Effects of Fertilizer Application on the Root and Aboveground Biomass of Sago Palm (*Metroxylon sagu* Rottb.) Cultivated in Peat Soil

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Abstract  In previous studies, fertilizer application to sago palms cultivated in peat soils did not appreciably improve the growth of sago palm. We applied ca. 7 times the general rates of nutrients (N, P, K, Ca, Mg, Cu, Zn, Fe and B) to sago palm cultivated in peat soils at Riau, and evaluated the response of the roots and aboveground biomass during the 16 months period following the fertilization (2 dry seasons and 1 wet season). The dry weight of the sago palm roots with fertilizer was smaller than that at the onset of the experiment, whereas the sago roots without fertilizer was similar in dry weight to the initial ones. The response of the aboveground biomass to fertilization differed among organs, i.e., the dry weights of the leaves, rachis, and trunk did not differ significantly between the palms with and without fertilizer application, while those of petioles and suckers were significantly greater in the palms with fertilizer. The percentage of the dry weight of mother palm in the total dry weight decreased linearly with increasing the dry weight of suckers, which ranged from 74% to 57% for the palms with fertilizer versus from 85% to 79% for the palms without fertilizer. This observation indicates that the application of fertilizer accelerated the accumulation of dry matter in suckers rather than in mother palm.

Key Words: Aboveground, Dry weight, Mother palm, Sucker

Introduction

Sago palm (*Metroxylon sagu* Rottb.) can survive in adverse environments, such as those created by peaty, submerged, acidic, or saline soil (Matsumoto et al., 1998). Average starch yield of sago palms cultivated in peat and mineral soils ranged from 164 to 180 kg per palm (dry weight basis), and the difference between the soil types was insignificant (Yamamoto et al., 2003). However, a longer period is taken until sago palms reach the harvesting stage in peat soils than in mineral soils (Jong and Flach, 1995; Yamamoto et al., 2003), possibly caused by nutrient limitations. Improving nutritional conditions in peat soils may enable starch yield of sago palms to increase in humid tropics.

Kakuda et al. (2000) found slower rate of nitrogen mineralization per unit volume of soil for peat soils than for mineral soils. Naganuma et al. (1993) also reported that zinc and copper are likely to be short in peat soils. The unproductive period may be shortened by supplying the required nutrients as fertilizer (Jong and Flach, 1995), which is also necessary for sustainable production of sago palm (Flach and Schuiling, 1991). However, the supply of the above elements has not improves the growth of sago palm appreciably (Kueh, 1995; Benito et al., 2002). The application rate of fertilizer in their experiments might be insufficient for the demand of sago palms, because availabilities of the supplied nutrients in peat soil could be lower than those in mineral soils (Naganuma et al., 1993; Yamaguchi et al., 1997; Kakuda et al., 2000). Hence, to establish the effective method of fertilizer application for sago palm cultivation in peat soils, the relationship between nutrient supply and sago palm growth should be revealed.

In sago palm cultivation performed in Indonesia, fertilizer is generally applied in shallow pockets at a 1-m distance from palm cluster (Jong, 2001). Hence, concentration of nutrient in the fertilized position is extremely high. Sago palm roots are likely to be affected by high concentration of nutrient in the fertilized position. However, the response of sago palm roots to fertilizer has never been evaluated.

In the present study, we supplied a larger dose of chemical fertilizers than general application
rates to sago palm cultivated in a peat land in Indonesia, and evaluated the response of the roots and aboveground biomass to fertilization.

**Materials and Methods**

**Experimental site and cultivation of sago palm**

The experiment was conducted in a sago palm plantation area at Tebing Tinggi, Riau, Indonesia (0°47’16” N, 102°58’10” E), where peat soil consisting of complex woody materials is distributed with the depth of over 3 m, and soil water table is regulated at about 20 to 50 cm below the soil surface (Jong, 2001). Soil pH (H2O) averaged 3.8 and the bulk density averaged 0.15 g cm⁻³. Sago palms were transplanted in 1998 with a 8 × 8 m spacing between plants and had been grown without fertilizer before the experiment was started. Sucker regulation has been carried out once a year since the transplanting. All the sago palms used in the present study belonged to the spiny-type, and had not reached the trunk formation stage.

**Fertilizer application**

Eleven plants similar in growth were chosen, and ca. 7 times the general rates of chemical fertilizers (Table 1) were applied to the four plants twice in July 2003 and January 2004. Dolomite was spread (top dressing) to draw a circular band with 3 cm width around the palm cluster at a 1-m distance. The other components were placed 0.2 m under the dolomite circle at four positions (North, South, East, and West). No fertilizer was given to the remaining palms. Suckers were not removed throughout the experimental period.

**Measurements of root distribution and root morphology**

Distribution and morphology of sago palm roots were measured for three non-fertilized palms in July 2003 and eight palms with and without fertilizer in November 2004. Cubic soil blocks (0.3 × 0.3 × 0.3 m) from the surface to a 0.6 m depth (November 2004) or a 0.9 m depth (July 2003) were collected from the four positions where the fertilizers were applied (Fig. 1). In November 2004, the 0.6 - 0.9 m soil was not collected because of high water table. Sago palm roots were manually separated from the soil and washed with tap water. Dry weight of the roots was measured after oven-drying at 70°C for 48 h.

