SAGO PALM 16: 1 − 9 (2008)

Influence of Slow-Release Fertilizers on Sago Palm Growth in the Early Growth Stage in a Sago-Taro Intercropping Field

Sonoko D. Kimura1, Shoji Matsumura[1], Suzette B. Lina[2], Masato Igura[2], Masanori Okazaki[2], Marcelo A. Quevedo[3], and Alan B. Loreto[3]

[1] Graduate School of Agriculture, Tokyo University of Agriculture and Technology, 3-5-8, Saiwaicho, Fuchu, Tokyo 183-8509, Japan

[2] Graduate School of Bio-Applications and Systems Engineering, Tokyo University of Agriculture and Technology, 2-24-16, Nakacho, Koganei, Tokyo 184-8588, Japan

[3] PhilRootcrops, Visayas State University, Baybay, Leyte 6521-A, Philippines

Abstract: The influence of nitrogen (N) fertilizer in the early growth stage of sago palms intercropped with taro was investigated using 3 types of fertilizer at 3 levels. The applied fertilizers were the slow-release fertilizers Meister 40 (M40) and Meister 70 (M70) and urea. The application rates of each fertilizer were 50 kg N ha^{-1}, 100 kg N ha^{-1}, and 150 kg N ha^{-1}, respectively. The plant height and leaf number of sago palm were monitored from 25 July 2005 to 20 December 2006. The growth rate was defined as the plant height increase during the half year adjusted by the number of days of the investigation period. Taro plants were harvested from 5 to 12 January 2006.

The dry matter yield of Taro was 1,637 to 2,080 kg ha^{-1}. Taro showed higher N accumulation in all fertilized treatments than in the control, but no significant difference was observed due to high variability in individual plants. Due to the initial difference and high variability in sago palms within one treatment, no clear influence of different fertilizer types and application rates on change in average height and leaf number could be determined. However, the growth rate tended to be lower with higher fertilizer application rate than with lower rates in the 1st phase (25 July 2005 to 30 November 2005) and the 3rd phase (26 July 2006 to 20 December 2006), especially for slow-release fertilizer treatments. The growth rate in the 2nd (30 November 2005 to 26 July 2006) and 3rd phases ranged from 27 to 87 cm half year^{-1} and was higher than that in the 1st phase, when it ranged from 8 to 31 cm half year^{-1}. The sago palm growth rate was inhibited under a N application rate of 150 kg N ha^{-1}, while a low fertilizer application of 50 kg N ha^{-1} showed an enhanced growth rate.

Key words: early growth, intercropping, nitrogen, sago, slow-release fertilizer, taro

緩効性肥料がサゴ-タロ混植条件下におけるサゴの初期生育に及ぼす影響

木村園子ドロテア[1]・松村昭治[1]・S. B. Lina[2]・井倉将人[2]・岡崎正規[2]・M. A. Quevedo[3]・A. B. Loreto[3]

[1] 東京農工大学 大学院 農学府, 183-8509　府中市幸町3-5-8

[2] 東京農工大学 大学院　生物システム応用科学府184-8588　東京都小金井市中町2-24-16

[3] PhilRootcrops, Visayas State University, Baybay, Leyte 6521-A, Philippines

要旨　本研究ではタロイモとの混植条件にあるサゴヤシの初期生育に及ぼす窒素肥料の影響を3種の肥料を3段階で施用することによって解析した。緩効性肥料のMeister 40 (M40)、Meister 70 (M70)およ

び尿素を供試し、施肥量は50 kg N ha^{-1}、100 kg N ha^{-1}および150 kg N ha^{-1}とした。サゴヤシの植物高および葉数を2005年7月25日から2006年12月20日まで定期的に測定し、一定期間における植物高の変化率を生長速度と定義して解析を行った。タロイモの収量は2006年1月5日～12日に調査した。

混植されたタロイモの乾物収量は1637～2080 kg ha^{-1}であった。窒素吸収量は施肥区でコントロールより高い値となったが、個体差が大きく有意な違いは認められなかった。サゴヤシについても移植時の違いが大きく、肥料の種類および6ﾊが植物高および葉数に及ぼす有意な影響は認められなかった。しかし、第1期（2005年7月25日～2005年11月30日）および第3期（2006年7月26日～2006年12月20日）の生長速度は施肥量が多いほど小さくなる傾向があり、その傾向は特に緩効性肥料で顕著であった。第2期（2005年11月30日～2006年7月26日）と第3期の成長速度は27～87 cm 半年$^{-1}$であり、8～31 cm 半年$^{-1}$であった第1期に対して大きかった。サゴヤシの生長速度はコントロールと比べ窒素施肥量が150kg N ha^{-1}では阻害されたが、50 kg N ha^{-1}では促進された。

日本語キーワード：混植、窒素、サゴ、緩効性肥料、タロイモ

Introduction

Sago palm (*Metroxylon sagu* Rottb.) is a unique tropical crop which accumulates starch in its trunk. It is known for its high biomass production. The dry yield of starch can be as high as 10-25 Mg ha^{-1} (Flach 1983). Sago palm has a high biomass production; however, it is traditionally cultivated without any fertilizer, and the N balance in a sago-ecosystem is estimated to be negative (Okazaki et al. 2001). Studies conducted on sago ecosystems indicate the importance of the water level, decomposition of soil organic matter, and nitrogen movement for sago palm growth (Palsolon et al. 2001).

