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Effect of Seasonal Changes in Groundwater Level and Mineral Element Concentrations on Growth of Sago Palm (*Metroxylon sagu* Rottb.) Suckers

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Abstract: The study was conducted from May 2008 to May 2009 at Abelisawa village, District of Pohara, Southeast Sulawesi Province, Indonesia, to clarify the effect of seasonal changes in the groundwater level and mineral element concentrations on the early growth of suckers and the mineral element concentrations in leaflets. Two sites under different soil groundwater conditions, dry (D: groundwater approximately 0 to – 15 cm below the soil surface) and waterlogged (W: groundwater approximately 0 to +10 cm above the soil surface), were selected. The groundwater levels were recorded, and the water was sampled to determine the inorganic-N, P, K, Ca, and Mg concentrations, pH, and EC every two months under D and W. Five suckers approximately 1-year-old growing in clumps with their mother palms and other suckers under D and W were selected to measure the growth characters and sample the leaflets of the youngest expanded leaf for the determination of the total-N, P, K, Ca, and Mg concentrations. The groundwater levels during the study period ranged from +2.0 cm to +8.8 cm under W and from +1.1 cm to – 16.3 cm under D. The changes in groundwater levels, however, did not correspond to the amount of rainfall. Few noticeable effects of the groundwater changes on sucker growth, mineral elements concentrations, pH and EC in the groundwater and in the mineral element concentrations of the young expanded leaf were found. These indicate that groundwater levels ranging from +10 cm to – 20 cm will not critically affect sucker growth.

Key words: groundwater level, mineral element, sago palm, seasonal change, sucker growth.

サゴヤシ（*Metroxylon sagu* Rottb.）の吸枝の生長に及ぼす地下水位とその無機元素濃度の季節的変動の影響

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要旨　本研究は，インドネシア，南東スラウェシ州ポハラ地区のアベリサワ村で2008年5月から2009年5月にわたり，サゴヤシの吸枝の生長と小葉の無機元素濃度に及ぼす地下水位とその無機元素濃度の変動の影響について明らかにすることを目的として行われた．地下水位の異なる2箇所（D：地下水位が土壌表面下0～15cm，W：同0～+10cm）を選び，2008年5月から2009年の5月まで2ヶ月毎に

DとWの各3箇所で地下水位を記録するとともに，地下水を採集して無機元素（無機態—N,P,K,Ca,Mg），ｐＨおよび電気伝導度（EC）を分析した．また，同時に，ＤとＷ下に生育している約1年生の吸枝各5個体を選び，生育調査を行うとともに，最も若い展開葉の小葉を採集して，全—N,P,K,Ca,Mgを分析した．調査期間中の地下水位は，Ｄ区では+1.1cmから-16.3cmの範囲で，Ｗ区では＋2cm〜+8.8cmの範囲で変動したが，この地下水位の変動は降水量の多少とは一致しなかった．地下水位の変動は，そこに含まれる無機元素濃度，ｐＨおよびEC，さらには吸枝の生長および最も若い展開葉の小葉の無機元素濃度にほとんど影響を及ぼさなかった．これらの結果は，約+10cm〜-20cmの地下水位の変動の範囲では，吸枝の生長に明瞭な影響を及ぼさないことを示唆した．今後，吸枝の生長に影響を及ぼす地下水位の範囲についての研究が必要である．

キーワード：季節変化，吸枝の生長，サゴヤシ，地下水位，無機元素

Introduction

Suckers are commonly used as a propagation material in the transplanting of sago palm (*Metroxylon sagu* Rottb.). Suckers used for planting material are usually cut from their mother palms at approximately 1 year of age and have a base diameter of 10–15 cm and a leaf length of approximately 3 m (Schuiling and Flach 1985). Before planting in a field, suckers are commonly nursed for 3–5 months in a small river or a pond, but sometimes they are planted directly during a wet season when monthly rainfall is more than 300 mm (Jong 1995). Investigating suckers grown with their mother palm in the cluster is important for selecting good planting materials and improving the management of suckers.

The natural environment of the growing sites of mother palms and their suckers, including the groundwater level and soil and groundwater nutrient concentrations, has an important role in their growth. However, little has been reported on the effects of the growing environment on the early growth of suckers prior to their separation from the mother palms. Therefore, this study aimed to clarify the effect of the groundwater level and nutrient concentration on changes in the early growth of attached suckers and the mineral element concentrations of their leaves over the course of a year.

