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Supplementary information: SOC Stock Changes and Greenhouse Gas Emissions Following Tropical Land Use Conversions to Plantation Crops on Mineral Soils with a Special Focus on Oil Palm and Rubber Plantations

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Limitations of the dataset

Most of the studies referred to in this review followed paired-site sampling technique; the relative changes in SOC stock and GHG emissions with reference to land use conversion are mostly estimated assuming linear changes over time (between 1-35 years). Although the paired-site sampling is largely used as an appropriate tool for ecological and soil development studies (Walker *et al*., 2010), the paired-site approach is less likely to be adaptable when there are higher disturbances and unpredictable changes occur in soil. Hence, there is a potential risk in relying on the paired-site sampling alone in predicting SOC stock and GHG emissions and applied for land use conversions (HCS, 2015). For example, soil sampling depth acts as a critical unknown factor that affects C storage and SOC stock measurement in oil palm plantations. IPCC (2006) proposes default sampling of the upper 30 cm of soil, whereas various studies in oil palm plantations have collected samples at a range of sampling depths (e.g., increments of 10-15 cm up to 50 cm or increments of 50 cm down to 150-300 cm; Ng *et al*., 2011; Padmanabhan *et al*., 2013; van Straaten *et al*., 2015). Such an extended sampling depth takes the deeper root zone into account and arrives at substantial SOC under oil palm. There is a knowledge gap in the current literature whether sampling should be extended beyond a depth of 30 cm to correctly address changes in SOC upon land use change. Soil erosion is another important factor that is being neglected often when estimating SOC stock change with reference to land use changes and the SOC loss could be up to 50 % due to soil erosion (Davidson & Ackerman, 1993; Sidle *et al*., 2006; Oliveira *et al*., 2013; Gharibreza *et al*., 2013; Guillaume *et al*., 2015); in particular, particulate organic C (POC) is the most important component of SOC lost due to soil erosion in tropical soils (Muller-Nedebock & Chaplot, 2015). Hence, SOC losses, especially as POC, from soil erosion must be taken into account and minimised following land use change when preparing the land for various agroecosystems.

Regarding the spatial coverage of information with reference to converted oil palm plantations, despite the growing availability of SOC stock dataset on the tropical mineral soils, the African sites where future oil palm expansion may occur, and Southeast Asian sites are still underrepresented for the SOC stock change as previously pointed by Don *et al*., (2011).

Effects of land use change on GHG emissions

In the land use sector, CO_2, CH_4 and N_2O are considered the major GHG. These gases are responsible for approximately 60%, 20% and 10% of the total human induced global warming (Dalal & Allen, 2008). Land use change alters processes in terrestrial ecosystems, which in turn modifies GHG fluxes (IPCC, 2006). Emissions of CH_4 and N_2O are converted into CO_2 equivalents (CO_2e) based on their global warming potential (GWP) and summed to calculate total GHG emissions. The GWP values used in this review are 28 for CH_4 and 265 for N_2O on a 100-year time horizon (Myhre *et al.*, 2013).

Key drivers of GHG (CO_2, CH_4 and N_2O) emissions from soil

The key driving factors affecting the production and release of GHG are organic matter substrate availability, temperature, soil moisture content, aeration, porosity and pH, as well as N fertiliser or other large mineral N sources for N_2O emissions. Management practices such as the application of fertilisers, manures, herbicides, pesticides and other amendments also affect GHG emissions through the above key drivers (see Dalal *et al*., 2003, 2008 for a detailed review).

Net GHG emissions are affected by both land-use change (e.g., native forests to grazing lands or croplands) and land management such as tillage, irrigation, fertilization, manuring and drainage practices. For example, the application of N fertilisers may result in high N_2O emissions if mineral N, especially NO_3-N, and readily available C substrate are available under partially anaerobic conditions (up to 70-80% water-filled pore space) (Dalal *et al*., 2003). Significant CH_4 emissions occur only when readily available organic C substrates are present under anaerobic conditions (Dalal *et al*., 2008).

SOC stock inventory and monitoring procedures

IPCC (2006) distinguishes six carbon pools (above ground biomass, below ground biomass, dead wood, harvested wood products, litter, and soil). There are inputs to and outputs from the total system and carbon is transferred between the six pools. The soil organic carbon (SOC) stock from a given area is assessed by sampling the site of interest using statistically rigorous soil sampling methods and analytical techniques. If a treatment and/ or time comparison of SOC stocks is required then all SOC stocks should be estimated on an equivalent soil mass (ESM) basis to account for differences in soil sampling depth and soil mass due to change in bulk density between treatments over time.

SOC stocks (t C/ha) are estimated from SOC concentration, soil depth and area, and bulk density following Equation 1.

$$\text{SOC stock (t C/ ha/ depth)} = \sum_{i=1}^{n} \text{SOC concentration x soil depth x area x BD} \qquad \text{[S1]}$$

where n = number of soil depth intervals, SOC concentration expressed in % of oven dry soil weight, soil depth in cm or m, area in hectare (10,000m^2) and bulk density in t/m^3 or g/cm^3 or Mg/m^3.

