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Nitrogen Uptake and Growth Response of Sago Palm (*Metroxylon sagu* Rottb.) to Two Types of Urea Fertilizer Application

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Abstract: This study was conducted to evaluate the effects of slow-release urea fertilizer on sago palm (*Metroxylon sagu* Rottb.) using nitrogen (N) uptake and growth factors. A pot experiment using a 1:2 mixture of Philippine soil (Eutropepts) and sand was performed by applying two types of urea fertilizer, common and slow-release (Meister 40), which are expected to release up to 80% of their nitrogen for 400 days at 20°C at 50 and 100 kg N ha^{-1}. Three replications of each treatment were arranged in a completely randomized design. Two types of urea fertilizer were applied twice at 2 weeks and 12 months after transplanting. Regardless to the forms of urea, the application of 50 kg N ha^{-1} significantly increased palm height, compared to the control (without fertilizer) plot. However, the application of 100 kg N ha^{-1} did not produce a remarkable difference in palm height. In the first few months after the application of urea fertilizer, the common urea treatment showed significantly higher N uptake by sago palm, while, with the application of the slow-release type of urea fertilizer, the N uptake became observable at 6 months, suggesting that the slow-release type controlled the release of N from the fertilizer and regulated N uptake by sago palm. Therefore, it is concluded that a slow-release type of urea fertilizer could be an appropriate fertilizer to use in sago production to mitigate N losses in the growth environment of sago palm.

Key words: urea fertilizer, pot experiment, growth parameter, N uptake

形態の異なる2種類の尿素肥料に対するサゴヤシの窒素吸収と応答

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要旨 本研究は，窒素吸収と生育因子を用いてサゴヤシに対する緩効性尿素肥料の効果を評価したものである．フィリピンの土壌（Eutropepts）と砂を1:2の混合割合で作製した培地をポットにつめて試験を実施した．異なる2種類の尿素肥料（通常の尿素肥料と緩効性尿素肥料（Meister 40）（20°C，400日で尿素肥料中の窒素の80％が放出される）を移植2週間後および12ヶ月後にha当たり50および100 kg施用し，3反復で，ランダム配置し，サゴヤシの窒素吸収と生育因子についてコントロール（尿素肥料無施用）区と比較した．いずれの尿素肥料施用区においても50 kg N ha^{-1} の施用は，コントロール区に比べてサゴヤシの樹高を増加させた．しかし，100 kg N ha^{-1}を施用すると，樹高の増加は明瞭ではなくなった．移植2週間後に通常の尿素肥料を施用すると，サゴヤシの窒素吸収は，施肥後短期間で有意に増加した．一方，移植2週間後に緩効性尿素肥料を施用すると，試験開始6ヵ月目にサゴヤシの窒素吸収の増加が明瞭となった．緩効性尿素肥料を用いれば，肥料からの窒素の放出を規制でき，サゴヤシの窒素吸収を制御することができた．したがって，サゴヤシの生育環境における窒素の損失を最小限にするために，緩効性尿素肥料をサゴヤシ生産にとって，より適切な肥料として位置づけ，利用すべきであると結論した．

日本語キーワード：緩効性尿素肥料，ポット試験，生長因子，窒素吸収量，

Introduction

Nitrogen (N) is the most important element in fertilization programs because plants usually need N in greater amounts than other nutrients (Escobar et al. 2004). Most commercial fertilizers supply N in easily water-soluble forms. Urea is one of the most widely used dry granular sources of N (SRI 2008) because of its higher N content (46%) than that of other N sources, such as ammonium sulfate. However, large quantities of urea fertilizers are often applied to achieve yield potentials of crops. However, this practice can lead to an increase in the risk of N leaching in most intensive cropping systems. The increasing fertilizer use efficiency (FUE) and the prevention of fertilizer loss to the environment are important goals of agronomic management. These objectives can be addressed by using an alternative source of N fertilizer that will meet the target yields of crops without further damaging the environment. Slow-release urea fertilizers manufactured to provide a gradual N supply for a long period of time (Shaviv 2000) have been used with success to reduce N leaching loss and increase FUE in the cultivation of agricultural crops, including rice, corn, forage grasses, and forest trees (e.g., Shoji and Gandeza 1992; Shoji et al. 2001; Drost et al. 2002; Fashola et al. 2002). In contrast, controlled-release fertilizer or dry-soluble granular fertilizer did not improve the growth of orange trees (Marler et al. 1987), and Meister 270, a slow-release urea, did not release N fast enough to meet the requirements of cotton (Chen et al. 2008).