The average maturity (flowering) of sago on mineral soil is 8-12 years (Yamaguchi et al. 1997). George and Singleton (1992) and McConnell and Mozaffari (2004) reported that N plays an important role in stimulating growth in many plants at the early growth stage. They also reported that initial advantages in the expansion of leaf area, chlorophyll concentration, and favorable conditions for photosynthesis influence later growth. However, those studies were generally conducted for annual or bi-annual crops, and, still, little is known about the influence of N on the early growth of perennial crops in the tropics. Studies conducted on the N response of sago palms reported no clear tendency in sago growth (Watanabe et al. 2005). Another study reported higher N concentration in leaf due to the use of a slow-release fertilizer (LP-100) and urea than in the control, but no stimulation in plant height with either fertilizer treatment was observed (Purwanto et al. 2002). Because sago palms might have low N uptake ability, slow-release fertilizers could be useful to reduce N losses and enhance N availability.

The late harvest time of sago palm is considered to be a major disadvantage of this crop. To increase the initial biomass production, intercropping may be useful. Intercropping is common in tropical agriculture. Taro (*Colocasia esculenta* (L.) Schott) is adapted to shade and is favorable for intercropping (Onwueme and Johnston 2000). In this study, we chose taro as an intercrop for sago palm since it is favorable at a high underground water level and tolerates surface water stands, which are often found in sago palm ecosystems in the Philippines.

The objective of this study was to investigate the N need of sago palms at an early growth stage intercropped with taro. The influence of fertilizers with different N availability on sago growth was investigated.

Study site

Experimental design

The study was conducted at the experimental field of Leyte State University (N 10° 45' 10.7, E 124° 47' 23.6), Philippines. A total of 55 plots were prepared.

Each plot was 8 m^2 (2m x 4m) and arranged in a completely randomized block design with 5 replications (denoted as blocks A, B, C, D, and E, Figure 1). Each replication was established with 10

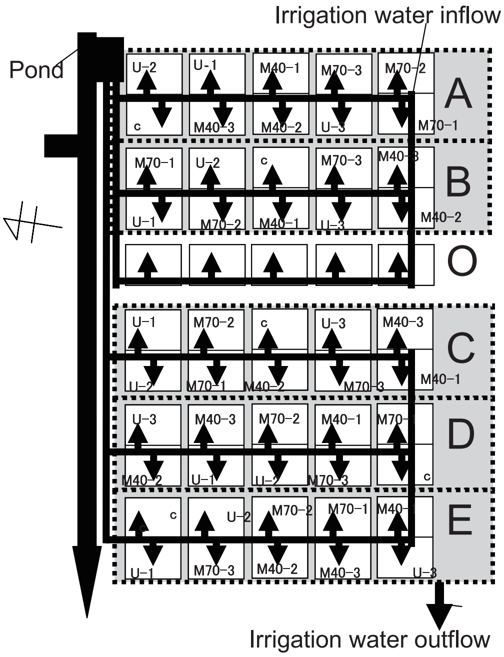

Fig. 1. Experimental design and irrigation system at the study site. Abbreviations: c stands for control, M40 for Meister40 and M70 for Meister 70. The numbers 1, 2 and 3 indicates application rates of 50 kgN ha^{-1}, 100 kgN ha^{-1} and 150 kgN ha^{-1}, respectively.

plots, including 3 different fertilizers at each 3 different application rate and a control plot with no fertilizer application. Five additional plots were set up for a control treatment with no fertilizer application and were not included in the analysis of this study (block O). The plots were established in May 2005. Two sago sackers and 12 purple taros were planted in each plot. Table 1 shows the basic characteristics of the experimental site. The soil, a Dystrudepts (Soil Taxonomy 1999), was shallower and siltier in plots A and B than in plots C, D, and E. The applied fertilizers were the slow-release fertilizers Meister 40 (Asahikasei, N content, 40%) and Meister 70 (same as Meister 40) and urea (a local product). Meister 40, Meister 70, and urea are hereafter referred to as M40, M70, and U, respectively. The N release rate of M40 and M70 was designed to be 80% at 400 and 700 days after application in a sigmoid release pattern, respectively (Chissoasahi 2001). The application rates of each fertilizer were based on the conventional N application rate for taro (i.e., 45 kg N ha^{-1}) and were set to 50 kg N ha^{-1}, 100 kg N ha^{-1}, and 150 kg N ha^{-1}, respectively. The amounts are referred to as 1, 2, and 3, for 50 kg N ha^{-1}, 100 kg N ha^{-1}, and 150 kg N ha^{-1}, respectively. Thus, for example, the application of Meister 40 of 50 kg N ha^{-1} is shown as M40-1.

