Studies on Trunk Density and Prediction of Starch Productivity of Sago Palm (*Metroxylon sagu* Rottb.): A Case Study of a Cultivated Sago Palm Garden near Kendari, Southeast Sulawesi Province, Indonesia

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Abstract: This research was carried out in a cultivated sago palm (*Metroxylon sagu* Rottb.) garden near Kendari, Southeast Sulawesi Province, Indonesia in 2006 to predict the annual starch yield from 2006 to 2015. The average trunk (with trunk height of >0.5 m) density and the average number of trunks in each class of length (at 1 m separation, from 1.0 to 10 m) per hectare were 228 palms/ha and 19 palms/ha, respectively. The trunk elongation rate was estimated to be 1m/year from the coefficient of regression line between the trunk length and the estimated years after trunk formation. The average number of harvestable trunks estimated by the elongation rate per year (1 m/year) and the trunk length at the harvesting stage (ca. 10 m) was 22 palms/ha/year, and the average annual starch yield per hectare was estimated to be 9.0 t from 2006 to 2015 with an average starch yield of 393 kg/palm by chemical analysis of mature palms grown around the surveyed area. However, the starch yield showed a downward trend from 13.5 t/ha in 2006 to 4.3 t/ha in 2015. This trend is caused by the decreasing numbers of harvestable trunks in each subsequent year. The above finding indicates that proper cultivation techniques to maintain a suitable trunk density with different trunk lengths (ages) by appropriate sucker thinning should be established for a stable annual starch production per unit area.

Key words: annual starch productivity, Indonesia, sago palm, starch yield, trunk density

サゴヤシの樹幹密度とデンプン生産性の予測―インドネシア，南東スラウェシ州クンダリ近郊における栽培サゴヤシ園での調査―

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要旨　本研究は，インドネシア南東スラウェシ州クンダリ近郊のサゴヤシ栽培農園において，2006から2015年までの10年間のデンプン収量を推定するために行われた．平均の樹幹（0.5 m以上の樹幹長）密度および各樹幹長別（1 m以下及び1 m以上は1 m毎の長さ）の平均樹幹数は，それぞれ228本/haおよび19本/haであった．幹立ち後の推定樹齢と樹幹長との関係から樹幹の伸長速度を算出した結果，約1 m/yearとなった．この値と収穫適期における樹幹長（10 m）より，2006年から2015年までの10年

間における収穫可能な樹幹数は平均22本/ha/yearと推定された．収穫適期の樹幹のデンプン収量は化学分析法により393 kg/palmとなったことから，2006～2015年の間の平均デンプン収量は9.0 t/ha/yearと推定された．しかし，デンプン収量は2006年での13.5 t/haから2015年での4.3 t/haへと顕著な減少傾向を示した．これは樹齢別樹幹密度の偏りによる年次間における収穫可能樹幹数の差から生じたものと考えられ，ha当たりの安定したデンプン生産には，サッカー調整を含む適正な樹幹密度を維持する栽培技術の確立の重要性が指摘された．

キーワード：インドネシア，サゴヤシ，樹幹密度，デンプン収量，年間デンプン収量

Introduction

Recently, much attention has been given to the sago palm for its high starch productivity, potentially for utilization as industrial raw materials for new biomass energy (bioethanol) and bio-degradable plastics. Very large areas of wild sago palm forest can be rehabilitated into sustainable sago plantations to produce an enormous quantity of sago-based industrial raw materials (Jong 2002).

For a stable supply of sago starch from sago palm forests for industrial utilization, the annual starch productivity per unit area needs to be investigated. Investigation of the sago palm densities per hectare with different growth stages on a sago garden in Batu Pahat, Malaysia (Watanabe 1986) showed varying sago trunk densities and discontinuity of harvest. Osozawa (1990) surveyed the starch productivity of individual palm grown in a semi-cultivated sago palm forest of South Sulawesi Province, Indonesia and suggested that the annual starch yield per hectare would decrease due to the variable trunk densities with different lengths. Yamamoto *et al.* (2008) reported the decreasing trend of the annual starch yield and the unevenness of the trunk densities in a cultivated sago palm garden in Riau Province, Indonesia.

