SAGO PALM 18: 6 − 18 (2010)

Physicochemical Properties of the Soils on Sago-Palm (*Metroxylon sagu* Rottb.)-Growing Areas around Kendari, Province of Southeast Sulawesi, Indonesia

Fransiscus Suramas Rembon[1], Yulius Barra Pasolon[1], Yoshinori Yamamoto[2] and Tetsushi Yoshida[2]

[1] Faculty of Agriculture, Haluoleo University, Kendari, Southeast Sulawesi 93232, Indonesia

[2] Faculty of Agriculture, Kochi University, Nankoku, Kochi 783-8502, Japan

Abstract: The physicochemical properties of soils from sago-palm-growing areas were studied and compared with the properties of the soils of surrounding cashew and cacao fields and the paddy fields around Kendari, Southeast Sulawesi Province, Indonesia. Soil samples were collected from 0-15 cm and 15-30 cm depth from Lalomasara and Lakomea in the Pohara Subdistrict, Watulondo in the Puwatu Subdistrict, and Konda in the Konda Subdistrict. The soil types in the sampled areas were mineral soil except for those in Watulondo, which were peat soil. The results revealed that the physicochemical properties of the mineral soils in the sago fields varied depending on the sites and kinds of crops being cultivated. The bulk densities ranged from 0.3-1.1 g cm^{-3}, and the texture varied from sandy loam to silty clay. The soil pH dominantly ranged from very acid to neutral. The nutrient contents of sago-palm-growing soils ranged from low to very high for total-N, very low to medium for available-P, low to medium for exchangeable-K, low to high for CEC, and low to very high for total-C content. The nutrient contents and pH of soils surrounding cashew and cacao were either lower or equal, but they were higher in bulk densities. However, higher total-C, N, and CEC and lower bulk density were observed in the neighboring paddy field than in sago palm fields due to the application of fertilizer and the straw incorporated into the soil every year. The pH in the peat soil in the sago-palm-growing areas ranged from very acid to acid, very high in CEC, organic-C, and total N contents, and low in available-P and exchangeable-K, with a bulk density of 0.3 g cm^{-3}. The effects of the soil physicochemical properties on the growth and starch production were discussed.

Key words: land-use change, sago palm, soil physicochemical properties, Southeast Sulawesi.

インドネシア、南東スラウェシ州クンダリ周辺における サゴヤシ生育地の土壌の理化学的性質

F. S. Rembon[1]・Y. B. Pasolon[1]・山本由徳[2]・吉田徹志[2]

[1] ハルオレオ大学農学部，クンダリ，南東スラウェン州，93232 インドネシア

[2] 高知大学農学部，783-8502，南国市物部乙200

要旨　2006年11月から2007年6月にかけて、インドネシア、南東スラウェシ州クンダリ周辺において、サゴヤシ生育地（園）の土壌の理化学的性質を明らかにするとともに、サゴヤシ生育地周辺のカシュー及びカカオ園並びに水田の土壌の理化学的性質と比較した。土壌は、ポハラ地区のラロマサラ村及びラコメア村、プワツ地区のワツロンド村及びコンダ地区のコンダ村で土壌表面から0-15cmと15-

30cmのところから採集した。採集地の土壌タイプは、ワツロンド村では泥炭質土壌であったことを除くと、いずれも鉱質土壌であった。本調査結果より、サゴヤシ園の土壌の理化学的性質は、周辺土壌の性質の影響を受け、採集場所によって異なることがわかった。サゴヤシ園土壌の容積重は、0.3-1.1g cm^{-3}を示し、土性は砂壌土からシルト質埴土であった。ｐＨは、強酸性～中性であった。全窒素は低～非常に高い、可給態リンは非常に低い～中、交換性カリは低～中、CECは低～高、全炭素は低～非常に高いであった。サゴヤシ園の周辺に位置するカシュー園及びカカオ園の土壌は、サゴヤシ園土壌に比べて養分含量及びｐＨは同等または低かったが、容積重は重かった。一方、サゴヤシ園の周辺に位置する水田土壌は、毎年すき込まれるイナわらに由来する有機物の増加により、サゴヤシ園土壌に比べて全炭素、全窒素及びCECが高く、容積重が低い傾向を示した。サゴヤシの生育する泥炭質土壌のｐＨは強酸性～酸性、CEC、全炭素及び全窒素は非常に高く、可給態リン及び交換性カリは低、容積重は0.3g cm^{-3}であった。土壌の理化学的特性とサゴヤシの生育、デンプン生産との関係について議論した。

キーワード：サゴヤシ、土壌の理化学的性質、土地利用の変化、南東スラウェシ

Introduction

Natural sago-palm-growing areas are mostly floodplains of alluvial and shallow peat land along rivers, freshwater wetlands that are associated with shallow water table or swampy areas including alluvial soil, gley soil, and/or peat soil. In general, the soil in sago-palm-growing areas can be classified into two groups, a mineral soil and an organic or a peat soil; predominantly, however, the soil is mineral soil. According to Flach (1997), sago palm grows well in humid tropical lowlands up to the altitude of 700 m above sea level. Water shortage is detrimental to growth. If there are short dry spells, the groundwater level should be kept, at most, at 40-50 cm depth (Flach and Schuillin 1989). Sago palm grows better on mineral soil than on peat soil. On undrained peat soil, sago palm grows 25% more slowly than it does on mineral soils (Jong and Flach 1995). The difference is related to the physicochemical constraints of peat soils, such as low bulk density, high acidity, and low level of N, P, K, Ca, Zn, and Cu contents (Purwanto et al. 2002). According to Mulyanto and Suwardi (2000), possible soil types in sago-palm-growing areas include 3 important orders, namely Entisols, Histosols, and Inceptisols, with 5 sub-orders (Aquents, Hemists, Saprists, Tropepts, and Aquepts) and 9 great groups (Fluvaquents, Sulfaquents, Hydraquents, Psammaquents, Tropohemists, Troposaprists, Sulfihemists, Humitropepts, and Tropaquepts). The soil water conditions are very important for sago palm (Notohadiprawiro and Louhenapessy 1992) to grow. Louhenapessy (1994) reported that the variation in the groundwater level between +10 and +150 cm (above the soil surface) during the wet season (November-April) and -10 and -40 cm (below soil surface) during the dry season (May-October) for 3-6 months showed good conditions for starch production.

Sago-palm-growing areas around Kendari in Southeast Sulawesi are dominated by mineral soil, mainly found in an occasional floodplain scattered along riverbanks or between foothills with 3 different soil/water regime conditions (dry land, riverbank, and swampy or continuously waterlogged areas). Areas with peat soils exist, but they are rare in the sago-palm-growing areas. The physical and chemical properties of the soils on sago-palm-growing areas might vary from place to place and affect the growth and starch productivity. Clarifying the soil properties on the sago-palm-growing areas is very important when evaluating the relationship between the soil properties and growth or starch production of sago palm and establishing the appropriate soil management for improving the growth and starch productivity. However, research on the soil properties on sago-palm-growing areas around Kendari is scarce (Pasolon and Rembon 2000, Yoshida et al. 2000; Pasolon et al. 2002). This research was conducted to clarify the differences in the physicochemical properties of soil in sago-palm-growing areas around Kendari and to compare the properties of the soil there with those of soil on the surrounding cashew or cacao fields and the neighboring paddy fields.

