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CARBON CYCLE IN SAGO PALM CULTIVATION SYSTEM IN TROPICAL PEATLAND

Akira Watanabe[1*], Shuhei Makabe[2], Ho Ando[3], Ken-ichi Kakuda[3], Sudid Donny[4], Zulhilmy Abdullah Mohd[4] and Lulie Melling[4]

[1]Graduate School of Bioagricultural Science, Nagoya University, Nagoya, Japan
[2]Agricultural Research Institute, Ibaraki Agricultural Center, Ibaraki, Japan
[3]School of Agriculture, Yamagata University, Yamagata, Japan
[4]Tropical Peat Research Laboratory Unit, Chief Minister's Department, Sarawak, Malaysia

**Corresponding author: akiraw@agr.nagoya-u.ac.jp*

SUMMARY

Sago palm (*Metroxylon sagu* Rottb.) is a high starch producing plant that can grow in a peat soil without intensive drainage. With such characteristics, sago palm is recommendable cash crop in tropical peatland. In this study, carbon (C) cycle in a sago palm cultivation system in Sarawak, Malaysia, was investigated to evaluate the potential of the system as C sink. For this purpose, the rate of C supply from sago palm to soil as litter, accumulation of C as aboveground biomass of sago and weeds, rate of sago litter decomposition on soil surface, and carbon dioxide (CO_2) and methane (CH_4) fluxes from soil were measured in one or two sago palm gardens managed by native farmers. The rate of annual C supply from sago palm was estimated to be 3–4 t C ha^{-1} y^{-1}. The amount of C accumulated as aboveground biomass of sago palm showed a large variation between the two gardens, 1–4 t C ha^{-1} y^{-1}, due to the difference in the proportion of sago palms in the trunk formation stage. The CO_2 and CH_4 fluxes from soil (at 1 m distance from sago cluster) measured manually ranged from 6–9 t C ha^{-1} y^{-1} and -2 to 27 kg C ha^{-1} y^{-1}, respectively. The CO_2 fluxes may be affected by root respiration because those were higher than the CO_2 flux recorded at the centre of four palms using a soil respiration monitoring system.

***Keywords**: Carbon Cycle, Litter Decomposition, Sago Palm, Tropical Peat*

INTRODUCTION

Peatland is a huge natural carbon (C) pool formed by the accumulation of partially decomposed plant material. In Southeast Asia, peatland that occupies 25 million ha (Page *et al.*, 2011) is a potential land source for producing food and energy sources balanced with increasing human population. However, due to high groundwater level, drainage is pre-requisite to facilitate plant root respiration for producing crops in peatland. The intense drainage may affect the decomposition of peat material and subsidence and (Blodau, 2002). In addition, characteristics of tropical peat soil, such as low pH (3–5; Purwanto *et al.*, 2002), high C/N ratio (14–49; Yonebayashi *et al.*, 1994; Purwanto *et al.*, 2005), and low plant-available nutrient contents (Miyamoto *et al.*, 2009), are unfavourable for most of the crops.

Sago palm (*Metroxylon sagu* Rottb.) is worthy of attention as a rare crop that can grow on tropical peat soil without intense drainage of groundwater. The growth of sago palm is divided into two stages of the rosette stage, when leaves emerge near the ground surface, and trunk formation/elongation stage. Trunk body accumulates 160–180 kg per plant of starch (on a dry weight basis; Yamamoto *et al.*, 2003). Total leaf area of sago palms reaches 100 m^2 per plant and fronds with 8–10 m length are deposited on soil periodically (Nakamura and Goto, 2015). Based on this with a high photosynthetic rate (max 130 mg CO_2 m^{-2} h^{-1}; Miyazaki, 2015) and the similarities in carbon dioxide (CO_2) and methane (CH_4) fluxes between a sago palm plantation and neighbouring forest (Watanabe *et al.*, 2008), it was expected that sago palm cultivation system can function as C sink. The objective of the present study was to evaluate the C accumulation potential of sago palm cultivation system in tropical peatland. For this purpose, the amount of C supplied from sago palm to soil as litter, rate of decomposition of sago litter C on soil, C (CO_2 and CH_4) flux from soil to the atmosphere, and rate of accumulation of plant biomass C (sago and weeds) as well as soil C pool were measured in sago palm gardens managed by native farmers.

