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Effects of Soil Types and Water Regimes on the Early Growth of Sago Palm (*Metroxylon sagu* Rottb.) Seedlings

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Abstract: To examine the effects of soil types [organic (OS) and mineral (MS) soils] and water regimes [W1: waterlogged, W2: making 10 holes (diameter: 1 cm) at even distances at the mid-height of the pot, and W3: making 5 holes of the same size at the bottom of the pot] on the early growth of sago palm seedlings, two pot experiments were conducted in Lalomasara, near Abelisawa village, District of Pohara Southeast Sulawesi Province, Indonesia from November 2006 to September 2007. The seedlings were grown under natural (non-protected rainfall) conditions, and watering was done at least once every day. The soil water content was higher in OS than in MS and in the order of W1 > W2 > W3 in both type soils. The results showed few interaction effects of the two factors in the shoot and root growth and the macroelement uptake. The soil types had a lesser effect on the growth of seedlings than the water regimes, although the physicochemical properties of the soils were remarkably different. The water regimes affected the shoot base diameter significantly and tended to be larger, in the order of W1 >W2 >W3 plot, although other shoot growth parameters were not significantly affected by them. On the other hand, root growth was more affected by the water regimes than shoot growth, and a higher number of large roots (LR: ＞5 mm in diameter) were observed in the W1 plot than in the W2 and W3 plots. The total LR length, the numbers of total medium-sized roots (MR: 2-5 mm in diameter) and upward roots of medium-sized roots (UR-MR) tended to be higher in the order of W1 >W2 >W3 plot. As a result, a higher root dry weight and shoot / root dry weight ratio were observed in the order of W1 >W2 >W3 and W3 >W2 >W1, respectively. The seedlings with a thicker base diameter of the shoot tended to have a longer total LR and a higher number of UR-MR.

Key words: early growth, nutrient uptake, sago palm, seedling, soil type, water regime

サゴヤシ実生苗の初期生育に及ぼす土壌の種類と水分条件の影響

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要旨　サゴヤシ実生苗の初期生育に及ぼす土壌の種類（有機質土壌；OS，鉱質土壌；MS）と土壌水分条件（W1：湛水，W2：ポット側面中央部に直径1cmの穴を等間隔に10個あける，W3：ポットの底面に直径1cmの穴を5個あける］の影響を明らかにするために，インドネシア，南東スラウェシ州ポハラ地区，アベリサワ村近郊のラロマサラにおいて，2006年11月から2007年9月にかけて，2要因を組み合わせて2回のポット実験を行った。実生苗植え付け後，ポットは自然条件下に置き、少なくとも1日に1回は潅水した。土壌水分含量はMSに比べてOSで高く，また両土壌ともW1 >W2 >W3の順に高く推移した。土壌の種類と水分条件を組み合わせた条件下では，植え付け後6ヶ月目の地上部及び根の生育，養分吸収量への有意な相互作用はほとんどみられなかった。供試土壌の理化学的特性

には大きな差異が見られたが，実生苗の初期生育に及ぼす土壌の種類の影響は，水分条件に比べて小さかった。水分条件は，地上部の基部直径に影響を及ぼし，W1 >W2 >W3区の順に有意に太くなったが，その他の地上部形質への有意な影響は見られなかった。一方，根の生育は地上部以上に土壌水分の影響を受け，W1区の太根（直径5mm以上）数はW2区やW3区に比べて有意に多くなり，さらに太根の総根長，中根（直径2-5mm）数及び中根のうち上向きに伸長した根の数は，W 1 >W2 >W3区の順に多くなる傾向にあった。これらの結果，根乾物重はW1 >W2 >W3区の順に，地上部／根乾物重比はW3 >W2 >W1区の順に高くなる傾向を示した。また，地上部の基部直径が太い実生苗ほど，太根総根長及び中根のうち上向きに伸長した根の数が多くなる傾向が見られた。今後は，さらに土壌水分の幅を広く設定し，サゴヤシの初期生育に及ぼす土壌水分の影響について検討する必要がある。
キーワード：サゴヤシ，水分条件，初期生育，土壌の種類，実生苗，養分吸収

Introduction

Generally speaking, the current sago palm transplanting practice entails using sucker as a propagating material. However, in large-scale planting, propagation by a sucker is difficult due to the time and cost involved in collecting a large number of uniformly grown and good-quality suckers. Therefore, seedlings are expected to contribute as propagation materials for large-scale planting, although the initial growth rate of seedlings might be slower than that of suckers. At fruiting, sago palm may produced approximately 3,000 fruits (seeds) (Sastradipradja 1986). Flach (1997) stated that the inflorescence of sago palm may carry up to 850,000 flowers. On the other hand, Kiew (1977) estimated that the palm can produce 120,960-376,320 flowers on its inflorescence, with about 2,500 fruits within the seeds. Moreover, according to Jong (1995), about 2,174-6,675 mature fruits can be produced per palm from 276,000 - 864,000 flower buds. Mature seeds from sago palm fruits can germinate in a short time and have more homogeneous growth than suckers. Such seeds need about 3-8 weeks to germinate and have a 50-70 % germination rate (Jong 1991).

Some reports are available on the seed germination of sago palm (Jong 1991, Ehara et al. 1998, 2001, Rembon et al. 2008); however, only a few studies have been performed on seedling growth after germination. Flach et al. (1986) and Paquay et al. (1986) reported on the environmental factors associated with the leaf emergence rate and the leaf area growth of sago palm seedlings in a hothouse of the Agricultural University in Wageningen, the Netherlands. According to these reports, the speed of leaf formation decreased considerably at lower temperature (25℃), humidity (R.H. of 90%), and irradiance (900 J cm^{-2} day^{-1}) (Flach et al. 1986), and increasing the fertilizer levels resulted in faster leaf area growth at 28-30℃ and R.H. of 50-70% with irradiance of more than 800 J cm^{-2} day^{-1} (Paquay et al. 1986).

The soil type and water regime play an important role on sago palm growth, depending on the physical and chemical properties and the water content in the soil. Some information is available regarding the relationship between sago palm growth and starch production and soil types and water regimes. Sago-palm-growing areas along the river banks with moist soils and affected by flooding due to river tides have been reported as the most productive areas in Malaysia (Jalil and Bahari 1991). Sago palm grown under organic and undrained peat soil was found to be 25% slower than that grown under well-drained mineral soil (Flach and Schuiling 1989). This difference in the growth rate was attributed to differences between organic and mineral soils regarding the water regime and the content of mineral elements. In deep peat (organic soil), sago palm growth is slower than it is in mineral soil. Sago palm takes 6 years to trunk formation and at least 12 years to reach the maturity stage in organic soil, compared to 4.5 years and 10 years in mineral soil, respectively. Moreover, the total leaf area is about 90 m^2, while that of sago palm grown in mineral soil is 220 m^2, and the trunk volume is about 37% smaller in organic than in mineral soil (Jong and Flach 1995). The difference appears to be related to the physical and chemical properties of peat soil, including low bulk density, high acidity, and low N, P, K, Ca, Zn, and Cu contents of organic soils compared to mineral soils (Purwanto et al. 2002).