Materials and Methods

The research was conducted at 4 villages (Lalomasara, Konda, Watulondo, and Lakomea) around Kendari (Fig. 1) in the Province of Southeast Sulawesi, Indonesia, from November 2006 to June 2007. Soil samples were collected from the two layers (0-15 cm and 15-30 cm depth from the soil surface) of soils on sago-palm-growing fields (SF), the surrounding cashew fields (CsF) or cacao fields (CoF), and the neighboring paddy fields (PF). The neighboring paddy field was converted from a sago-growing field about 18 years ago. Soil samples taken from the sago fields in Lalomasara village were collected from 2 sites (Sago 1 and Sago 2). Sago 1 was located on the border between the cashew field and the sago field, while Sago 2 was located in the center of the sago field, separated about 200 m from Sago 1. Moreover, Sago 1 and 2 were separated due to the initial differences in soil properties.

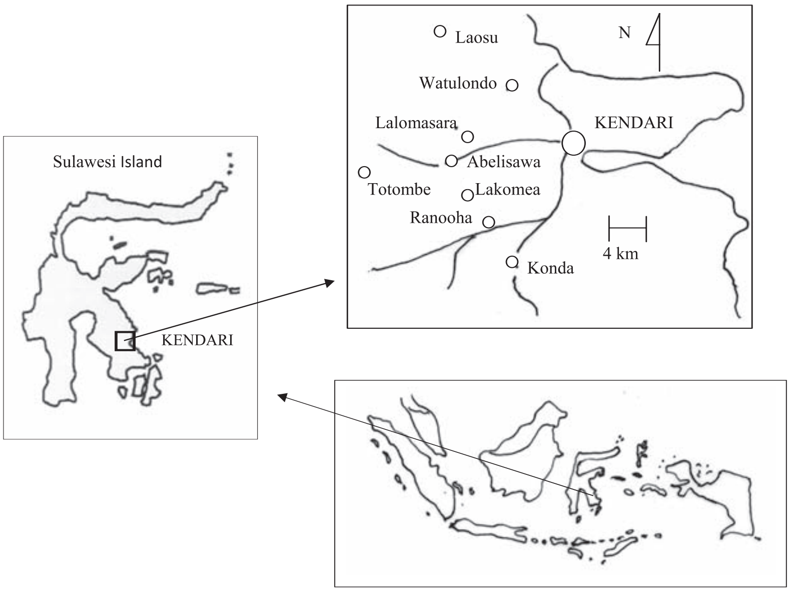

Fig. 1. Map showing the study sites of sago-palm-growing areas around Kendari City, Southeast Sulawesi Province, Indonesia. Sampling sites including Lalomasara, Watulondo, Lakomea, and Konda.

The soil type of the sampled fields was mineral soil except for that from Watulondo, which was peat soil (peat thickness, about 1 m). Fertilizers were not commonly applied to the sago, cashew, and cacao fields, but they were applied to the paddy field. In general, SP-36 (Superphosphate with 36% P_2O_5 content, 75-80 kg ha^{-1}) was applied at transplanting time, while potassium chloride (50-75 kg ha^{-1}) and urea (100 kg ha^{-1}) were applied about 1-2 weeks and 2-3 weeks after transplanting, respectively.

The soil texture was determined following the pipette method (Gee and Bauder 1986) and then classified based on the textural triangle (Brady and Weil 1996), while the bulk density (BD) was determined following the soil core method (Blake and Hartge 1986). The groundwater levels were directly recorded in the field by digging a mini-pit, and the depth from the soil surface was measured using a meter tape. Groundwater levels above and below the soil surface are indicated by plus (+) and minus (–) signs following the values, respectively.

The air-dried soils for chemical analyses were prepared from 300 g, homogenized, and screened through a 2 mm opening sieving net. Their pH, total-N, organic-C, available- P, and exchangeable-K contents and CEC were then analyzed in the Soil Test Lab. of the Faculty of Agriculture Haluoleo University in Kendari.

The pH values for H_2O and KCl were measured with a pH meter after dilution in distilled water and 1 *M* KCl with a ratio of 1 to 2.5 and 1 to 5 (w/v) for mineral soil and peat soil, respectively. Total-C was determined using the Walkey and Black method (Nelson and Sommers, 1982). Total-N and available-P were determined using the Kjeldhal method and the Bray-2 procedure, respectively. The exchangeable-K was determined using a chemical method by precipitating K as $K_2NaCo(NO_2)_6H_2O$ in a dilute solution of 1.0 *N* HNO_3 titrated with 0.05 *N* $KMnO_4$ (Knudsen *et al.*, 1982). The soil cation exchangeable capacity (CEC) was determined by the measurement of the ammonium retained by the negative charges on soil particles after soil saturation with the ammonium acetate solution (pH 7.0).

The criteria used for each element were then classified into 5 categories following Hardjowigeno (1987): (very low =VL, low = L, medium = M, high = H, and very high = VH), and the pH values were classified into very acid = VA, acid = A, slightly acid = SA, neutral = N, and slightly alkaline = Sal. The following are the details of the five categories of elements: soil pH (VA < 4.5, A = 4.5-5.5, SA = 5.6-6.5, N = 6.6-7.5, and Sal > 7.5); total-N (VL < 1.0 g kg^{-1}, L = 1.0-2.0 g kg^{-1}, M = 2.1-5.0 g kg^{-1}, H = 5.1-8.0 g kg^{-1}, and VH > 8.0 g kg^{-1}); available-P (VL < 2.2 mg kg^{-1} , L = 2.2-3.1 mg kg^{-1}, M = 3.2-4.4 mg kg^{-1}, H = 4.5-6.6 mg kg^{-1}, and VH > 6.6 mg kg^{-1}); exchangeable-K (VL < 0.10 $cmol_c$ kg^{-1}, L = 0.10-0.20 $cmol_c$ kg^{-1}, M = 0.21-0.50 $cmol_c$ kg^{-1}, H = 0.51-1.00 $cmol_c$ kg^{-1}, and VH > 1.00 $cmol_c$ kg^{-1}); total-C (VL < 10.0 g kg^{-1}, L = 10.1-20 g kg^{-1}, M = 20.1-30 g kg^{-1}, H = 30.1-50.0 g kg^{-1}, and VH > 50.0 g kg^{-1}); CEC (VL < 5.0 $cmol_c$ kg^{-1}, L = 5.0-16.0 $cmol_c$ kg^{-1}, M = 16.1-24.0 $cmol_c$ kg^{-1}, H = 24.1-40.0 $cmol_c$ kg^{-1}, and VH > 40.0 $cmol_c$ kg^{-1}).

