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# Growth of Sago Palm Seedlings under Different Soil pH Conditions at the Experimental Farm in Kendari, Indonesia

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## Introduction

The sago palm (*Metroxylon sagu* Rottb.) is a monocotyledon plant that grows in swampy and peaty soils where almost no other major crops can grow without drainage or soil improvement (Sato et al., 1979; Jong, 1995). The sago palm is one of the most important bioresources, not only for sustainable agriculture, but also for rural development in swampy areas of the tropics (Ehara, 2009). Its carbohydrates can be further processed into various basic raw materials for food, animal feed, and industrial uses (Ehara et al., 2000). In Indonesia, the sago palm has been culturally significant and has played an important socioeconomic role for hundreds of years. According to Oates (1999), by the early 14th century, the sago palm was a major agricultural product in the region from South Mindanao and Northern Borneo to South Sulawesi and the Maluku Islands. At the mature stage, it produces a huge trunk that may reach 7-15 m in height and 1.2 m in average girth at the base of the palm (Flach and Schuiling, 1989). However, its size depends on several factors that include the planted area and physiological characteristics. According to Anugoolprasert et al. (2012b), the sago palm can grow in a widely different soil pH range, from 4.3 to 7.0, under natural conditions in tropical areas.

Plant growth is generally affected by relative concentrations of hydrogen ions ($H^+$). A plant's ability to endure various pH levels depends largely on its ability to take in and utilize nutrients at varying concentrations in the soil solution. Most crops grow well in soil that is neutral, mildly acidic, or mildly basic. Soils are naturally acidic or alkaline, so when correcting the pH of soil for healthy plant growth, it is important to better understand the growth response to soil pH and to be sensible about the long-term effects of different soil management on soil pH. Blagodatskaya and Anderson (1998) reported that the variations in soil pH are natural, due to the chemical characteristics of different types of soils. Generally, plant growth is limited by various factors relating to each soil type; for example, acidic soils significantly limit crop production worldwide, with approximately 50% of the world's potentially arable soils being acidic, illustrating an important constraint on

agriculture (von Uexkull and Mutert, 1995). Some fertilizers can change the soil pH, and thus cause other nutrients to be more available, or can reduce certain nutrient availability to plants. Land utilization often faces problems such as unsuitability for plant growth or unwanted changes in soil pH. In the case where soil pH is exceedingly low, lime or dolomite can be used to improve the soil pH, bringing it to the desired level. Calcium carbonate ($CaCO_3$) is one of the liming materials used to improve or amend the soil, which is a common solution to acidity. However, the soils are characterized by high calcium carbonate ($CaCO_3$) content (more than 5%), which increases the amount of $CaCO_3$ in the soil, and as a result, the availability of most nutrients is considerably decreased (Chein and Somponges, 1987). Hence, the amount of lime or dolomite required to correct an acidic pH will vary from soil to soil. It is generally known that excessive use of lime or dolomite causes saline soils, and saline soils contain soluble salts in quantities that affect plant growth at various stages and create yield differences between crops, along with differences in the ion composition of crops at maturity (Sharma, 1997).

In this study, we analyzed the growth of sago palm seedlings grown in the native acid soil and in soil treated with calcium to increase the soil pH at the experimental farm in Southeast Sulawesi, Indonesia. Although the growth of the sago palm is generally considered to decelerate under a low pH condition, such growth depression is usually observed in peat soil compared with that in mineral soil, as reported by Sato et al. (1979). The purpose of the current study is to clarify the effect of different pH levels in soils that are amended with $CaCO_3$ and that have the same parent material on the growth of the sago palm.