On the other hand, few reports are available on the effects of soil types and water regimes on the growth of sago palm seedlings. Therefore, this study was conducted to clarify the effect of soil types and water regimes on the early growth of sago palm seedlings under pot culture conditions, including shoot and root growth, to obtain basic information for using the seedlings as a propagation material. Expecting different responses from seedlings of different ages, we used seedlings of two ages i.e., one-year-old and 3-month-old, for Experiment 1 and 2, respectively. Moreover, as fertilization is a common cultivation practice for raising seedlings, we examined the growth responses of seedlings to the soil types and water regimes under a fertilizer application condition in Experiment 2.

Materials and Methods

Two pot experiments were conducted at a sago-palm-growing area in Abelisawa, District of Pohara Southeast Sulawesi Province, Indonesia, from November, 2006 to September, 2007. Experiment 1 (Exp. 1) was conducted in a 70 L pot using mineral and organic soils with 1-year-old seedlings without the application of any fertilizer. On the other hand, Experiment 2 (Exp. 2) was conducted in a 20 L pot, using the same soil types as in Exp. 1 but with 3-month-old seedlings and with the application of N, P, and K fertilizers as described below.

Two types of soil (mineral and organic) were selected and used for these experiments. The organic soil used was taken from Watulondo, District of Mandonga, Kendari on Nov. 18, 2006. The soil was collected from 0-20 cm and 20-50 cm depths and then mixed. Mineral soils were taken from Lalomasara, Abelisawa District of Pohara. The soils were selected from two sites with semi-dry and periodically waterlogged conditions. Both types of soils were air-dried, separated from the roots, refined, mixed, and screened using a 0.5 cm wire mesh. Then, the pots were filled with the soil for Exp. 1 and 2, respectively. The pot size used for Exp. 1 was: the top and bottom inner diameters were 47 and 38.5 cm, respectively, and the height was 42 cm (volume: 70 L); on the other hand, for Exp. 2, the top and bottom inner diameters were 31 and 23 cm, respectively, and the height was 27 cm (volume: 20 L).

Both experiments were set up in a factorial randomized block design in three replications with 2 factors, two types of soils (organic = OS and mineral = MS), and three levels of water regimes [W1: waterlogged, W2: making 10 holes (diameter: 1 cm) at even distances at mid-height of the pot, W3: making 5 holes with the same size at the bottom of the pot]. Prior to the transplanting, both types of soils were fully watered and then sampled using a soil core sampler to determine the soil water content. Soil samples were taken from both the upper and lower layers (0-20 and 20-40 cm and 0-12 and 12-25 cm for Exp. 1 and 2, respectively) of the treated pots under shelter. Then, the soil samples were oven-dried at 105 °C for 24 hours in the soil test laboratory of the Faculty of Agriculture, Haluoleo University. The soil water content was expressed on a dry weight base.

Transplanting of seedlings was conducted on December 28, 2006 (Exp. 1) and on March 2, 2007 (Exp. 2). The sago palm seeds used in this experiment were collected from the palms grown in Sentani, near Jayapura Papua Province, Indonesia, known by local people as *Manno kecil* (small *Manno*) (Rembon et al. 2008). They were germinated beforehand in the nursery in Kendari as a source of seedlings. The seedlings were transplanted at 1 year and 3 months after seeding for Exp. 1 and 2, respectively. The average plant height and the base diameter of the 18 seedlings used (average ± SE) were 121 ± 6.3 cm and 4.3 ± 0.16 cm for Exp. 1 and 66.5 ± 2.4 cm and 2.0 ± 0.10 cm for Exp. 2, respectively. The number of living leaves were 6.36 ± 0.41 and 5.08 ± 0.16; the leaflet lengths of the youngest expanded leaf were 35.2 ± 0.88 cm and 25.2 ± 0.85 cm; and the leaflet widths were 2.4 ± 0.12 cm and 1.3 ± 0.09 cm for Exp. 1 and 2, respectively.

Fertilizer was applied for only Exp. 2 as follows: all pots were fertilized with urea 1.5 g pot^{-1} (N content: 45-46% N), superphosphate-36 (SP-36) 7.0 g pot^{-1} (P content: 36% as P_2O_5), and potassium chloride (KCl) 6.5 g pot^{-1} (K content: 46% as K_2O) split between two application dates. The first application was performed on March 2, 2007 at the time of transplanting with superphosphate-36 (SP-36) 6 g and KCl 5 g pot^{-1}, followed by the second application at 4 months after transplanting on July 2, 2007 with urea and KCl 1.5 g pot^{-1} and SP-36 1.0 g pot^{-1}. After transplanting, the seedlings were grown under natural conditions with watering at least once every day.

Growth measurement

1) Shoot growth

The growth performance of sago palm seedlings, including the base diameter, plant length, leaf number, leaf length, leaflet number, and width and length of the expanded youngest leaf, was measured at each month after transplanting. The base diameter was measured at about 1-2 cm above the soil surface in the pot using a caliper. The palm height was measured using a measure tape from the base to the top of the highest leaf. The leaf number was counted from all leaves that appeared from the growing period until the harvesting time. The leaflet number was counted from the total number of leaflets that appeared in the uppermost expanded leaf. The leaflet width was measured at the widest, selected from the longest leaflets in the leaf. Seedlings were harvested at 6 months after transplanting. The harvested plants were separated into shoots (aboveground biomass) and roots. The dry weight of each shoot part was measured after drying up to 80 °C for 2 days in a drying oven.

2) Roots

The roots were washed from the soil and wiped. The roots were then cut at the base of each root and separated into three categories based on their diameter [large (LR), > 5 mm; medium-sized (MR), 2.0-5.0 mm; and small (SR), < 2.0 mm)], following Kasuya (1996). The medium-sized roots were then classified into roots growing upward (UR-MR) and downward (DR-MR) on the basis of the performance of the apex or root cap color. UR-MR was characterized by reddish-brown to blackish-brown root cap color and was slightly harder than DR-MR which was whitish in body and apex color and softer. The other root characteristics, such as the number of downward and upward roots of medium-size roots, number of LR, total large root length, and longest large root length, were measured. The dry weights of each classified root were recorded following the same method used for the shoots after oven-drying.

