COMPARATIVE STUDIES ON PHYSICOCHEMICAL PROPERTIES OF THE MINERAL SOILS IN THE MAJOR SAGO-PALM (*METROXYLON SAGU* ROTTB.)-GROWING AREAS OF EASTERN INDONESIA

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Abstract

Physicochemical properties of the mineral soils, under major sago-palm-growing areas in the eastern Indonesia around Sentani near Jayapura, Papua Province (hereafter Jayapura); Kairatu, Seram Island, Maluku Province (Seram); Kendari, Southeast Sulawesi Province (Kendari); were studied and compared. The soil samples of 0-15 cm and 15-30 cm depth were collected from every site, respectively, from September 2005 to January 2008. The results revealed that the average of physicochemical properties of the soils from 0-30 cm depth in the sago-palm-growing areas varied depending on the site. Soil bulk densities were averagely higher in Seram (1.35 g cm^{-3}) than those in Kendari (0.98 g cm^{-3}) and Jayapura (0.89 g cm^{-3}). Soil textures around Jayapura were dominated by silty loam. While in Seram soil texture was dominated by silty loam and loam, and around Kendari it was dominated by sandy loam, loam and silty clay. The averages of soil pHs were slightly acid (6.4) in Jayapura, acid in both Seram (5.5) and Kendari (4.9). Total carbons (total-C) in Kendari were higher (30.5 g kg^{-1}) than those in Jayapura (27.2 g kg^{-1}) and Seram (9.9 g kg^{-1}). Based on the averages of nutrient contents including the CEC and the total-C, the sago-palm-growing areas showed the same trend in the order of Kendari > Jayapura > Seram in the CEC, total-N and total-C. On the other hand, the exchangeable-K, and the available-P were showed the trend in the order of Jayapura > Seram > Kendari. Variations of soil fertility such as the exchangeable-K, CEC, and total-N among the soils collected sites in each area are higher in the order of Kendari > Jayapura > Seram. And also we tried to discuss about the relation between the soil physicochemical properties and the reported growth parameters or starch productivity of sago palms grown on the same researched areas.

Keywords: Eastern Indonesia, soil physicochemical property, sago palm, mineral soil.

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INTRODUCTION

About more than 1.0 million hectares of sago palms are grown in Indonesia. Of this, about 96 % is in the eastern archipelagos region, mainly found around Papua, West Papua, Moluccas, North Moluccas, Southeast, South, Central and North Sulawesi, and West and Central Kalimantan (Mashud *et al.*, 2008). Sago palms scattered along the swampy areas of every island in Papua, Maluku, Kalimantan, Sulawesi and Western region of Sumatera (Flach, 1983). Sago palm grows well on mineral than on peat soil (Flach and Schuiling, 1989). Moreover, main soil type found in sago-palm-growing areas classified in two groups, a mineral soil and an organic or a peat soil, but mineral soil was more dominant. According to Mulyanto and Suwardi (2000), possible soil types in sago-palm-growing areas include 3 important Orders, namely Entisols, Histosols and Inceptisols. Further, sago-palm-growing areas commonly found on a typical soils that are classified into: *tropaquent* (riped soil developed under waterlogged condition); *fluvaquent* (riped soil developed under river seasonal flooding); *hydraquent* (unriped soil develop under waterlogged condition); *tropaquept* (soil developed under high water content condition which has a developed profile); *dystropept* (similar with *tropaquept* but developed without waterlogged condition); *tropohemist* (riped peat soil); and *troposaprist* (half riped peat soil) (Shimoda and Power, 1985, Tie *et al.*, 1991).

The soil physicochemical properties on the sago-palm-growing areas around Kendari have been reported (Rembon *et al.*, 2010). However, detailed descriptions of the soil physicochemical properties, especially around the main sago-palm-growing areas were still poorly documented. Furthermore, some reports on the variation of sago palm production in the eastern archipelago of Indonesia were closely related to the natural soil fertility (Ehara *et al.*, 1995; Ehara *et al.*, 2000).

In order to establish the appropriate soil management for improving the growth and starch productivity of sago palm, clarification of the soil properties in the major sago-palm-growing areas, especially in the eastern Indonesia is very important. Therefore, this research was conducted to clarify and to compare the differences in the physicochemical properties of the mineral soil in the major sago-palm-growing areas of the eastern Indonesia and tried to discuss about the relation between the soil physicochemical properties and the growth parameters or starch productivity of sago palms grown on the same researched areas.

MATERIALS AND METHODS

Research was conducted in the eastern part Indonesia from 2005-2008 at several villages around Lake Sentani near Jayapura (2° 33' 0" S and 140° 37' 0" E) of Papua Province (hereafter Jayapura), Kairatu (3° 21' 0" S and 128° 22' 0" E) of Seram Island in Maluku Province (Seram), and around Kendari (3° 57' 59" S and 122° 26' 59" E) of Southeast Sulawesi Province (Kendari) (Fig.1). Sago-palm-growing areas around Sentani are spreading around lakeside on the flood plain under Mount Cyclops valley. In Seram spreading on the upland swampy flood plain between foot hill, and in Kendari scattered along the river bank and or flood plain of back swampy between foot hill.

Soil samples were collected using a soil auger, 2 samples were taken for each site from the two depths (0-15 and 15-30 cm depth from the soil surface) of soils from each selected sago-palm-growing field in the areas. The amount of soil composite samples taken from each site were as follows: (Jayapura, Seram, and Kendari were 18, 10, and 12 samples, respectively).