In view of the limited reports on the prediction of continuous sago starch productivity over a specific time, this study was conducted to estimate the starch productivity per hectare for over 10 years at a cultivated sago garden in Kendari, Southeast Sulawesi Province, Indonesia.

Materials and Methods

The survey was carried out in a cultivated sago palm garden with mineral soil near Kendari City, Southeast Sulawesi Province, Indonesia in 2006. Only the ‘Molat’, one of the folk varieties in Sulawesi Island (local name: ‘Roe’), was observed in the garden. The garden was mature, although the date of the establishment of this garden is unknown, and harvesting of sago palms has been done for many years. No agronomic management of this garden, including fertilizer application, sucker thinning, or weeding, has been performed.

Four surveyed areas (quadrate; plots Ⅰ～Ⅳ) covering 40 m × 40 m square were selected, and each quadrate was divided into 4 quarters (20 m × 20 m). The number of clumps, trunks with over 50 cm in height, and suckers (including trunks with heights of less than 50 cm) in the divided squares were recorded. For palms with trunks exceeding 50 cm in height, the lengths were measured. Moreover, the trunk locations and the crown sizes were also recorded to describe the distribution of trunk density in the surveyed areas. The average crown size of each plot was determined by 12 palms.

Four palms at the harvesting stage were sampled to record the growth parameters and the estimation of the individual palm starch yield. After felling the palms using a chainsaw and removing the remains of the leaf sheath on the trunk, the trunk length, diameter, and weight were measured. The trunk length was measured from the felled trunk base to the attached position (base) of the leaf sheath of the oldest living leaf on the trunk. The trunks were evenly cut into 4 sections (log), and the diameters at each cut position were measured to calculate the average trunk diameter. The trunk weight was weighed using a 100 kg balance after cutting the trunk into smaller pieces. Pith samples (50-100 g, unit of 0.1 g) using a portable electronic balance (HL-200 type, Kagakukoei Co., Ltd.) were collected radially from the center of a disc with 2-3 cm thickness at each position where the diameter was measured. Each pith sample was dried for two days in a ventilation oven at 80℃, and the dry weight was measured after drying for two days in the ventilation oven at 65℃. The dried pith samples were ground and milled to fine powder (100 mesh <). After sugars were extracted from the ground sample (0.2 g) using 80% hot ethanol, starch was extracted six times from the residue using $HClO_4$ (4.6 *N*) following the procedure of Murayama *et al.* (1955). The analyses of total sugar and starch as glucose were performed using the anthrone-sulfulic acid method (Tamura 1975). Total sugar and starch were expressed as glucose and multiplied by 0.9 to obtain the percentage of glucose per dry weight. The average values of pith dry matter, total sugar, and starch percentages were calculated from the values of the pith samples. The total amount of starch content (starch yield) of a trunk was calculated by the following formula: trunk fresh weight × 0.8 × average dry matter (in %) of pith /100 × average starch (in %) of pith /100. Since the weight of bark accounted for about 20% of the trunk weight (Yatsugi, 1977), the value was multiplied by 0.8 in the formula.

Results and Discussion

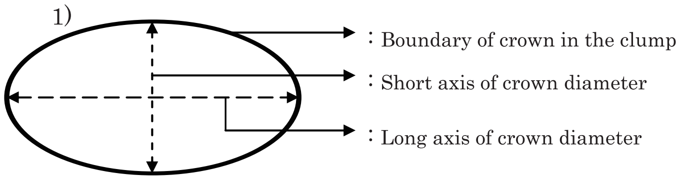
The diameters of the maximum and minimum crown axes were 17.9 m and 10.3 m, respectively, and the average in the whole crown was 14.9 m (Table 1). The shape of crowns in plot Ⅰ was elliptical since the long and short axes were 13.9 m and 11.7 m, respectively. On the other hand, the long and short axes in plots Ⅱ ~ Ⅳ were almost the same length, and the crown shape in these plots, therefore, was considered to be circular.

Figure 1 shows the distribution of sago palm

Table 1 Average diameter of long and short axes in sago palm crown.