Physicochemical properties of soil

The physicochemical properties of soils used in the experiments were determined following the same methods used in a previous study (Rembon et al. 2009).

Plant tissue analysis

The dried samples were ground using a UIRE milling machine (Yoshida Product Co., Japan). Then, samples were taken and about 0.5 g was weighed 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 forms were completely digested. The solution was then cooled down, filtered, and added with distilled water up to 100 ml in a 100 ml volumetric flask as a stock solution for further element determination. Nitrogen was analyzed using the Kjeldhal method. Phosphorous was determined with a vanadomolybdate-yellow solution following the method described by Murphy and Riley (1962), and the P concentration was measured with a spectrophotometer (UV-1200, SHIMADZU, Japan) at λ = 710.0 nm. The potassium, calcium, and magnesium concentrations were determined using the lanthanum chloride ($LaCl_3$) method, and the value was determined using an atomic absorption spectrophotometer (AA-6800, SHIMADZU, Japan).

Statistical analysis

Analyses of variance (ANOVA) at 95% and 99% levels were performed using a Statistical Analysis System (SAS, 2002) Program version 9.0 for Windows and were followed with Tukey's test at $p < 0.05$ to distinguish the difference among treatments. The leaf emergence rate between Exp. 1 and 2 was examined using the *t*-test.

Results

The physicochemical properties of the soil used in Exp. 1 and 2 are presented in Table 1. The mineral soil had a more neutral pH (6 ~ 6.6), with medium organic-C and total-N contents, low CEC, low nutrient content, a sandy loam texture, and bulk density of around 1.0. On the other hand, the organic soil was more acidic, with pH ca. 4.5, very high organic-C and N contents, very high CEC, low nutrient content, a silty clay texture, and lower bulk density than mineral soil.

Changes in the temperature, solar radiation, rainfall, and relative humidity during the experimental period for both experiments are shown as the average of every 10 days in a month in Fig. 1. The average temperature ranged from 24 to 27℃ and tended to be lower from February to August, 2007. The average solar radiation varied from 10 to 20 MJ m^{-2} day^{-1}. There was a decreasing tendency of solar radiation from March to June, 2007. The average rainfall fluctuated significantly during the experimental period, although higher and lower rainfall was observed from the end of March to mid-May and July and August, 2007, respectively. The relative humidity (R.H.) was high and changed from 80 to 90% in both experiments. The average temperature, solar radiation, rainfall, and R.H. for the whole period of Exp. 1 and 2 were 26.0℃, 14.5 MJ m^{-2} day^{-1}, 6.7 mm day^{-1}, and 86% and 25.3℃, 13.7 MJ m^{-2} day^{-1}, 6.6 mm day^{-1}, and 87%, respectively.

The soil water contents of the MS and OS used in Exp. 1 and 2 were determined prior to transplanting. The soil water contents of the upper and lower layers in a pot were almost constant from 2 to 144 hours after full watering in some treatments, and little

Table 1. Characteristics of the chemical and physical properties of mineral and organic soils used for Experiments 1 and 2.

Soil properties	Mineral soil				Organic soil			
	Soil depth (cm)				Soil depth (cm)			
	0-15		15-30		0-15		15-30	
pH (H_2O)	6.6	N	6	SA	4.5	A	4.3	VA
Organic-C (g kg^{-1})	23	M	50	H	513	VH	245	VH
Total N (g kg^{-1})	2	M	2	M	11	VH	11	VH
CEC ($cmol_c$ kg^{-1})	12.5	L	10.7	L	65.8	VH	44	VH
Available P (mg kg^{-1})	1.1	VL	1.7	VL	2.9	L	2.8	L
Exc. K (mg kg^{-1})	0.3	L	0.3	L	0.4	M	0.3	L
Soil texture	Sandy Loam		Sandy		Silty Clay		Silty Clay Loam	
Sand (%)	69.8		55.3		3.5		5.0	
Silt (%)	22.4		36.9		55.5		55.9	
Clay (%)	7.8		7.8		41.0		39.1	
Water table (cm)*	30.0		30.0		30.0		30.0	
Bulk density (g cm^{-3})	1.0		1.1		0.3		0.3	

* Measured during dry season.

A = Acid; SA = Slightly acid; VA =Very acid; N = Neutral; L = Low; VL = Very low; M = Medium; H = High; VH = Very high.

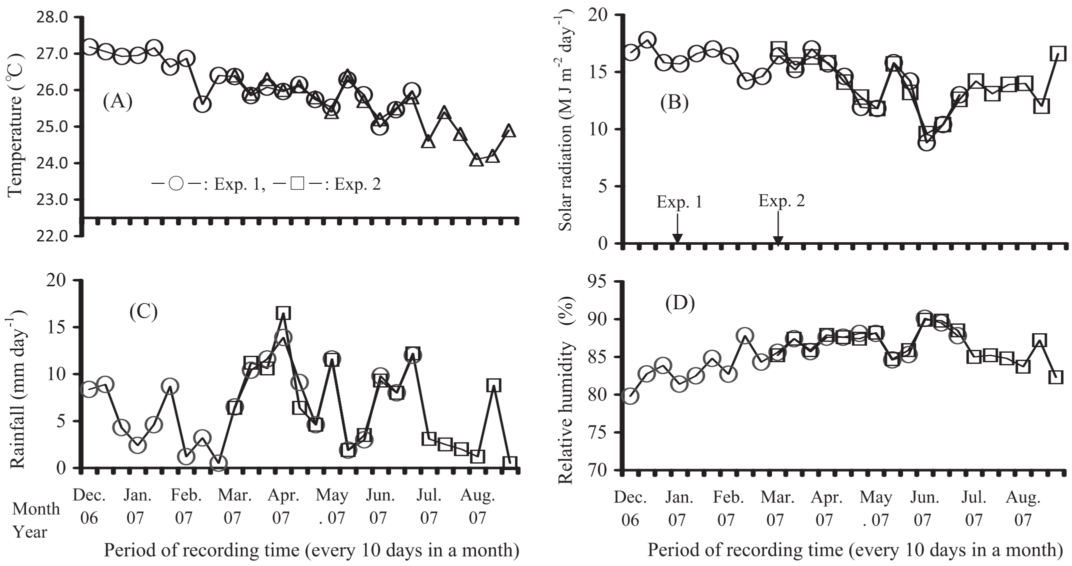

Figure 1. Changes in average temperature (A), solar radiation (B), rainfall (C), and relative humidity (D) in each 10 days of month after transplanting in Experiments 1 and 2.
Bars of Exp. 1 and 2 indicate the transplanting date (Exp. 1: Dec. 28, 2006; Exp. 2.: Mar., 2007).
[Source: BPTP Kendari (2006 and 2007)]

difference was observed in both experiments irrespective of the soil types. The water contents in the upper and lower layers of pots were generally higher, in the order of W1 > W2 > W3 plot. The average water contents of both layers of the W1, W2, and W3 plots during that time varied from 55-67, 55-61, and 51-55% for the MS and 434-484, 343-482 and 251-320 % for the OS, respectively.