Materials and Methods

The study was conducted at a selected sago-palm-growing area around Abelisawa village, District of Pohara Southeast Sulawesi Province, Indonesia, from May 2008 to May 2009. Two sites under different soil groundwater conditions, dry (D: groundwater approximately 0 to –15 cm below the soil surface) and waterlogged (W: groundwater approximately 0 to +10 cm above the soil surface), were selected. The selected sites were surrounded by conventional drainage canals. Five suckers about 3–4 m in total length, approximately 1-year-old, growing in clumps with their mother palms, were selected under D and W. Other suckers were also attached to the same mother palm and grown in the same clumps. The sago palms of the site were planted randomly; thus, the planting density lacked uniformity.

To measure changes in groundwater levels, plastic pipes (PVC) 1.2 m long and 5 cm in diameter were inserted to a soil depth of 100 cm, approximately 1 m from the selected sucker samples. Three pipes were installed in each of the D and W sites. To allow groundwater to enter the pipe to a level equal to that in the soil, holes were drilled in the pipes before they were inserted in the soil. The top of the pipes protruded 20 cm above the soil surface, and the end was capped to prevent rain from falling into the pipe. Groundwater levels were measured and sampled every two months from May 2008 until May 2009 to analyze mineral concentrations (inorganic-N, P, K, Ca, and Mg), pH, and electrical conductivity (EC).

Growth measurement

The height, leaf number, leaflet number, and width and length of the youngest expanded leaf of the selected 5 suckers under D and W were measured every two months starting from the first observation on May 10, 2008. A tape measure was used to measure sucker height from the base to the top of the highest leaf. Leaflet number was counted as the total number of leaflets appearing on the youngest expanded leaf. Leaflet width was measured at the widest part of the four leaflets on both the left and right sides of a leaf. Leaf number was counted as the total number of leaves, including the youngest expanded leaf. Several leaflets from the middle portion of the youngest expanded leaves were sampled and dried for two days at 80°C in a drying oven.

Plant tissue analysis

The dried leaflet samples were ground using an UIRE milling machine (Yoshida Product Co., Japan), and approximately 0.5 g was then taken for digestion with 5 ml sulfuric acid (H_2SO_4). The digested supernatant was then oxidized with hydrogen peroxide (H_2O_2) to facilitate the reaction and heated until all organic constituents were completely digested. The solution was then cooled, filtered, and brought to final volume of 100 ml with distilled water in a 100-ml volumetric flask as a stock solution for further element determination. N was analyzed using the Kjeldhal method. P was determined by the vanadomolybdate-yellow solution following the method described by Murphy and Riley (1962), and the P concentration was measured using a spectrophotometer (UV-1200; Shimadzu Co., Japan) at $\lambda = 710.0$ nm. The concentrations of P, Ca, and Mg were determined by the lanthanum chloride ($LaCl_3$) method, and the P, Ca, and Mg values, with an atomic absorption spectrophotometer (AA-6800, Shimadzu Co., Japan).

Analysis of groundwater mineral elements

Groundwater samples were filtered using Advantec 5C, 110-mm filter paper. Filtered water samples were analyzed for the inorganic-N, P, K, Ca, and Mg concentrations and pH and EC.

The N concentration was analyzed by the Davarda alloy method (Hidaka, 1997). The P, K, Ca, and Mg concentrations were analyzed as for plant tissue samples. The pH was measured with a pH-meter (Horiba D-24), and EC, with a conductivity-meter (Horiba DS-51).

Data analysis

Data means and standard errors at 95% levels were calculated using an Excel spreadsheet Microsoft Windows Program (Microsoft Corp. 2007), and the statistical analysis was conducted using JMP 7 (SAS Institute, Inc. V7.0.2). The means for the D and W conditions were compared by a *t*-test.

Results and Discussion

1. Changes in meteorological conditions

The mean temperature ranged from 24.3°C to 27.1°C and tended to be below the average (25.8°C) from May to Sept. 2008, and above the average from Oct. 2008 to May 2009 (Fig. 1A). The lowest temperature (24.3°C) occurred in July 2008, and the highest (27.1°C), in Nov. 2008. Changes in the mean temperature from Dec. 2008 to May 2009 were relatively small (25.9–26.7°C). The mean solar radiation varied from 9.9 MJ m^{-2} day^{-1} in July to 16.5 MJ m^{-2} day^{-1} in Oct. 2008 (Fig. 1B). Solar radiation tended to decrease from May to July 2008 and to increase from Aug. to Oct. 2008. The mean rainfall fluctuated from 47.6 mm $month^{-1}$ in Sept. 2008 to 385.4 mm month-1 in March 2009. The amount of rainfall decreased sharply from May to Sept. 2008 (dry season) and increased from Oct. 2008 to March 2009 (wet season) (Fig. 1C). The mean relative humidity (RH) was almost stable, varying little (79.9–88.9%) throughout the year. The lowest and highest RH occurred in Nov. 2008 and May 2008, respectively (Fig. 1D).