On the other hand, few studies have reported the use of slow-release fertilizers to improve the efficiency of fertilizer use for important plantation crops, such as sago palm (*Metroxylon sagu* Rottb.). Unlike other perennial plants, the understanding of sago palm and its utilization is limited, and there is little information related to sago palm production in the Philippines. This palm is called *lumbia* or *landang* in the local dialect of Mindanao of the Philippines (Josue and Okazaki 1998). Sago palm is the crop par excellence for sustainable agriculture (Singhal et al. 2008). It is an extremely hardy plant, thriving in swampy acidic peat soils and submerged high-salinity soils, where few other crops survive, although it grows more slowly in peat than in mineral soil (Flach and Schuilling 1989; Jong and Flach 1995; Flach 2006). In the Philippines, sago palm grows in mineral soils along the creeks and streams of fresh water and marshlands (Quevedo et al. 2005; Loreto et al. 2006).The average yield of dry starch from a mature sago palm (10-15 years old) has been reported to range between 88 and 179 kg palm^{-1} in peat soils and between 123 and 189 kg palm^{-1} in mineral soils in Sarawak, Malaysia (Sim and Ahmed 1991). Jong et al. (2006) reported that starch accumulated progressively in the trunk of sago palm and that each palm was capable of producing about 200 kg of dry starch. It is so far the highest in productivity among the starchy crops of the world (Ishizaki 1997).

For the sustainable production of sago palm, its nutrient requirements should be verified to increase productivity and shorten the period until maturity. Previous results revealed that sago palm has low FUE using urea with ^{15}N stable isotope (Lina et al. 2008). In a pot experiment, the FUE values for sago seedlings (< 6 months) treated with 50 and 100 kg N ha^{-1} were 10.5 and 13.2%, respectively, whereas, for the 2-year-old sago palms in the field, the corresponding FUE values were 14.8 and 12.0% (Lina et al. 2008). The FUE values were similar between the two levels of N application in either experiment. The use of N fertilizer in sago palm production can only be justified after determining and fully understanding the response of sago palm to N application (Lina et al. 2008). Therefore, in this study, the N uptake and growth responses of sago palm to the form of urea application were evaluated.