Shoot growth

The growth parameters of shoots at 6 months after transplanting in Exp. 1 and 2 are shown in Table 2 (data of each treatment were not shown). All growth parameters, except the number of living leaves, were higher in Exp. 1 than in Exp. 2. The plant length and

Table 2. Effects of soil types and water regimes on the vegetative growth of sago palm seedlings at 6 months after transplanting.

Treatment [1]	Base diameter (cm)	Plant length (cm)	Living leaf number	YEL[2] length (cm)	Leaflet of YEL [2] number	Leaflet of YEL [2] length (cm)	Leaflet of YEL [2] width (cm)
Experiment 1							
W1	8.9 a	122.9 ns	12.1 ns	120.4 ns	28.0 ns	35.9 b	2.8 b
W2	7.8 b	128.4 ns	11.1 ns	126.6 ns	29.3 ns	38.7 b	3.1 ab
W3	7.1 c	129.3 ns	11.1 ns	127.5 ns	28.8 ns	41.7 a	3.3 a
MS	7.8 ns	125.8 ns	11.6 ns	124.1 ns	29.4 ns	38.8 ns	3.0 ns
OS	8.0 ns	127.9 ns	11.3 ns	125.6 ns	28.0 ns	38.8 ns	3.1 ns
Soil x Water	ns	ns	ns	ns	ns	ns	ns
Experiment 2							
W1	5.6 a	88.1 ns	11.5 ns	84.4 ns	22.8 ns	33.1 ns	2.8 ns
W2	5.5 ab	93.3 ns	11.9 ns	90.3 ns	23.0 ns	35.2 ns	3.1 ns
W3	5.1 b	89.1 ns	11.3 ns	86.0 ns	21.2 ns	34.0 ns	3.0 ns
MS	5.4 ns	91.1 ns	11.8 a	87.8 ns	22.3 ns	34.8 ns	2.9 ns
OS	5.4 ns	89.2 ns	11.3 b	86.1 ns	22.3 ns	33.4 ns	3.0 ns
Soil x Water	ns	ns	ns	ns	ns	ns	ns

[1] MS= Mineral soil, OS= Organic soil, W1: waterlogged, W2: making 10 holes (diameter: 1cm) at even distance at the mid-height, W3: making 5 holes as the same size at the bottom of pot. YEL [2]= Youngest expanded leaf.
Values follows by different alphabetical letters in the same column in each corresponding rows were significantly different at $p < 0.05$ level by Tukey's test ; ns = the ANOVA was not significant.

base diameter were 110-140 cm and 7-9 cm in Exp. 1 and 80-100 cm and 5-6 cm in Exp. 2, respectively. The number of living leaves was almost the same, 10-12, in both experiments, and the youngest expanded leaf length was near the value of the plant length. The leaflet number and the length and width of the longest leaflet in the youngest expanded leaf were about 30 leaves, 40 cm, and 3 cm in Exp. 1 and about 20-25 leaves, 35 cm, and 3 cm in Exp. 2, respectively.

The leaf emergence rate (coefficient of the regression line) on the main stem after transplanting in each treatment of Exp. 1 and 2 shows that the rates in Exp. 2 (1.23-1.28 leaves/month) were significantly different from ($p < 0.001$) and higher than those in Exp. 1 (0.92-1.18 leaves/month). The leaf emergence rates in the W1 plot in Exp. 1 tended to be faster than those of the W2 and W3 plots, irrespectively of the soil types.

No significant differences in any of the growth parameters of shoots were observed among the treatments combining soil types and water regimes in Exp. 1 and 2 (Table 2). The base diameter was affected by the water regimes, and it was greater, in the order of W1 > W2 > W3 plot, showing significant differences among the water regimes in Exp. 1 and between the W1 and W3 plots in Exp. 2. Moreover, the leaflet number and the longest leaflet width of the youngest expanded leaf tended to be higher in the W1 plot than in the W2 and W3 plots, and those differences in Exp. 1 were significant. On the other hand, comparing the water regimes, few effects of the soil types on the shoot growth parameters were observed, and only the leaf number in the MS plot showed a significantly higher value than that in the MS plot.

Root growth

The growth parameters of LR and MR at 6 months after transplanting in Exp. 1 and 2 are shown in Table 3 (data of each treatment were not shown). All of the root growth parameters in Exp. 1 were higher than those in Exp. 2.

The number of LR and MR varied from 26 to 32 and 330 to 520 pot^{-1} in Exp. 1 and from 16 to 24 and 110 to 210 pot^{-1} in Exp. 2, respectively. The difference in the number of LR among treatments or between Exp. 1 and 2 was smaller than that of MR. The ratio of the number of MR to LR was 12-18 in Exp. 1 and 6-11 in Exp. 2. The total length of LR varied from 1,200 to 1,900 cm in Exp. 1 and from 520 to 810 cm in Exp. 2. Regarding the MR, the number of UR-MR was higher than that of the DR-MR in Exp. 1 except for the OS-W2 plot, but the reverse was found in many plots in Exp. 1.

No significant differences in any of the growth

Table 3. Effects of soil types and water regimes on root growth parameters at 6 months after transplanting.