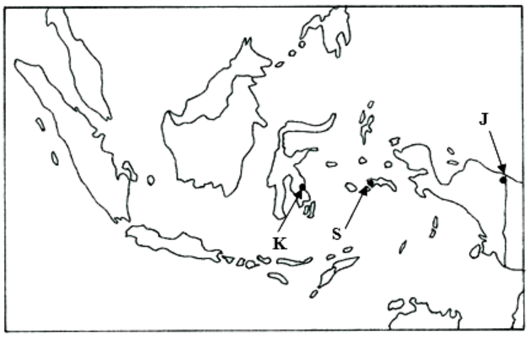

Fig.1. Three sago-palm-growing areas researched for soil physicochemical properties in eastern Indonesia.
K: Kendari. S: Kairatu, Seram. J: Jayapura.

The samples were collected from 18, 10, and 12 points, respectively based on the variation of soil that shown in the color changes and physical appearance in the field. Some village has a replication, such as in Jayapura (Yabaso village 5 replications, Yahim village has 2 replications), and in Haturapa, Seram 2 replications. Soil physicochemical properties were determined in the soil test Laboratory, Faculty of Agriculture, Haluoleo University in Kendari. The soil texture was determined following the pipette method (Gee and Bauder, 1986) and was then classified based on the textural triangle (Brady and Weil, 1996), and the bulk density (BD) was determined following the soil core method (Blake and Hartge, 1986) using a cylindrical metal ring sampler with 7.5 cm long by 5.5 cm diameter. The groundwater levels in each site were directly measured in the field using a mater tape.

The air-dried soils for chemical analyses were prepared from 300 g of field fresh soils taken from each site which were homogenized and screened passing through 2 mm opening sieving net, and then analyzed for physicochemical properties such as pH, total-N, total-C, available-P and exchangeable-K, Ca, Mg, and cation exchangeable capacity (CEC). The pH values for H_2O and KCl were measured with pH meter after suspension in distilled water and in 1 *M* KCl with a ratios of 1 to 2.5 and 1 to 5 (w/v) for the mineral soil, respectively. Organic-C was determined with Walkey and Blackmore method (Nelson and Sommers, 1982). The total-N and available-P were determined with Kjeldhal method and Bray-2 procedure, respectively. The exchangeable-K was determined by chemical method by precipitating of 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.*, 1985). Soil cation exchangeable capacity (CEC) was determined by the measurement of the ammonium retained by the negative charges on soil particles after the soil saturated with the ammonium acetate solution (pH 7.0). No replication of measurement applied for all parameters as all measured collected samples taken using a composite one.

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). While the pH values were classified into: very acid =

VA, acid = A, slightly acid = SA, neutral = N and slightly alkaline = Sal. The followings are the details of five categories of the elements: The pH (VA < 4.5, A = 4.5-5.5, SA = 5.6-6.5, N = 6.6-7.5, Sal > 7.5); the 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}); the total-C (VL < 10.0 g kg^{-1}, L = 10.0-20 g kg^{-1}, M = 20.1-30.0 g kg^{-1}, H = 30.1-50.0 g kg^{-1} and VH > 50.0 g kg^{-1}); the 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}); the available-P (VL < 2.20 mg kg^{-1} , L = 2.21-3.10 mg kg^{-1}, M = 3.11-4.40 mg kg^{-1}, H = 4.51-6.60 mg kg^{-1} and VH > 6.60 mg kg^{-1}); the 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}).

According to Heckman (2006), the soil fertility test criteria commonly used in relation to the soil nutrient content categories included: Very Low, Low, Medium (below optimum), High (optimum) and Very High (above optimum). Below the optimum nutrient category is considered deficient and will probably limit the crop yield. The optimum is considered adequate nutrient and will probably not limit crop growth, and above the optimum is considered more than adequate and will not limit crop yield.

RESULTS AND DISCUSSION

Physical properties of soil in major sago-palm-growing areas

a. Groundwater level

Groundwater levels among the major sago-palm-growing areas in the researched sites at sampling date varied from 10 cm to lower than 60 cm (below the soil surface) (Table 1).

The groundwater was slightly varied from 10 cm to lower than 60 cm in Jayapura, from 15 cm to 60 cm in Seram, and from 10 to 30 cm in Kendari. These depended on the given rainfall and the landform of the each site. Pasolon *et al.* (2007) also reported that the groundwater tables fluctuated from 10 cm to 80 cm in some villages near Jayapura, depending on the seasonal rainfall and the distance from the lakeside, and while those in Kendari more between 20 cm to 67 cm. They also observed that in a relatively dry sago garden near Lake Sentani, where sago palms produced few suckers. According to Flach *et al.* (1986) the wetter the land or the closer the groundwater level to the soil surface in the sago-palm-growing areas, the smaller the palms, the shorter the trunks, and the fewer the leaves.

b. Soil bulk density

As mentioned in the materials and methods, we took soil samples from 2 depths (0-15 and 15-30 cm). Our data results showed that only small differences in soil physicochemical properties between the two depths. In order to simplify in the following discussion for all parameters we consider to compare the soil characteristics between the growing areas of each investigated province by their average results from 0-30 cm depth of every samples in all sites.