Five replantings of sago seedlings from May to July were made due to the weak transplanting tolerance of sago suckers. Sago palm survived better in clayey plots (D and E). Taro seedlings were transplanted on 8 May 2005. Taro showed good growth, even though many hoppers were found on its leaves. Fertilizers were applied on 25 July 2005. Each plot was surrounded by a vinyl sheet to control the water level. An irrigation system supplied water individually to each plot and kept the field flooded at a water depth of 5 to 10 cm. The application of N fertilizer was carried out around the two sago palms and 12 purple taros. Fertilizer was applied at 10 cm distance from the plant at a depth of 5 cm. A mound was created around each plant.

Only maximum and minimum temperatures were measured at the study site. The average maximum temperature in 2005 was 33.8 °C, almost the same as the average of 10 years of 33.6 °C (Figure 2) (Leyte State University Meteorological Station unpublished). The average minimum temperature was 22.4 °C and did not change significantly throughout the year. The annual precipitation in 2005 was 3,140 mm, slightly above the average of the previous 10 years (2,996 mm). While the precipitation from January to June was slight, ranging from 9 to 276 mm monthly, the precipitation from July to December ranged from 197 to 624 mm and made up

Table 1. Soil properties of the experimental site.

Soil depth	pH	TC	TN	C/N	CEC	Ca	Mg	K	Na
(cm)		($g\ C\ kg^{-1}$)	($g\ N\ kg^{-1}$)		(me 100 g^{-1})				
0-15	5.3	10.8	1.0	10.6	19.7	5.3	3.2	0.5	0.1
15-30	5.8	9.2	1.6	5.7	18.3	5.6	3.6	0.4	0.1
30-45	6.1	12.0	0.9	13.6	20.0	6.0	4.0	0.4	0.1

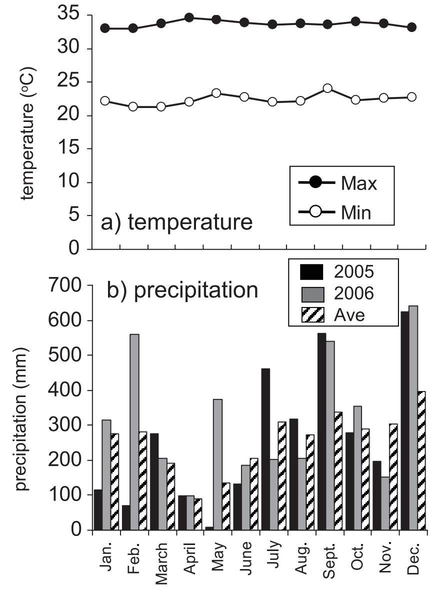

Fig. 2. Monthly maximum and minimum temperature (a) and precipitation (b). The maximum temperature is the average from 1997 to 2006; precipitation for 2005 and 2006 as well as the average from 1997 to 2006.

78% of the annual rainfall. The investigated period from 25 July 2005 to 20 December 2006 was divided into 3 phases based on the precipitation patterns: 1st phase (25 July 2005 to 30 November 2005), 2nd phase (30 November 2005 to 26 July 2006), and 3rd phase (26 July 2006 to 20 December 2006).

Plant material preparation

The height from the ground to the top of the leaf blade and the number of leaves were measured on 25 July, 27 October, and 30 November 2005 and 26 July and 20 December 2006. Initial sago suckers were determined by measuring the total dry weight and N content of 12 suckers, collected at Hilsing, Leyte on 25 July 2005.

Taro was harvested from plots A, B, and O on 5 January 2006, from plots C and D on 11 January 2006, and from plot E on 12 January 2006. All 12 taro plants were pulled from each field, and the height from the end of the petiole to the beginning of the leaf blade, number of leaves, corm weight, and weight of petiole and leaf were then measured for each plant. The corm was defined as the part below the end of the petiole without any root. The roots of each plot were weighed.

On 26 July 2006, two sago palms from the control, one from M70-3, one from M40-1, and one from U-1 were harvested and analyzed for their N contents. The plant was divided into sucker, root, and the following three parts: upper, middle and lower part of leaflet and petiole.