Treatment 1)	Large root 2)			Medium root 3)				MR/LR
	Number of large roots	Total large root length (cm)	Longest large root length (cm)	Number of downward roots (a)	Number of upward roots (b)	Total number of medium roots	b/a	
Experiment 1								
W1	31.8 ns	1735 a	129.7 ns	180.5 ns	298.2 ns	478.7 a	1.7	15.1 ns
W2	26.7 ns	1279 b	126.5 ns	227.5 ns	192.2 ns	419.7 a	0.8	15.7 ns
W3	27.5 ns	1316 b	123.9 ns	119.2 ns	201.0 ns	320.2 b	1.7	11.6 ns
MS	29.1 ns	1461 ns	124.3 ns	171.8 ns	218.0 ns	389.8 ns	1.3	13.4 ns
OS	28.2 ns	1425 ns	129.0 ns	179.7 ns	242.9 ns	422.6 ns	1.4	15.0 ns
Soil x Water	ns	ns	ns	ns	ns	ns	ns	ns
Experiment 2								
W1	20.7 ns	765.6 ns	63.8 ns	84.0 ns	99.5 a	183.5 ns	1.2	8.9 ns
W2	17.0 ns	622.8 ns	70.5 ns	94.2 ns	65.0 ab	159.2 ns	0.7	9.4 ns
W3	17.5 ns	588.3 ns	75.8 ns	92.0 ns	41.5 b	133.5 ns	0.5	7.6 ns
MS	18.1 ns	699.2 ns	73.8 ns	65.8 b	70.8 ns	136.6 b	1.1	7.5 b
OS	18.7 ns	618.6 ns	66.2 ns	114.3 a	66.6 ns	180.9 a	0.6	9.7 a
Soil x Water	ns	ns	ns	ns	ns	ns	ns	ns

1-3) Refer to Table 2. Values follows by different alphabetical letters in the same column were significantly different at $p < 0.05$ by Tukey's test ; ns = The ANOVA was not significant.

parameters (number and length) of LR and MR were observed among the treatments combining soil types and water regimes in Exp. 1 and 2 (Table 3). The water regimes affected the total LR length and the number of MR in Exp. 1 and the number of UR-MR in Exp. 2, and these characters were higher in the W1 plot than in the W3 and W2 plots, showing significant differences between the W1 and W3 plots in the total LR length and the number of MR in Exp. 1 and the number of UR-MR in Exp. 2. As for the effect of the soil type, the numbers of the MR and DR-MR in the OS plot in Exp. 2 were significantly higher than those in the MS plot.

Growth in dry weight

The dry weights of the shoot, root, and whole plant at 6 months after transplanting in Exp. 1 and 2 are shown in Table 4. The whole plant dry weight in Exp. 1 varied from 285 to 377 g, and these values were 3.0-3.6 times higher than those in Exp. 2 (ca. 89-105 g). The shoot dry weight was higher than the root dry weight in both experiments, and the shoot / root ratio was about 1.8-2.5 in Exp. 1 and 2.8-4.0 in Exp. 2. Differences in the whole dry weight and the shoot / root dry weight ratio were observed between Exp. 1 and 2, in accordance with the difference in plant age at transplanting.

Of the shoot dry weight, the dry weight of the leaflet was smaller than that of other leaf portions, leaf rachis + petiole + leaf sheath, in both experiments. The root dry weight in each classified root was heavier, in the order of SR > LR > MR, except for the OS-W2 plot in Exp. 1, and in the order of LR >SR >MR, except for the MS-W1 plot, in Exp. 2. The average root dry weights of each classified root for Exp. 1 and 2 were: LR: 32.3 g, 10.1 g; MR: 25.5 g, 4.0 g; and SR: 56.8 g, 7.5 g, and the ratios of Exp. 1 to Exp. 2 in each classified root weight were: LR: 3.2; MR: 6.3; and SR: 7.6. The root weight ratio of the SR and MR to the whole root increased with aging compared to LR.

Significant differences in the total LR length among the treatments combining soil types and water regimes were observed in Exp. 1. The highest and lowest values in Exp. 1 were found in the MS-W2 plot and the OS-W3 plot, respectively, and a significant difference was observed between them. In Exp. 2, significantly higher values in the SR and total root dry weight and lower shoot / root ratio were observed in the MS-W1 plot due to the extraordinarily high value in the SR dry weight compared to that in the other plots.

The effects of soil water regimes were observed in the dry weights of (leaf rachis + petiole + leaf sheath), SR, and total root in Exp. 1, but only in the SR in Exp. 2 (Table 4). These values tended to be higher in the W2 and W1 plots than in the W3 plot, and significant differences in these characters were more pronounced in Exp. 1 than in Exp. 2. On the other hand, significant effects of soil types were only observed in the LR dry weight in Exp. 1 and the shoot / root dry weight ratio in Exp. 2, showing higher values in the MS and OS plots than in the OS and MS plots, respectively.

Nutrient uptake

The nutrient uptakes of the whole plant at 6 months after transplanting in Exp. 1 and 2 are shown in Table 5 (data of each treatment were not shown). Nutrient uptakes were higher, in the order of K > N > Ca > Mg ≒ P, in both experiments. The differences in nutrient contents in the whole plant observed between Exp. 1 and 2 were related to differences in plant age at transplanting.

No significant differences in the nutrient uptakes among the treatments combining soil types and water regimes were observed (Table 5). The effects of water regimes were observed in the P and Ca uptakes in Exp. 1 but not in Exp. 2. In Exp. 1, the P uptake in the W3 and W2 plot was significantly higher than that in the W1 plot, and the Ca uptake was significantly higher in the W2 plot than that in the W3 plot. The effects of soil types were observed in the P and Mg uptakes in Exp. 1 and the Mg uptake in Exp. 2. A higher P uptake in the MS plot than in the OS plot was observed in Exp 1. In contrast, the Mg uptake was significantly higher in the OS plot than in the MS plot in both experiments.

Table 4. Effects of soil types and water regimes on the dry weight of each organ and whole plant at 6 months after transplanting.