**Measurement of aboveground biomass**

Dry weight of the aboveground biomass of sago palm was measured in November 2004. Leaves were separated from the trunk and classified according to their age. Fresh weight was measured for trunk (T), suckers (S), and the leaflets (L), rachis (R), and petioles (P) of each leaf. Dry weight was measured for a portion of respective organ samples after oven-drying at 70°C for 48 h. Total dry weight of each organ of a palm was calculated based on the ratio of dry weight to fresh weight as follows:

\[
Trunk \ dw (Tdw) = Tfw \times Tdw/fw \\
Sucker \ dw (Sdw) = Sfw \times Sdw/fw \\
Petiole \ dw (Pdw) = \sum_{i=1}^{n} (Pifw \times Pidw/fw)
\]

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**Table 1 Application rates of fertilizer**

<table>
<thead>
<tr>
<th>Fertilizer</th>
<th>Application rate g palm⁻¹ y⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dolomite</td>
<td>2000</td>
</tr>
<tr>
<td>Urea</td>
<td>6666</td>
</tr>
<tr>
<td>Rock Phosphate</td>
<td>2340</td>
</tr>
<tr>
<td>KCl</td>
<td>10000</td>
</tr>
<tr>
<td>CuSO₄</td>
<td>66</td>
</tr>
<tr>
<td>ZnSO₄</td>
<td>66</td>
</tr>
<tr>
<td>FeSO₄</td>
<td>20</td>
</tr>
<tr>
<td>Borate</td>
<td>10</td>
</tr>
</tbody>
</table>

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Fig. 1 Schematic representation of the sampling pattern: a vertical section through the soil, showing the locations of root collection. Samples were collected 1 m to the north, south, east, and west of the palm cluster.
Leaflet dw (Ldw) = \sum_{i=1} n (Lifw \times Lidw/fw)

Rachis dw (Rdw) = \sum_{i=1} n (Rifw \times Ridw/fw)

Total dw = Tdw + Sdw + Pdw + Ldw + Rdw

where dw and fw indicate dry and fresh weights, respectively. The subscripts following P, L, and R indicate the age of leaves, in which the youngest is expressed by 1 and the oldest by n.

Results and Discussion

Growth of sago palm

The three sago palms harvested in July 2003 had 5.2-5.4 m height and 9-11 leaves (Table 2). These values were similar or somewhat smaller in comparison with sago palms grown for 4-7 years after transplanting on peat soil in Dalat, Sarawak, Malaysia, that had 4-7 m height and 11-16 leaves (Kaneko et al., 1996). The eight sago palms harvested in November 2004 had 5.1-8.6 m height and 8-12 leaves irrespective of fertilizer application (Table 2). Thus, no significant change in sago growth was observed between fertilizer and no-fertilizer applied palms.

Response of sago palm roots to fertilizer

The dry weight of the sago palm roots at a 1-m distance from the cluster ranged from 0.31 to 0.87 kg m\(^{-3}\) (Table 3), which was similar to that of irrigated rice, an annual crop (Pradeep et al., 1994). The dry weight of the sago palm roots with fertilizer applied at a high dose was smaller than that at the onset of the experiment, whereas the sago roots without fertilizer was similar in dry weight to the initial ones. Since the roots were collected at the positions where fertilizers were applied, the smaller dry weight might be due to its decrease under locally high level of nitrogen in the soil. The decrease in root biomass following nitrogen fertilization was also observed for other tree species (Alexander and Farley, 1983; Vogt et al., 1985).

In broad-leaved and needle-leaved forests, significant negative correlation between fine root biomass and the amount of nitrogen in litter was observed (Vogt et al., 1986). Our hypothesis was that the biomass ratio of fine root to coarse root would be influenced by nitrogen fertilization, and its phenomenon could be expressed by an index; root dry weight ratio (Dry weight / Fresh weight). However, the root dry weight ratio did not respond to the fertilizer application in the present study (Table 4). This result implies two possibilities: one is that the root dry weight ratio of fine root and that of coarse root might be the same, and the other is that the biomass ratio of fine root to coarse root might not be influenced by the fertilizer application. Further study is required to identify the part of

<table>
<thead>
<tr>
<th>Season</th>
<th>Treatment</th>
<th>Sample No.</th>
<th>Height m</th>
<th>No. of leaves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jul. 2003</td>
<td></td>
<td>1</td>
<td>5.4</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>5.4</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>5.2</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>mean</td>
<td>5.3 (0.1)</td>
<td>10.0 (0.6)</td>
</tr>
<tr>
<td>Nov. 2004</td>
<td>Fertilizer</td>
<td>1</td>
<td>6.4</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>6.7</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>7.1</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>7.1</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>mean</td>
<td>6.8 (0.2)</td>
<td>11.3 (0.5)</td>
</tr>
<tr>
<td>Nov. 2004</td>
<td>No Fertilizer</td>
<td>1</td>
<td>8.6</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>7.6</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>6.0</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>5.1</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>mean</td>
<td>6.8 (0.8)</td>
<td>9.3 (0.8)</td>
</tr>
</tbody>
</table>

Numbers in parentheses represent standard error.
the roots, which reduced its biomass after the fertilizer application.