Results and Discussion

1. Physical properties

a. Groundwater level

The groundwater level in the SF in both Lalomasara and Watulondo during the wet and dry seasons varied from +30 cm to +50 cm (above) and -10 cm to -30 cm (below) the soil surface, respectively, while, in Konda, the groundwater level of the SF during the wet and dry seasons varied from +20 cm to +50 cm and -20 cm to -50 cm, respectively. Some variations may have occurred due to fluctuations in the amount of rainfall. Yamamoto et al. (2000) reported that the groundwater level in the mineral soil of SF around Kendari ranged from +100 cm during the wet season and -60 cm during the dry season. Variation in the groundwater level during the wet and dry seasons in Lakomea ranged from 0 cm to +10 cm and -50 cm to -60 cm, respectively. The groundwater levels in the CsF and CoF fields were not directly measured but might have been deeper than those in the SF during both the wet and dry seasons because most of the CsF and CoF were located in the upper slope areas rather than in the lower flood plains of the SF. On the other hand, in the wet season, the groundwater in the PF was lower, relative to the water levels needed for the cultivation of rice, than in the SF which is controlled by the outlet of the waterways in the paddy field areas.

According to Flach and Schuilling (1989), water shortage is detrimental to sago palm growth. Therefore, the groundwater level should be, for the most part, from -40 cm to -50 cm. On the contrary, sago palms grown in deep peat soil under minimal drainage or high water table and seasonal flooding conditions were retarded in growth, and such conditions might cause less than 10% palms producing trunks at 8-9 years after planting (Jong et al. 2006). The majority of the palms remained at the rosette stage with palm heights ranging from 2 m to 4 m. Hashimoto et al. (2006) reported that lowering of the groundwater table from ca. -40 cm to -80 cm tended to decrease the number of leaves and trunk diameters of sago palms grown on deep peat soil. According to Notohadiprawiro and Louhenapessy (1992), sago palm grown in groundwater level conditions from +10 cm to more than +50 cm and -10 cm to -40 cm during wet and dry seasons, respectively, with 6-9 month periods of waterlogging can produce 328 kg - 348 kg starch per palm. On the other hand, sago palms grown under permanent waterlogged conditions with the groundwater level from +10 cm to more than +75 cm during the wet season and higher than +10 cm during the dry season can produce only 94 kg starch per palm. Based on this information, the groundwater table conditions in sago-growing areas around Kendari, which are from +20 cm to +50 cm and -10 cm to -50 cm during the wet and dry seasons, respectively, might be considered good for sago starch yield.

Kho et al. (2005) observed that lower groundwater levels would cause the organic soil to dry and shrink extensively, which may result in subsidence and increase in soil bulk density due to compaction and consolidation. Certain changes in the chemical properties were also reported after prolonged exposure to air. Maintaining the groundwater level at -30 cm or less can effectively slow down the rate of such changes, at least, of subsidence and loss of organic matter.

b. Soil texture

The soil textures of the SF were dominantly classified into sandy loam in Lalomasara and Konda and silty to silty clay in Lakomea (Table 1). On the other hand, the peat soil in Watulondo was silty clay. The texture of soil at Sago 2 in Lalomasara and Watulondo was similar, i.e., silty clay. On the other hand, the CsF and the CoF were found to be more predominantly coarse-texture, sandy loam in Lalomasara and Lakomea and silty loam in Konda. In the PF soil, the soil texture was classified as silty loam, which is slightly different from that in the SF.

Notohadiprawiro and Louhenapessy (1992) found that the sago palms in Ambon, Seram, Halmahera, and Papua commonly grew under sandy (Psammaquent), loamy, and heavy clay (Vertic) soils. So far, no specific report on soil textures has been related to the growth and starch yield of sago palm. Heavy clay conditions are usually associated with low-porosity and high-density soil, under which roots cannot grow well due to the soil compactness. As for Kendari, it was found that sago-palm-growing areas were silty loam, silty, and silty clay, which are lighter and better for root growth and development than the texture of heavy clay soil.

c. Soil bulk density (BD)

The soil bulk density (BD) in the SF varied from 0.3 g cm^{-3} to 1.1 g cm^{-3} (Table 1). In the mineral soils, the lowest BD was found at Sago 2 (0.7 g cm^{-3} - 0.8 g

Table 1. Physicochemical properties of the soils in the sago-palm-growing areas, in the surrounding cashew and cacao fields, and in the neighboring paddy field at four villages around Kendari, Province of Southeast Sulawesi, Indonesia.

Researched year and site	Garden (site)	Depth (cm)	Texture	Bulk density (g cm^{-3})
2006 Lalomasara	Sago 1	0-15	Sandy loam	1.0
		15-30	Sandy loam	1.1
	Sago 2	0-15	Silty clay	0.7
		15-30	Silty clay	0.8
	Cashew	0-15	Sandy loam	1.4
		15-30	Loam	1.5
Konda	Sago	0-15	Sandy loam	0.7
		15-30	Sandy loam	1.1
	Rice	0-15	Silty loam	0.8
		15-30	Silty loam	0.9
	Cashew	0-15	Silty loam	1.3
		15-30	Silty loam	1.4
Watulondo	Sago	0-15	Silty clay	0.3
		15-30	Silty clay	0.3
2007 Lakomea	Sago	0-15	Silty clay	0.8
		15-30	Silty	0.9
	Cacao	0-15	Sandy loam	1.3
		15-30	Sandy loam	1.5

All the soils except for Watulondo (peat soil) are mineral soil.

cm^{-3}) in Lalomasara, which is located in a more swampy area, while the BD of Sago 1 (1.0 g cm^{-3} - 1.1 g cm^{3}), which is located on the border of dry and swampy land, was higher. The highest BD was found in the CsF (1.4 g cm^{-3} - 1.5 g cm^{-3}) and was followed by the CoF. In the PF, the BD was around 0.8 g cm^{-3} - 0.9 g cm^{-3}, while the BD values in the peat soil in Watulondo and those in the mineral soil (Sago 2) were found to be the lowest (0.3 g cm^{-3}) and were clearly lower than the BD of the general values under mineral soil. According to Ambak and Melling (2000), peat soil having a high moisture content and water-holding capacity resulted in high pore volume and, consequently, led to low bulk density and low bearing capacity. The BD values in the SF were mostly lower than those in the CsF and CoF due to lower groundwater level with a compacted soil condition in the CsF and CoF. The low BD in the PF might be due to the increase of organic matter content derived from rice straws incorporated into the soil every year.

Soil BD values related to sago growth and starch yield are also poorly documented. Kakuda et al. (2000) reported that very different values of soil BD between peat and mineral soil were observed in sago-palm-growing areas. They suggested that mineralization and CEC expressed as the volume basis are more practical for the comparison of mineral and peat soils than the weight basis. Nitrogen mineralization and CEC calculated by the volume basis indicated that the fertility of the mineral soil was higher than that of the peat soil, and this might have caused the growth rate difference between the sago palms grown in the two soil types.