The average soil bulk density from 0-30 cm depth (Tables 2, 3, and 4) in Jayapura was lower (0.89 g cm^{-3}) compared to those in Kendari (0.98 g cm^{-3}), and Seram (1.35 g cm^{-3}) (Fig. 2a). These indicated that the soil solid phase in Jayapura were comparatively not so dense or more porous than those in the others sites. Further, high organic matter content in the soil in Jayapura resulted in low soil bulk density. Comparing among all sites indicated that sago-palm-growing areas in Jayapura and Kendari did not show much difference; However the ones in Seram soil seem to be more compacted and solid than those in Jayapura and Kendari. The difference might be related to the land form developmental process; Jayapura was developed around the lake, and some parts of Kendari were developed under high groundwater level around the swamps and affected by the river tide, while Seram developed under lower groundwater level. The sites in every area showed that the soil bulk densities were fairly similar or less variation in Seram (CV=15.0 %) and Jayapura (CV=15.8 %), compared to Kendari (CV= 24.6 %). This indicated that *in situ* condition of each site in Kendari and Jayapura will affect the soil bulk densities. The same results were reported by Pasolon *et al.* (2007) by comparing the soil in sago-palm-growing areas in Kendari and Jayapura. They found that bulk densities of mineral soils around Kendari 1.25 g cm^{-3}-1.47 g cm^{-3} were higher than those in Jayapura (0.13 g cm^{-3}-1.18 g cm^{-3}). They also stated that the soil bulk density depended on the constituent of soil particles (clay and organic matter), and the soil bulk density was negatively correlated with the organic carbon content. According to Arshad *et al.* (1996), bulk density is dependent on soil texture, the densities of

Table 1. Researched sites where soil sampling was conducted in the major sago-palm-growing areas of eastern part of Indonesia

Researched Year	Researched Month	Province	Island	Near city	Researched village	Groundwater level (cm)*
2005	September	Papua	New Guinea	Sentani	Ifar Besar	> 60
	September	Papua	New Guinea	Sentani	Yahim	10-20
	September	Papua	New Guinea	Sentani	Yabaso	15-20
	September	Papua	New Guinea	Jayapura	Koya	20-40
2006	November	Southeast Sulawesi	Sulawesi	Kendari	Lalomasara	10-20
2007	May	Southeast Sulawesi	Sulawesi	Kendari	Lakomea	15-25
	May	Southeast Sulawesi	Sulawesi	Kendari	Konda	10-25
	July	Papua	New Guinea	Sentani	Yabaso	15-20
	July	Papua	New Guinea	Sentani	Ifar Besar	> 60
	September	Maluku	Seram	Kairatu	Haturapa	30-60
	September	Maluku	Seram	Kairatu	Waisari	20-40
	September	Maluku	Seram	Kairatu	Tinanurui	40-60
	September	Maluku	Seram	Kairatu	Mampokur	15-25
2008	January	Southeast Sulawesi	Sulawesi	Kendari	Rawa Aopa	15-25
	January	Southeast Sulawesi	Sulawesi	Kendari	Tinondo	10-30

* : Depth from the soil surface, directly measured in the field using a meter tape at the sampling date.

soil mineral (sand, silt, and clay), and organic matter content.

c. Soil textures

The soils in the major sago-palm-growing areas showed slightly varied in textural class. Soils were dominantly silty loam in Jayapura. They were also in silty loam followed by loam (Table 2 and 3) in Seram. Compared to the texture of soil in Jayapura and Seram, the soil in Kendari are coarser (sandy loam and loam) (Table 4).

Table 2. Characteristics of physical and chemical properties of mineral soil in the sago-palm-growing areas around Sentani, Lake near Jayapura (Data from 2005 and 2007).