**Materials and Methods**

The seeds of *Manno* type sago palm that were collected from Sentani, Jayapura, Province of Papua, Indonesia, on July 11, 2010, were transferred to Kendari, Province of Southeast Sulawesi, as explained by Rembon et al. (2008). The germinated seeds grown in Kendari were used as planting materials. The two experimental plots were placed under natural sunlight in the experimental farm, Faculty of Agriculture, Halu Oleo University. In each plot (14.44 $m^2$) set in the 1 ha sago palm pilot farm, 16 sago seedlings at the third leaf stage (three leaves that have leaflets expanded) or 4 months after germination in a polyvinyl bag were transplanted. The compost with the trade name MOF-821 (Rembon et al., 2008) made from the sago pith residue after starch extraction (123 g C, 10 g N, 6 g $P_2O_5$, 20 g $K_2O$, 30 g CaO, 10 g MgO/kg) was applied in all the plots at the rate of 40 kg with physiological neutral fertilizers, 300 g urea, and 210 g superphosphate of lime (SP36 containing 36% $P_2O_5$). The two treatment plots were set up as follows: (1) control: native acid soil with fertilizers applied as described above; (2) calcium application plot: 3kg calcium carbonate ($CaCO_3$) was also applied to increase soil pH to above 6 prior to transplanting. The soil profile was characterized based on USDA classification methods (Pasolon et al., 2009). The experiment was conducted beginning on December 7, 2011, and 3 plants each among 16 plants in the experimental plot were taken as samples at the beginning of the experiment as well as on June 24, 2012, and October 2, 2012.

The plant growth parameters such as plant height (from soil surface to the top of the standing palm) and plant length (from soil surface to the tip of the longest leaf: total length of shoot) were measured, and the leaf number per plant, leaflet number per leaf, and dead leaf number were counted at the plant sampling in June and October 2012. The dry matter weight of leaflets, rachises, petioles, bases of shoots (leaf sheath part holding the other leaves' sheath inside) and roots, and the leaflet area was measured, and analyses of the growth from December 2011 to June 2012 and from June 2012 to October 2012 were performed. The leaflets of the most active leaves (the uppermost or second expanded leaf from the top) were used for measuring the Soil and Plant Analyzer Development

(SPAD) value, indicating chlorophyll content, using the Chlorophyll Meter SPAD-502 (Minolta Co., Ltd., Japan), and the stomatal conductance using a leaf porometer (Decagon Devices, Inc., Pullman, USA) at the sampling in October 2012. The statistical difference of the data was determined using the Statistical Analysis System (SAS) for Windows v9.0.

**Results and Discussion**

The soil type of the experimental site was alluvial fans, which originally formed from the surrounding sedimented yellow podzolic soils. The texture of the virgin soil was loam, which contained 44% sand, 44% silt, and 12% clay, and its soil pH was 3.5 (KCl) to 4.2 ($H_2O$). The soil pH in the control and calcium application plots was 4.4 (KCl) to 5.4($H_2O$) and 6.5 (KCl) to 6.9 ($H_2O$) respectively, and recognized as acid (control) and neutral (calcium application plot) (Table 1). Calcium application treatment increased Olsen $P_2O_5$, exchangeable Ca content, and CEC and decreased $Al^{3+}$ content in the soil. Then $K_2O$ (HCl 25%), Morgan $K_2O$, exchangeable Mg, and K contents in the soil tended to be lower in the calcium application plot than in the control.

The sago seedlings grew to around 100 cm in plant length in both the control and calcium application plots (Table 2). The growth in plant height, plant length, leaflet number per leaf, dead leaf number per plant, and dry matter weight of each part for 6 months after transplanting were almost the same as in the control and calcium application plots (Table 2). There was a significant difference in leaf number per plant; however, the difference was not so large. Additionally, in the results of growth analysis for 6 months, there were no remarkable differences between the control and calcium application plots (Table 3).

Growth parameters at 10 months after transplanting are shown in Table 4. There were no apparent differences in plant height and plant length between the control and calcium application plots. The leaf number per plant was 16.9 and 16.1 in the control and calcium application plots, respectively, and they were at almost the same level. Considering the result that the leaf number and dead leaf number were at the same level in the two plots, the different soil pH levels in the case of the same soil parent material had no apparent effect on leaf emergence and senescence. These results were in agreement with a former report by Anugoolprasert et al. (2012a), in which a different