2. Chemical properties of soil under growing sago palm

a. Soil acidity (pH)

In Lalomasara, the soil pHs in the SF ranged from slightly acid to neutral (6.0-6.6) at Sago 1 and acid (5.0) at Sago 2 (Table 1, Fig. 2). The pH in the CsF around the site was lower and very acid (3.9 and 4.1). In Konda, the soil pH in the SF was slightly different, being very acid in both layers (4.0 and 4.2). The soil pHs in the PF (4.3-4.4) and the CsF (4.0-4.3) were almost the same. On the other hand, in Lakomea, the soil pH in SF was slightly acid (5.7) in the upper layer and acid (5.1) in the deeper layer. It was very acid (4.1) and acid (4.5) in the CoF, and these values were lower than those in SF. It has been reported that the soil pH in the SFs of Konda, Ranooha, and Lakomea villages was acid, ranging from pH 4.5-5.1 (Pasolon and Rembon, 2000). The same acid soil conditions were prevalent in the SF around Laosu village near Pohara, which has 3 different soil/water regimes, i.e., dry land, riverbank, and swampy (Pasolon et al. 2002). The soil acidity ranged quite widely from acid to neutral. Yoshida et al. (2000) reported that the soil pHs in the SF around

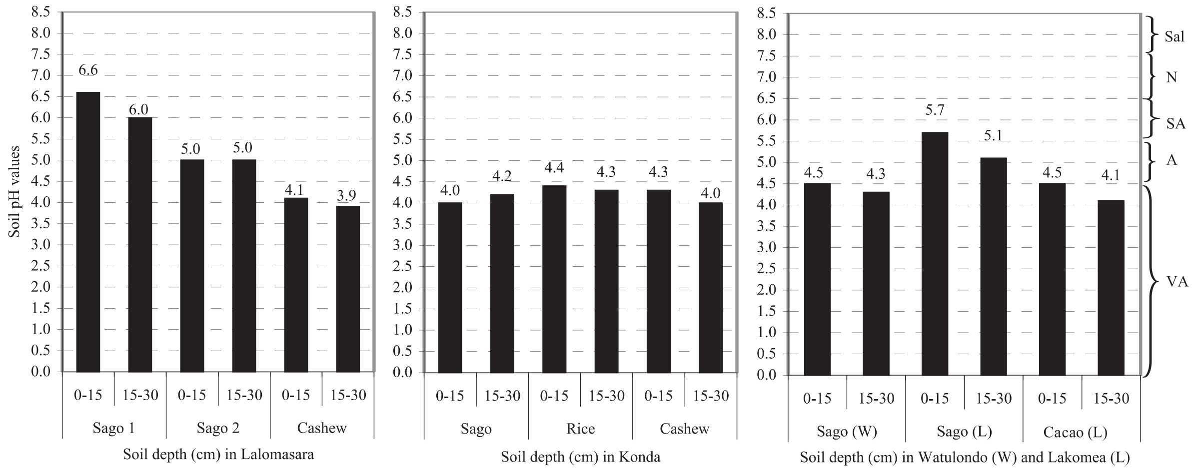

Fig. 2. Soil pH of various research sites around Kendari.
VA: very acid, A: acid, SA: slightly acid, N: neutral, sal: slightly alkaline.

Kendari were very acid to neutral (pH 4.4-6.9). If we compare the soil pH in the SF to those in the CsF and the CoF, that in the SF was slightly acid due to periodical changes in the water conditions (waterlogged, dry, and semi-dry). This was almost the same condition as that for the PF. On the other hand, the dry land condition in the CsF and CoF tended to be more acid, possibly due to the loss or leaching out of base cations from the soil solution by cropping and excessive water during the wet season (Tisdale et al. 1985). In Watulondo (peat soil), the soil pH was 4.5 and 4.3 in the upper and lower layer, respectively. The pH values of peat soil in Watulondo were higher than those of the peat soils in which sago palms were grown in Johor and Sarawak, Malaysia, and Riau, Indonesia, where the pH ranged from 3.2 to 4.3 (Kakuda et al. 2000; Jong et al. 2006), and the riverine alluvial clay soil in which sago palms were grown in Johor, Malaysia (pH 3.3-3.8) (Jalil and Bahari 1991). It was found that the soil pH in Lalomasara was relatively higher than that at other SFs sites. This might be related to the different original soil properties, particularly, those for the CECs, which were dominated by the bases in the exchangeable cations, such as Ca, Mg, K, and Na. Unfortunately, in this research not all of those elements could be determined, although the exchangeable-K was found to be relatively higher than it was at other sites (Fig. 5).

Anugoolprasert et al. (2008) confirmed that there were no significant differences in dry matter weight, weekly increment of plant length, leaf emergence rate, and total leaf area of sago palm seedlings or in the P concentration in whole plants growing under different low pH conditions of 5.7, 4.5, and 3.6 for 5 months. Therefore, they concluded that sago palm could tolerate even pH 3.6 for 5 months in the growth media. Jong et al. (2006) also stated that sago palm was one of the very few crops that were highly tolerant to a low pH and could be cultivated on peat and sulphuric acid soils. Moreover, Louhenapessy (1994) reported that even though sago palm could tolerate a low pH, growth and starch yield were inhibited at pH lower than 3.5.

b. Total-N

The soil total-N (T-N) contents in the mineral soils ranged from 1.2 g kg^{-1} to 8.1 g kg^{-1} (low to very high) (Table 1, Fig. 3). A medium content of the total-N at Sago 1 in Lalomasara (2.1 g kg^{-1}) and in the SF in Lakomea (2.9 g kg^{-1} - 4.4 g kg^{-1}). High to very high values (6.8 g kg^{-1} and 8.1 g kg^{-1}) of the T-N content were found at Sago 2 in Lalomasara due to the high organic matter content. On the other hand, the T-N contents in the PF were medium (2.7 g kg^{-1} - 3.0 g kg^{-1}) and slightly higher than those in the CsF (1.2 g kg^{-1} - 1.8 g kg^{-1}) and CoF (1.7 g kg^{-1}). The T-N contents found in the mineral soils in which sago palms were grown fell within the values of Sarawak and Johor, Malaysia, Riau, Indonesia, and Southern Thailand reported by Kakuda et al. (2000). Yoshida et al. (2000) reported that the T-N content found in the mineral