MATERIALS AND METHODS

Field experiments were conducted in two sago palm gardens (SG1, SG3) in Mukah, Sarawak, Malaysia (Figure 1). Two fields were different in the thickness of peat layer (SG1 < SG3) and the proportion of sago palms in the trunk formation/elongation stage (SG1 < SG3). Unfortunately, SG3 was burned down by the flame spread from a distant field in the third year and the palms used for monitoring growth were lost.

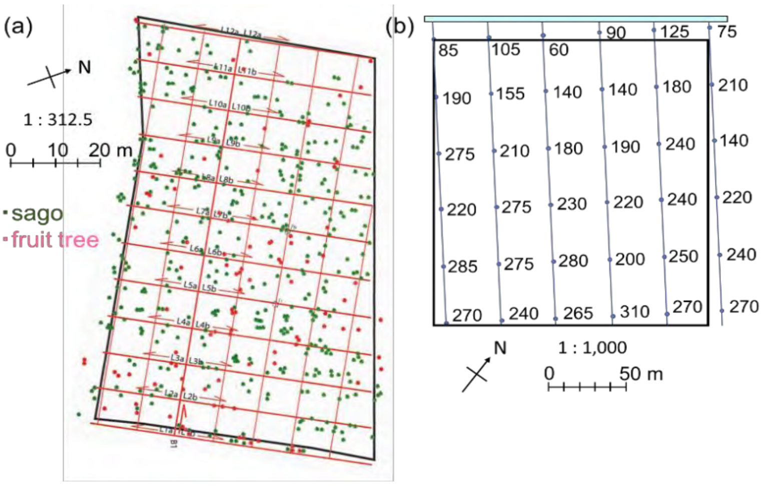

Figure 1: Distribution of sago palms in SG1 (a) and distribution of the thickness (cm) of peat layer in SG3 (b).

Number of fronds and plant height were recorded for each 10 palms in the rosette and trunk elongation stages at an interval of 6 months for 3 years (Sep. 2011–Sep. 2014). For the palms in the trunk elongation stage, the trunk length and trunk girth at a height of 130 cm were also measured. As a new frond emerges inside of existing fronds, one of fronds was marked and the rate of frond emergence and that of litter fall (a, plant^{-1} y^{-1}) were estimated from the increase and decrease in the number of inner and outer fronds of the marked one. The rate of C supply to soil (Y, t C y^{-1} ha^{-1}) was obtained by multiplying a by the average amount of C in a litter (b) and the number of palms in a unit area. The b value was obtained using 10 samples. Aboveground biomass was estimated for each 5 palms in the rosette and trunk elongation stages by weighing total fresh weight and determining the water and C contents of pieces for all the leaflets, rachises, and petioles, and trunk.

Rate of decomposition of litter C was estimated from the change in the amount of C in fronds placed on the soil surface in the frame of 4 m x 4 m ($n = 8$). Total fresh weight of frond samples was measured in the field once a half year. A portion of leaflet, rachis, and petiole were brought back to the laboratory, and the water and C contents were determined. This experiment could be done only in SG3 because soil surface in SG1 was frequently submerged even in dry season. Litter bag method using nylon bags with 5-mm mesh was also applied.

Weed biomass was estimated using the quadrat method. Weeds in a 2 m×2 m frame were harvested, separated into fens and others, and total fresh weight and the fresh and dry weights as well as C content of a portion of them were determined in dry and wet seasons ($n = 10$).