All plant tissue fractions of taro and sago palms were dried at 75°C for 2 days and weighed to determine the dry weight. The total N concentration of plant tissues was analyzed in the Chemical Laboratory of the Philippines Root Crop Center LSU by the Kjeldahl method.

Statistical analyses

Two-way ANOVA and Fisher's LSD were analyzed by SigmaStat 3.11 (Systat Software, Inc.).

Results and Discussion

Growth of taro

The dry weight of taro showed different trends among treatments (Figure 3a). In the M40- and urea-treated plots, the lowest N application level of 50 kg N ha^{-1} seemed to stimulate growth, while the highest application level (150 kg N ha^{-1}) reduced the total amount. The main reduction was found for corm, although it was not significantly different. For M70, fertilization showed no effect. The difference in total

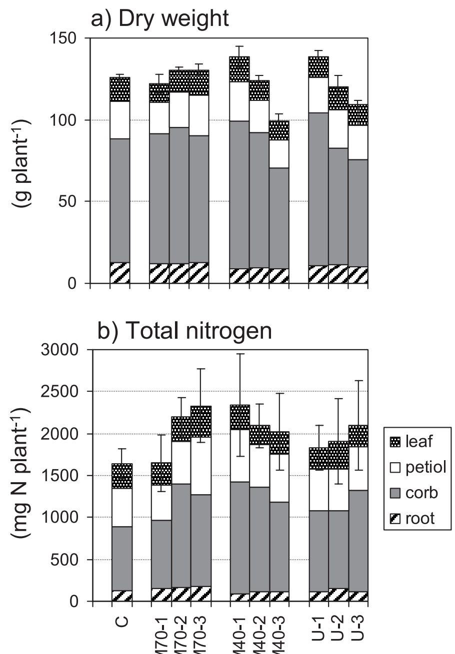

Fig. 3. Dry weight (a) and total nitrogen (b) in harvest of taro plants.
Error bar stands for standard error. See for treatment abbreviation Figure 1.

weight was mainly due to the difference in corm weight. The highest yield was found for U-1 and M40-1, and the lowest, for M40-3.

Due to the increased N concentration, the total N in plants increased in all treatments compared to that in the control (Figure 3b). The main difference was due to the higher amount of N in the corm for N-applied plots than in the control as well as to the higher amount in the petiole. As a result, the total N accumulation in taro increased from 1,638 mg N plant^{-1} in the control to 1,652 mg N plant^{-1} in M70-1 to 2,335 mg N plant^{-1} in M40-1. The reduction of the TN accumulation due to an increase in the applied fertilizer remained in M40. However, all treatments in M40 had higher N accumulation than that in the control, ranging from 2,015 to 2,335 mg N plant^{-1}, but no significant difference was observed due to high variability in individual plants. The planting density of this experiment was 15,000 plants ha^{-1}; thus, the total harvested biomass ranged from 1,637 to 2,080 kg ha^{-1}, and that of total N ranged from 24.6 to 35.0 kg N ha^{-1}. The average yield of starchy root and tuber in the Philippine was reported to be 5,130 kg ha^{-1} (FAO 2006), more than twice that of this study. Since shading is not believed to have affected the growth of taro plants (Onwueme and Johnston 2000), continuous flooding may have been responsible. Growth conditions must be improved to increase the yield of taro in an intercropping system with sago palm. Even though the yield is not as good as that in a monoculture of taro, intercropping of taro with sago palm can encourage sago palm cultivation by additional starch yield at the early growth stage of sago, as no products from sago palms can be harvested.

Growth of sago

Sago suckers were, on average, 66 ± 23 cm in height and had leaves of 2.5 ± 1.2 (Table 2). The N concentration was 8.0 ± 0.3 mg N g^{-1} for leaflets, 4.8 ± 0.1 mg N g^{-1} for petioles, and 4.0 ± 0.1 mg N g^{-1} for the roots (Table 3). The total dry weight was 0.10 ± 0.06 kg per sucker; the total N content was 0.58 ± 0.34 g N per sucker (Table 2).

Table 2. Plant height, leaf number, dry weight and contents of total N of sago suckers.

	Height (cm)	Leaf Number	Weight (kg DW)	Weight (gN)
Average	66.3	2.5	0.10	0.58
Standard Deviation	22.7	1.2	0.06	0.34

Table 3. Nitrogen concentration in leaflet, petiole and root of sago suckers.