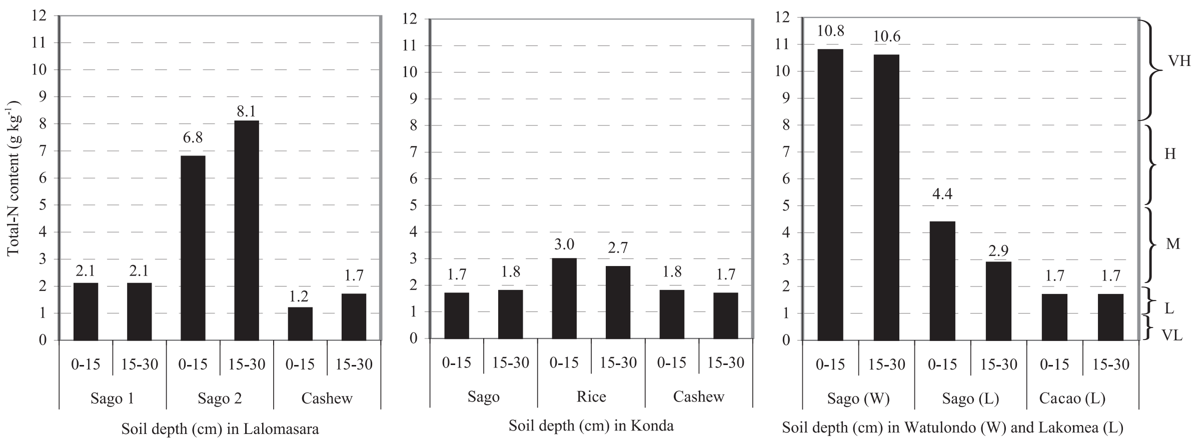

Fig. 3. Soil total-N contents of various research sites around Kendari.
VL: very low, L: low, M: medium, H: high, VH: very high.

soils in which sago palms were grown around Kendari were very low to medium, ranging from 0.39 g kg^{-1} to 4.35 g kg^{-1}. On the other hand, extraordinarily high contents (10.6 g kg^{-1} - 10.8 g kg^{-1}) of T-N were observed in the peat soil in Watulondo. The high T- N content in the peat soil was related to the very high organic matter content. Kakuda et al. (2000) and Ambak and Melling (2000) observed higher T-N contents in the sago-palm-growing peat areas in Sarawak and Johor, Malaysia (12.5 g kg^{-1} - 17.2 g kg^{-1}) and Riau, Indonesia (15.6 g kg^{-1} - 19.9 g kg^{-1}), respectively. Purwanto et al. (2002) reported that the total N in soils and the concentration of N in leaves were not significantly correlated. Furthermore, Louhenapessy (1994) also reported that the soil total-N content was very low and was not significantly correlated with the sago palm starch yield.

c. Available-P (P-Bray 2)

In the SF with mineral soil, the soil available phosphate (AP) contents were generally very low (1.1 mg kg^{-1} - 1.8 mg kg^{-1}), except in the upper layer soils in Lakomea, in which they were medium (3.6 mg kg^{-1}), and Sago 2 in Lalomasara (3.1 mg kg^{-1}), in which they were low (Table 1, Fig. 4). On the other hand, in Watulondo, the AP content was low (2.8 mg kg^{-1} - 2.9 mg kg^{-1}). The AP contents were also very low in the CsF (1.4 mg kg^{-1} and 1.9 mg kg^{-1}) and the CoF (1.8 mg kg^{-1} - 1.6 mg kg^{-1}) in both layers. Although we found low to very low AP contents (2.3 mg kg^{-1} and 2.1 mg kg^{-1}) in the PF, the values were slightly higher than those in the SF, CsF, and CoF. This might be the result of the residual fertilizer P left in the soil from the previous rice-cropping season. The fertilizer P usually applied in the paddy field was around 75-80 kg SP-36 (Super Phosphate with 36 % P_2O_5 content) ha^{-1}. No fertilizers were usually applied in the SF, CsF, and CoF.

Yoshida et al. (2000) reported that the AP contents in the SFs around Kendari ranged from very low to very high (0.67 mg kg^{-1} - 17.9 mg kg^{-1}) and the AP contents in the deeper layers tended to decrease relative to those in the upper soil layers. Pasolon et al. (2000) also reported that the AP contents of soils under 3 different soil/water regime conditions (dry land, river bank, and swampy areas) ranged from low to medium in Laosu village, but the APs reported above were determined using a different (Bray-1) method.

The relationship between the soil P content and sago palm growth or starch yield was very weak (Louhenapessy 1994). Therefore, the soil P as well as the soil N content reported above might be not closely related with the growth and starch yield of sago palm. As for the soils around the sago-palm-growing areas Kendari, they generally showed a relatively critical condition regarding the available-P content.

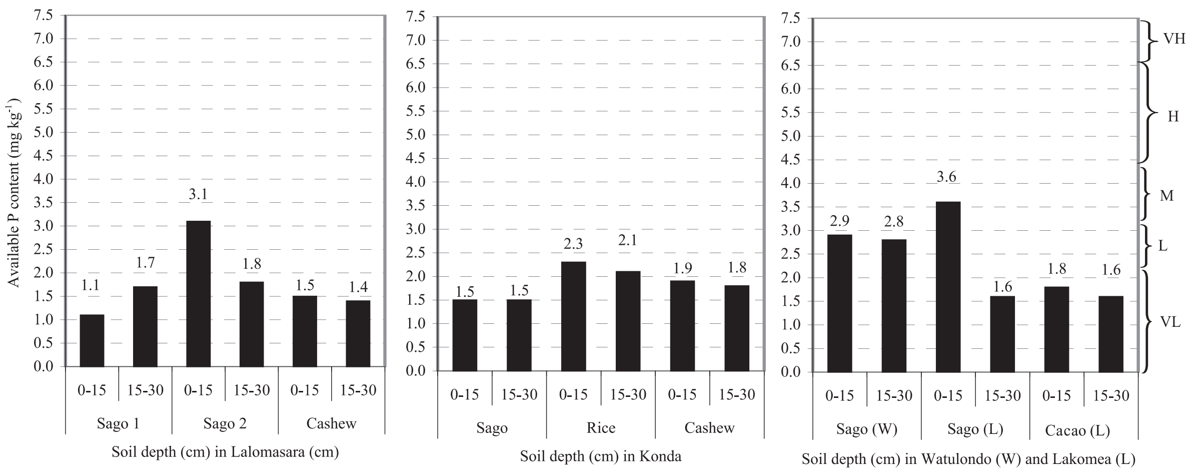

Fig. 4. Soil available-P contents of various research sites around Kendari.
VL: very low, L: low, M: medium, H: high, VH: very high.

c. Exchangeable-K

The exchangeable-K at all sites within the mineral soil was not very different. It ranged from low to medium (0.1 $cmol_c\ kg^{-1}$ - 0.4 $cmol_c\ kg^{-1}$) (Table 1, Fig. 5). These values were generally lower than those of sago-palm-growing soils in Riau, Indonesia (Kakuda et al. 2000). In the SFs, the exchangeable-K was low (0.1 $cmol_c\ kg^{-1}$ - 0.2 $cmol_c\ kg^{-1}$) in Konda. A medium exchangeable-K was found in the SF in Lalomasara and Lakomea. On the other hand, the exchangeable-Ks were found to be low in the CsFs, the CoF, and the PF, except in the deeper soil layer of CsF in Konda, which showed a medium content (0.3 $cmol_c\ kg^{-1}$). The exchangeable-K was also low (0.1 $cmol_c\ kg^{-1}$) in the peat soil in Watulondo. Yonebayashi (2006) reported that the exchangeable-K in tropical peat soils in Malaysia was less than 1.0 and 0.5 $cmol_c\ kg^{-1}$ in the surface and subsurface soil, respectively. According to the report, the low exchangeable-K in the soil solution profile was observed in the deep peat. The report by Funakawa et al. (1996) concluded that the concentration of exchangeable-K in the soil solution composition was not appreciably low in oligotrophic peat, except in the deep peat under sago palm cultivation. They stated that, once a large part of this nutrient is lost from the solution phase, it may not be easily replenished from the solid phase, which may account for the clear depletion of exchangeable-K in the soil in the sago palm cultivation.