**Table 1.** Property of the virgin soil and soils in experimental plots.

| Plot | pH (HCl) | pH (KCl) | Total N (mg/kg) | $P_2O_5$ (HCl 25%) (mg/kg) | $K_2O$ (HCl 25%) (mg/kg) | Olsen $P_2O_5$ (mg/kg) | Bray I $P_2O_5$ (mg/kg) | Morgan $K_2O$ (mg/kg) |
|---|---|---|---|---|---|---|---|---|
| Virgin soil | 4.2 | 3.5 | 400 | 20 | 60 | - | 5.0 | 27 |
| Control | 5.4 | 4.4 | 900 | 380 | 170 | - | 140.9 | 103 |
| Calcium application | 6.9 | 6.5 | 600 | 410 | 90 | 53 | 122.3 | 46 |

| Plot | Exchangeable cation ($cmol_c/kg$) | | | | CEC | $Al^{3+}$ |
|---|---|---|---|---|---|---|
| | Ca | Mg | K | Na | ($cmol_c/kg$) | ($cmol_c/kg$) |
| Virgin soil | 0.73 | 0.20 | 0.05 | 0.13 | 2.34 | 0.84 |
| Control | 1.40 | 0.55 | 0.20 | 0.12 | 2.66 | 0.02 |
| Calcium application | 6.05 | 0.28 | 0.09 | 0.16 | 4.17 | 0.00 |

**Table 2.** Growth parameters of the control and calcium application plots at 6 months after transplanting (June 2012).

| Plot | Plant height (cm) | Plant length (cm) | Leaf number/plant | Leaflet number/leaf | Dead leaf number |
|---|---|---|---|---|---|
| Control | 87.3 ± 2.9 a | 100.3 ± 2.8 a | 11.9 ± 0.2 a | 13.1 ± 0.3 a | 0.5 ± 0.2 a |
| Calcium application | 82.6 ± 3.1 a | 96.4 ± 2.4 a | 10.6 ± 0.3 b | 13.1 ± 0.4 a | 1.3 ± 0.3 a |

| Plot | Leaflet (g plant$^{-1}$) | Rachis (g plant$^{-1}$) | Petiole (g plant$^{-1}$) | Base (g plant$^{-1}$) | Root (g plant$^{-1}$) | Whole (g plant$^{-1}$) |
|---|---|---|---|---|---|---|
| Control | 40.0 ± 2.3 a | 3.6 ± 0.2 a | 69.7 ± 5.1 a | 9.4 ± 1.1 a | 27.1 ± 2.5 a | 149.7 ± 10.3 a |
| Calcium application | 33.5 ± 0.3 a | 3.0 ± 0.1 a | 57.6 ± 2.2 a | 5.0 ± 0.9 a | 28.3 ± 1.6 a | 127.3 ± 3.0 a |

Each value represents the mean ± SE (n=3). Different letters in the table indicate significant difference at the 0.05 probability level, according to the T-test.

**Table 3.** Parameters of growth analysis from December 2011 to June 2012.

| Plot | RGR (mg g$^{-1}$ d$^{-1}$) | NAR (mg cm$^{-2}$ d$^{-1}$) | LAR (cm$^2$ g$^{-1}$) | SLA (cm$^2$ g$^{-1}$) | LWR (g g$^{-1}$) |
|---|---|---|---|---|---|
| Control | 15.56 ± 0.34 a | 0.543 ± 0.023 a | 28.9 ± 0.6 a | 113.2 ± 1.8 a | 0.255 ± 0.002 a |
| Calcium application | 14.44 ± 0.12 a | 0.470 ± 0.024 a | 31.5 ± 1.5 a | 116.3 ± 4.8 a | 0.271 ± 0.003 a |

Each value represents the mean ± SE (n=3). Different letters in the table indicate significant difference at the 0.05 probability level, according to the T-test.