	Leaflet (mg N g^{-1})	Petiole (mg N g^{-1})	Root (mg N g^{-1})
Average	8.0	4.8	4.0
Standard Deviation	0.3	0.1	0.1

The plant height increased slowly from 25 July to 30 November 2005 for all treatments (Figure 4a-c). Plant height had an initial difference before the application of fertilizer. On 25 July, M70-1, U-3, and M40-2 had the lowest values, which were significantly different from the highest value of M40-3. M70-1 and M40-2 still had the lowest values, which were significantly lower than the highest value

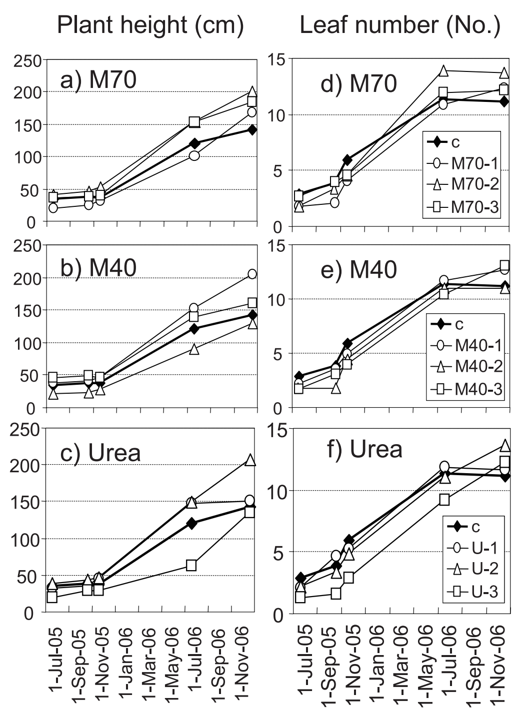

Fig. 4. Time course of sago plant height and leaf number at different fertilizer treatments at Leyte from 25 July 2005 to 20 December 2006. For a list of abbreviations used, please see Figure 1.

of M40-3, while U-3 was not significantly lower than M40-3 on 27 October 2005. The plant heights of M70-2, M70-3, M40-1, and U-2 were significantly higher than those of M40-2 and U-3 on 26 July 2006, one year after N application. The values for M70-2, M70-3, M40-1, and U-2 tended to be higher than those for other treatments until 20 December 2006, although a significant difference was found only between M40-1 and M40-2 and between U-2 and M40-2. The initial difference and large variability within one treatment did not show a clear influence of different fertilizer types and application rates. The height of the suckers was greater than the initial sago height in the field, which averaged 33 ± 17 cm on 25 July 2005 (Table 4). This might be due to the fact that the suckers were measured from the bottom of the plant to the top, while, in the field, the height was measured from the soil surface and the part below the soil surface was not accounted for.

The leaf number in the control tended to be higher than that in the N-treated plots, although the relationship changed after one year, and the leaf number in the control became lower than that in the N-applied plots for all treatments after 1.5 years (Figure 4d-f). Except for the lowest value of U-3 compared to that of other plots until 20 November, when it became higher than that of the control, no significant difference was observed among the treatments. Due to the high variability in leaf numbers, the differences were not significant. Thus, the detailed results of statistical analyses are not shown.

Table 4. Sago plant height at different fertilizer treatments at Leyte from 25 July 2005 to 20 December 2006.

	25-Jul-05		27-Oct-05		30-Nov-05		26-Jul-06		20-Dec-06	
	Ave	(SD)	Ave	(SD)	Ave	(SD)	Ave	(SD)	Ave	(SD)
c	35	(20) abc	38	(19) ab	37	(20) ab	121	(32) ab	142	(31) ab
M70-1	20	(10) bc	24	(9) b	31	(13) ab	101	(59) abc	168	(60) ab
M70-2	42	(22) ab	47	(24) ab	53	(21) a	154	(36) a	201	(55) ab
M70-3	36	(17) abc	38	(17) ab	39	(17) ab	153	(40) a	185	(40) ab
M40-1	38	(17) abc	41	(17) ab	46	(15) ab	151	(56) a	204	(71) a
M40-2	21	(5) bc	23	(4) b	28	(1) b	90	(21) bc	129	(29) b
M40-3	45	(20) a	49	(23) a	45	(22) ab	138	(44) ab	160	(42) ab
U-1	32	(13) abc	36	(18) ab	45	(19) ab	147	(46) ab	151	(66) ab
U-2	39	(16) ab	43	(16) ab	46	(20) ab	149	(74) a	207	(87) a
U-3	20	(7) c	30	(21) ab	29	(6) ab	63	(25) c	135	(34) ab
Ave	33	(17)	37	(18)	40	(17)	128	(52)	168	(57)

Numbers with different letters are significantly different (Fisher's LSD (p<0.05))
See for treatment abbreviations Figure 1.