Researched site	Palm (Field code)	Depth (cm)	Texture	Bulk density (g cm^{-3})	pH H_2O (1:2.5)	Exchangeable-K (cmol$_c$ kg^{-1})	CEC (cmol$_c$ kg^{-1})	Total C	Total N (g kg^{-1})	Available P (mg kg^{-1})
Ifar besar	Para	0-15	Silty loam	0,92	5.89 ^{SA}	0.33 ^{M}	13.32 ^{L}	21.02 ^{M}	2.62 ^{M}	3.2 ^{M}
		15-30	Loam	1,16	6.19 ^{SA}	0.33 ^{M}	9.11 ^{L}	10.38 ^{L}	2.13 ^{M}	2.74 ^{L}
Yahim	Para	0-15	Silty loam	nd	5.43 ^{A}	0.28 ^{M}	25.64 ^{H}	25.4 ^{M}	4.24 ^{M}	2.88 ^{L}
		15-30	Silty loam	nd	6.14 ^{SA}	0.30 ^{M}	15.81 ^{L}	21.57 ^{M}	1.20 ^{L}	2.85 ^{L}
Yahim	Yebha	0-15	Silty loam	0,92	7.55 ^{N}	0.37 ^{M}	10.14 ^{L}	7.07 ^{VL}	1.2 0^{L}	2.95 ^{L}
		15-30	Silty loam	1,16	7.41 ^{N}	0.34 ^{M}	9.78 ^{L}	6.64 ^{VL}	1.18 ^{L}	2.78 ^{L}
Yabaso	Follo	0-15	Silty loam	0,71	6.2 ^{SA}	0.41 ^{M}	13.32 ^{L}	23.7 ^{M}	1.81 ^{L}	2.53 ^{L}
		15-30	Silty loam	0,73	6.09 ^{SA}	0.38 ^{M}	9.11 ^{L}	19.7 ^{L}	1.70 ^{L}	2.43 ^{L}
Yabaso	Para	0-15	Silty loam	0,88	5.78 ^{SA}	0.32 ^{M}	25.64 ^{H}	9.19 ^{VL}	1.66 ^{L}	2.40 ^{L}
		15-30	Silty loam	0,80	5.88 ^{SA}	0.33 ^{M}	15.81 ^{L}	5.41 ^{VL}	1.66 ^{L}	2.34 ^{L}
Koya	Mix	0-15	Silty clay	1,04	7.37 ^{N}	0.39 ^{M}	10.14 ^{L}	27.18 ^{M}	2.24 ^{M}	4.69 ^{H}
		15-30	Silty clay	nd	7.45 ^{N}	0.40 ^{M}	9.78 ^{L}	12.49 ^{L}	2.03 ^{L}	3.67 ^{M}
Yabaso	1-1	0-15	Silty loam	0.80	6.95 ^{N}	0.39 ^{M}	17.44 ^{M}	39.50 ^{H}	3.20 ^{M}	4.19 ^{M}
	1-2	15-30	Silty loam	0,83	6.62 ^{N}	0.39 ^{M}	13.21 ^{L}	36.00 ^{H}	2.50 ^{M}	3.51 ^{M}
	2-1	0-15	Silty loam	0,81	7.36 ^{N}	0.35 ^{M}	17.54 ^{M}	68.00 ^{VH}	5.90 ^{H}	3.35 ^{M}
	2-2	15-30	Silty loam	0,85	5.30 ^{A}	0.29 ^{M}	24.68 ^{H}	97.10 ^{VH}	2.70 ^{M}	1.89 ^{VL}
	5-1	0-15	Silty loam	0,80	6.02 ^{SA}	0.32 ^{M}	17.29 ^{M}	43.80 ^{H}	5.80 ^{H}	3.38 ^{M}
	5-2	15-30	Sandy loam	0,85	5.83 ^{SA}	0.19 ^{L}	9.43 ^{L}	14.90 ^{L}	2.60 ^{M}	3.04 ^{L}
	Average	**0-30**		**0,89**	**6.41^{SA}**	**0.34 ^{M}**	**14.84 ^{L}**	**27.17 ^{M}**	**2.66 ^{M}**	**3.05 ^{L}**
	SD			0,14	0,75	0,05	5,69	23,61	1,41	0,69
	CV (%)			15,82	11,62	15,96	38,31	86,89	53,22	22,50

^{A}: acid; ^{SA}: slightly acid; ^{N}: neutral; ^{M}: medium; ^{H}: high; ^{VH}: very high; ^{L}: low; ^{VL}: very low. Values in square indicate the maximum and minimum value in each property.

The same results reported by Pasolon *et al.* (2007), who found that soil texture of the mineral soil in sago-palm-growing areas in Kendari was coarse, while around Sentani lake was fine. In Seram, Halmahera and Papua, Notohadiprawiro and Louhenapessy (1992) found that sago palm commonly grew on sandy, loamy and heavy clay soils. Soils with loamy textures and high in organic matter content (> 20 %) and acidity was reported as naturally suitable for the sago palms to grow (Louhenapessy, 1994; Flach, 1977; Flach, 1983; Flach and Schuiling, 1988). According to White (1987), finer-textured soils are better in water holding and nutrients retention compared to the coarse-textured ones.

Chemical properties of soil in major sago-palm-growing areas

a. Soil acidity (pH)

Soil acidities in the investigated sago-palm-growing areas varied among the sites. Most of the sites in Jayapura showed that the pHs values ranged from slightly acid to neutral, with the average value of 6.4 (Table 2, Fig. 2a). While in Seram (Table 3, Fig. 2a) the pHs showed

Table 3. Characteristics of the physical and chemical properties of mineral soil in the sago-palm-growing areas around, Kairatu Seram Island, (Data 2007)

Researched site	Field code	Depth (cm)	Texture	Bulk density (g cm^{-3})	pH H_2O (1:2.5)	Exchangeable-K (cmol$_c$ kg^{-1})	CEC (cmol$_c$ kg^{-1})	Total C	Total N (g kg^{-1})	Available P (mg kg^{-1})
Haturapa	1-1	0-15	Silty loam	1.26	6.20 ^{SA}	0.38 ^{M}	8.18 ^{L}	8.10 ^{VL}	2.20 ^{M}	3.12 ^{M}
	1-2	15-30	Silty loam	1,47	6.25 ^{SA}	0.28 ^{M}	8.10 ^{L}	0.70 ^{VL}	1.70 ^{L}	2.91 ^{L}
	2-1	0-15	Silty loam	1,09	5.85 ^{SA}	0.38 ^{M}	9.59 ^{L}	7.30 ^{VL}	2.10 ^{M}	2.20 ^{VL}
	2-2	15-30	Silty loam	1,20	5.97 ^{SA}	0.19 ^{L}	6.25 ^{L}	5.80 ^{VL}	1.70 ^{L}	1.45 ^{VL}
Waisari	3-1	0-15	Silty loam	nd	5.62 ^{SA}	0.38 ^{M}	10.37 ^{L}	9.70 ^{VL}	1.70 ^{L}	1.86 ^{VL}
	3-2	15-30	Silty loam	nd	5.56 ^{SA}	0.38 ^{M}	8.21 ^{L}	3.00 ^{VL}	1.20 ^{L}	2.58 ^{L}
Tinanurui	7-1	0-15	Loam	1,17	5.04 ^{A}	0.33 ^{M}	8.98 ^{L}	16.10 ^{L}	1.70 ^{L}	2.56 ^{L}
	7-2	15-30	Loam	1,60	4.58 ^{A}	0.28 ^{M}	7.69 ^{L}	3.60 ^{VL}	1.20 ^{L}	2.18 ^{VL}
Mampokur	11-1	0-15	Loam	1,34	4.92 ^{A}	0.19 ^{L}	5.70 ^{L}	23.00 ^{M}	2.10 ^{M}	2.68 ^{L}
	11-2	15-30	Sandy loam	1,56	4.89 ^{A}	0.19 ^{L}	3.83 ^{VL}	21.70 ^{M}	1.70 ^{L}	2.41 ^{L}
Average	**0-30**			**1,35**	**5.49 ^{A}**	**0.30 ^{M}**	**7.69 ^{L}**	**9.90 ^{VL}**	**1.73 ^{L}**	**2.40 ^{L}**
SD				0,20	0,59	0,08	1,95	7,80	0,34	0,49
CV (%)				14,96	10,83	28,20	25,30	78,83	19,85	20,63