Plot	Ave. diameter of crown (m)	
No.	Long axis 1)	Short axis 1)
Ⅰ	13.9	11.7
Ⅱ	16.6	15.2
Ⅲ	16.1	14.5
Ⅳ	16.0	15.0
Longest	17.9	-
Shortest	-	10.3
Average	14.9	

1)



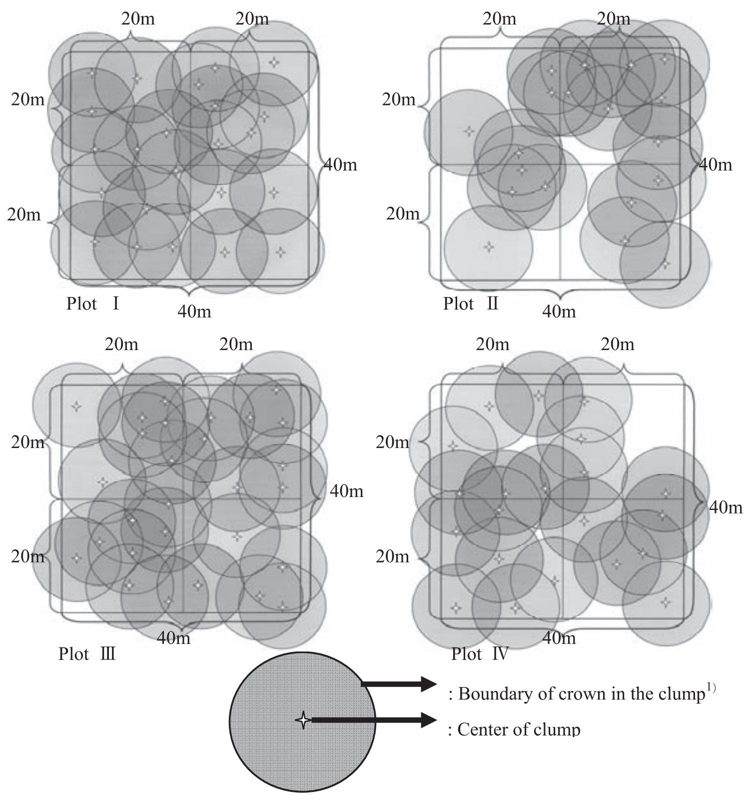


Fig. 1 Distribution of sago palm crown in each plot.
1) The crown was expressed as circle for simplicity.

crowns. The crown showed an uneven distribution in plot Ⅱ when compared to other plots. Therefore, areas that were non-shaded and shaded by the crowns were observed in plot Ⅱ. On the other hand, in other plots, the trunks were rather evenly distributed, and almost the entire area was covered by the crowns. These results indicate that most of the palms might have been shaded by the crowns of taller and older palms before trunk formation (Osozawa 1990) in all plots except for some plants of plot Ⅱ. Moreover, Osozawa (1990) reported that high weed density was observed in his surveyed area, where sunshine penetrated the soil surface. To improve the unevenness of the trunk distribution in the unit area, transplanting of suckers to places of low trunk density should be conducted (Osozawa 1990).

Table 2 shows the number of clumps, trunks, and suckers per hectare recorded in the quadrates. The average number of clumps was 169 clumps/ha, corresponding to 7.7 m × 7.7 m square planting density. An interview with a sago palm farmer in the surveyed area indicated that this planting density was considered to be near the conventional density from 8.0 to 9.0 m square. The average number of trunks and

Table 2 Density of clump, trunk, and sucker in each plot.

Plot No.	Clump density (palm/ha)	Trunk density (palm/ha)	Trunk density (palm/clump)	Sucker density (sucker/ha)	Sucker density (sucker/clump)
Ⅰ	181	263	1.4	2156	11.9
Ⅱ	163	163	1.0	2575	15.8
Ⅲ	194	263	1.4	1844	9.5
Ⅳ	138	225	1.6	2450	17.8
Average	169	228	1.4	2256	13.8
S.D.	25	47	0.3	326	3.8
C.V.(%)	14.5	20.7	19.6	14.5	27.3

S.D.: Standard deviation, C.V.: Coefficient of variance.