Materials and Methods

Establishment of pot experiment

The two-month-old sago palm seedlings (previously germinated seeds) from Leyte, the Philippines, were transplanted in a double-layered polyethylene pot with the inner pot having a 14-cm top diameter x 17 cm height in October 2006. The potting medium used was a mixture of sand and a Philippine soil (Eutropepts) (Bureau of Soils and Water Management 1993) at 2:1 w/w sand to soil ratio. The original soil sample (Lina et al. 2008) was collected at 0-20 cm depth from the sago experimental field in Visayas State University (VSU), Leyte, the Philippines (10° 45’ 10.7" N, 124° 47’ 23.6" E). The soil used had a near-neutral pH of 6.4. The total carbon (TC) and total N (TN) contents were 7.97 and 0.74 g kg^{-1}, respectively, and the available phosphorus content was 36.2 mg kg^{-1} (Lina et al. 2008). The amounts of exchangeable cations were 10.5 $cmol_c$ kg^{-1} for Ca, 2.40 $cmol_c$ kg^{-1} for Mg, and 0.53 $cmol_c$ kg^{-1} for K. The soil texture was silt loam. The two types of N fertilizer tested were common urea and Meister 40 (M40), a slow-release type of urea (Chissoasahi, 2001). M40 is expected to release 80% of its N during a 400-day period at 20°C. We used each fertilizer at three levels: 0 (control), 26, and 52 mg of N per pot. The latter two doses were equivalent to 50 and 100 kg N ha^{-1}, respectively, based on the surface area of the soil in the pots. Three replications were prepared for each treatment with one palm per pot. The treatments were designated as control, Urea-50, Urea-100, M40-50, and M40-100 depending on the kind and application rate of fertilizer. The amount of common urea was applied twice. One half of the dose was applied two weeks after transplanting, and the other half was added one month after the first application. For the M40 treatments, a bulk application was done two weeks after transplanting. At 12 months after transplanting, the same dose of urea or M40 as that in the first application was applied to all treatments except for the control. Each fertilizer was applied evenly around 5 cm from the base of the plant and covered with soil. Watering was done as necessary under controls to minimize leaching. The experiment was conducted in a greenhouse at the Graduate School of Bio-Applications and Systems Engineering, Tokyo University of Agriculture and Technology, Japan, with an average minimum and maximum temperature of 20°C and 25°C, respectively, during the investigation period.

Sago palm growth parameters

Plant height was measured monthly from the base of the plant to the tip of the tallest leaf. In addition, the base diameter of sago was measured, and the leaves and leaflets were counted.

Nitrogen uptake by sago palm

To elucidate the N uptake by sago palm, sago leaflets were collected in a pot experiment. Since the leaves of sago palm in the early growth stage were few and small, there were few leaflets; one leaflet was taken from a recently fully expanded mature leaf in each pot every month. Newly matured leaflets were chosen to avoid bias and to standardize the physiological stage of the leaflet being sampled (Lina et al. 2008). Thus, every 2 months, the leaflet sampling point was changed to a newly fully developed leaf with differing size and number of leaflets.

Leaflet samples were washed with deionized water, oven-dried for 2-3 days at 70°C using a forced-draft oven, and ground with a ball mill (Retsch MM 301). The total N content in leaflet samples was determined using an NC analyzer (Yanagimoto MT-700). The N uptake per palm was calculated as the product of the N content in a leaflet (mg g^{-1} DW), the oven-dry weight of a leaflet, and the number of leaflets under the assumption that the dry weight of leaflets is the same in a palm in the early stage.

Statistical analysis

Statistical analyses (One-way and Two-way ANOVA) for all the parameters measured and Fisher's LSD for comparing significant differences between means were carried out using SigmaStat (SSI, Version 3.11, California, USA).

Results

Sago palm growth parameters

Each sago palm growth parameter was averaged every six months to determine whether significant differences among the treatments were present at different periods. The base diameter varied from 6.7 to 7.8 cm, 7.5 to 8.5, and 7.5 to 9.9 cm at the 6th, 12th, and 18th month after the first urea application, respectively. Although there were no significant differences among the five treatments at all periods (Table 1), the base diameter increased significantly

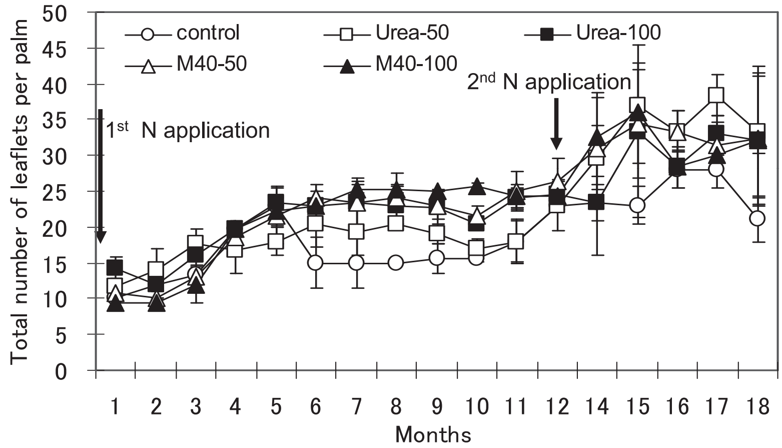
Table 1. Growth parameters of sago as influenced by the form of urea and the timing of urea application at 6, 12 and 18 months after application