^{A}: acid; ^{SA}: slightly acid; ^{M}: medium; ^{L}: low; ^{VL}: very low; nd: not determined; ^{H}: high; ^{VH}: very high. Values in square indicate the maximum or minimum value in each property.

the same range (slightly acid to acid) with the average value of 5.5, lower than those in Jayapura. We found slightly different in Kendari (Table 4, Fig. 2a), where the pHs ranged from very acid to neutral with the average value of 4.9, more acidic than in Jayapura and Seram sites. This might be related to the original condition of the land surrounded the sago-palm-growing areas in Kendari, and the lands dominated by the acidic soils. Similar results were reported by Djaenudin *et al.* (2002) who found that in the Southeast Sulawesi around 40 % of the soils were formed by and developed from the sedimentary rock under wet climate resulting in low pH (< 5.5). On the contrary, soils in Papua, partly developed from the same type of parent materials, and slightly developed under different climate (drier) condition which in turn formed the soil with higher pH (> 6.3).

Variation among the sampling sites was almost the same (CV= 11.6 %, 10.8 %, and 12.2 % for Jayapura, Seram and Kendari, respectively). This indicates that the pH values do not varied much within each area, and the range of the pH values among the sites are slightly narrow (Fig. 2a).

Slightly different finding was reported by Pasolon *et al.* (2007). From their study they concluded that the total-N content in Kendari ranged from very low to low, while in Jayapura, it ranged from medium to high. The difference might be related to the sampling sites. In general, based on the comparison among the investigated sites

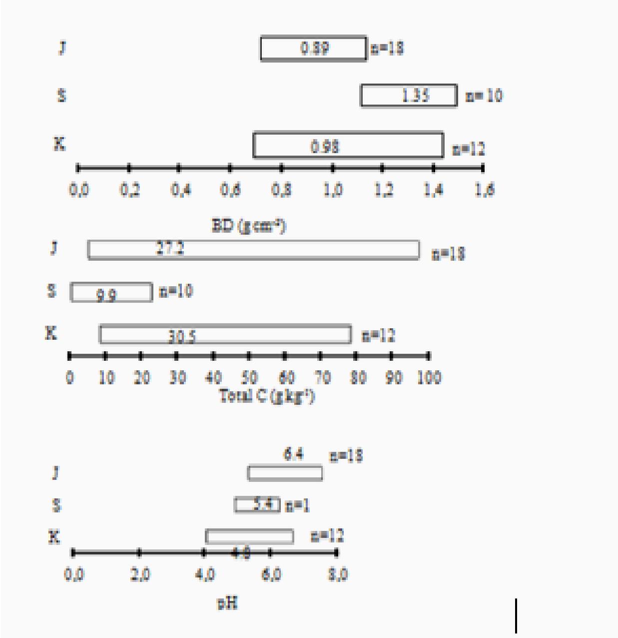

Fig 2 a. Comparisons among the averages of soils BDs, total-C contents, and pHs in the major sago-palm-growing areas of eastern Indonesia (J: Jayapura, S: Seram, and K: Kendari; n: number of samples). The bars show the range of each property of soil from 0-30 cm, and the numeral in the bar shows the average value of each area.

Table 4. Characteristics of the physical and chemical properties of mineral soil in the sago-palm-growing areas, around Kendari (Data 2007 and 2008)