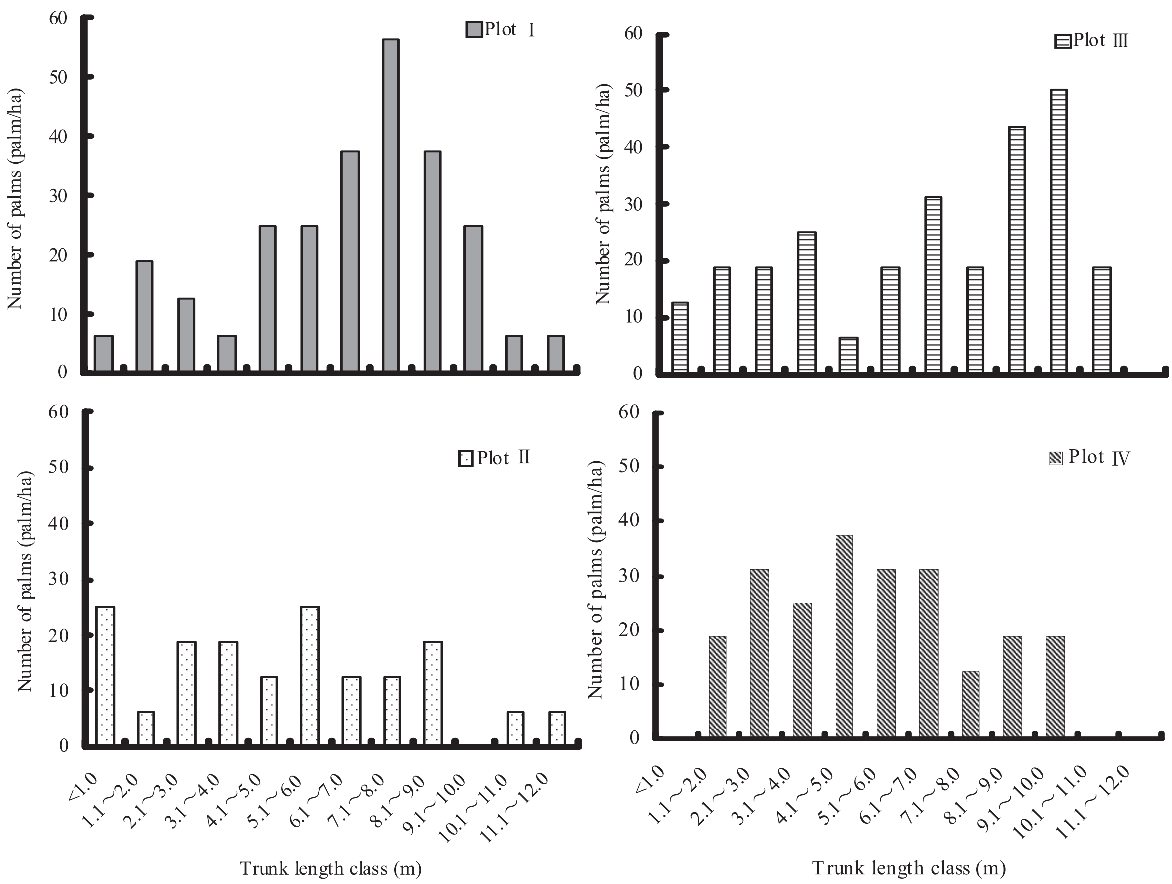


Fig. 2 Frequency distribution of number of palms with different trunk lengths in each plot.

suckers was 1.4 palms/clump (228 palms/ha) and 13.8 suckers/clump (2256 suckers/ha), respectively, although considerably high variations (C.V.; 20.7% and 14.5%) were observed among the plots. The lower number of trunks in spite of higher number of suckers per clump indicated that trunks were not formed at a constant rate in most of the clumps even though sufficient suckers were produced in the palm cluster.

Unevenness of trunk density in each trunk length (height) class was observed (Fig.2). The maximum number of palms was 56.3 palms/ha in the 7.1-8.0 m class of plot Ⅰ. The minimum number of palms (0 palm/ha) was observed in the 9.1-10.0 m class of plot Ⅱ and 11.1-12.0m class of plot Ⅲ, and the classes of less than 1.0 m, 10.1-11.0 m and 11.1-12.0 m in plot Ⅳ. Osozawa (1990) also observed unevenness of trunk density with different length, ranging from 4.4 to 22.5 palms/ha. The average number of trunks in plots Ⅰ ~ Ⅳ showed an upward trend up to 8-9 m class, although the downward trend was observed in the classes over 10.0 m (Fig. 3), and the average trunk density including all trunk length classes was around 19 palms/ha.