There were only a limited number of harvests, and the difference in N concentration in the crop could not be statistically analyzed for individual treatments. However, a significant increase in the N concentration was found (Table 5) compared to the initial concentration found in the suckers (Table 3). The highest difference was found for the leaflet, where it increased from 8.0 ± 0.3 (Table 3) to 22.3-30.7 mg N g DW^{-1}. This increase did not differ among the treatments. Compared to the N concentration in the control, the fertilization did not change the N concentration. There were significant differences in the N concentration depending on the position of leaves. The N concentration of the petiole was 11.1 mg N g DW^{-1} for the higher positions but 5.8 and 5.7 mg N g DW^{-1} for the low and middle positions, respectively. Similarly, the N concentration in leaflets was 30.7 mg N g DW^{-1} for the higher and middle positions but 22.3 mg N g DW^{-1} for the lower positions. The average N concentrations in suckers and the sum of the root and corm were lower than those in leaves and were 14.1 and 11.3 mg N g DW-1, respectively. The weighted mean of the N accumulation in those plants was 13.7 ±

Table 5. Nitrogen concentration (mg N g DW^{-1}) in sago tissues measured on 26 July 2006.

		Total Nitrogen (mg N g DW^1)						
		C_1[1)]	C_2[1)]	M70-3	M40-1	U-1	Ave	SD
Leaflet	low	18.2	25.8	23.3	24.7	19.6	22.3 a	3.3
	middle	25.8	29.8	28.1	28.8	29.0	28.3 a	1.5
	high	32.0	32.5	27.8	32.0	29.0	30.7 b	2.1
Petiole	low	5.3	6.9	6.2	5.0	5.8	5.8 a	0.8
	middle	5.1	6.0	6.1	5.5	5.8	5.7 b	0.4
	high	6.6	17.6	14.7	9.4	7.2	11.1 b	4.8
Sucker		11.4	16.2	16.3		13.4 13.3	14.1	2.1
Root+ corm		11.4	10.4	9.4	8.3	17.2	11.3	3.5

1) Small letter 1 and 2 for control plants indicate two different plants.
Numbers with different letters are significantly different (Fisher's LSD (p<0.05))
See for treatment abbreviations Figure 1.

5.0 g N per plant for the total plant in 1.5 years, i.e., 9.2 ± 3.2 g N per plant in one year after transplanting.

Since the initial variability among individual plants showed a strong influence on subsequent growth (Figure 4, Table 4), the growth rates of the 1st phase (25 July 2005 to 30 November 2005), 2nd phase (30 November 2005 to 26 July 2006), and 3rd phase (26 July 2006 to 20 December 2006) were analyzed. The growth rate was defined as the increase in height during the half year, which adjusted by the number of days during the investigation period for each sampling period. The time span was adjusted to a half year (182.5 days) for all phases. The calculation was conducted for each individual plant before averaging to eliminate the initial differences.

In the 1st phase, the highest application rate showed the lowest growth rate for all fertilizer types (Figure 5a). Those growth rates were lower than that in the control and differed significantly from that in U-2. The growth rate in the 2nd and 3rd phases ranged from 27 to 87 cm half year^{-1} and was higher than that in the 1st phase, when it ranged from 8 to 31 cm half year^{-1}. In the 2nd phase, U-3 showed the lowest value, while M40-3 and M70-3 showed enhanced growth (Figure 5b). Compared to U-3, M40-2 and M70-1 showed lower values than the control. No clear pattern of the influence of fertilizer types or application rates was found in this phase. In the 3rd phase, the control exhibited the lowest growth rate (Figure 5c), while the highest growth rate was found for M70-1, which was significantly higher than that of the control. The growth rate tended to decline as the amount of fertilizer increased for M70. The highest application rate showed the lowest growth rate for M40, while no clear tendency was found for urea. A two-way ANOVA showed that the influence of fertilizer type and amount of the fertilizer on plant growth rate differed significantly in phase 1. No significant influence was found for the 2nd and 3rd phases (Table 6). In the 1st phase, the significance was higher for the amount (p=0.008) than for the type of the fertilizer (p=0.025).

Table 6. P values for the influence of the type of fertilizer (Meister70, Meister40 and urea) and amount (50, 100 and 150 kg N ha^{-1}) on plant growth rate at each growth phase

	1st Phase	2nd Phase	3rd Phase
Type	0.025	0.875	0.319
Amount	0.008	0.912	0.479
Type * Amount	0.361	0.030	0.678

In the treatment of M70 and M40, the 1st and 3rd phases showed a similar pattern, and the higher application rate showed a lower growth rate. The period from July to December is characterized by high monthly precipitation above 200mm (Figure 2); thus, the precipitation was similar for the 1st and 3rd phases. The comparison of the control among the 1st, 2nd, and 3rd phases showed that the 2nd phase differed significantly from the 1st (p<0.01) and 3rd phases (p<0.05, Fisher's LSD), while the 1st and 3rd phases did not differ significantly. In a tropical forest, photosynthesis can be enhanced in the dry season if sufficient water is supplied to the trees (Goulden et al. 2004). In this experiment, the 2nd phase was in the dry season, in which sago palms could take advantage of the longer daylight hours than in the rainy