**Table 4.** Growth parameters of the control and calcium application plots at 10 months after transplanting (October 2012).

| Plot | Plant height (cm) | Plant length (cm) | Leaf number/plant | Leaflet number/leaf | Dead leaf number |
|---|---|---|---|---|---|
| Control | 124.4 ± 4.0 a | 134.0 ± 1.0 a | 16.9 ± 0.2 a | 34.0 ± 0.7 a | 3.1 ± 0.0 a |
| Calcium application | 112.5 ± 4.6 a | 123.5 ± 3.8 a | 16.1 ± 0.4 a | 30.5 ± 1.2 a | 3.0 ± 0.2 a |

| Plot | Leaflet (g plant$^{-1}$) | Rachis (g plant$^{-1}$) | Petiole (g plant$^{-1}$) | Base (g plant$^{-1}$) | Root (g plant$^{-1}$) | Whole (g plant$^{-1}$) |
|---|---|---|---|---|---|---|
| Control | 127.0 ± 6.6 a | 14.0 ± 1.3 a | 199.7 ± 19.6 a | 38.1 ± 3.8 a | 34.3 ± 1.0 a | 413.5 ± 31.8 a |
| Calcium application | 101.0 ± 10.4 b | 10.6 ± 1.7 a | 123.7 ± 12.8 b | 26.2 ± 3.3 b | 37.8 ± 1.9 a | 299.2 ± 30.2 b |

Each value represents the mean ± SE (n=3). Different letters in the table indicate significant difference at the 0.05 probability level, according to the T-test.

pH condition of culture solution, such as pH 3.6, 4.5, and 5.7, had no effect on the number of emerged leaves, live green leaves, or dead leaves for 4.5 months during summer in a greenhouse at Mie University, Japan.

The difference in dry matter weight tended to be different from plant part to part (Table 4). There were no significant differences in rachis and root dry weights between the two plots, though the leaflet, petiole, base, and total dry weights were larger in the control, with a lower soil pH condition, than in the calcium application plot with a higher soil pH condition. Considering that there were no significant differences in the leaf number per plant and leaflet number per leaf in the two experimental plots and that the leaf dry weight was larger in the control than in

the calcium application plot, the size of a single leaflet might be larger in a lower soil pH condition than in a higher soil pH condition. It took longer than 6 months to observe the difference in the size of single leaflet, which might be related to the leaf emergence rate, one leaf per month in general (Jong, 1995). It was considered that a comparatively long period would be needed for the emergence of a leaf to reflect the effect of the experimental procedure.

Table 5 shows the results of growth analysis for 4 months from 6 months after transplanting. There was a significant difference in relative growth rate (RGR), and the value was larger in the control than in the calcium application plot. RGR can be divided into net assimilation rate (NAR), which is a good index to evaluate photosynthetic activity, and leaf area ratio (LAR) to investigate the morphogenesis of an individual plant. The NAR of the control plants was large compared with that of the plants in the calcium application plot. The components of the LAR, specific leaf area (SLA), indicating leaf thickness, and leaf weight ratio (LWR), which is the ratio of leaf weight to whole plant weight, were the same in the two experimental plots. Although there was a significant difference in NAR, there was no difference in the LAR. Based on these results, the difference in the growth rates of individuals might be attributed to the difference in assimilation rate, not to morphological characteristics.

Considering that there was no difference in the LAR, dry matter might increase, keeping a good balance with the increase in the single leaflet area and total leaf area. Two parameters relating to the NAR, SPAD value and stomatal conductance, are shown in Table 6. There was no significant difference in the SPAD value indicating chlorophyll content per unit leaf area; however, the stomatal conductance was higher in the control than in the calcium application plot. Omori et al. (2000) reported that stomatal density is related to thickness of leaf. Ehara (2009) stated that higher stomatal density would be observed in sago palms grown in soil that contains higher exchangeable Ca. However, there was no significant difference in the SLA indicating leaf thickness between the two experimental plots, and the exchangeable Ca content in the soil was much higher in the calcium application plots. Considering these results, the difference in stomatal conductance in the current experiment might be attributed to stomatal aperture, which might account for the difference in growth rate through assimilation rate, that is, photosynthesis ability. Such differences in stomatal