Treatment	Base diameter (cm)			Number of leaves			Total number of leaflets per palm		
	Month			Month			Month		
	6	12	18	6	12	18	6	12	18
Control	7.4 ±0.4	7.5 ±0.6	7.5 ±0.9	6.7 ±0.5	8.0 ±0.7	5.1 ±0.8	15.5 ±0.8	17.2 c ±1.5	24.5 b ±2.4
Urea-50	6.7 ±1.1	8.2 ±0.2	9.7 ±1.4	6.4 ±0.5	7.8 ±0.3	5.8 ±0.5	16.4 ±1.1	19.8 bc ±1.8	33.6 a ±2.8
Urea-100	7.6 ±0.3	8.5 ±1.3	9.5 ±2.4	6.9 ±0.2	7.4 ±0.1	5.5 ±0.3	18.1 ±0.2	23.0 ab ±2.8	28.9 a ±6.1
M40-50	7.8 ±0.1	8.5 ±0.5	9.9 ±1.1	6.6 ±0.4	8.0 ±0.4	5.8 ±0.3	16.3 ±1.0	24.2 a ±3.0	32.3 a ±5.5
M40-100	7.1 ±1.3	7.9 ±1.0	8.6 ±0.8	5.9 ±1.4	8.0 ±0.7	5.7 ±0.2	15.9 ±1.4	25.0 a ±0.1	31.9 a ±3.3

Number of replicates = 3
Means with different letters are significantly different ($p \leq 0.05$; Fisher's LSD).
± denotes standard deviation.
urea-50 : urea at 50 kg N ha^{-1}
urea-100 : urea at 100 kg N ha^{-1}
M40-50 : Meister 40 at 50 kg N ha^{-1}
M40-100 : Meister 40 at 100 kg N ha^{-1}

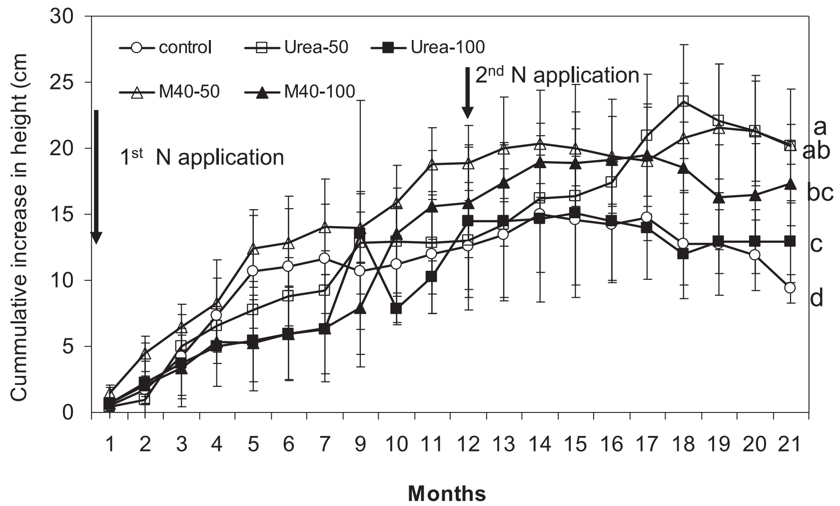
($p < 0.01$) from 6 months to 18 months, especially that of sago palms to which urea had been applied. The number of leaves was not significantly influenced by urea application in any period. The effect of urea application on the total number of leaflets per palm was apparent specifically at the 12th and 18th month after the first application. Twelve months later, the total number of leaflets per palm in the treatments with slow release fertilizer applied at either rate was significantly larger ($p < 0.01$) than that in the control but not significantly different from that in the treatment with common urea applied at 100 kg N ha^{-1}. At the 18th month, although some trends were evident, urea application resulted in statistically significant improvement in only one growth parameter, the total number of leaflets per palm (Table 1). Those treatments, added with either urea or Meister 40, resulted in a significantly ($p < 0.05$) greater number of leaflets, whereas the control plants had the smallest number of leaflets (Figure 1). In addition, the total leaflets per palm increased significantly ($p < 0.01$) from 1 month to 18 months, especially in the treatments added with urea fertilizers in either form (Figure 1).