The relationship between the concentrations of soil exchangeable-K and the concentration of K in the leaves of sago palm was significant (Purwanto et al. 2002). Yamamoto et al. (2003) reported that the potassium contents in the sago palm piths at an estimated palm age between 4-8 years were around 3 $g\ kg^{-1}$ - 20 $g\ kg^{-1}$, while the N and P contents were only 1 $g\ kg^{-1}$ - 4 $g\ kg^{-1}$ and 0.3 $g\ kg^{-1}$ - 0.6 $g\ kg^{-1}$, respectively. This might be related to the functions of potassium in plants. According to Tisdale et al. (1985), K is an important element for starch-producing crops, such as sago palm, which controls the rate of starch synthesis through starch enzyme activation. As for the soils around Kendari, the soils generally showed that the exchangeable-Ks are included, to some extent, in the same range category as other reported mineral soils.

d. Total-C

The total-C contents in the soils at the researched sites ranged widely from very low to very high (9.4 $g\ kg^{-1}$ - 78.1 $g\ kg^{-1}$) in the mineral soils, and the total-C content was extraordinarily high (245 $g\ kg^{-1}$ - 513 $g\ kg^{-1}$) in the peat soil in Watulondo (Table 1, Fig. 6). This was one indication of the characteristics of the peat soil. This result is very similar to the data reported by Melling et al. (1999) about the peat soil in sago-palm-growing areas in Malaysia. They found that the total-C content was very high (411 $g\ kg^{-1}$ and 438 $g\ kg^{-1}$) almost everywhere at depths of 0 cm - 25 cm and 50 cm-100 cm, respectively. In the SF in Lalomasara, the total-C contents were higher compared with those in other sago fields, and higher total-C contents were found at sago site 2 (67.7 $g\ kg^{-1}$

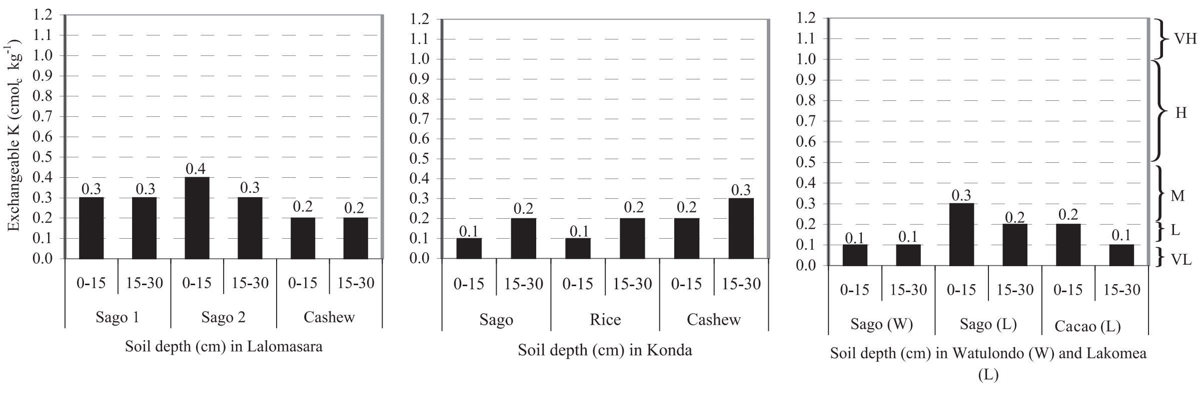

Fig. 5. Soil exchangeable-K contents of various research sites around Kendari.
VL: very low, L: low, M: medium, H: high, VH: very high.

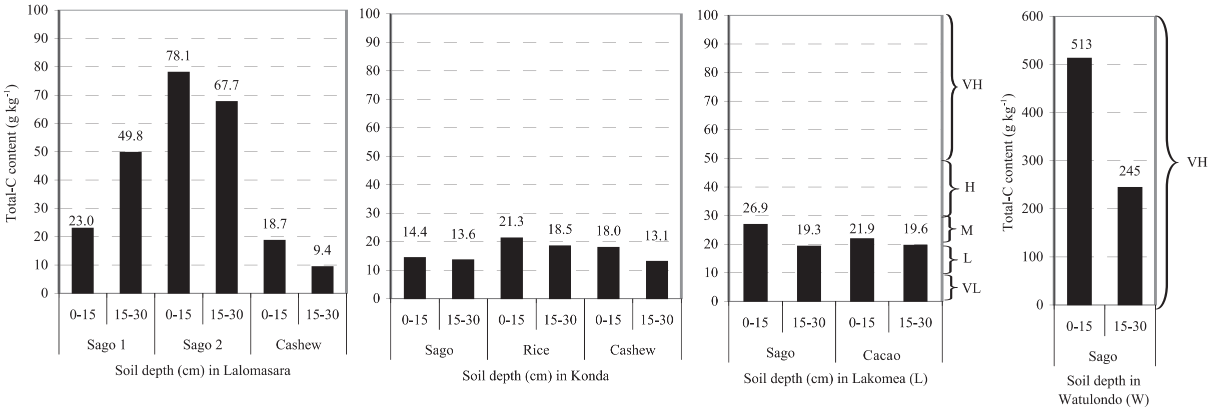

Fig. 6. Soil total-C contents of various research sites around Kendari.
VL: very low, L: low, M: medium, H: high, VH: very high.

- 78.1 g kg^{-1}) than at Sago 1 (23.0 g kg^{-1} - 49.8 g kg^{-1}). On the other hand, the total-C contents in Konda and Lakomea were low (13.6 g kg^{-1} - 14.4 g kg^{-1}) and low to medium (19.3 g kg^{-1} - 26.9 g kg^{-1}), respectively. The total-C content in the PF ranged from low to medium (18.5 g kg^{-1} - 21.3 g kg^{-1}) and was almost the same as the total-C content in the SF in Lakomea. The total-C contents in the CsF were almost the same as those in the SF in Konda, and they were also low in both layers (18.0 g kg^{-1} and 13.1 g kg^{-1}). On the other hand, the total-C contents in the CoF in Lakomea were medium and low in the upper and the deeper layer (21.9 g kg^{-1} and 19.6 g kg^{-1}), respectively. According to the report by Pasolon et al. (2000), the total-C content in the SF ranged from medium to high (22.1 g kg^{-1} - 30.3 g kg^{-1}) in Laosu village in 3 mineral soils with different water regime conditions (dry land, river bank, and swampy areas), which were comparable with those obtained in the SF in Lalomasara village.