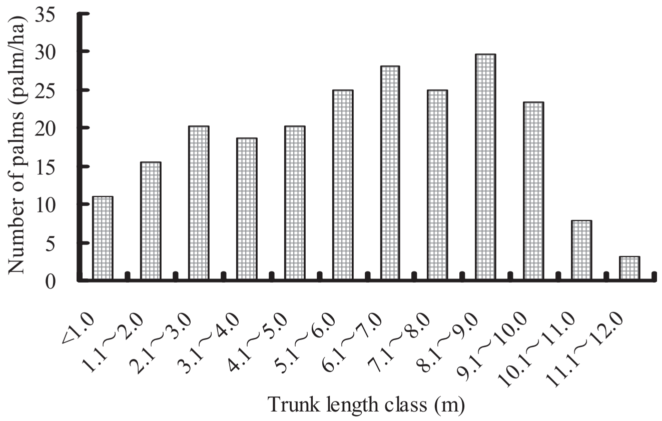


Fig. 3 Frequency distribution of average number of palms with different trunk lengths through plots Ⅰ ~ Ⅳ.

A higher significant and positive correlation (r = 0.98, *p=0.001*) was observed between trunk length and years after trunk formation (Fig. 4). From the coefficient of the regression line (1.09), the trunk elongation rate was estimated to be around 1 m/year. This value was almost the same as those reported by Yamamoto *et al*. (2000) at the same district and Osozawa (1990) in the Luwu district of South Sulawesi Province.

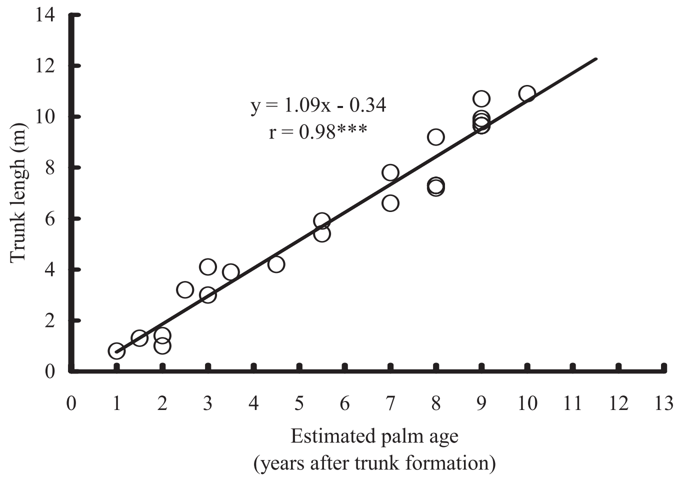


Fig. 4 Relationship between estimated palm age and trunk length. ***, Significant at the 0.1% level.

Considering the trunk length at the harvesting stage, ca. 10 m long in this area, an average of 22 palms/ha could be harvested annually from 2006 to 2015. This number was similar to those reported by Osozawa (1990) at 21.5 palms/ha/year, surveyed in South Sulawesi Province, but lower than the results of Yamamoto *et al*. (2008), at 24.1-44.7 palms/ha/year, surveyed in Riau Province, Indonesia, and those of Istalaksana *et al.* (2006), at 125 palms/ha/year, surveyed in Waropen, Papua Province, Indonesia. On the other hand, the survey results of the Japan Papua New Guinea Goodwill Association (1984) reported a lower number (10-17 palms/ha/year) in East Sepik Province, Papua New Guinea, than we had reported. As noted above, the trunk density of each unevenly distributed length class depends on the surveyed gardens, and notable differences were observed in the number of harvestable trunks per hectare in subsequent years.

The average trunk length and diameter of sago palms at the harvesting stage were 9.8 m and 55.9 cm, respectively, and the fluctuation of these values was small among the harvested palms (Table 3). The average fresh trunk weight was 1,934 kg, and the pith dry matter was 36.5%. The dry starch yield of each trunk ranged from 329 kg to 495 kg (avg. 393 kg) and was considered as a reasonable yield in comparison to the result of Yamamoto *et al.* (2000), who reported 425 kg for the 'Molat' variety in Kendari.

