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Soil carbon dioxide and methane fluxes from lowland forests converted to oil palm and rubber plantations in Sumatra, Indonesia

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Demand for palm oil has increased strongly in recent decades. Global palm oil production quadrupled between 1990 and 2009, and although almost half of the global supply is already produced in Indonesia, a doubling of current production is planned for the next ten years. This agricultural expansion is achieved by conversion of rainforest. Land-use conversion affects soil carbon dioxide (CO_2) and methane (CH_4) fluxes through changes in nutrient availability and soil properties which, in turn, influence plant productivity, microbial activity and gas diffusivity. Our study was aimed to assess changes in soil CO_2 and CH_4 fluxes with forest conversion to oil palm and rubber plantations. Our study area was Jambi Province, Sumatra, Indonesia. We selected two soil landscapes in this region: loam and clay Acrisol soils. At each landscape, we investigated four land-use systems: lowland secondary rainforest, secondary forest with regenerating rubber (referred here as jungle rubber), rubber (7-17 years old) and oil palm plantations (9-16 years old). Each land use in each soil landscape was represented by four sites as replicates, totaling to 32 sites. We measured soil-atmosphere CH_4 and CO_2 fluxes using vented static chamber method with monthly sampling from November 2012 to December 2013. There were no differences in soil CO_2 and CH_4 fluxes (all $P > 0.05$) between soil landscapes for each land-use type. For soil CO_2 fluxes, in both clay and loam Acrisol soil landscapes oil palm were lower compared to the other land uses ($P < 0.007$). In the clay Acrisol, soil CO_2 fluxes were 107.2 ± 7.2 mg C m^{-2} h^{-1} for oil palm, and 195.9 ± 13.5 mg C m^{-2} $h^{-1}$for forest, 185.3 ± 9.4 mg C m^{-2} $h^{-1}$for jungle rubber and 182.8 ± 16.2 mg C m^2 $h^{-1}$for rubber. In the loam Acrisol, soil CO_2 fluxes were 115.7 ± 11.0 mg CO_2-C m^2 h^{-1} for oil palm, and 186.6 ± 13.7, 178.7 ± 11.2, 182.9 ± 14.5 mg CO_2-C m^{-2} h^{-1} for forest, jungle rubber and rubber, respectively. The seasonal patterns of soil CO_2 fluxes were positively correlated with water-filled pore space (WFPS) in loam Acrisol jungle rubber ($P < 0.05$), and positively correlated with soil temperature in loam Acrisol forest ($P < 0.05$) andclay Acrisol oil palm ($P < 0.01$). For soil CH_4 fluxes, in the clay Acrisol CH_4 uptake was highest in the forest (40.3 ± 10.3 μg CH_4-C m^{-2} h^{-1})followed by the jungle rubber (20.8 ± 7.2 μg CH_4-C m^2 h^{-1}) and both were higher than in the rubber (3.0 ± 1.3 μg CH_4-C m^{-2} h^1) and oil palm (6.4 ± 3.1 μg CH_4-C m^{-2} h^{-1}) ($P = 0.005$). In the loam Acrisol, two out of four forest plots generally showed net CH_4 emissions, resulting to a large variation around the mean CH_4 flux from the forest (1.6 ± 17.1 μg C m^{-2} h^{-1}); comparing only the three land uses, a similar trend was observed as that in the clay Acrisol: larger CH_4 uptake in jungle rubber (26.9 ± 3.9 μg C m^{-2} h^{-1}) than in rubber (9.7 ± 3.8 μg C m^{-2} h^{-1}) and oil palm (14.9 ± 3.1 μg C m^{-2} h^{-1}). The seasonal patterns of soil CH_4 fluxes for each land use and soil landscape were all positively correlated with WFPS (all $P < 0.05$). Across landscapes and land uses, annual soil CH_4 fluxes were correlated with soil fertility index (r = -0.38, $P = 0.04$, n = 32). Conversion of forest to oil palm and rubber plantations decreased soil CO_2 fluxes and CH_4 uptake mainly due to changes in soil moisture, temperature and fertility. These changes in soil trace gas fluxes should be considered in the greenhouse gas life-cycle analysis of these economically important crops.