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Soil greenhouse gas fluxes from large-scale oil palm plantation under conventional and reduced management systems

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Conventional intensive management, such as high fertilizer and herbicide applications, are common practice in large-scale oil palm plantations. One of the proposed solutions to lessen its environmental impact is to reduce fertilization and employ mechanical weeding without sacrificing yield and profit. A full factorial experiment with two fertilization rates (260 N, 50 P, 220 K kg ha^{-1} yr^{-1} as conventional practice, and 136 N, 17 P, 187 K kg ha^{-1} yr^{-1}, equal to harvest export, as reduced management) and two weeding methods (conventional herbicide application, and mechanical weeding as reduced management) was established in 2016 at a large-scale oil palm plantation (planted in 1998-2002) on a sandy clay loam Acrisol soil in Jambi, Indonesia. Soil CO_2, N_2O, and CH_4 fluxes were measured monthly from July 2019 to June 2020, using vented static chambers. At each plot, the measurements were conducted on two randomly selected subplots, and in each subplot, we measured at three management zones (palm circle, inter-row, and frond-stacked area). During 2017-2020, fruit yield did not differ among treatments (fertilization: $P=0.35$; weeding control: $P=0.11$). Soil CO_2, N_2O, and CH_4 fluxes also did not differ among treatments (fertilization: $P>0.81$; weeding control: $P>0.28$). Area-weighted from the three management zones, soil CO_2 fluxes (mg C m^{-2} h^{-1}) were 61±2 for conventional and 65±4 for reduced fertilization and 64±4 for herbicide and 62±2 for mechanical weeding. Soil N_2O fluxes (µg N m^{-2} h^{-1}) were 46±12 for conventional and 45±16 for reduced fertilization and 57±15 for herbicide and 34±12 for mechanical weeding. Soil CH_4 fluxes (µg C m^{-2} h^{-1}) were -17±2 for conventional and -17±3 for reduced fertilization and -17±3 for herbicide and -17±2 for mechanical weeding. Distinct differences were observed among the three management zones. Frond-stacked area, with high soil organic carbon and low soil bulk density, had the highest soil CO_2 emission and soil CH_4 uptake ($P\leq0.01$). Palm circle, with fertilizer application and high soil bulk density, had the highest soil N_2O emission and lowest soil CH_4 uptake ($P\leq0.01$). Inter-row area, with low soil organic carbon and no direct fertilizer application, had the lowest soil CO_2 and N_2O emission ($P\leq0.01$). Soil CO_2 (rho=0.64, $P\leq0.05$) and N_2O (rho=0.53, $P\leq0.05$) fluxes were positively correlated with total mineral N. Soil CH_4 flux was negatively correlated with total mineral N (rho=-0.30, $P\leq0.05$) and positively correlated with water-filled pore space (rho=0.66, P≤0.05). Although the frond-stacked area only accounted for 15% of the oil palm plantation area, it contributed 30% of soil CO_2 emission and 41% of soil CH_4 uptake. The palm circle accounted for 18% of the oil palm plantation area and contributed 79% of soil N_2O emissions. Our results indicated that the inherent management zones in oil palm plantations should be spatially represented for accurate quantification of soil greenhouse gas fluxes. Our findings showed that reduced management maintained yield whereas soil greenhouse gas fluxes remained high at least during the 3-4 years of this management experiment, which signified the legacy effect of more than a decade-long conventional management in this mature oil palm plantation.