Table 3 Starch yield and its related characteristics.

Palm No.	Estimated Palm age 1)	Trunk Lgth (m)	Trunk Diam.(cm)	Trunk Fresh Wt. (kg)	Pith DM (%)	Pith Dry Wt. 2) (kg)	Pith Starch (%)	Starch (kg)
1	9	9.7	59	2142	38.9	666	74.3	495
2	9	9.7	58	2056	36.1	594	65.5	389
3	9	9.8	53	1810	36.7	531	67.2	357
4	9	9.9	53	1727	34.3	474	69.4	329
	Average	9.8	55.9	1933.5	36.5	566.4	69.1	392.6
	S.D. 3)	0.1	3.3	197.0	1.9	82.7	3.8	72.7
	C.V. 3)	1.4	5.9	10.2	5.2	14.6	5.5	18.5

1) Years after trunk formation. 2) Pith dry weight = trunk fresh weight x 0.8 (ratio of pithweight) x pith dry matter percentage/100. 3) Refer to Table 2.

Figure 5 shows the starch productivity per ha in each year in each plot in the following 10 years, as estimated from the average trunk density with different trunk length and the average starch yield described above. This result was based on the estimation that the trunk elongation rate at 1.0 m/year and the trunk length at the harvesting time were 9.0-10.0 m. The annual starch yield through the plots and years ranged from 0 (plot Ⅳ in 2015) to 27.0 t/ha/year (plot Ⅲ in 2006). In plot Ⅰ, the decreasing trends of starch yield were observed after

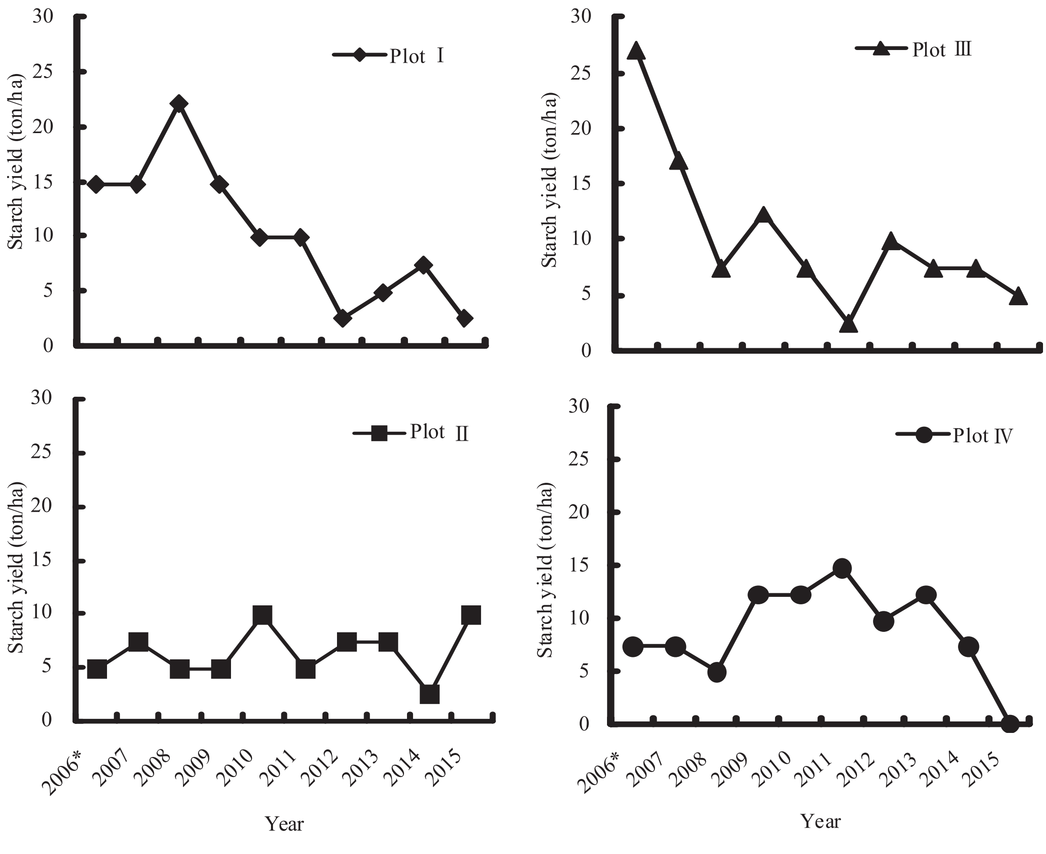


Fig. 5 Prediction of starch yield in each plot in 2006-2015.
*Starch yield including three classes of trunks (9.1-10.0, 10.1-11.0, and 11.1-12.0m) in 2006.