In relation to the total-C content, sago-palm-growing areas can be classified into organic or peat soils if they have a high total-C content, and mineral soils if they have a low or very low total-C content. Yamaguchi et al. (1997) reported that, in deep peat soil, sago palms have significantly shorter and fewer fronds than those under shallow peat. The trunk and diameter growth is more rapid in shallow peat soil than in deep peat soil. Furthermore, it is speculated that, in shallow peat soil, sago palms accumulate more starch at an earlier growth stage than those in deep peat soil. On the other hand, in the sandy soils with a total-C content of 47 g kg^{-1}, as reported by Louhenapessy (1994), a medium yield (243 g starch palm^{-1}) was obtained, while, in that with a 12 g kg^{-1} total-C, a low yield of only 189 kg palm^{-1} was obtained.

e. Cation exchangeable capacity (CEC)

The soil CEC in the mineral soils ranged from low to high (6.0 cmol$_c$ kg^{-1}-36.7 cmol$_c$ kg^{-1}) (Table 1, Fig. 7). In the SFs, the CECs were low at Sago 1 in Lalomasara and in Konda but medium to high at Sago 2 in Lalomasara and high in Lakomea. On the other hand, in the CsF and the CoF, the CECs were low at all sites, showing the same values of the CECs as in the SF bordering them. The CECs in the PF were low to high (12.5 cmol$_c$ kg^{-1} - 24.5 cmol$_c$ kg^{-1}) and slightly higher than those in the SFs due to the contribution from rice straw. The CECs were much higher in the upper and lower layers of peat soil in Watulondo (65.8 cmol$_c$ kg^{-1} - 44.0 cmol$_c$ kg^{-1}) than they were in the mineral soils (Kakuda et al. 2000). This is one indication of peat soil that has a high total-C content, and the result was very similar to the data reported by Melling et al. (1999) in peat soil in which sago palms were grown in Malaysia. They found that CECs were very high (70.8 cmol$_c$ kg^{-1} and 66.4 cmol$_c$ kg^{-1}) at depths of 0 cm - 25 cm and 50 cm -100 cm, respectively. Ambak and Melling (2000) concluded that peat soils with high CECs (40 cmol$_c$ kg^{-1} - 143 cmol$_c$ kg^{-1}) have a strongly buffered characteristic.

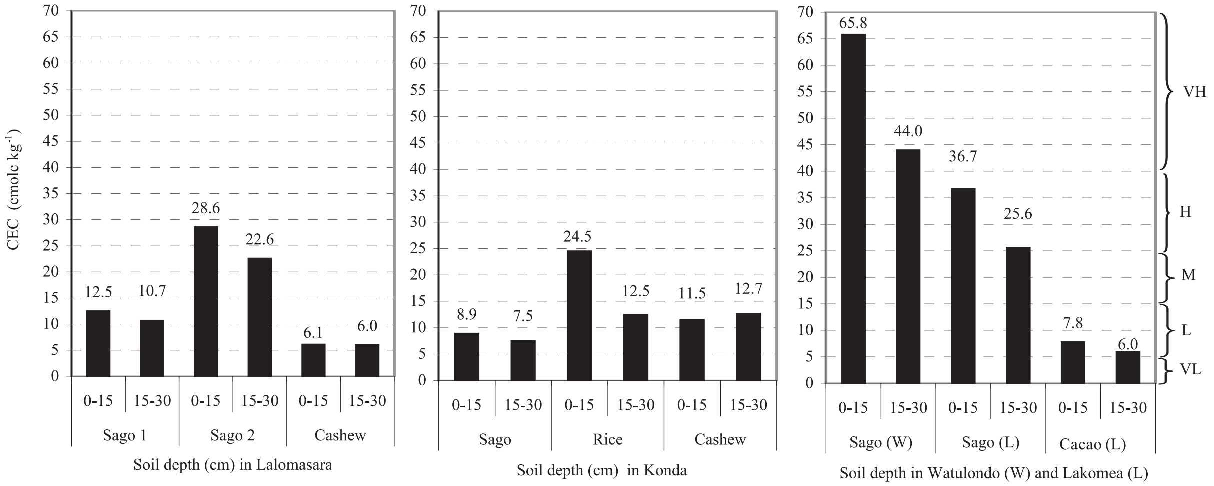

Fig. 7. Soil CEC of various research sites around Kendari.
VL: very low, L: low, M: medium, H: high, VH: very high.

Different soil CECs were found under 3 soil/water regime conditions (dry land, river bank, and swampy areas) in Laosu village (Pasolon et al. 2000). The CECs ranged primarily from low in dry land (15.4 $cmol_c$ kg^{-1}) to medium (21.6 $cmol_c$ kg^{-1} - 21.9 $cmol_c$ kg^{-1}) in the riverbank and swampy areas. This is related more to the dominant type of mineral colloids in the soil. There is lack of information on CEC related to the sago palm growth and starch yield.

Conclusions

The groundwater levels in the SF during the wet and dry seasons ranged from +20 cm to +50 cm and -10 cm to -50 cm, respectively, and these levels in both wet and dry seasons might be higher than those in the CsF and CoF. On the other hand, the level in the PF was almost the same as that of the SF during the dry season.

The physicochemical properties of the soils in the SF around Kendari varied depending on the sites and the type of crops cultivated in the surroundings. In general, the soil texture under the SF around Kendari varied from sandy loam to silty clay or coarse to medium. Such conditions are relatively good for the support of sago palm root growth. The soil BDs (0.3 g cm^{-3} - 1.1 g cm^{-3}) in the SF were, for the most part, lower than those in the CsF and the CoF due to the differences in water regimes. The tendency towards a lower BD in the soil of PF than in that of the SF might be due to the increase in organic matter content derived from rice straw incorporated into the soil every year.

The soil pHs in the SF were dominantly acid. The T-N contents varied from low to very high in the SF, while, in the surrounding dry land of CsF and CoF and in the PF, they ranged from low to medium, and the values were lower than those in the SFs. The AP contents in the researched sites were predominantly from very low to medium, whereas the exchangeable-K was primarily low except in the upper layer in Lakomea and in the Sago 1 and 2 in Lalomasara, where it was medium. The soil CECs in the mineral soils around Kendari varied widely from low to high except in the peat soil in Watulondo, where the CECs were very high. The total-C contents in the researched sites ranged widely from very low to very high in the mineral soils, while extraordinarily high in the peat soil of Watulondo.

The physicochemical properties in the PF that was previously converted from the SF were not significantly different from those in the SF, except regarding the total-C and T-N contents and CEC. The soil chemical properties in the SF were more fertile than those in surrounding dry land of CsF and CoF.

Further detailed studies on the relationship between the soil physicochemical properties and both the growth and starch yield of sago-palm-growing areas around Kendari should be undertaken in the future. Moreover, to characterize the soil physicochemical properties of the sago-palm-growing area around Kendari in comparison with those of the main sago-palm-growing area in Indonesia, it would be important to establish the appropriate soil management for improving the growth and starch productivity of sago palms growing there.