Treatment [1)]	Leaflet (g)	Rachis+petiole+ leaf sheath (g)	Total shoot (g)	Root [2)] Small root (g)	Medium root (g)	Large root (g)	Total root (g)	Whole plant (g)	Shoot/Root ratio
				Experiment 1					
MS-W1	77.8 a	130.9 a	208.7 a	58.0 a	28.0 a	32.5 ab	118.5 a	327.2 a	1.78 a
MS-W2	112.1 a	129.0 a	241.1 a	66.3 a	26.9 a	36.3 a	111.8 a	352.9 a	2.16 a
MS-W3	84.9 a	125.7 a	210.6 a	40.6 a	28.7 a	34.9 ab	104.2 a	314.8 a	2.03 a
OS-W1	73.8 a	155.9 a	229.7 a	50.0 a	20.3 a	34.4 ab	104.8 a	334.5 a	2.23 a
OS-W2	91.7 a	155.2 a	246.9 a	90.2 a	28.7 a	28.1 ab	130.1 a	377.0 a	1.95 a
OS-W3	86.6 a	114.2 a	200.8 a	35.7 a	20.5 a	27.7 b	83.9a	284.7 a	2.53 a
W1	75.8 A	143.4 A	219.2 A	54.0 AB	24.2 A	33.5 A	111.7 AB	330.9 A	2.01 A
W2	101.9 A	142.1 AB	244.0 A	78.2 A	27.8 A	32.2 A	121.0 A	365.0 A	2.05 A
W3	85.8 A	120.0 B	205.7 A	38.1 B	24.6 A	31.3 A	94.0 B	299.7 A	2.28 A
MS	91.6 X	128.5 X	220.1 X	55.0 X	27.9 X	34.6 X	111.5 X	331.6 X	1.99 X
OS	84.1 X	141.8 X	225.9 X	58.6 X	23.2 X	30.1 Y	106.3 X	332.2 X	2.24 X
Soil x Water	ns	ns	ns	ns	ns	*	ns	ns	ns
				Experiment 2					
MS-W1	30.7 a	45.5 a	76.2 a	12.7 a	5.0 a	9.8 a	27.6 a	103.8 a	2.76 b
MS-W2	32.2 a	45.4 a	77.6 a	5.8 b	4.1 a	11.5 a	21.6 ab	99.2 a	3.59 ab
MS-W3	28.6 a	42.3 a	70.9 a	5.7 b	2.8 a	9.8 a	18.4 b	89.3 a	3.85 a
OS-W1	30.8 a	48.1 a	78.9 a	6.7 b	3.7 a	9.3 a	20.0 ab	98.9 a	3.95 a
OS-W2	35.2 a	47.4 a	82.6 a	7.7 b	4.1 a	10.1 a	22.1 ab	104.7 a	3.74 a
OS-W3	33.2 a	41.3 a	74.5 a	6.6 b	4.0 a	10.1 a	20.7 ab	95.2 a	3.60 ab
W1	30.8 A	46.9 A	77.5 A	9.7 A	4.3 A	9.6 A	23.8 A	101.3 A	3.26 A
W2	33.7 A	46.4 A	80.1 A	6.8 B	4.1 A	10.8 A	21.9 A	102.0 A	3.66 A
W3	30.9 A	41.8 A	72.7 A	6.2 B	3.4 A	10.0 A	19.6 A	92.3 A	3.71 A
MS	30.5 X	44.4 X	74.9 X	8.1 X	4.0 X	10.4 X	22.5 X	97.4 X	3.33 Y
OS	33.1 X	45.5 X	78.6 X	7.0 X	3.9 X	9.8 X	20.9 X	99.5 X	3.76 X
Soil x Water	ns	ns	ns	**	ns	ns	**	ns	*

1) Refer to Table 2. 2) Large root (diameter at base > 5 mm), medium root (diameter at base = 2-5 mm), small root (diameter at base < 2mm). Values follows by different alphabetical letters in the same column were significantly different at $p < 0.05$ and $p < 0.01$ by Tukey's test, respectively.

Table 5. Effects of soil types and water regimes on the nutrient uptake in whole plants.

Treatment [1)]	Nutrient uptake (g palm $^{-1}$) N	P	K	Ca	Mg
			Experiment 1		
W1	5.078 A	0.840 B	6.703 A	3.401 AB	1.110 A
W2	5.491 A	1.296 A	8.587 A	3.874 A	1.382 A
W3	5.320 A	1.330 A	7.114 A	2.881 B	1.118 A
MS	5.093 X	1.284 X	6.998 X	3.411 X	1.047 Y
OS	5.499 X	1.026 Y	7.958 X	3.361 X	1.359 X
Soil x Water	ns	ns	ns	ns	ns
			Experiment 2		
W1	2.079 A	0.272 A	4.030 A	0.780 A	0.299 A
W2	2.156 A	0.309 A	3.908 A	0.696 A	0.347 A
W3	2.131 A	0.337 A	3.799 A	0.684 A	0.324 A
MS	2.017 X	0.325 X	4.052 X	0.694 X	0.273 Y
OS	2.226 X	0.288 X	3.772 X	0.751 X	0.374 X
Soil x Water	ns	ns	ns	ns	ns

1) Refer to Table 1. Values follows by different alphabetical letters in the same column in each corresponding rows were significantly different at $p < 0.05$ level by Tukey's test ; ns = the ANOVA was not significant.

Correlations among the growth parameters

The correlation coefficients between the plant base diameter, which was significantly affected by the water regimes (Table 2), and the root characters showed that only the total LR length and the number of UR-MR were significant in both Exp. 1 and 2 (Table 6). The number of LR was significantly correlated with the base diameter in Exp. 1 but not in Exp. 2. In contrast, in Exp. 2, significant correlations were observed between the base diameter and the number of MR and LR or the total root dry weight as well as the shoot dry weight. Moreover, the correlation coefficients between the total root dry weight and each classified root showed that the MR dry weights in both Exp. 1 and 2 were significant, while the SR and LR dry weights were only significant in Exp. 1 and 2, respectively (Table 7). The correlations between the shoot dry weight and the root characters are shown in Table 8. None of the root characters was significantly correlated with the shoot dry weight in Exp. 1. On the other hand, all the root characters, except the number of LR, the total LR length, and the number of DR-MR, were significantly correlated with the shoot dry weight in Exp. 2. The shoot dry weight was more closely correlated with the LR dry weight compared with the MR and SR dry weights in Exp. 2.

Table 6. Correlation coefficients *(rs)* between the plant base diameter and root characters.

Root character	Exp.1	Exp.2
Shoot dry weight	0.154	0.795 ***
Number of LR[1]	0.600 **	0.414
Total LR length	0.769 ***	0.569 *
Number of MR[2]	0.385	0.536 *
Number of UR-MR[3]	0.640 **	0.649 **
Number of DR-MR[4]	-0.076	0.021
Total root dry weight	0.346	0.588 *
LR dry weight	0.383	0.574 *
MR dry weight	0.038	0.411
SR[5] dry weight	0.356	0.266

LR[1]: Large root (dimaeter; > 5 mm), MR[2]: Medium root (diameter; 2-5 mm), UR-MR[3]: Upward root of medium root, DR-MR[4]: Downward root of medium root. SR[5] = Small root (diameter < 2.0 mm). *, **, *** : significant at 5, 1 and 0.1 % , respectively.