On the other hand, the cumulative increase in plant height at 6, 12, and 18 months after urea application did not appear to be generally affected by urea application. The increases in plant height were in the ranges of 6.0-12.8 cm, 12.6-18.9 cm, and 12.7-21.2 cm during the periods of 6, 12, and 18 months, respectively, after the first urea application (Figure 2). A rapidly increasing trend in plant height was noted in the cumulative increase after 9 months, in which sago palms with Meister 40 applied at 50 kg N ha^{-1} grew consistently faster until 12 months. However, 21



Vertical bars indicate the standard deviation of the three replications.
Urea-50 : urea at 50 kg N ha^{-1}
Urea-100 : urea at 100 kg N ha^{-1}
M40-50 : Meister 40 at 50 kg N ha^{-1}
M40-100 : Meister 40 at 100 kg N ha^{-1}

Figure 1. Total number of leaflets per palm as influenced by the form of urea and timing of urea application



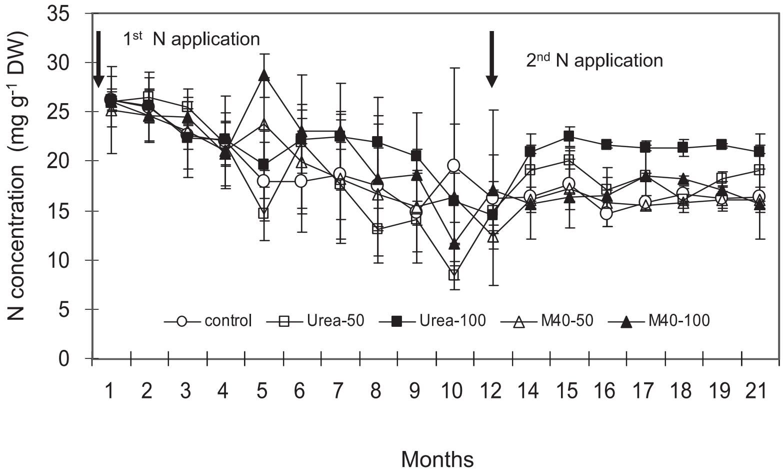
Urea-50 : urea at 50 kg N ha^{-1}
Urea-100 : urea at 100 kg N ha^{-1}
M40-50 : Meister 40 at 50 kg N ha^{-1}
M40-100 : Meister 40 at 100 kg N ha^{-1}

Figure 2. Cumulative increase in height (cm) of sago palm as influenced by the form of urea and the timing of area application

months after the N application, sago palms were taller in the treatments added with urea in either form, especially those with 50 kg N ha^{-1}, than in the control treatment ($p < 0.05$).

Nitrogen concentration in leaflets of sago palm

The N concentration in sago palm leaflets added with common urea or slow-release urea is shown in Figure 3. The N concentration in sago palm leaflets did not vary among the five treatments except at the 5th month, when exceptionally high variation was observed. Interestingly, the N concentration significantly decreased ($p < 0.01$) from 25.9 mg g^{-1} DW at the 5th month to 15.0 mg g^{-1} DW at the 12th month. After the second N application, significant differences were observed among treatments during the 15th, 16th, and 18th months. During the 15th and 16th months, the application of common urea at 100 or 50 kg N ha^{-1} significantly increased the N concentration in sago palm leaflets.