According to Flach (1980) and Flach *et al*. (1986), the optimum temperature required for sago palm seedling growth is 24.5–29°C, and the optimum

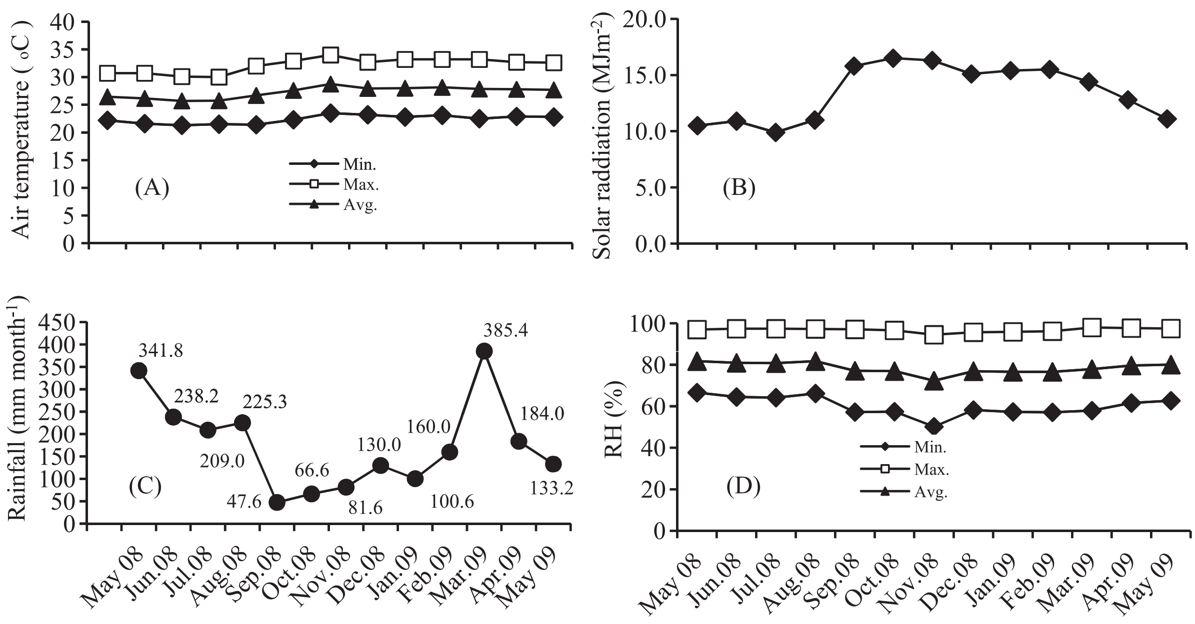

Fig. 1. Changes in air temperature (A), solar radiation (B), amount of rainfall (C), and relative humidity (RH) (D) (May 2008 – May 2009).

mean air temperature is approximately 25°C. The RH required is approximately 90%, and the solar radiation at least 9.0 MJ $m^{-2}day^{-1}$. These data show that the meteorological conditions during the study period were optimum for sago palm sucker growth.

2. Changes in groundwater levels

The mean groundwater levels under D varied from +1.1 cm to −16.3 cm during the dry and wet seasons (Fig. 2). The lowest level (−16.3 cm) occurred on Nov. 10, 2008, and the highest (+1.1 cm), on July 10, 2008. Under W, the mean groundwater levels ranged from +2.0 cm to +8.8 cm. The highest level (+8.8 cm) occurred on Sept. 10, 2008, and the lowest (+2.0 cm), in May 2009. The maximum and minimum differences in groundwater levels between D and W occurred in Nov. 2008 and July 2008, respectively. The correlation between the amount of rainfall and changes in groundwater level was not significant (*r* value: 0.227 for D and 0.559 for W).

