Modelling and Simulation

The Allometric Model of Sago Palm Above Ground Drymatter Partitioning in Relation to Phenological Stages

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Abstract— **Sago palm is gaining more attention in the last decades, regarding to its various benefits, such as economically profitable, sustainable and environmental friendly. Many studies have been addressed to this crop, including modeling of biomass partitioning during its growing stages. In this study, biomass or carbon allocation into different growing crop organ was modeled empirically based on data collected from farmer gardens in two provinces of Indonesia. The sampled palms which were selected from different phenological stages (rosette stage until fruit ripening stage) were felled and separated into different organs. Proportion of drymatter of each organ to its total above ground drymatter (AGD) was calculated. The results showed that during rosette stage, most of AGD was allocated to leaf formation. In the next stage (trunk formation), allocation of AGD to leaf formation was decreasing, while portion to trunk formation was increasing significantly. In the flowering stage and fruit ripening stage, most of AGD was allocated to flower or fruit formation. A portion of AGD that was probably allocated to organs other than flower or fruit during these stages is assumed to be zero in the allometric model.**

Keywords- *Above Ground Drymatter (AGD), Allometic model, Phenological Stages, Sago Palm*

I. INTRODUCTION

Contrary to its important role in socio-economic and cultural aspect since hundred years ago [1,2], currently sago palm is still found as underutilized plant. Most of sago stands spread over Indonesia archipelago are natural stands, and the small portion of the total sago stands which is categorized as cultivated stand is mostly grown unmaintained [3]. The consumption level of sago starch as staple food is also found decreasing [4].

However, in research area sago palm is gaining attention significantly increased in the last decade. It may due to its various advantages, such as economically acceptable, relatively sustainable, environmentally friendly, uniquely versatile, vigorous, and can promote socially stable agro-forestry systems [5]. Many studies have been addressed to this crop, including crop simulation model [6].

One component in crop simulation model with great importance is carbon allocation among crop organs. It plays role in determining crop growth, development and yield. However, the regulation of carbon allocation at the whole-plant level is still poorly understood. Therefore, carbon allocation is usually described as empirical models in many crop models [7]. Consequently, simulation models developed so far are rather species-specific. Within species, genotype (e.g. in [8]), developmental stage of the plant, many growth conditions and internal regulation by the plant may also affect drymatter allocation (e.g. [9], [10]).

There are five approaches in modeling carbon allocation that have been reviewed by several authors (e.g. [7], [11]). These five models are ordered in increasing complexity: 1. Descriptive allometry; 2. Functional equilibrium; 3. Canonical modelling; 4. Sink regulation; and 5. Transport-resistance [12].

During this study we used empirical model (descriptive allometry model) to derive relationship between dry-matter among plant organ with phenological stages. This approach was selected regarding to its simplicity, and consideration of model that being developed is also in early level.

II. METHODS

A. Sampled Palms

There were three sets of data used in this study. Two sets of data which were collected from sago palm garden in Tebing tinggi, Riau province, Indonesia (0°30'N, 101°50'E) and Pontianak, West Kalimantan Province, Indonesia (0°7'S, 109°30'E) were used to build equations of phenological relations to above ground dry matter partitioning. The third data set which also collected in Pontianak but from different garden and different time of collection was used to validate the equations.

The palms were selected from normal performance palms at various ages representing all stages of sago palm phenology. All palms were sampled destructively and then separated into crop organ such as leaf (leaflets, rachis, and petiole) and trunk. Roots were not included in sampling process due to difficulty in digging and collecting intact crop roots without any destruction. Each of crop organs was weighted to get the fresh biomass and took a small amount as samples for moisture analyses in laboratory. This analysis was conducted to convert fresh weight into dry weight.