Urea-50 : urea at 50 kg N ha^{-1}
Urea-100 : urea at 100 kg N ha^{-1}
M40-50 : Meister 40 at 50 kg N ha^{-1}
M40-100 : Meister 40 at 100 kg N ha^{-1}

Figure 3. Nitrogen concentration in leaflet of sago palm as influenced by the form of urea and the timing of urea application

Nitrogen uptake by sago palm

A significant effect of treatment on the N uptake by sago palm was observed at 1 month after urea application. During the 1st month, the N uptake in the Urea-100 treatment, 402 mg palm^{-1}, was significantly larger than that in the other treatment, 197-214 mg palm^{-1} (Figure 4). In the 2nd month, the N uptake in the urea-50 treatment was also larger than those in the M40-50 and M40-100 treatments. An exceptionally high N uptake was observed in the M40-100 treatment at the 3rd month. However, in the 6th month, the N uptake in the M40-50 treatment was larger ($p < 0.05$) than that in the control. During the 16th and 17th months, the N uptake was significantly higher in the urea-50 treatment ($p < 0.05$) than those in the urea-100, M40-50, and M40-100 treatments (Figure 4A and 4B). However, at the 18th month, the N uptake in the M40-100 treatment was larger ($p < 0.01$) than that in the control and comparable to those in the other treatments.

Discussion

Sago palm growth parameters

The results of the current study revealed that the growth of the 2-month-old sago palm seedlings was slightly affected by urea application during the 21st month of the pot experiment. The application of urea resulted in a significant gain in the height of sago palms after 18 months, and the total leaflets per palm increased. Sago palms applied with slow-release urea at 50 kg N ha^{-1} showed a slightly higher cumulative increase in plant height during the first 12 months of observation. However, after the second N application (18 months later), sago palms applied with urea at 50 kg N ha^{-1} in either form grew significantly faster than the control plants. In contrast, Purwanto et al. (2002) did not report any significant effect of N fertilizers on plant height and leaf formation for sago palms grown in peat soil even after a second application.