3. Groundwater mineral element concentrations, pH, and EC

The mineral element concentrations in groundwater were, in declining order, Ca > K > Mg > inorganic-N > P; the inorganic-N and P concentrations were especially low (Fig. 3). The EC, pH, and concentrations of all mineral elements in groundwater did not differ significantly under D and W, except for the pH in Sept. 2008 and inorganic-N in Nov. 2008. The pH in Sept. 2008 under D was significantly ($p < 0.05$) higher than that under W when the rainfall was the lowest (Fig. 1). According to Younger (2007), the concentrations of cations, such as Ca^{++} and Mg^{++}, as well as Na^{+} and K^{+}, are high (almost always > 1 mg L^{-1}) in most groundwater of the common soil environment. These minerals are classified as exchangeable bases that can raise the groundwater pH. The different water contents under D and W affected the groundwater ion concentrations, and high ion concentrations promoted a greater release of bases under D than under W, resulting in a higher pH under D than under W. These changes correspond with the trend in changes in the groundwater Ca and Mg concentrations, even though they did not differ significantly under D and W.

The groundwater inorganic-N concentrations under W were clearly higher than those under D in Sept. and

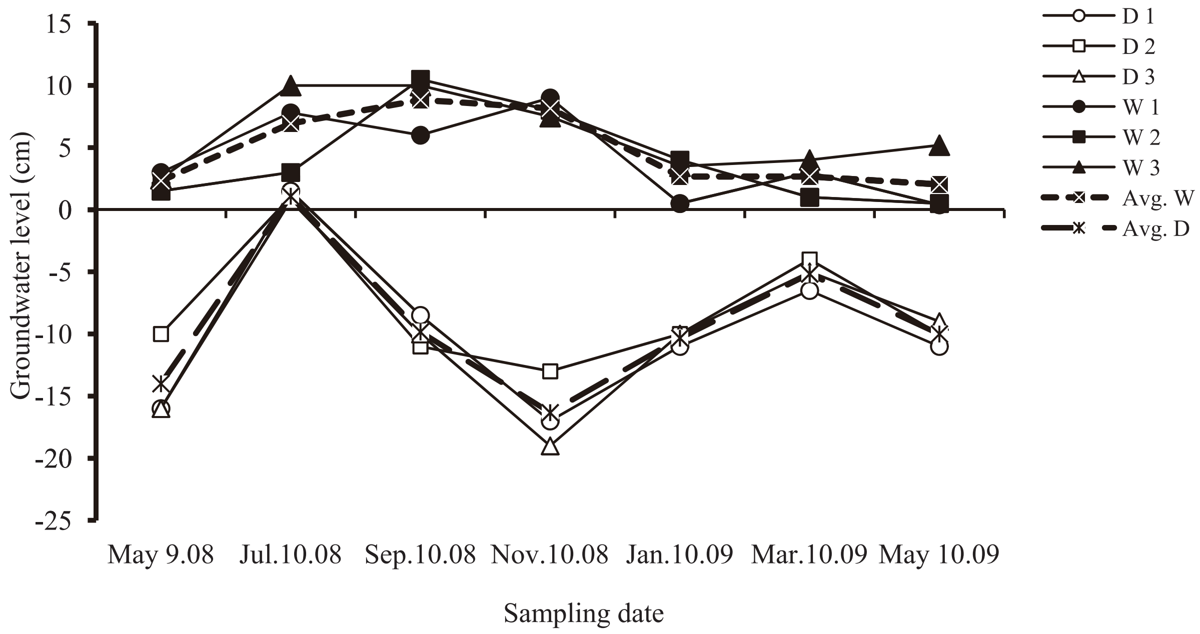

Fig. 2. Changes in groundwater levels (May 2008 – May 2009). D: dry condition, W: waterlogged condition.

Nov. 2008, when rainfall was the lowest, with a significant difference ($p < 0.05$) in Nov. 2008.

The EC tended to be higher under W than under D from May to July 2008 but was nearly the same under both conditions from Sept. to Nov. 2008. The EC was higher under W than under D from Jan. to May 2009 but not significantly.

The correlations between groundwater levels and groundwater pH, EC, or mineral element showed no significant *r* values.