Researched site	Depth (cm)	Texture	Bulk density (g cm-3)	pH	Exchangeable-K (cmolc kg-1)	CEC (cmolc kg-1)	Total C (g kg-1)	Total N (g kg-1)	Available P (mg kg-1)
Lalomasara 1	0-15	Sandy loam	1,00	6. 60 ^{N}	0.30 ^{M}	12.50 ^{L}	23.00 ^{M}	2.10 ^{M}	1.10 ^{VL}
	15-30	Sandy loam	1,10	6.00 ^{SA}	0.30 ^{M}	10.70 ^{L}	49.80 ^{H}	2.10 ^{M}	1.70 ^{VL}
Lalomasara 2	0-15	Silty clay	0,70	5.00 ^{A}	0.40 ^{M}	28.60 ^{H}	78.10 ^{VH}	6.80 ^{H}	3.10 ^{L}
	15-30	Silty clay	0,80	5.00 ^{A}	0.30 ^{M}	22.60 ^{M}	67.70 ^{VH}	8.10 ^{VH}	1.80 ^{VL}
Konda	0-15	Sandy loam	0,68	4.03 ^{VA}	0.14 ^{L}	8.93 ^{L}	14.40 ^{L}	1.70 ^{L}	1.46 ^{VL}
	15-30	Sandy loam	1,10	4.21 ^{VA}	0.15 ^{L}	7.50 ^{L}	13.60 ^{L}	1.80 ^{L}	1.47 ^{VL}
Lakomea	0-15	Silty clay	0,80	5.71 ^{SA}	0.29 ^{M}	36.66 ^{H}	26.90 ^{M}	4.40 ^{M}	3.58 ^{M}
	15-30	Silty clay	0,90	5.11 ^{A}	0.20 ^{L}	25.55 ^{H}	19.30 ^{L}	2.90 ^{M}	1.59 ^{VL}
Rawa Aopa	0-15	Loam	1.41	4.67 ^{A}	0.19 ^{L}	9.54 ^{L}	26.89 ^{M}	4.57 ^{M}	2.19 ^{VL}
	15-30	Loam	1,50	4.40 ^{VA}	0.24 ^{M}	9.54 ^{L}	13.03 ^{L}	5.42 ^{H}	2.26 ^{L}
Tinondo	0-15	Loam	1,17	4.75 ^{A}	0.19 ^{L}	10.27 ^{L}	24.55 ^{M}	2.64 ^{M}	2.36 ^{L}
	15-30	Sandy loam	0,99	4.65 ^{A}	0.23 ^{M}	4.04 ^{VL}	8.78 ^{VL}	1.65 ^{L}	2.23 ^{L}
Average	**0-30**		**0,98**	**4.87 ^{A}**	**0.24 ^{M}**	**15.54 ^{L}**	**30.50 ^{H}**	**3.68 ^{M}**	**2.07 ^{VL}**
SD			0,24	0,59	0,08	10,18	22,54	2,17	0,71
CV (%)			24,57	12,22	31,12	65,52	73,88	58,98	34,51

^{A}: acid ; ^{SA}: slightly acid; ^{VA}: very acid; ^{N}: neutral; ^{H}: high; ^{VH}: very high; ^{M}: medium; ^{L}: low; ^{VL}: very low.
Values in square indicate the maximum or minimum value in each property.

b. Total-N

The total-N contents in Jayapura widely ranged from low to high with the average of 2.66 g kg^{-1} (Table 2, Fig. 2b), while the total-N content in Seram, the average was 1.73 g kg^{-1}, ranged from low to medium (Table 3, Fig. 2b). On the contrary, the total-Ns in Kendari ranged from low to high with the average was 3.68 g kg^{-1}, except in one site, in Lalomasara, which was found very high (Table 4, Fig. 2b).

(Fig. 2b) the order of the total-N value status is in the order of Kendari > Jayapura > Seram. The higher value of total-N contents found in Kendari might be related to the location of the sites that were dominantly situated between the foot of the hills and flood plain where plenty of organic matter derived from the surrounding rivers and erosion through the flowing water, and this all accumulated around the sago-palm-growing areas. In Jayapura the N contents derived from the accumulated organic matter around the lake Sentani, a main source of N in the soil.

Based on the coefficient of variation values presented in Tables 2, 3 and 4, most of the sites showed very high variations in their total-N contents, particularly in Kendari and Jayapura (53.2 %, 19.9 % and 59.0 % in Jayapura, Seram and Kendari, respectively). The variation in Seram sites showed a narrow range (Fig. 2b). This implies that in the sampling sites of each growing area, the total-N varied depending on the *in situ* source of N, particularly the source of an organic matter in the soil. In Seram sites compared to the others, they seemed to be narrower in the total-N range. In terms of soil N supplying capability, total-N does not indicate plant available N (Marx *et al.*, 1999). They suggested that soil N available concentrations are depended on the biological activity that might fluctuate with the changes in conditions such as temperature and moisture.

c. Total-C

The total-C contents in Jayapura ranged widely from very low to very high with the average 27.2 g kg^{-1} (Table 2, Fig. 2a). Further, the total-C contents in Seram, the

Average of which was 9.9 g kg^{-1}, ranged from very low to medium (Table 3, Fig. 2a), while the average in Kendari (30.5 g kg^{-1}) was slightly higher than those found in Jayapura (Table 4, Fig. 2a). In general, the total-C contents were higher in the order of Kendari > Jayapura > Seram (Fig.2a). Higher total-C contents found in Kendari and Jayapura referred to the previous explanation in the total-N contents.

Based on the coefficient of variation (73.9 %, 86.9 %, and 78.8 % in Kendari, Jayapura and Seram, respectively), the sampled sites in each sago-palm-growing area varied very much in the total-C contents. However, it was found that the patterns of the total-N and total-C were similar. This was commonly appeared that the source of N in the soil was mostly derived from the organic matter contents which can be affected by the total-C content. That was confirmed by Pasolon *et al.* (2007), who found that the level of organic-C was strongly correlated with the total-N (r = 0.82* and 0.99**) in the 0-15 cm and 15-30 cm from the soil surface near Jayapura.