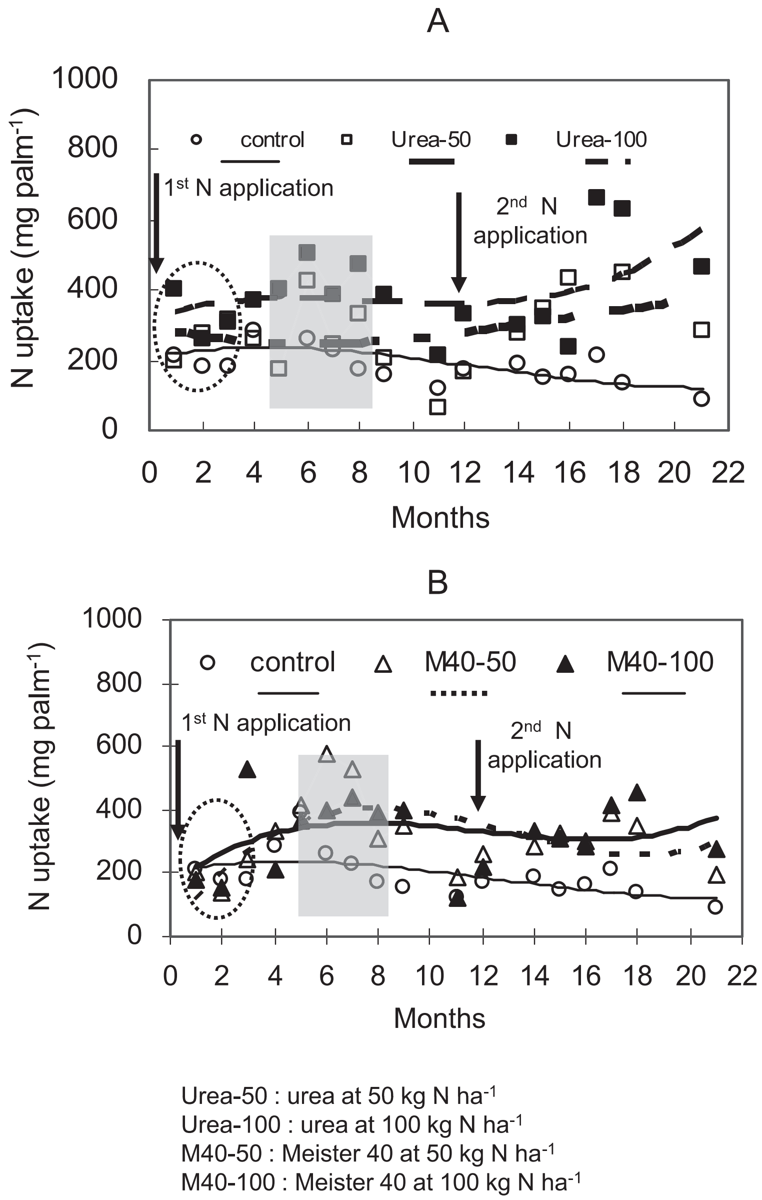


Figure 4. Nitrogen uptake by sago palm as influenced by the form of urea (A) easily soluble and (B) slow-release, and the timing of urea application. The control treatment in both graphs is the same.

Earlier studies also reported that sago palm showed variable responses to fertilizer application, especially to nitrogen (N) fertilizer (Kimura et al. 2008). Sago growth parameters, such as the rate of leaf (frond) production, diameter growth, height increase (Kueh 1995), and leaf formation (Purwanto et al. 2002), were not affected by N application. Watanabe et al. (2005) reported that the growth and growth rates did not increase under 20 different fertilizer regimes. However, the results from the current study showed slightly improved growth parameters of the 2-month-old sago palm seedlings as influenced by urea application, especially during the 18th month following transplanting. In contrast, Paquay et al. (1986) reported that increasing fertilizer levels using a standard liquid fertilizer resulted in faster leaf area growth per palm. They also stated that, at all fertilizer levels, the application of extra N generally showed a positive effect on the growth and development of sago palm seedlings. Similarly, in a nutrient omission trial, sago palms cultured with N had a relatively consistent leaf emergence rate across the different treatments (Jong et al. 2008). From the different results presented, the growth response of sago palm was apparent when the palm had been grown in a culture medium and not in soil. Furthermore, Kueh (1995) reported that the lack of growth response to fertilizer application was probably due to the fact that sago is a suckering palm and the total rate of sucker and leaf emergence may be a better indicator of growth. Sensitivity in nutrient analysis to detect the growth response may be lower in perennial crops than in annual crops because the former may require a long time (> 5 years) to react to nutrient additions (Yost et al. 1999 as cited by Ares et al. 2003). Therefore, longer-term observations of the growth parameters of sago palm are necessary to determine how it is affected by fertilizer application.

N concentration in leaflet of sago palm

Slow-release fertilizers are made to release their nutrient components gradually and, if possible, to coincide with the nutrient requirement by a plant (Liang et al. 2006). However, the N concentration in the leaflet of sago palm in the M-40-applied treatments decreased during the first 12 months. After the second N application, the N concentration at the 18th month did not differ significantly from that at the 12th month. The significant decreasing trend in the N concentration in leaflets with time can be attributed to the significant increase in the total number of leaflets with time. The rate of N uptake by crops is highly variable during crop development between years and sites (Gastal and Lemaire 2002). Gastal and Lemaire (2002) reported that, under abundant N, the uptake of N supplied depends largely on the growth rate via internal plant regulation. Carbon assimilation of the crop is related to the distribution of N among mature leaves with consequences for leaf and canopy photosynthesis. Therefore, crop growth rate fundamentally relies on the balance of N allocation between growing and mature leaves. Hence, the lower N concentration in sago palm leaflets at a later stage was due to the translocation of N in other parts of sago palm.