4. Sucker growth

No significant difference was observed in the growth parameters between W and D at the start of the experiments (May 2008). All growth parameters under W tended to be greater than those under D except for the numbers of leaves and leaflets, although only the number of leaves and leaflet length differed significantly ($p < 0.05$) (Fig. 4). The leaflet length was significantly ($p < 0.05$) shorter under D (70.95 and 75.63) than under W (83.48 and 85.98) in Sept. and Nov. 2008. The difference in the groundwater level between W and D increased from Sept. to Nov. 2008 (Fig. 2). Under deeper groundwater conditions, the leaflet elongation growth under D was more significantly suppressed than that under W (Fig. 4D). However, the prolonged flooded water conditions of approximately 10cm during this period might have caused the slower leaf emergence rate under W (Fig. 4B). Jong et al. (2006) reported that the number of leaves in the crown of sago palm under a deeper water table (– 9.2 cm) was greater than that under a higher water table (+43 cm). On the other hand, Hashimoto et al. (2006) reported that the number of leaves of sago palm grown under higher groundwater conditions was higher than that of sago palm grown under lower groundwater conditions within the range of 40-80 cm groundwater. As the prolonged flooded conditions lowered the leaf emergence rate in this experiment, as had been reported by Jong et al. (2006), the effects of groundwater level on the leaf emergence rate need to be clarified under a wider range of groundwater levels, including flooded conditions.

On the other hand, the root growth under D might be promoted due to the lower groundwater level, and,

