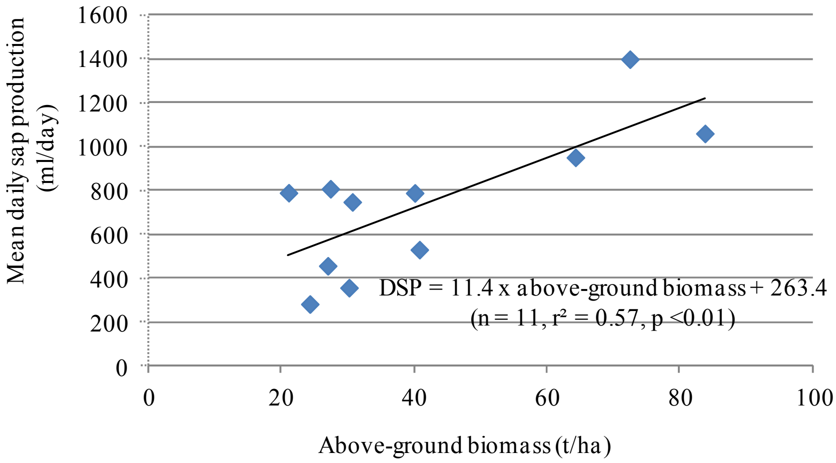

Figure 7. Relationship between nipa above-ground biomass (t/ha) and mean daily sap production (ml/day). Nipa above-ground biomass was measured in five farms

3.6 Effects of Soil Factors on Sap Production

Stepwise multiple regression analysis was performed to obtain a model for prediction of nipa sap daily production. In this analysis, daily sap production which was monitored in five farms, was used as a dependent variable, and standardized scores of the three PCs from PCA were used as independent variables. The most appropriate model obtained with a p value of <0.05 provided the following equation:

$$\textit{Daily sap production} = 609.7 - 92.9 \times PC1 - 58.5 \times PC2 \ (r^2 = 0.93) \quad (4)$$

The equation (4) implies that organic matter and nitrogen contents as well as brackish water may influence on amounts of daily sap production.

4. Discussion

4.1 Characteristics of Nipa Plantation Stands

As a conventional practice, farmers practice thinning and control the number of fronds because an excessive number of fronds are believed to reduce sap production. However, the number of fronds is not likely to be a significant factor for sap production, as shown by the observation that Yong Yot's farm has a smaller number of fronds than Sompong's farm, but the sap production was higher in Yong Yot's farm.

Density is also considered to be a factor that determines nipa stand productivity. Sap production is reported to be higher in wider spacing, that is, a lower density (Dalibard, 1999). Natural nipa stands have a density range between 1,025 and 6,400 clusters per hectare (Roazainah & Aslezaeim, 2010). When reduced to 500 clusters per hectare, sap production will increase (Dalibard, 1999). Cluster density in this study was in the range between 725 and 1,050. Cluster density was almost similar in Sompong and Yong Yot's farms, but their sap productions were rather different. Therefore, density may also not be a major criterion that determines sap yield.

H–DBH ratio [H (m)/DBH (cm) x 100] is used as the index of tree form. By this ratio, the form of a nipa frond in Kovit's farm was defined as having a roly-poly shape, which was in contrasts to the slim fronds in other farms. Considering that the fronds in Kovit's farm are slow-growing (Part I; Figure 8), it is probable that the nipa plant in Kovit's farm is a variety different from those in the other farms.

4.2 Above-Ground Biomasses

The above-ground biomasses were 20–30 t/ha in most of the farms, whereas Kovit's farm showed the highest above-ground biomass (83 t/ha). The biomass of oil palm FFB differs according to the plantation age. A 3-year-old oil palm plantation has above-ground biomasses of 17.9 t/ha in Indonesia, 21.3 in Malaysia, and 6.5 in the rest of world (FAO, 2010). For a mature plantation, the biomass is nearly 80 ton/ha (Khalid et al., 1999). A biomass of 75 ton/ha is reported for coconut palm (European Commission, 2009). Considering these, the nipa biomass is similar to that of a young oil palm plantation.

The biomass of the nipa plantation studied is controlled by the thinning of fronds. With 20 – 30 t/ha of standing biomass, a nipa farm could produce 3.2-6.5 t/ha of sugar yearly. Apparently, a higher biomass seems to produce more sap; but many of farmers thin fronds to maintain adequate number of fronds with the belief that excess number reduce sap production.

4.3 Soil Properties of Nipa Stands

Soil formation in nipa stands is characteristically determined by three separate factors, inflow of brackish water, organic matter, and topography, as indicated by PCA (Table 5), which would affect above-ground biomass and sap production.

The ground levels determined at Kovit, Yong Yot, and Sompong's farms were 19 – 31cm. This would lead to a high variance in EC, indicating that salt accumulates unevenly in a farm. In the correlation matrix of measured soil properties (Table 4), pH showed a statistically significant negative relationship with total C and total N. This finding indicates that organic matter is decomposed when soil becomes dry, resulting in the decrease in pH (Table 4). Furthermore, a positive relationship of pH with exchangeable Mg content ($p < 0.01$) indicates that brackish water flows into a nipa farm, resulting in an increase in pH. Inflow of brackish water does not directly determine the water content in soil. Topography is also another factor that affects water content because it affects the duration of water inundation in a farm.

4.4 Effects of Biomass and Soil Properties on Sap Production

Both the frond biomass surrounding fruit stalk and above-ground biomass are related to sap production. Frond biomass explained the variance of sap production by 48% (Equation (2)) and above-ground biomass explained by 57% (Equation (3)). Although the number of datasets is small (5), stepwise regression analysis showed that a model including soil properties could explain better sap production (Equation (4)). Sap production will increase by an increase of soil organic matter content and when the influence of brackish water decreases. This finding has a practical significance. Sap could be produced more when the farm is managed such that the influence of brackish water is reduced in a nipa farm.

5. Conclusions

The above-ground biomass of five nipa stands were quantified on the basis of the allometric relationship formulated for this study. The allometric equation for nipa frond biomass was expressed as $\text{Log DW} = 0.85 \times \text{Log } D^2L + 1.54$ ($r^2 = 0.94$), for which the L-DBH relationship was determined for each of the farms. The highest above-ground biomass was 83 t/ha, whereas the average biomass in other farms was 32 t/ha, which corresponds to the biomass of young oil palms in a plantation. The soils of nipa stands were characterized by a high variation of EC and a highly exchangeable Na. PCA showed that three factors, organic matter, salt content and brackish water were associated with soil properties. Fronds surrounding fruit stalk and above-ground biomasses explained sap production by 48% and 57%, respectively; however, sap production could be better explained by 93% when soil properties are considered.

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