Response of aboveground biomass to fertilizer

Despite the larger average value of total dry weight of sago palms with fertilizer application than that without fertilizer, their difference was statistically insignificant (Table 5). However, the response of the sago palms to fertilization differed among organs, i.e., the dry weights of the leaves, rachis, and trunk did not differ significantly between the palms with and without fertilizer application, while those of petioles and suckers were significantly greater in the palms with fertilizer. The rates of increase in dry weight were 2.6 and 9.0 kg palm\(^{-1}\) y\(^{-1}\) for petioles and suckers, respectively. Therefore, it appears that the suckers showed the largest response to the fertilizer.

Although the total dry weight related positively to the sucker dry weight, two groups in the correlation were observed (Fig. 2). In the first group, which consists of the palms without fertilizer, the sucker dry weight ranged from 2.7 to 10.4 kg palm\(^{-1}\), and the slope obtained from the linear regression was 5.15. In the second group, which consists of the palms with fertilizer, the sucker dry weight ranged from 11.9 to 26.8 kg palm\(^{-1}\), and the slope of the linear regression was 1.26. This result indicates that the rate of increase of total dry weight to increasing sucker dry weight were influenced by the fertilizer application.

The percentage of the dry weight of mother palm in the total dry weight related negatively to the dry weight of suckers (P = 0.01), which ranged from 74% to 57% for the palms with fertilizer versus from 85% to 79% for the palms without fertilizer (Fig. 3). This observation indicates that the application of fertilizer accelerated the accumulation of dry matter in suckers rather than in mother palm.
Cultural practices for an effective production of sago palms

The present study suggested that the continuous application of fertilizer to sago palms at a heavy dose has a potential to lead a decrease in overall nutrient recovery rate due to the decrease in root biomass. However, Alexander and Farley (1983) reported that tree roots increase longevity with increasing nitrogen fertilizer. Bakker et al. (1999) observed that liming increased bulk soil pH, exchangeable Mg, Ca and the Ca/Al molar ratio, and decreased exchangeable Al, and then resulted in improve longevity of oak fine roots. These findings suggest that physiological activities of the roots are maintained for a long duration by the nitrogen supply or the liming with dolomite. In addition, the negative effect is not definitive, because the root biomass located far from the positions where fertilizers were applied was not measured. To determine the optimal fertilization regime, long-term observations of the fertilizer effect on sago palm growth are required.

Sago palm produces a number of suckers through the whole growth period. In intensive sago palm cultivation, one desirable sucker is retained for each cluster to propagate the plant at an interval of 18 to 24 months. With this approach to sucker control, a cluster of mature palms is expected to consist of six to eight palms at different growth stages, thereby providing a regular supply of palms for subsequent harvesting (Jong, 2001). However, our results suggest that sucker control should be done more frequently after fertilization, because suckers compete with the mother palm for the nutrients, and the dry weight of suckers increases faster than that of all other plant parts in response to fertilization. A long interval of sucker control would lead to unproductive accumulation of dry matter in the suckers. This phenomenon may be responsible for the lack of a significant increase in total dry weight of the mother palm in response to fertilization. It is possible to reduce the rate of fertilizer for achieving a high yield of sago starch by conducting a frequent sucker control.

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References


泥炭土壌に生育するサゴヤシの根と地上部の生育量に及ぼす施肥の影響

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要 約 泥炭土壌で栽培されているサゴヤシの施肥試験では、これまで生育に対する顕著な改善がみられなかった。本試験では、インドネシア、リアウ州の泥炭土壌で栽培されているサゴヤシに対し慣行の約7倍量の養分（N, P, K, Ca, Mg, Cu, Zn, Fe, B）を施肥し、施肥16ヶ月後（乾季1回、雨季2回）にサゴヤシの地上部および地下部生育量について評価した。多量施肥のサゴヤシ根の乾物重は試験開始時よりも低下したのに対し、無施肥のサゴヤシ根の乾物重は試験開始時とほぼ同じであった。一方、地上部乾物重の肥料反応性は各器官により異った。小葉、葉軸および枝幹の乾物重は施肥および無施肥のサゴヤシ間に有意差はみられなかったのに対し、葉柄および枝条の乾物重は施肥したサゴヤシで有意に増加した。地上部全乾物重に占める母本の乾物重（全乾物重－吸枝の乾物重）の割合は、吸枝の乾物重の増加に伴い直線的に減少し、施肥したサゴヤシでは74%から57%、無施肥のサゴヤシでは85%から79%に減少した。この結果より、サゴヤシに対する施肥は母本よりも吸枝への乾物重の蓄積を促進することが明らかとなった。

キーワード 乾物重、吸枝、地上部、母本