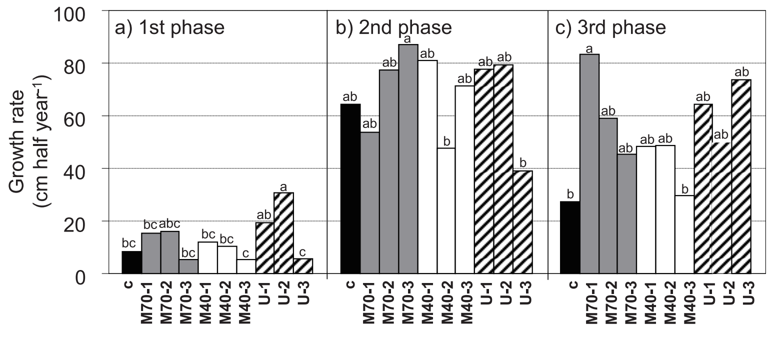

Fig. 5. Increase in height for 6 months (growth rate) of sago palm from 25 July 2005 to 30 November 2005 (1st phase) from 30 November 2005 to 26 July 2006 (2nd phase), and from 26 July 2006 to 20 December 2006 (3rd phase).
Different letters stands for significant differences (Fisher's LSD (p<0.05)). For a list of abbreviations used, please see Figure 1.

season. Since irrigation provided sufficient water, sago palm showed higher growth rate in the 2nd phase than in the 1st and 3rd phases.

Influence of fertilizer on sago palm growth

Previous studies confirmed that sago palm requires an input of 5.2 kg N, 1.1 kg P, and 6.7 kg K per plant before the first harvest (Jong and Flach 1995). If 100 clusters were established per ha, the nutrients taken up by the sago palms would be estimated to be 520, 110, and 670 kg ha^{-1} for N, P, and K, respectively (Jong and Flach 1995). If the maturity time were 10 to 20 years, the annual fertilizer requirement would be 52, 11, and 67 kg ha^{-1} for N, P, and K, respectively. The lowest fertilizer application rate in this study was 50 kg N ha^{-1}, just meeting the requirement proposed by Jong and Flach (1995). Jong and Flach (1995) also reported that sago palm took up 0.03 kg N per plant in 0-1 year after transplanting, while it increased to 0.06 in 1-2 years and to 0.19 kg N in 2-3 years. After 3 years, the growth increment increased gradually from 0.31 to 0.64 kg N per plant for 9 years. In the present study, the average N increase in 0-1.5 years was 0.0137 kg N per plant, considerably lower than the reported values. The sago suckers used in this study are considerably smaller than those used conventionally in Malaysia (2 kg, Flach 1983). The application rate of 50 kg N ha^{-1} might be more than sufficient to meet the N demand.

The growth of sago palm was analyzed in this study from 0-513 days after N application. The N release rate of M40 and M70 is designed to be 80% in 400 and 700 days after application in a sigmoid release pattern, respectively (Chissoasahi 2001). Thus, the N availability in the 1st phase should be highest for urea, followed by M40 and M70. A significant difference among fertilizer types in the 1st phase (Table 6) shows that urea had the highest stimulating effect on the growth rate. In the 2nd phase, no influence of the fertilizer type or amount was observed. The high growth rate in the control indicates that nutrients were not the limiting factor at that growth stage. In the 3rd phase, N was still released from M70, which might be the reason for the high growth rate for M70-1. In other studies dealing with the response of N fertilizer to sago growth, no clear enhanced growth was observed. Watanabe et al. (2005) reported that there was no increase in growth under 20 different fertilizer regimes. In another study, Purwanto et al. (2002) showed that plant height did not change, while N concentration in the leaf increased due to fertilizer application, which contradicts the results of our study. These results indicate that sago palms do not react quickly to N fertilizer and suffer from high N fertilizer application rates. Lower fertilizer application rates performed better than higher ones (Figure 5). Higher amounts of fertilizer might alter the rhizosphere chemical properties and lead to inhibition of root growth (Jacobs and Timmer 2005).

Continuous flooding was applied, since sago palms in Leyte are found near riverbanks (Quevedo et al. 2005) and grow in flood conditions. Thus, a high water table should not inhibit the growth of sago palm; however, N uptake efficiency might be reduced due to leaching and denitrification losses. Recommended water tables for sago palms are 20-50 cm (Flach and Schuiling 1990, Jong 2001), and a lower water table might enhance sago palm growth as well as its N uptake efficiency. Intermittent irrigation might also enhance taro growth, and further studies will be required to optimize the sago palm cultivation conditions.