Discussion

The temperature, relative humidity (R.H.), and irradiance during the experiments (Exp. 1 and 2) ranged from 24-27℃, 80-90%, and 10-20 MJ m^{-2} day^{-1} (1,000-2,000 J cm^{-2} day^{-1}), respectively (Fig. 1). Such meteorological conditions might be almost optimum for the leaf growth of sago palm seedlings (Flach et al. 1986, Paquay et al. 1986). By comparing the physicochemical properties of soils used in the experiments (Table 1), the OS showed remarkably lower pH and bulk density, as reported by Kakuda *et al.* (2000). On the other hand, the N content and CEC (Kakuda et al. 2000), as well as the available P content, were higher in the OS than in the MS. The uptakes of macroelements, except the Mg in Exp. 1 and 2, however, were not significantly different according to the soil types, irrespectively of the large differences in the contents of macroelements, and the P uptake was higher in the MS than in the OS in Exp. 1 (Table 5). As a result, few differences were observed in the shoot and root growth with the soil types. This might be caused by the remarkable differences in the bulk density of the MS and OS; i.e., the bulk density of the OS is usually lower (0.1-0.2 g cm^{-3}) than that of the MS (1.0 g cm^{-3} ≦) (Funakawa et al. 1996, Tie and Lim 1977, Kakuda et al. 2000). Thus, the nutrient levels of the OS per volume basis are lower

Table 7. Correlation among the dry weights of the total root and each classified root.

Character	(1)		(2)		(3)		(4)	
	Exp.1	Exp.2	Exp.1	Exp.2	Exp.1	Exp.2	Exp.1	Exp.2
Total root dry weight (1)	-	-						
LR[1] dry weight (2)	0.251	0.585 *	-	-				
MR[2] dry weight (3)	0.694 **	0.840 ***	-0.069	0.437	-	-		
SR[5] dry weight (4)	0.930 ***	0.312	-0.020	0.265	0.446	0.329	-	-

[1] LR: Large root (diameter; > 5 mm),[2] MR: medium root (diameter; 2-5 mm),[3] UR-MR: upward root of MR,[4] DR-MR: downward root of MR. *, ** and ***; significant at 5, 1 and 0.1 % level, respectively.

Table 8. Correlation coefficients *(rs)* between the shoot dry weight and the total roots or each classified root.

Root character	Exp.1	Exp.2
Number of LR[1)]	- 0.249	0.217
Total LR length	- 0.141	0.402
Number of MR[2)]	0.042	0.625 ***
Number of UR-MR[3)]	0.077	0.521 *
Number of DR-MR[4)]	- 0.016	0.292
Total root dry weight	0.301	0.648 **
LR dry weight	0.096	0.663 **
MR dry weight	- 0.237	0.567 *
SR[5)] dry weight	0.454	0.490 *

LR[1)]: Large root (diameter; > 5 mm), MR [2)]: Medium root (diameter; 2-5 mm), [3)] UR-MR: upward root ,of MR , [4)] DR-MR: downward root of MR, SR [5)]: Small root (diameter; < 2.0 mm), *, **, *** = significant at 5, 1 and 0.1 % , respectively

than those of the MS; for instance, the amount of mineralized N and CEC calculated on a volume basis was only 20% of that calculated on a weight basis (Tie et al. 1991, Kakuda et al. 2000), and this might result in the difference of nutrient contents per pot. Generally, the growth rate of sago palm grown on peat soil is 25% slower than that of sago palm grown on mineral soil (Flach and Schuiling 1989), and Kakuda et al. (2000) suggested that the growth difference caused the difference in the N content in the soils due to the lower mineralization of soil organic nitrogen in the OS than in the MS. Additional factors, such as pot experiments and fertilizer application in Exp. 2, might also be responsible for the decrease in the difference in seedling growth in both types of soils. However, comparing the leaf emergence rates between Exp. 1 and 2, it was revealed that younger seedlings with a fertilizer application grew faster than older ones without fertilization, irrespectively of the soil types and water regimes.

Larger effects of the water regimes than of the soil types were observed on the early growth of sago palm seedlings. The water regimes affected the base diameter of the shoots, which tended to be larger, in the order of W1 > W2 > W3 plot, although other shoot growth parameters were not significantly affected by them (Table 2). On the other hand, root growth was more affected by the water regimes than shoot growth, showing a higher number of LR in the W1 plot than in the W2 and W3 plots and increasing the tendencies of the total length of LR and the numbers of MR and UR-MR, in the order of W1 > W2 > W3 plot (Table 3). These results brought about the higher root dry weight and shoot / root dry weight ratio in the order of W1 > W2 > W3 and W3 > W2 > W1, respectively (Table 4). Comparing the effects of the groundwater level on the growth of sago palm suckers at one year after transplanting, Omori et al. (2002) reported that the shoot growth was not affected by the high (0-30 cm) and low (40-50 cm) groundwater levels but the root length and dry weight in the low groundwater level were superior to those in the high groundwater level. The results for shoot growth obtained in this research were coincident with those reported by Omori et al. (2002) but not with those for root growth. The different results for root growth might come from differences in plant materials used (sucker vs. seedling) and cultivation methods (field vs. pot) between the experiments.

As a significant difference was observed in the base diameter of shoots with the water regimes, the correlations between the base diameter and other growth parameters were discussed. It was suggested that seedlings with a thicker base diameter of the shoot tended to have a longer total LR and a higher number of UR-MR in Exp. 1 and 2 (Table 6). This result implies that seedlings grown under a waterlogged condition have a larger base diameter and enhanced root growth. In rice seedlings, good seedlings with a thicker base diameter form a higher number of root primordia in the stem, and a larger number of thicker roots emerge compared with spindly grown seedlings with a slender base diameter (Hoshikawa 1989). The roots of sago palm seedlings are the same adventitious roots, except for the seminal roots used as rice seedlings. Nitta et al. (2002) reported that the adventitious root primordia were formed just below the epidermis of the trunk from the base to the top, and the density and diameter of root primordia were larger at the base and the top of trunk, respectively. A further study on the issue of root primordial formation and their emergence, such as the anatomical position in the stem, density, and size, needs to be performed, and the emergence and growth of the root primordia will then be clarified.

The base diameter of shoots was positively and significantly correlated with the shoot and root dry weight in Exp. 2 but not in Exp. 1. This might be due to the difference in the seedling age used in Exp. 1 and 2, and the shoot growth was suggested to perform more in parallel with the root growth in the younger seedlings in Exp. 2 compared to the age-advanced seedlings in Exp. 1. The positive and significant correlation between the shoot and root dry weight observed only in Exp. 2 but not in Exp. 1 also suggested the same situation (Table 8). The increase of the dry weight of the classified roots advanced in the order of LR >MR >SR, and the shoot dry weight was positively and significantly correlated with each classified root weight in Exp. 2, although the correlation was closer, in the order of LR >MR >SR (Table 8). On the other hand, only the SR dry weight showed a considerably higher positive correlation with the shoot dry weight ($r = 0.454$, $p < 0.10$) in Exp. 1.