CO_2 and CH_4 fluxes were measured 3 times in 2013–2014 at various points in the sago gardens using the closed chamber method. A stainless pipe (20 cmφ × 20 cm height) was placed on soil with the bottom approximately 8 cm below the soil surface ($n = 10$). After 1 h, the top of pipe was closed with an acrylic plate and fastened. Gas samples were collected at 0, 10, 20, and 30 min after enclosure through a W-shaped butyl rubber cap, which was installed in the acrylic plate beforehand, into 30-mL vacuumed glass vials using a double-ended needle. Soil temperature and soil moisture content at 5 cm depth were also recorded. CO_2 and CH_4 concentrations in the samples were determined using a gas chromatograph equipped with a flame ionization and thermal conductivity detectors. CO_2 flux in SG3 was also monitored for a 6-month period using an automatic soil respiration analyzer (ACE-001/L).

RESULTS AND DISCUSSION

The number of fronds ranged from 5–11 or from 5–17 for the plants in the rosette and trunk elongation stages, respectively, which did not increase during the monitoring period. The dry weight of a frond was 1.9±0.5 kg before trunk formation and 2.9±0.9 kg after trunk formation, and the rate of litter fall was in the range of 4.3–6.4 y^{-1} for both growth stages in the two gardens. Based on these values with C content, it was estimated that the rate of C supply from sago palm to soil was 2.9–3.8 t C ha^{-1} y^{-1}.

An increase in the plant height of the sago palms in the rosette stage with time was unclear, as was the case of the number of fronds. Trunk length increased at a rate of 1.1 (SG3) –1.2 (SG1) m y^{-1}, while trunk girth did not change significantly. Thus, the rate of C accumulation as the aboveground biomass of sago palms was determined mainly by the change in trunk length. Based on the relationship between the amount of trunk C (136–215 kg plant^{-1}) and trunk length (8–12 m) in SG1 (*n* = 5) with the number of sago palms in the trunk elongation stage, annual C accumulation as aboveground biomass of sago palms was estimated to be 3.7 t C ha^{-1}. Similar data could not be obtained for SG3 due to the fire. An application of the SG1 data to the rate of trunk elongation and the number of plants rate in SG3 gave the annual C accumulation of 0.8 t C ha^{-1}. Since the number of sago palms in the rosette stage in SG3 is 4 times of that in SG1, the annual C accumulation in SG3 will be larger than that in SG1 within a few years.

Figure 2 shows the change in sago litter left on the soil surface in the in-situ decomposition experiment in SG3. By regressing the variation in the percentage of residual sago litter C with time to an exponential equation (Figure 2b; $r^2 = 1.00$), the rate constant of litter decomposition and annual C loss were estimated to be 0.105 month^{-1} and 72%, respectively. Combination of the rate of litter decomposition with the rate of litter fall and stand density of sago palms in the rosette and trunk elongation stages gave the rate of sago litter C accumulation in SG3, 1.9 t C ha^{-1} y^{-1}. However, as the litter fragments that were too small to be collected was regarded as ‗decomposed‘ in this experiment, the C loss rate might be overestimated. The C accumulation rate as was estimated using the data from the litter bag experiment was 3.0 t C ha^{-1} y^{-1}. However, decomposition of litter in the nylon mesh bag might be slower than that deposited directly on the soil surface because of insufficient contact with soil. Thus, real C accumulation rate may be distributed between 1.9–3.0 t C ha^{-1} y^{-1}. Assuming that the rate of litter decomposition was similar between SG1 and SG3, the rate of accumulation of sago litter C in SG1 was estimated to be 1.5–2.5 t C ha^{-1} y^{-1}.

Figure 2: Comparison of sago litter at the onset of in-situ decomposition experiment and after 13 months (a) and variation in percentage of residual litter C in SG3 (b).

In both sago gardens, major weed was fen. Weed species observed in SG1 other than fens included *Areca catechu*, *Scleria sumatrensis*, *Brachiaria mutica*, *Macaranga gigantean*, and *Punicum maximum* and those in SG3 included *Macaranga gigantean* and *Hevea brasiliensis*. Weed biomass C derived from fens ranged from 58–480 and 210–790 kg C ha^{-1} in SG1 and SG3, receptively. Weed biomass C derived from the other species ranged from 30–44 and 9–60 kg C ha^{-1} in SG1 and SG3, respectively. Total weed biomass C (Figure 3) fluctuated in the range of 61–510 kg C ha^{-1} in SG1 and 390–800 kg C ha^{-1} in SG3. The smallest value in SG1 was due to weeding by the owner. When weeds in the same plots were harvested twice with an interval of 1 year, total weed biomass C at the second harvest was equivalent to 68–73% of that at the first harvest. Thus, the influence of the fluctuation in weed biomass C on the whole C budget in the sago palm cultivation system was small.