**Table 5.** Parameters of growth analysis from June 2012 to October 2012.

| Plot | RGR ($mg\ g^{-1}\ d^{-1}$) | NAR ($mg\ cm^{-2}\ d^{-1}$) | LAR ($cm^2\ g^{-1}$) | SLA ($cm^2\ g^{-1}$) | LWR ($g\ g^{-1}$) |
|---|---|---|---|---|---|
| Control | 10.18 ± 0.75 a | 0.388 ± 0.036 a | 26.7 ± 0.5 a | 91.3 ± 1.1 a | 0.293 ± 0.005 a |
| Calcium application | 8.30 ± 0.97 b | 0.297 ± 0.037 b | 28.2 ± 0.2 a | 92.8 ± 0.9 a | 0.303 ± 0.001 a |

Each value represents the mean ± SE (n=3). Different letters in the table indicate significant difference at the 0.05 probability level, according to the T-test.

**Table 6.** Stomatal conductance and SPAD value at 10 months after transplanting in October 2012.

| Plot | Stomatal conductance ($mmol\ m^{-2}\ s^{-1}$) | SPAD |
|---|---|---|
| Control | 62.4 ± 5.3 a | 67.1 ± 2.0 a |
| Calcium application | 43.5 ± 5.2 b | 67.3 ± 2.4 a |

Each value represents the mean ± SE (n=3). Different letters in the table indicate significant difference at the 0.05 probability level, according to the T-test.

conductance and NAR would be reflected in difference in soil properties, such as the $K_2O$ and/or exchangeable K content in soil, of the two experimental plots. Anugoolprasert et al. (2012b) reported that the sago palm adapts to a range of pH values from 4.3 to 7.0 even in soils that have different texture in southern Thailand. They supposed that the sago palm grown under any conditions of soil pH might exhibit an avoidance mechanism to restrict the distribution of any excess of undesirable nutrients in the plant, which would account for the mineral contents in the plant under a wide range of soil pH conditions. According to Anugoolprasert et al. (2012a), sago palm seedlings can maintain nutrient uptake under a wide range of low pH conditions (pH 5.7 to pH 3.6) in a culture solution.

Peaty soil is highly to weakly acidic and contains low levels of calcium, potassium, and phosphorus compared with mineral soil (Tie et al., 1991; Yamaguchi et al., 1994). Although the sago palm grows in mineral soil and in deep to shallow peat soil, the growth of the sago palm will be better in mineral soil or shallow peat soil (Sato et al., 1979). Kakuda et al. (2000) supposed that the reason the growth of the sago palm in peat soil will decelerate compared with that in mineral soil might be the small amount of nitrogen supply per unit of cubic capacity in peat soil. Considering the former studies, nitrogen provision will be one of important factors limiting sago palm growth. On the other hand, Lina et al. (2009) reported that nitrogen did not significantly improve the growth parameters, such as cumulative increase in height, monthly growth rate, base diameter, number of leaves per palm, and number of leaflets per palm, in the early growth stages in the field experiment because nitrogen was provided by nitrogen fixation bacterium. Shrestha et al. (2007) reported that beneficial microbial interactions occur in the sago palm to enhance nitrogen-fixing activity. In our current experiment, the total nitrogen concentration in soil was higher in the control than in the calcium application plot, as shown in Table 1. However, there were no significant differences in plant size and growth rate between the two experimental plots, as shown in Table 2, which might be related to microbial interaction. This experiment indicated that the growth and biomass production of sago palm seedlings at 10 months after planting tended to be better in acidic soil than in neutral soil conditions, as shown in Table 4. This phenomenon may be due to nutrient competition between Ca and Mg with K. Table 1 indicates that lime application reduced the availability $K_2O$ and the exchangeable K cation. In the current study, the growth of sago palm seedlings at soil pH 5.4 ($H_2O$) [4.4 (KCl)] was not small in comparison with that at soil pH 6.9 ($H_2O$) [6.5 (KCl)] on an experimental farm.

It is still unclear whether the sago palm will show a preferable growth at a lower soil pH condition. Based on the results of the current study, the experimental procedures at field level show that the growth of the sago palm will not decelerate under acidic conditions compared with that under neutral conditions in soils that have the same parent material.

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