At a very early stage, the N concentration in sago palm in the control treatment was comparable to that in palms applied with fertilizer, indicating that sago palm took up N from sources other than the soil and fertilizer. In the earlier months, the seed of sago palm was still attached to the roots and contributed to the nutrient supply, especially N to sago palm. In addition, Shrestha et al. (2007) reported a beneficial interaction between sago palm and free-living microorganisms. Therefore, it is possible that aerobic N_2-fixing bacteria colonizing sago palm contribute to a similar N concentration in the treatment without N addition to the urea-applied treatments. Kimura et al. (2004) reported that the common bean with a lower level of symbiotic N_2 fixation has a higher efficiency in soil N absorption, while the adzuki bean is superior in fixing atmospheric N_2 when mineral N in the soil is low. In this study, aerobic N_2-fixing bacteria colonizing the sago palm might have been active when N was not added from urea fertilizer.

Nitrogen uptake by sago palm

Nutrient uptake efficiency is greater and leaching losses are lower for controlled-release fertilizer products than they are for readily available forms of fertilizers (Shoji and Gandeza 1992). In the present study, the N uptake by sago palm was immediately affected when the N was applied in an easily soluble form, as shown in the Urea-100 treatment at one month after the first application (Figure 4A and 4B). On the other hand, the effect of slow-release type of N fertilizer on the N uptake became visible in the succeeding months (6 months later) but comparable to that of common urea. In the absence of urea (control), the N uptake by sago palm was consistently smaller than that in the urea-applied treatments, especially after the second N application. The N uptake of those treatments added with slow-release urea decreased toward the 12th month, probably due to the gradual but continuous release of N from the fertilizer. The polymer-coated fertilizers have the potential for optimal supply of nutrients during the growth period of crops, and their application should benefit the environmental and economic aspect (Shoji and Gandeza 1992; Shaviv 2000). After the second fertilizer application, a trend of N uptake by sago palm similar to that of the first year of fertilizer application was observed. The fast release of N from common urea resulted in a significantly higher N uptake during the first 6 months after the first and second fertilizer applications, especially with the application of 50 kg N ha^{-1}.

However, among the rates of urea applied, the N uptake by sago palm did not differ significantly. Our previous results revealed that, even though sago palm is considered to be a semi-domesticated plant, it did take up N from the added fertilizer at low percentages. The results from the present study reinforce our earlier findings that sago palm responds to normal or slow-release applications of urea fertilizer. The timing of urea fertilizer application in the field is governed by the demand of N by the plant and environmental safety to minimize eutrophication (Brady and Weil 2002). Both types of urea significantly affected the N uptake of sago palm, and the addition of 50 kg N ha^{-1} translated to significantly better growth performance of sago palm. The application of nitrogen is ideal for increasing crop yield. However, its benefits can be more appreciated if the nitrogen uptake efficiency of the crop is high and nitrogen losses through leaching are minimized. High amounts of nitrogen, especially in the form of nitrate, can easily be lost in the soil through leaching. A slow-release type of urea fertilizer is advantageous because of its gradual and continuous supply of nitrogen during the growth period of the crops, and its application could be beneficial to the environmental due to the low risk of N leaching (Shoji and Gandeza 1992; Shaviv 2000).

Conclusions

The form of urea fertilizer did not significantly affect the growth of sago palm, except for the total number of leaflets, in the pot experiment. However, the application of 50 kg N ha^{-1} in either form of urea significantly improved the increase in sago palm height from 18 months onward. On the other hand, in the earlier months after the application of urea fertilizer, the common urea treatment showed significantly higher N uptake by sago palm, while, in the application of Meister 40, a slow-release type of urea, the N uptake was observable at 6 months after application. Both types of urea significantly affected the N uptake of sago palm, and the addition of 50 kg N ha^{-1} translated to significantly better growth performance than the non-application of urea. Therefore, to mitigate N losses in the environment, slow-release urea could be used as fertilizer in sago production.

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