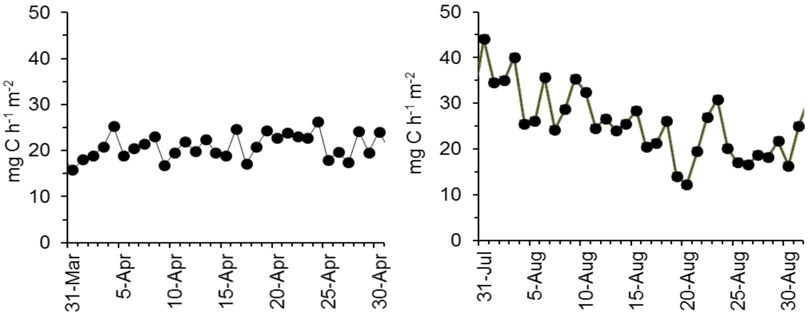

Figure 3: Weed biomass C in sago palm gardens (*n* = 10). Data in September 2013 was obtained at the plots where weeds were harvested in October 2012.

CO_2 flux measured using the closed chamber method ranged from 10–205 mg C h^{-1} m^{-2}. There were no differences between September and March and between the sites. CH_4 flux differed between SG1 and SG3. The CH_4 flux in SG1 ranged from -3 to 1220 µg C h^{-1} m^{-2} with positive mean values, while that in SG3 ranged from -65 to 93 µg C h^{-1} m^{-2} with negative mean values. The CO_2 and CH_4 emissions were estimated to be 6.1–8.5 t C ha^{-1} y^{-1} and -1.5–27 kg C ha^{-1} y^{-1}, respectively. These results suggest that the amount of C emitted from soil was comparable to the sum of the increase in the above biomass C of sago palms and the amount of sago litter C accumulated in soil in SG1. In SG3, C output as CO_2 emission from soil was larger than the sum of C input, 2.3–3.3 t C ha^{-1} y^{-1}. CO_2 flux recorded on the automatic soil respiration analyzer (Figure 4) was small compared with those measured manually, and the average value, 20 mg C h^{-1} m^{-2}, suggested that the C output did not exceed the C input. Since gas samples for estimating CO_2 and CH_4 fluxes were collected at 1 m distance from a sago cluster while the automatic soil respiration analyzer was installed at the centre of 4 palms (ca 5 m distance from the sago clusters), CO_2 fluxes measured manually may be affected by root respiration.

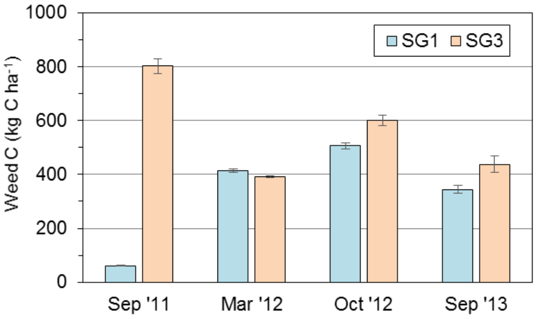

Figure 4: Variation in CO_2 flux from SG3 soil measured twice a day (11 a.m. and 11 p.m.) using the automatic soil respiration analyzer in April and August 2013.

CONCLUSION

The present study showed that the C accumulation in sago palm cultivation system depends on the accumulation of sago litter C and the increase in aboveground biomass C of sago palms in the trunk elongation stage. Total amounts of C accumulated can be comparable with the CO_2 emission from soil, and the rate of sago litter C accumulation can also be comparable with the rate of soil organic C decomposition. Therefore, the regulation of palms population in the trunk elongation stage is suggested to maintain large C input in sago plantation on tropical peatland.

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