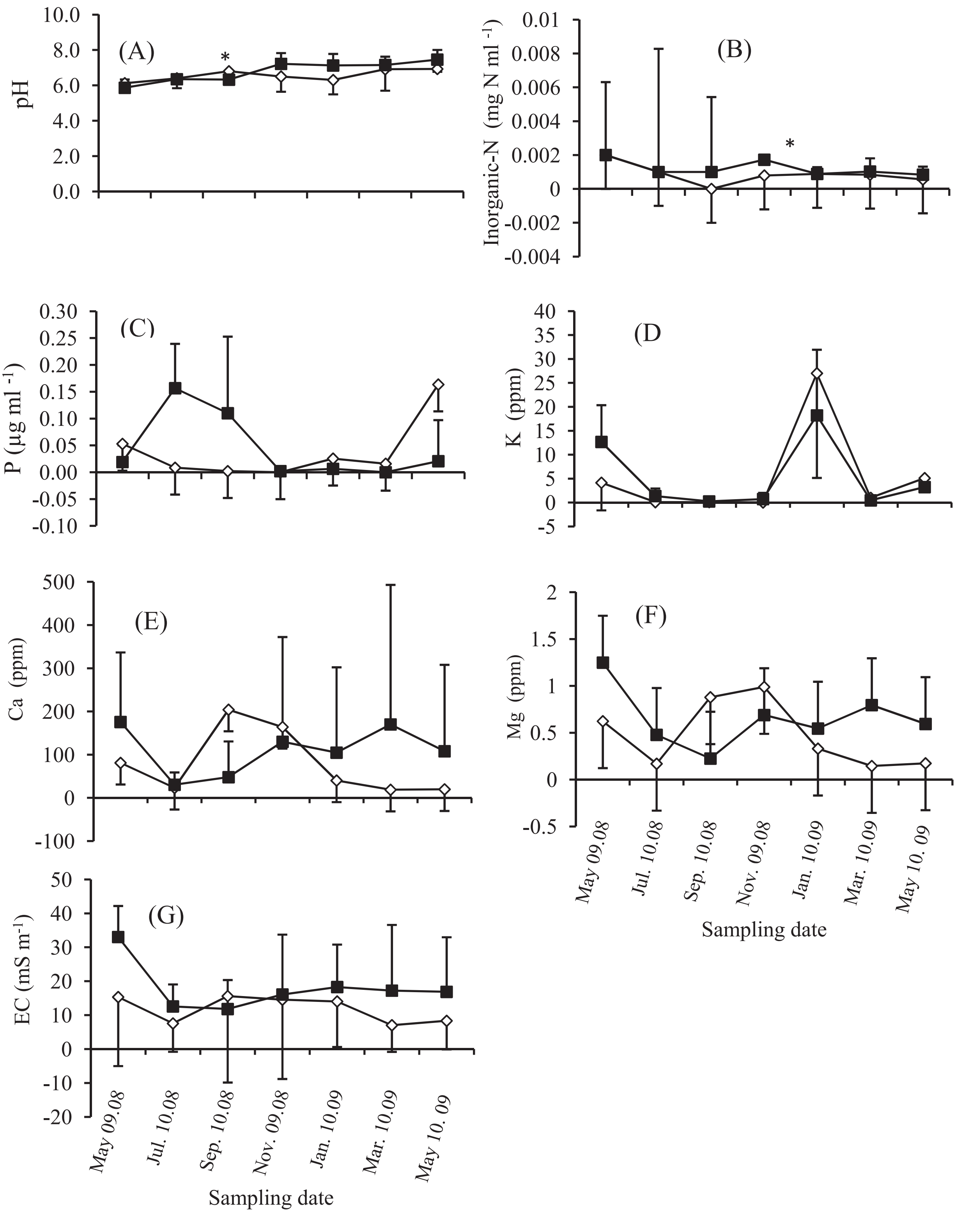

Fig. 3. Changes in groundwater pH (A), inorganic-N (B), P (C), K (D), Ca (E), Mg (F) concentrations, and EC (G) (May 2008 - May 2009). Bars on the symbols indicate the standard error. D (◇); W (■).
* : significant at $p < 0.05$ by t-test.