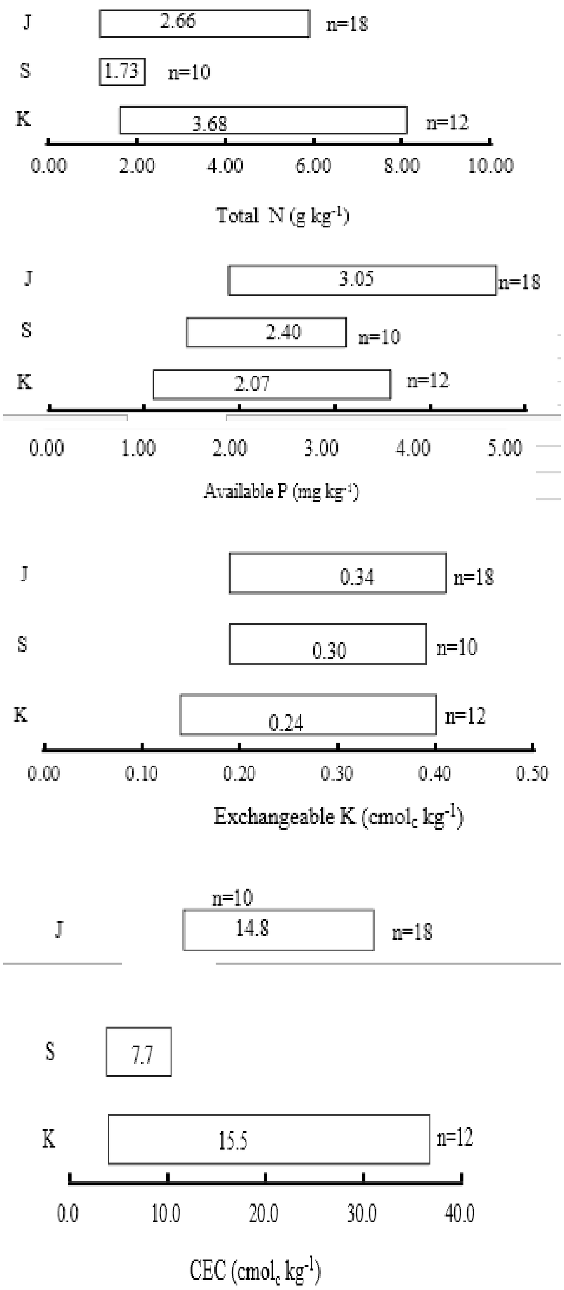

Fig. 2b. Comparisons among the averages of total-Ns, available-Ps, exchangeable-Ks, and CECs in the major sago-palm-growing areas of eastern Indonesia. (J: Jayapura, S: Seram, and K: Kendari; n: number of samples). The bars show the range of each property of soil fro 0-30 m, and the numeral in the bar shows the average value of each area.

d. Exchangeable-K

Further, exchangeable-K contents in Jayapura ranged from low to medium with the average value of 0.34 $cmol_c\ kg^{-1}$ (Table 2, Fig. 2b) The average value were 0.30 $cmol_c\ kg^{-1}$ and 0.24 $cmol_c\ kg^{-1}$ in Seram (Table 3, Fig. 2b) and Kendari (Table 4, Fig. 2b), respectively. The exchangeable-K contents showed similar values, although the value in Jayapura showed a little higher than those in Seram and Kendari. Similar results were reported by Pasolon *et al.* (2007), who found that higher level of exchangeable-K contents in Jayapura than in Kendari. This might be related to the soil texture. The coarse texture in Kendari resulted in extensive leaching and account for the for the loss of potassium from the soil, while finer texture in Jayapura with higher level of CEC promoted to the higher exchangeable-K contents. The variations of exchangeable-K among the sites in each area in Jayapura, Seram, and Kendari (CV=16.0 %, 28.2 % and 31.1 %, respectively) indicated that there was a slightly lower variation among the sites in Jayapura than the ones in Kendari and Seram. This means that exchangeable-K contents of the soil in Kendari comparatively more varied according to the sites.

e. Available-P (P-Bray 2)

The available-P (AP) contents in Jayapura ranged widely from very low to high with the average value of 3.05 mg kg^{-1} (Table 2, Fig. 2b). They were found very low to medium contents in the sago-palm-growing areas of Seram with the average of 2.40 mg kg^{-1} and Kendari with the average of 2.07 mg kg^{-1}, respectively (Table 3, Fig. 2b). In comparison, the range of AP contents of the sites in Jayapura were slightly higher and wider (Fig. 2b) than those of sites in Seram and Kendari; the sites in the latter two were of almost of the same trend. Lower AP contents in Kendari and Seram compared to the ones in Jayapura might be attributed to higher soil acidity or lower pH in Kendari and Seram as describe in the Fig.2a (the average values were 4.87 and 5.49, respectively) and the low quantities of P in the mineral content of the parent materials from which those soils were formed. According to Tisdale *et al.* (1993), under acidic soil condition the dominant minerals found are *variscite* ($AlPO_4.2H_2O$) and *strengite* ($FePO_4.2H_2O$). Further, Busman *et al.* (2002) also reported that in acidic soils (especially when the soil pH is less than 5.5), Al, that will react with phosphate, is the dominant ion released. In these soils, the first product formed would be amorphous Al and Fe phosphates. The amorphous Al and Fe phosphate gradually change into compounds that resemble crystalline *variscite* and *strengite*. On the other hand, soils around Jayapura might have been dominated by the different mineral contents derived from the surrounding, nearby mountain (Mount Cyclops) containing dicalcium phosphates, octacalcium phosphates, hydroxyapatite and flourapatite. The AP contents of those minerals are appreciably higher than those of the *variscite* and *strengite*.