References

Ambak, K. and L. Melling 2000 Management practices for sustainable cultivation of crop plants on tropical peatland. Proceedings of the International Symposium on Tropical Peatlands. Bogor, Indonesia, 119-134.

Anugoolprasert, O., S. Konishita, H. Ikegami, M. Shimizu, H. Naito and H. Ehara 2008 Growth of sago palm seedling under low pH condition. Japanese Journal of Crop Science. 77 (Extra issue 2): 248-249.

Blake, G. R. and K. H. Hartge 1986 Bulk Density. *In*: Methods of Soil Analysis, 2nd Edition, Part 1-Physical and Mineralogical Methods (A. Klute ed.). Am. Soc. of Agron. Inc., Soil Sci. Soc. of Am. Inc., Publisher Madison, Wisconsin. USA. p.364.

Brady, N. C. and R. R. Weil 1996 The nature and properties of soils. 11th edition. Prentice Hall, Inc. (New Jersey). p.108.

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

Flach, M. 1997 Sago palm (*Metroxylon sagu* Rottb.). Promoting the conservation and use of underutilized and neglected crops. 13. Institute of Plant Genetics and Crops Plant Research, Gatersleben/International Plant Genetic Resources Institute (Rome). p. 52.

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.

Gee, G. W. and J. W. Bauder 1986 Particle size analysis. *In*: Methods of Soil Analysis 2nd Edition, Part 1 - Physical and Mineralogical Methods (A. Klute, ed.). Am. Soc. of Agron. Inc., Soil Sci. Soc. of Am. Inc., Publisher Madison, Wisconsin, USA. p. 399.

Hashimoto, K., Y. Sasaki, K. Kakuda, A. Watanabe, F. S. Jong and H. Ando 2006 Relationship of sago palm and groundwater in tropical peat soil. The 15th Conference of the Society of Sago Palm Studies, 25-26. (In Japanese)

Hardjowigeno, S. 1987 Ilmu tanah. P.T. Melton Putra (Jakarta). pp. 233. (In Indonesian)

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

Jong, F. S., A. Watanabe, D. Hirabayashi, S. Matsuda, B. H. Purwanto, K. Kakuda and H. Ando 2006 Growth performance of sago palm (*Metroxylon sagu* Rottb.) in peat of different depth and soil water table. Sago Palm 14: 59-64.

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 B. H. Purwanto 2000 Soil characteristics in sago palm grown area. Factors associated with fate of inorganic nitrogen in soil. Sago Palm 8: 9-16.

Kho, L. K., M. Mohamed and W. S. W. Harun 2005 Studies on soils: Chronological influence of water table on the oxidation rate of organic soils. Abstract in University of Malaysia Sarawak (Unimas) Research Gateway, RIMC Unimas 2: 1-2.

Knudsen, D., G. A. Peterson and P. F. Pratt 1985 Exchangeable and soluble potassium. *In*: Methods of Soil Analysis 2nd Edition, Part-2 Chemical and microbiological properties (A.L. Page, R.H. Miller, and D.R. Keeney, eds.). Am. Soc. of Agron., Inc., Soil Sci. Soc. of Am. Inc., Publisher Madison, Wisconsin. USA. p. 231-233.

Louhenapessy, J. E. 1994 Evaluasi dan klassifikasi kesesuaian lahan bagi sagu (Metroxylon spp.). Disertasi Doktor pada Universitas Gadjah Mada. pp. 165-184. (In Indonesian)

Melling, L., K. Ambak, J. Osman and A. Husni 1999 Water management for the sustainable utilization of peat soils for agriculture. Paper presented at the International Conference and Workshop on Tropical Peat Swamps, Penang, Malaysia. pp. 18-35

Mulyanto, B. and Suwardi 2000 Distribution and characteristics of land, the sago palm (*Metroxylon spp*.) habitat in Indonesia. *In*: Sago 2000. Sustainable Utilization of Sago Palm as an Alternative Source of Food and Materials for Agroindustry in the Third Millenium (H. M. H, Bintoro, Suwardi, Sulistiono, M. Kamal, K. Setiawan and S. Hadi, eds.). Proceeding of the International Sago Seminar, Bogor, Indonesia, pp. 38-44.

Nelson, D. W. and L. E. Sommers 1982 Total carbon and organic matter. *In*: Methods of Soil Analysis, Part 2- Chemical and Microbiological Properties (A.L. Page, R.H. Miller, and D.R. Keeney, eds.). Am. Soc. of Agron., Inc., Soil Sci. Soc. of Am. Inc., Publisher Madison, Wisconsin. USA. p.539-579.

Notohadiprawiro, T. and J. E. Louhenapessy 1992 Potensi sagu dalam penganekaragaman bahan pangan pokok ditinjau dari persyaratan lahan. Prosiding Simposium Sagu Nasional. Ambon, 99-106. (In Indonesian)

Pasolon, Y. B. and F. S. Rembon 2000 Diversity and characteristics of agro-ecophysiology of sago palm (*Metroxylon sagu* Rottb.) in Southeast Sulawesi 2000. Workshop on Biodiversity of Prime Commodity in the Southeast Sulawesi. Kendari, p. 8.

Pasolon, Y. B., Subair, Masudin, F. S. Rembon, M. Hamundu 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 (K. Kainuma, M. Okazaki, Y. Toyoda and J. E. Cecil, eds.). Universal Academy Press (Tokyo) 51-59.

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.) to controlled-release N fertilizer on coastal lowland peat in the tropics. Soil Science and Plant Nutrition 48: 529-537.

Tisdale, S. L., W. L. Nelson and J. D. Beaton 1985 Soil fertility and fertilizers. Fourth edition. MacMillan Publishing Co. (New York) 67-72, 493.

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.

Yamamoto, Y., K. Omori, T. Yoshida, Y. Nitta, Y. B. Pasolon and A. Miyazaki 2000 Growth characteristics and starch productivity of three varieties of sago palms in Southeast Sulawesi, Indonesia. The 9th Annual Meeting of Japanese Society of Sago Palm Studies, 15-22. (In Japanese)

Yamamoto, Y., T. Yoshida, Y. Gotoh, F. S. Jong and L. B. Hilary 2003 Changes in macroelement content in the pith of sago palm (*Metroxylon sagu* Rottb.) with palm age. Japanese Journal of Tropical Agriculture 47: 206-214.

Yoshida, T., K. Omori, Y. Yamamoto, Y. Nitta, A. Miyazaki and Y. B. Pasolon 2000 Contents of mineral elements in leaf blade and pith of three varieties of sago palms in Southeast Sulawesi, Indonesia. The 9th Annual Meeting of Japanese Society of Sago Palm Studies, 23-30. (In Japanese)

Yonebayashi, K. 2006 Studies on sustainable land use and soil ecosystem in tropical peat land. Tropics 15: 313-320.