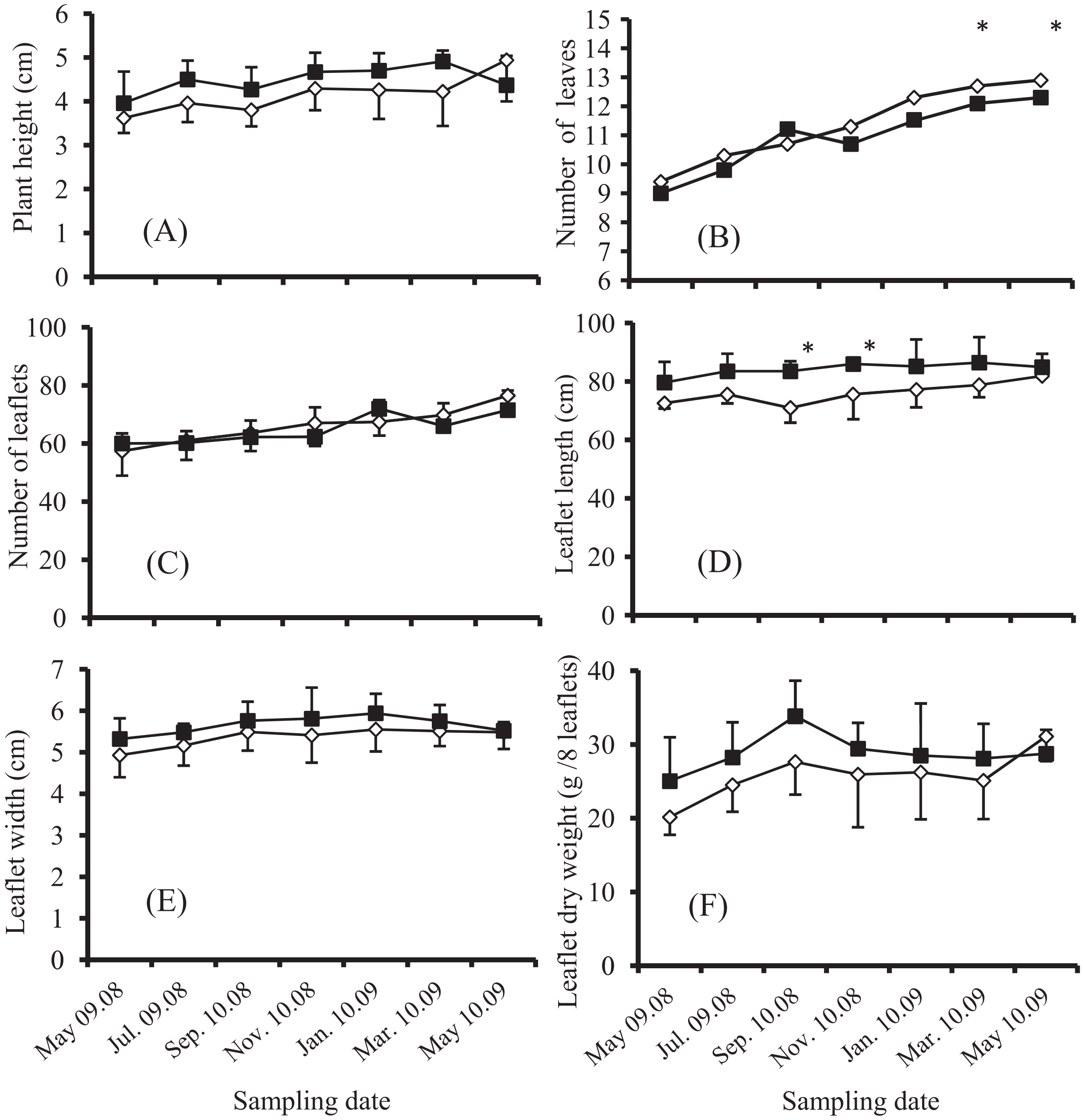

Fig. 4. Changes in plant height (A), number of leaves (B), number of leaflets (C), leaflet length (D), width (E), and leaflet dry weight (F) of the youngest expanded leaf (May 2008 - May 2009). Bars on the symbols indicate the standard error. D (◇); W (■).
*: significant at $p < 0.05$ by t-test.

as a result, the mean number of leaves under D (11.9 and 11.6) was significantly ($p < 0.05$) higher than that under W (10.5 and 10.7) at the end of two months, March and May 2009. The deeper groundwater level, according to the above report (Jong et al. 2006) or similar to the D condition in our study, might have promoted conditions that were conducive for root development, resulting in better shoot growth. According to Miyazaki et al. (2011), more than 50% of 1-3-year-old sago palm root development was at a 0-30 cm depth; therefore, the higher water level resulted in less favorable environment conditions for root growth.

5. Mineral element concentrations in the leaflets of the youngest expanded leaves

The N concentrations under D and W were very similar (Fig. 5). This indicated that, under D and W conditions the N absorption was similar to the difference in groundwater levels, which was only 5 cm; this resulted in a very similar N concentration in the leaflets. The P contents in leaflets were similar under D and W from May to Sept. 2008. From Sept. 2008 to May 2009, the P contents tended to be lower, but not significantly so, under D than under W due to the higher amount of rainfall particularly from Jan. to March 2008 (Fig. 1). N is more water-soluble than P, and, therefore, N availability under conditions of plentiful water is higher than that of P (Shuman, 2001). According to Tisdale et al. (1985), most P moves to roots by diffusion, while N is transported to roots by mass water flow.

The K concentrations in the leaflets were very similar under D and W, but they were significantly