2008, and the average starch yield was 10.3 t/ha/year. In plot Ⅱ, the starch yield was broadly flat, although the yield was lower (avg. 6.4 t/ha/year) than those in other plots. A sharp decrease of the starch yield was observed from 2006 to 2011 in plot Ⅲ, and the average starch yield was the same as that in plot Ⅰ. On the other hand, a constant starch yield (avg. 8.8 t/ha/year) was observed from 2006 to 2013 in plot Ⅳ, but the yield seemed to be null in 2015.

The average starch productivity of plot Ⅰ to Ⅳ showed a decreasing trend from 13.5 t/ha in 2006 to 4.3 t/ha in 2015 (Fig. 6). The average starch yield and the number of harvestable trunks would be 9.0 t/ha/year and 22 trunk/ha/year during the following 10 years, respectively. The average starch yield corresponded to the 10.2 t/ha/year reported by Yamamoto *et al.* (2008) in the Riau Province, Indonesia. On the other hand, Osozawa (1990) observed a lower average starch yield (4.3 t/ha/year) in South Sulawesi Province than that in our results. However, he determined the starch yield of individual palms by traditional extraction, which gave lower results than those determined by chemical digestion. Schuiling (2006) and Yamamoto *et al.* (2007) reported the efficiency of starch extraction by traditional methods in West Seram and Riau, Indonesia, respectively. The starch extraction rates by traditional extraction were around 50% of the values determined by chemical analysis. As such, the average starch yield reported by Osozawa (1990) might correspond to 8.6 t/ha/year determined by chemical analysis, which is close to our yield.

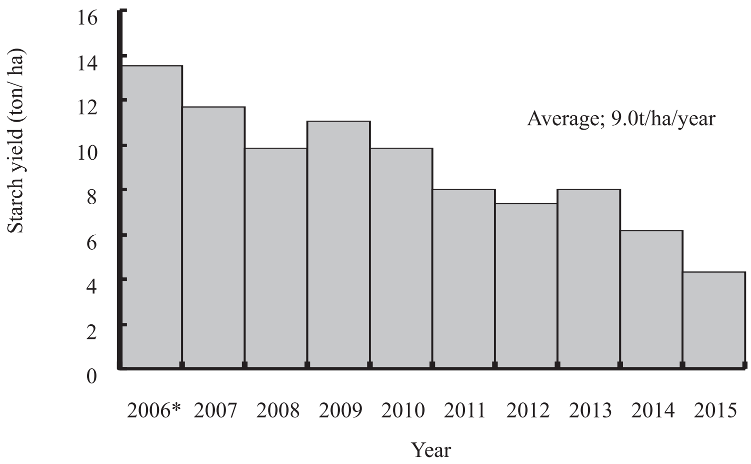


Fig. 6 Prediction of average starch yield in 2006-2015.
*Starch yield including three classes of trunks (9.1-10.0, 10.1-11.0, and 11.1-12.0m) in 2006.

These results showed that the current annual starch yields per ha of sago palm gardens in South and Southeast Sulawesi were almost the same, ca. 9 t/ha/year. However, the current research clearly indicated that the number of harvestable trunks in each year was unevenly distributed, showed a clear tendency of decreasing yield in subsequent years, and resulted in a remarkable variation in starch yield annually for the following 10 years. Osozawa (1990) also reported that there was a decreasing trend of starch productivity in a semi-cultivated sago garden in South Sulawesi Province. Yamamoto *et al.* (2008) suggested that good cultivation and management techniques would possibly contribute to the constant starch yield and even to an increase in it. Appropriate management of trunk density by progressive sucker control might be important to improve the annual starch productivity per unit area and time. Moreover, regarding sucker control, Flach (1977) advocates allowing one palm per clump to grow every second year.

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