B. Estimation of Phenological Stages (s)

The life cycle of sago palm is divided into four stages: rosette, trunk formation, flowering, and fruit ripening. The stages (s) are aligned on a scale ranging from 0 to 1 with the same portion of each stage (0.25 each), where 0 corresponds to the sucker planting stage and 1 corresponds to the timing of palm death (Fig. 1). Development within a stage is stated in thermal units and is calculated as the accumulation of the difference between air temperature (°C) on day i (Ti) and the base or critical temperature of the crop (Tb) divided by the total thermal units (TU) required for the completion of each stage (1). Given that sago palm tolerates temperatures around 17 °C [5] and the minimum tolerable temperature is 15 °C [3], Tb is assumed to be equal to 15 °C. The TU values may differ from one variety to another. In this study, the TU values are based on [13] and [5] observations of the developmental sequences of spineless-type sago palm, which were converted into thermal units with temperature data.

$$s = \frac{\sum_{i=1}^{n} (T_i - T_b)}{TU} \qquad (1)$$

The estimation of phenological stages of sampled palm was based on information of palm ages from local farmers. The palm ages then were converted into phenological stage (s) by applying (1)

III. RESULTS AND DISCUSSION

There were six palms sampled in Tebing Tinggi, and seven palms sampled in Pontianak for calculation AGD partitioning and derivation of empirical equation between phenological stage and the AGD partitioning. Each palm organ was separated and weighed in fresh and converted into drymatter. None of flower and fruit of sampled palm can be found during the study. The palm sampled at flowering stage (s=0.6030 in Tebingtinggi, and s=0.6671 in Pontianak) were found with no flower on they stalk. The same condition found at palm sampled in s=0.8725 (in Pontianak). According to the farmer, the palm supposed to be in fruiting stage. Unfortunately there was no fruit found on its stalk. Information gathered from farmers in Tebingtinggi and Pontianak indicated that it is rarely to find flower or fruit of sago palm nowadays. It may due to common practice to harvest sago palm before flowering stage which is believed to have the highest content of sago starch.

The calculation results of partitioning of above ground dry matter (AGD) are shown in Table 1 and Fig. 2. During rosette stage (s<0.25) biomass produced from photosynthesis is used for root growth and leaf formation. There is no trunk is formed during this stage, therefore all AGD is allocated for leaf formation. Hence, we modeled the partition of AGD for leaf formation (ηL) to be equal to 1, and partition for trunk formation (ηS) to be equal to 0 during this stage.

In the next stage (trunk formation, 0.25≤s<0.5), trunk was starting to grow and became completed when crop proceed to bolting stage when the crop is preparing for flowering stage. The allocation of AGD during this stage for leaf formation was decreasing, while for trunk formation was increasing significantly. This trend can be modeled as function of phenological s (s), i.e. $\eta_L = \dfrac{0.0032}{1 - 1.0005\, e^{-0.0258\, s}}$ and $\eta_S = 0.9524 + 0.4020 \ln(s)$ respectively.

In the flowering stage (0.5≤s<0.75) and fruit-ripening stage (s≥0.75), sago palm is starting to use its starch stored in the trunk for accomplishment of its life cycle. Leaves are gradually become senescent; therefore it is assumed that drymatter flow to organs other that flower/fruit is stopped during these stages. For simplicity ηF is modeled to be equal to 1, while ηL and ηS are equal to zero. The simplification is also based on the condition during field campaign as described above about the un-ideal condition of sago palm sampled at flowering and fruiting stage. However this bias may have small impact as sago palm usually harvested before flowering stage.

The empirical model then was applied to generate modeled ηL and ηS data sets and compared to the third data set for validation. The results can be seen in Fig.3 and Fig.4. The figures show that simulated data from the empirical model obtained in the previous works fitted well with measured data in sago field, with the values of R^2 were more than 90% for both ηL and ηS. It implies that the dry matter partitioning model derived from this study is sufficient enough to be used in sago palm simulation model.

IV. CONCLUSION

The allocation of above ground drymatter (AGD) among crop organ of sago palm was investigated in this study. The result shows that phenological stages affect the proportion of drymatter allocated to each crop organ. The equation describing the relationship of phenological stages and drymatter derived empirically during this study show a good agreement with field data during model validation. It seems feasible to be used as part of sago palm growth model.

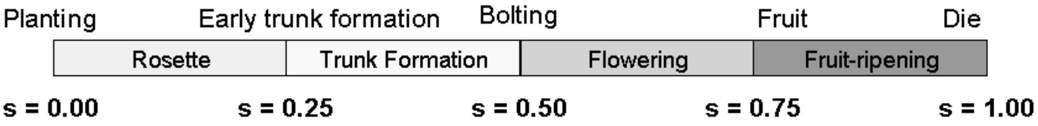

Figure 1. Phenological model of sago palm

TABLE I. CALCULATION RESULTS OF ABOVE GROUND DRY MATTER PARTITIONING IN TEBING TINGGI AND PONTIANAK.