Conclusion

Intercropping in sago palm with taro can increase the starch yield per unit area. Even though the yields are not as good as the monoculture of taro, intercropping of taro with sago palm can encourage sago palm cultivation by additional starch yield in the early growth stage of sago, as no products from sago palms are available. Sago palm responded very reluctantly to N fertilizer, and its growth was inhibited under a high N application rate. Low fertilizer applications showed enhanced growth rates. Since the maturity age of sago palms is from 10 to 12 years, long-term effects of fertilizers are required to achieve higher yields.

Acknowledgement

We deeply appreciate the financial support by the Nagato Isao Academic Research Fund of the Society of Sago Palm Studies 2005. Thanks are also due to Cynthia Dolores Godoy for assistance with the chemical analysis at Leyte State University.

References

Chissoasahi 2001 The controlled-release fertilizer, Chissoasahi Co. (Tokyo) pp.7.

FAO (Food and Agriculture Organization of the United Nations) 2006 FAOSTAT http://faostat.fao.org/

Flach, M. 1983 The Sago sago palm. UN-FAP Plant protection and production Paper No.47, Rome, pp.85.

Flach, M. and D. L. Schuiling 1990 Growth and yield of sago palms in relation to their nutritional needs. In Proceedings of the 4th International Sago Symposium: 103-110.

George, T. and P. W. Singleton 1992 Nitrogen assimilation traits and dinitrogen fixation in soybean and common bean. Agronomy Journal 84: 1020-1028.

Goulden, M. L., S. D. Miller, H. R. da Rocha, M. C. Menton, H. C. de Freitas, A. M. E. S. Figueira and C. A. D. de Sousa 2004 Diel and seasonal patterns of tropical forest CO_2 exchange. Ecological Applications 14: 42-54.

Jacobs, D. F. and V. R. Timmer 2005 Fertilizer-induced changes in rhizosphere electrical conductivity: Relation to forest tree seedling root system growth and function. New Forests 30: 147-166.

Jong, F. S. and M. Flach 1995 The sustainability of sago palm (*Metoxylon sagu*) cultivation on deep peat in Sarawak. Sago Palm 3: 13-20.

Jong, F. S. 2001 Commercial sago palm cultivation on deep peat in Riau, Indonesia. Sago Palm 9: 16-20.

McConnell, J. S. and M. Mozaffari 2004 Yield, petiole nitrate, and node development responses of cotton to early season nitrogen fertilization. Journal of Plant Nutrition 27: 1183-1197.

Okazaki, M., C. Yamaguchi and A. H. Hassan 2001 The non-molecular nitrogen balance in an experimental sago garden at Dalat, Sarawak. *In*: New Frontiers of Sago Palm Studies. (Kainuma K., M. Okazaki, Y. Toyoda and J.E. Cecil eds.). Universal Academy Press, Inc. (Tokyo) 297-302.

Onwueme, I. C. and M. Johnston 2000 Influence of shade on stomatal density, leaf size and other leaf characteristics in the major tropical root crops, tannia, sweet potato, yam, cassava and taro. Experimental Agriculture 36: 509-516.

Pasolon, Y. B., S. M. Udin and Y. Yamamoto 2002 Growth and starch production of sago palms in southeast Sulawesi: The effect of soil/water regimes. *In*: New Frontiers of Sago Palm Studies. (Kainuma K., M. Okazaki, Y. Toyoda and J.E. Cecil eds.). Universal Academy Press, Inc. (Tokyo) 51-59.

Purwanto, B. H., K. Kakuda, H. Ando, J.F. Shoon, Y. Yamamoto, A. Watanabe, and T. Yoshida 2002 Nutrient availability and response of sago palm (*Metroxylon sagu* Rottb.) to controlled release N fertilizer on coastal lowland peat in the tropics. Soil Science and Plant Nutrition 48: 529-537.

Quevedo, M. A., A. B. Loreto, A. M. Mariscal, M. Okazaki and K. Toyota 2005 Distribution and traditional use of sago palm (*Metroxylon sagu* Rottb) in the Eastern and Central Visayas regions of the Philippines. Sago Palm 13: 17-25.

Watanabe, A., K. Kakuda and H. Ando 2005 Research on sago palm plantation sustainability in Tebing Tinggi, Indonesia. Sago Palm 13: 12-15.

Yamaguchi, C., M. Okazaki, T. Kaneko, K. Yonebayashi and A. H. Halim 1997 Comparative studies on sago palm growth in deep and shallow peat soils in Sarawak. Sago Palm 5: 1-9.