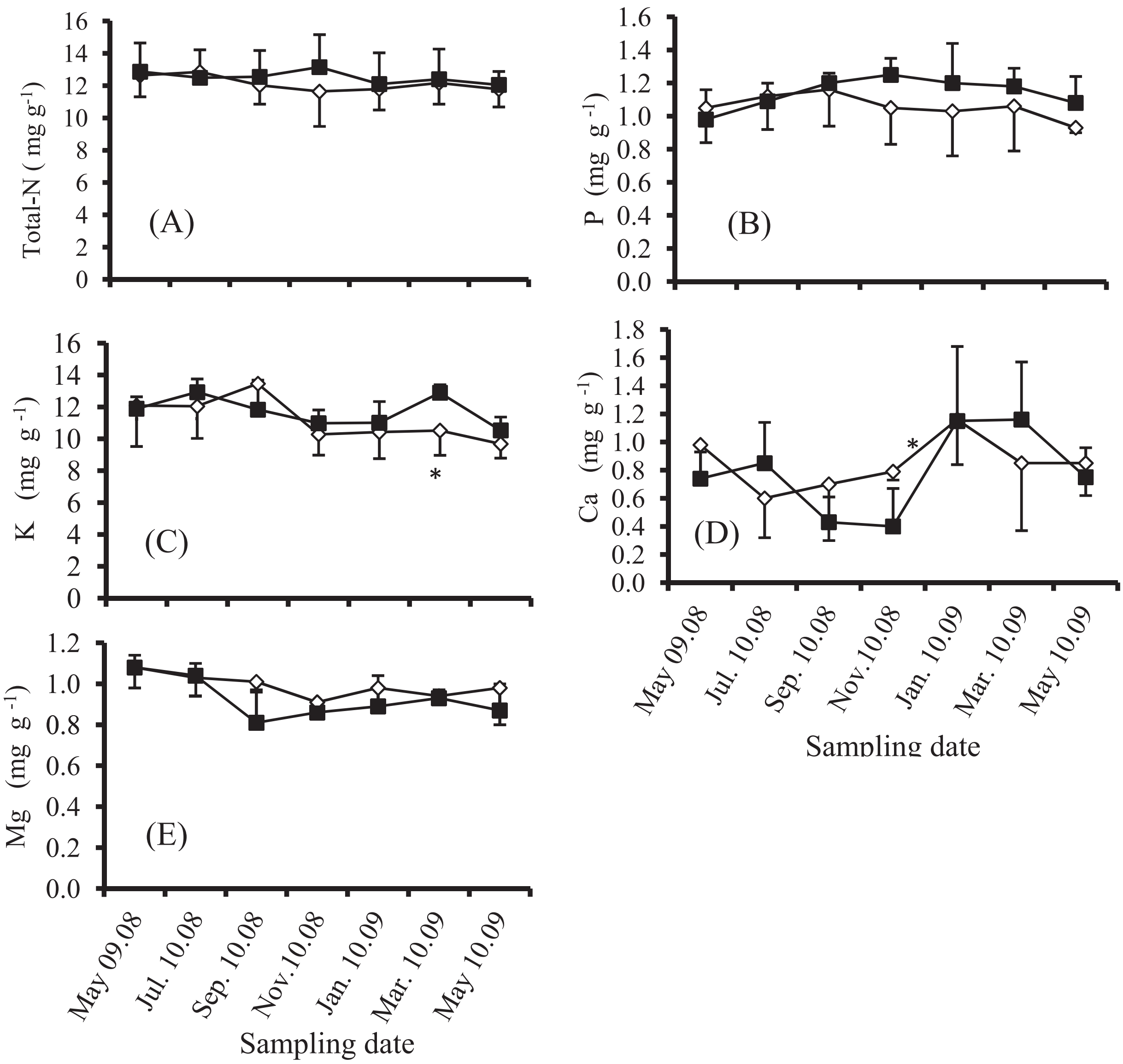

Fig. 5. Changes in total-N (A), P (B), K (C), Ca (D), and Mg (E) concentrations in the leaflets of the youngest expanded leaf (May 2008 – May 2009). Bars on the symbols indicate the standard error. D (◇); W (■).
*: significant at $p < 0.05$ by t-test.

($p < 0.05$) lower under D than under W in March 2009, when rainfall for the experimental period peaked (385.4 mm) (Fig. 1). This result indicates that K absorption depended on the groundwater conditions. As K dissolves relatively easily to form K^+ in water, it is more easily absorbed from a soil solution by roots in the form of K^+ (Tisdale et al. 1985). Furthermore, Tisdale et al. (1985) stated that K was absorbed by roots through diffusion, moving from an area of high concentration to one of low concentration. This was in agreement with our K concentration measurements in the leaflets, which were significantly lower under D than under W, particularly during the peak of rainfall.

Changes in the Ca and Mg concentrations in the leaflets of suckers differed slightly from those in changes in groundwater (Fig. 3). The Ca concentration under D and W tended to decrease or increase as the groundwater level decreased or increased after rainfall. The differences in the Ca and Mg concentrations between D and W were not significant, except for the Ca concentration in Nov. 2008 and the Mg concentration in Sept. 2008, when the Ca and Mg concentrations under D were significantly ($p < 0.05$) higher than those under W. According to Tisdale et al. (1985), the amount of minerals, such as Ca and Mg, reaching the root by mass flow is determined by the rate of water flow or water consumption of plants and the mean soil water mineral concentrations. Our findings are similar to those of Purwanto et al. (2002), who found that the K, Ca, and Na concentrations in leaflets of mature leaves increased significantly as their concentrations increased in the soil solution. They concluded that the cation concentration of sago palm leaflets depended directly on the soil solution cation concentrations, which, in turn, depended on the groundwater level.

Most changes in the leaflet and groundwater nutrients were not significantly correlated, except for P under D, which was significantly and negatively correlated ($r = -0.800$*). This result might be related to the slow water solubility of P, depending on the water content (Shuman 2001). According to Barker and Pilbeam (2007), phosphorus availability is affected by the soil water content by governing the release and diffusion of P in the soil solution and the positional relative to root growth. They also stated that, under conditions of excessive water resulting in poor aeration, P uptake by crops, except aquatic crops, would be restricted in spite of enhanced P solubility.

Conclusions

Groundwater levels during the experimental period fluctuated from +2.0 cm to +8.8 cm under W and from +1.1 cm to −16.3 cm under D. Generally, changes in the groundwater levels did not affect sucker growth or the mineral element concentrations of groundwater and of the youngest expanded leaves. These results indicate that groundwater levels ranging from approximately +10 cm to −20 cm did not critically affect sucker growth.

Further research that would include a wider range of groundwater levels affecting sago palm sucker growth might be worthwhile.

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