Tebing tinggi					
s	η_S	η_{Pt}	η_{Rc}	η_{Lf}	η_L
0.0460	0.0000	0.7818	0.0911	0.1271	1.0000
0.1842	0.0000	0.7401	0.1233	0.1366	1.0000
0.2301	0.3195	0.4232	0.1639	0.0934	0.6805
0.3221	0.5652	0.2386	0.1207	0.0756	0.4348
0.6030	0.6315	0.1988	0.0957	0.0740	0.3685
1.0000	0.9336	0.0401	0.0140	0.0123	0.0664
Pontianak					
s	η_S	η_{Pt}	η_{Rc}	η_{Lf}	η_L
0.1402	0.0000	0.7894	0.0865	0.1242	1.0000
0.2804	0.5166	0.3596	0.0672	0.0566	0.4834
0.3272	0.5968	0.2774	0.0734	0.0524	0.4032
0.4205	0.6988	0.1890	0.0645	0.0477	0.3012
0.6671	0.7374	0.1527	0.0587	0.0512	0.2626
0.8725	0.8641	0.0675	0.0384	0.0301	0.1359
1.0000	0.8927	0.0560	0.0288	0.0225	0.1073

Note: ηS: trunk partition, ηL: leaf partition, ηPt: petiole partition, ηRc: rachis partition, ηLf: leaflet partition

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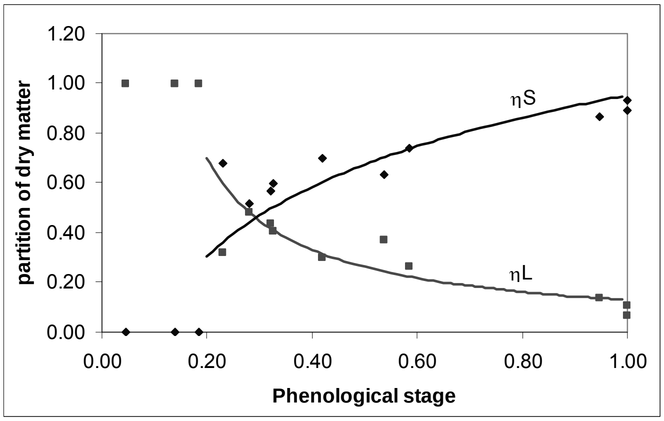

Figure 2. AGD partitioning to leaf (ηL)and trunk (ηS) formation at different phenological stages

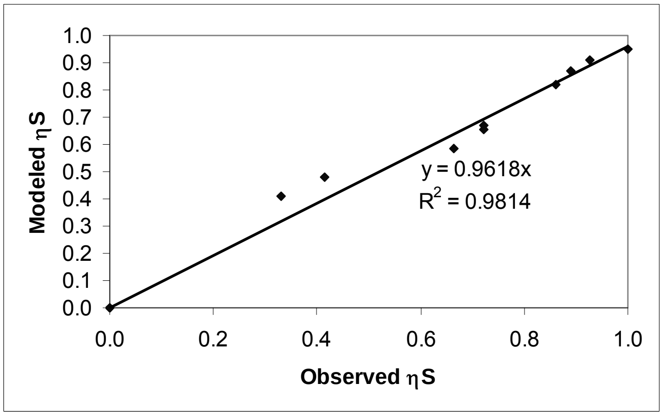

Figure 3. Comparison of observed ηS and modeled ηS

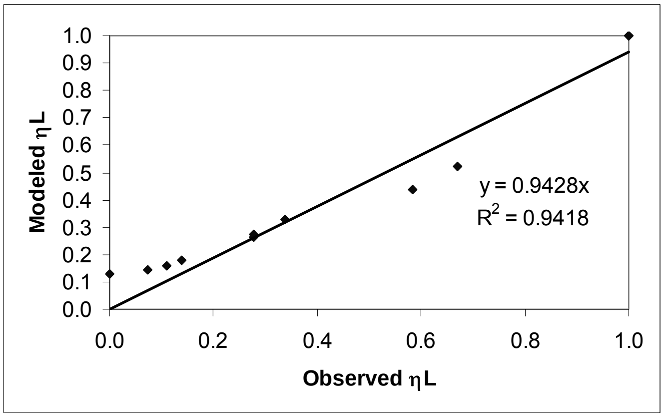

Figure 4. Comparison of observed ηL and modeled ηL

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