This study was performed to clarify the effects of soil types and water regimes on the growth of sago palm seedlings to obtain basic information for the use of seedlings as a propagation material. The water regimes used in this study, however, were not significantly different because the experiments were performed under natural (non-protected rainfall) conditions and watering was done at least once every day. The seedlings in the driest plot, the W3 plot, might not have suffered from severe water stress. A further study needs to be performed to clarify the effects of water conditions on the early growth of sago palm seedlings under a wider range of water regimes. Moreover, the appropriate age and size of seedlings used for transplanting materials and the growth characteristics of seedlings after transplanting as compared with those of suckers should be determined.

References

Ehara, H., C. Komada and O. Morita 1998 Germination characteristics of sago palm seeds and spine emergence in seedlings produced from spineless palm seeds. Principes 42: 212-217.

Ehara, H., O. Morita, C. Komada and M. Goto 2001 Effect of physical treatment and presence of the pericarp and sacrotesta on seed germination in sago palm (*Metroxylon sagu* Rottb.). Seed Science and Technology 29: 83 − 90.

Flach, M., K. D. Braber, M. J. J. Fredrix, E. M. Monster and G. A. M. Van Hasselt 1986 Temperature and relative humidity requirements of young sago seedlings. *In*: Proceedings of the Third International Sago Symposium (N. Yamada and K. Kainuma eds.) Sago Palm Research Fund (Tokyo) 139-143.

Flach, M. and D. L. Schuiling 1989 Revival of an ancient starch crop: A review of the agronomy of the sago palm. Agroforestry Systems 7: 259-281.

Flach, M. 1997 Promoting the conservation and use of underutilized and neglected crops. 13. Sago Palm (*Metroxylon sagu* Rottb.). International Plant Genetic Resources Institute, Rome, Italy, 76 pp.

Funakawa, S., K. Yonebayashi., J. F. Shoon and E. O. K. Chai 1996 Nutritional environment of tropical peat soils in Sarawak, Malaysia based on soil solution composition. Soil Science and Plant Nutrition 42: 833-843.

Hoshikawa, K. 1989 The growing rice plant. An anatomical monograph. Nosan Gyoson Bunka (Nobunkyo), Tokyo, Japan. pp. 199-205.

Jalil, M. N. H. and J. Bahari 1991 The performance of sago palms on riverine alluvial clay soils of peninsular Malaysia,1991 Proceedings of the forth International Sago Symposium, Kuching Sarawak, Malaysia. pp. 114-121.

Jong, F. S. 1991 Srudies on the seed germination of sago palm (*Metroxylon sagu*). *In*:Towards Greater Advancement of the Sago Industry in the '90s. (Ng Thai-Tsiung T. Yiu-Liong and K. Hong-Siong eds.) Proceedings of the forth International Sago

Symposium August, 6-9, 1990, Kuching, Sarawak, Malaysia. pp. 88-93.

Jong, F. S. 1995 Research for development of sago palm (*Metroxylon sagu* Rottb.) cultivation in Sarawak, Malaysia. Sadong Press. Sdn. Bhd., 139 pp.

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

Kakuda, K., H. Ando, T. Yoshida, Y. Yamamoto, Y. Nitta, H. Ehara, Y. Goto and H. P. Benito 2000 Soil characteristics in sago palm grown area. Factors associated with fate of inorganic nitrogen in soil. Sago Palm 8: 9-16 (in Japanese with English abstract).

Kasuya, N. 1996 Sago root studies in peat soil of Sarawak. Sago Palm 4: 6-13.

Kiew, R. 1977 Taxonomy, ecology and biology of sago palms in Malaya and Sarawak. *In*: The Equatorial Swamp as a Natural Resource. (Koonlin, T. ed.) The first International Sago Symposium (Kuching) 147-154.

Murphy, J. and J. P. Riley 1962 A modified single solution method for the determination of phosphate natural waters. Analytica Chimica Acta 27: 31-36.

Nitta, Y., Y. Goto, K. kakuda, H. Ehara, H. Ando, T. Yoshida, Y. Yamamoto, T. Matsuda, F. H. Jong and A. H. Hassan 2002 Morphological and anatomical observations of adventitious and lateral roots of sago palms. Plant Production Science 5: 139-145.

Omori, K., Y. Yamamoto, F. S. Jong, T. Wenston, A. Miyazaki and T. Yoshida 2002 Changes in some characteristics of sago palm sucker growth in water and after transplanting. *In*: New Frontiers of Sago Palm Studies. (K. Kainuma, M. Okazaki, Y. Toyoda and J.E. Cecil eds.) Universal Academy Press, Inc. Tokyo, Japan. p.265-269.

Paquay, L. E. C. R., D. L. Schuiling, G. H. De Bruijn, R. W. P. Roos and M. Flach 1986 Effects of nutrient shortage on young sago palm seedlings. *In*: Proceedings of the Third International Sago Symposium (N. Yamada and K. Kainuma eds.) Sago Palm Research Fund (Tokyo) 144-152.

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

Rembon, F. S., Y. B. Pasolon and Y. Yamamoto 2008 Characteristics of seed and germination of wild-type sago “*Manno*” (*Metroxylon sagu* Rottb.) collected from sago palm field around lake Sentani near Jayapura, Indonesia. Sago Palm 16: 1-6.

Rembon, F. S., Y. B. Pasolon, Y. Yamamoto and T. Yoshida 2009 Physicochemical properties of the soils on sago-palm (*Metroxylon sagu* Rottb.)-growing areas around Kendari, Province of Southeast Sulawesi, Indonesia. (in press)

Sastradipradja, S. 1986 Seedling variation in Metroxylon sagu Rottb. *In*:Protect Mankind from Hunger and the Earth from Devastation (N. Yamada and K. Kainuma eds.) Proceedings of the third International Sago Symposium, May 20-23, 1985, Tokyo. pp. 117-120.

SAS 2002 The SAS system for Windows version 9.0. SAS Institute Inc., Cary, NC. USA.

Sato T., T. Yamaguchi and T. Takamura 1979 Cultivation, harvesting and processing of sago palm. Japanese Journal of Tropical Agriculture 23: 130-136.

Tie, Y. L. and C. P. Lim 1977 Lowland peat soil for sago-growing in Sarawak. *In*: Sago -'76:Papers of the 1st International Sago Symposium. (Tankoolin, M. A. ed.) (Kuala Lumpur) 186-189.

Tie, Y. L., K. S. Loi and L. E. T. Kelvim 1991 The geographical distribution of sago (*Metroxylon* spp.) and the dominant sago-growing soils in Sarawak. *In*: Proceedings of the 4th International Sago Symposium (Ng, T. Y., Y. L. Tie and H. S. Kueh eds.) (Kuching) 36-45.

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