Variations among the sites in each area, indicated that AP contents of the sites in Kendari slightly higher (CV= 34.5 %) compared to those of the sites in Jayapura (CV= 22.5 %) and Seram (CV= 20.6 %).

f. Cation exchangeable capacity (CEC)

The soil CEC around Jayapura ranged widely from low to high with an average of 14.84 $cmol_c$ kg^{-1} (Table 2, Fig.2b). On the other hand, the CECs were mostly low in Seram (the average of which was 7.69 $cmol_c$ kg^{-1}) (Table 3, Fig.2b). Further, the CEC in Kendari (Table 4, Fig. 2b), ranged between very low to high (the average was 15.54 $cmol_c$ kg^{-1}) that was higher than those in Seram. In general, based on the CEC status, the investigated sites of sago-palm-growing areas ranked in the order of Kendari > Jayapura > Seram. The results followed the same pattern with the total-C content. The CEC increased by the increase of the organic carbon or organic matter content in the soil. According to Marx *et al.* (1999), soils with high organic matter content tend to have a high CEC.

The CEC variations of the sites in each area indicated that Kendari (CV= 65.5 %) was higher than Jayapura and Seram (CV = 38.3 % and 25.3 %, respectively). Further, a very wide range of CECs was also found in Kendari, followed by Jayapura, whereas the narrowest was in Seram, meaning that the CECs in Seram did not much varied among the sampling sites (Fig. 2b).

Relation between the soil physicochemical properties and growth or starch productivity of sago palms

Some reports are available on the growth and starch productivity of sago palms growing in the eastern areas in Indonesia where the soil physicochemical properties were studied in this research. Trunk growth parameters such as length, diameter and weight, pith weight, starch percentage in pith and starch yield at harvesting stage were reported for 3 (Yamamoto *et al.* 2010), 4 (Yamamoto *et al.* 2008) and 10 folk varieties (thereafter varieties) (Yamamoto *et al.* 2005, Yanagidate *et al.* 2007) around Kendari, Kairatu in Seram and Jayapura, respectively. The varietal differences in growth and starch productivity were clearly found around Kendari and Jayapura, but not so remarkable around Kairatu in Seram. On the other hand, the variations among individual palms in the same variety were clearly found in all the three areas. Moreover, the starch yields of individual palms were mainly determined by the trunk (pith) weight which was closely related with the soil environment as well as the genetic traits of varieties (Yamamoto 2006) and more than 500kg dry starch was yielded in the high-yielding varieties in each researched area. Due to the differences in the sago palm varieties growing in each researched area, it is difficult to relate the growth or starch productivity and the soil properties in the three researched areas together. However, the greater trunk growth and starch yield of sago palms in Jayapura (Yamamoto et al. 2005) and Seram (Yamamoto et al. 2008) compared with those in Kendari (Yamamoto et al. 2010) might be partly caused by the relatively higher contents of exchangeable-K (averagely 0.34 and 0.30 $cmol_c$ kg^{-1}) and AP (averagely 3.05 and 2.40 mg kg^{-1}) in the soils in Jayapura and Seram than those in Kendari (averagely only 0.24 $cmol_c$ kg^{-1} K and 2.07 mg kg^{-1} AP). Moreover, the smaller differences in trunk growth and starch yield of sago palms in Seram compared with those in Jayapura and Kendari might be partly related with the less variations of exchangeable-K, CEC and total-C among the soils surveyed in Seram than those in Jayapura and Kendari. In addition, the individual differences in growth and starch productivity in the same variety in each researched area might be based on the differences in the soil physicochemical properties on the growing fields. Soil BDs for instance are higher in order of Seram (averagely 1.35 g cm^{-3}) > Kendari (0.98 g cm^{-3}) > Jayapura (0.89 g cm^{-3}). Soil pH are higher in order Jayapura (averagely 6.41) > Seram (5.49) and Kendari (4.87). Ehara *et al.* (1995a, b, 2000) also reported that the remarkable variations of growth and starch productivity among the 11 sago palm varieties growing in Southeast and North Sulawesi Provinces and North Maluku Province might be closely related with the differences in the soil environments as well as the genetic traits of varieties.

Further detail researches are needed to clarify the effects of soil physicochemical properties on the growth and starch productivity of sago palm.

CONCLUSIONS

In general, the average nutrient contents of the selected sites of sago-palm-growing areas in Kendari showed lowest in the exchangeable-K (0.24 $cmol_c\ kg^{-1}$), available-P (2.07 $mg\ kg^{-1}$) and soil pH (4.9), but highest in CEC (15.5 $cmol_c\ kg^{-1}$), total-N (3.68 $g\ kg^{-1}$) and total-C (30.5 $g\ kg^{-1}$). On the contrary these were found lowest in Seram, 7.70 $cmol_c\ kg^{-1}$, 1.73 $g\ kg^{-1}$, and 9.90 $g\ kg^{-1}$ for the CEC, total-N, and total-C, respectively. While in Jayapura highest in exchangeable-K (0.34 $cmol_c\ kg^{-1}$), available-P (3.05 $mg\ kg^{-1}$), and soil pH (6.4) were found. The nutrient contents of the soils on sago-palm-growing areas in Kendari were widely varied compared to Jayapura and Seram. Most of the nutrient contents in Seram showed the narrowest range. Therefore, we can conclude that higher variation of soil fertility among the sago-palm-growing areas around Kendari compared to those in Jayapura and Seram.

The differences in the soil physicochemical properties among the sites in the same area as well as the major sago-palm-growing areas might affect the growth and starch yield of sago palms growing there. Our findings coincided with some previous reports on the sago palm production, where large variation of sago palm production in the eastern part of the archipelago of Indonesia was reported to be closely attributed to the environmental factors, especially natural soil fertility (Ehara *et al.*, 1995a, b; Ehara *et al.*, 2000).

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