Assessing bulk density

Soil bulk density (BD) measurements are crucial for estimating SOC stocks in a changed land use system (Adams, 1973; Eswaran *et al*., 1993; Don *et al*., 2011) since BD changes over time, depending on cultivation and field management operations (Don *et al*., 2011; Lestariningsih et al., 2013). A global meta-analysis (> 380 studies) of land use change in tropical mineral soils (0-30 cm soil depth) reported increased relative BD values (5-32 %) primarily associated with SOC losses in the surface 0-20 cm or 0-30 cm soil layers (Don *et al*., 2011). Considering the variation in bulk density, simplified values can be used (if actual BDs were not measured) for estimating relative bulk density changes following land use change from primary forest to cropland, to perennial cropland, and to grassland of increases of 30, 20 and 20%, respectively (Don *et al*., 2011). When considering conversion of primary forest to secondary forest and secondary forest to cropland or secondary forest to grassland, the relative bulk density changes are 10, 20 and 5%, respectively. While land use change from grassland to cropland led to an increase in relative bulk density by 5% that from cropland to secondary forest led to a decrease by 5%. No significant changes in bulk density were observed with respect to conversion of grassland to secondary forest, cropland to grassland and cropland to fallow according to Don *et al*. (2011).

Alternatively, site and regional specific BD values can be assessed by using pedotransfer functions (PTF) when BD data are not available for SOC stock calculation. Pedotransfer functions are simple but robust regression models for estimating site specific soil properties (e.g., BD values) where direct measurements are not available (Wösten, 2002; De Vos *et al*., 2005), using correlations with measured soil properties such as sand and clay content, total organic corbon (TOC), total N, cation exchange capacity (CEC) and soil pH from the site (Manrique & Jones, 1991; Asadu *et al*., 1997; Bernoux *et al*., 1998; Kaur *et al*., 2002; Heuscher *et al*., 2005; Benites *et al*., 2007). However, predicted BD data using the PTF are likely to have higher uncertainties while estimating the SOC stock change at global land use scale; the accuracy of PTF is site specific.

If more measured data on basic soil properties are available, mixed models can estimate the BD values more accurately through multiple regression (Suuster *et al*., 2011). However, even more simple regression models, which use only soil textural classes and basic pedon descriptions of a particular horizon, can also be used to predict the BD values (Sequeira *et al*., 2014).

Estimating carbon stocks

Universal methods are available to measure the total carbon stock for various types of land use. These methods consider both above and below ground biomass, and SOC generally to a depth of 30 cm, and surface organic litter (such as dead and decaying leaf and woody fractions of 2-10 mm size) (IPCC, 2006). For estimating the C stock in mineral soil under native vegetation, the IPCC (2006) suggests to include by default the living and dead fine roots and dead organic matter present within the upper surface layers (0-30 cm) of the soil fractions (<2 mm size) since responses of SOC and associated fluxes to changing land use are in most soils largely limited to the upper 30 cm of the soil (Sombroek *et al*., 1993; Batjes & Dijkshoorn, 1999; Ng *et al*., 2011; Griffin *et al*., 2013).

Estimating carbon stock changes

Generally, net SOC stock changes are determined by repeated sampling (Hartemink, 2003, 2006) of soil organic carbon stock at the same site at different time intervals. Timeframes typically vary between 5 to 20 years (IPCC, 2006) to account for the slow pace of change in total soil C (Dalal & Allen, 2008). Alternatively, changes in SOC stock can be quickly estimated by using paired-site sampling (Hartemink, 2003, 2006; Harms *et al*., 2005), but very large replication is needed to account for potentially significant initial differences in soil C stocks between the paired locations.

SOC stocks and SOC stock changes caused by conversion of tropical ecosystems to other land uses

Organic carbon is an integral component of soil organic matter (SOC = 58% of SOM, IPCC, 2006) that is essential for soil structural stability. It provides significant long term storage of C in the Earth system - by containing almost three times the amount of C stored in the atmosphere, soils play an important role in global C cycling. Soil C sequestration can thus help mitigate global warming and associated climate change (Schlesinger, 1995; Metz *et al*., 2007). The SOC stock of a soil depends on the relative rates at which organic matter is added to and lost from the soil. Loss takes place by decomposition, transport and soil erosion. Thus, the change in SOC over time can be expressed as:

$$dSOC/dt = -kSOC + A \qquad [S2]$$

where k is the rate of SOC loss/yr, A is the rate of addition (t C/ha/yr) and SOC is the SOC stock (t C/ha) at time t (year, yr). Assuming one SOC pool Equation (1), on integration, yields:

$$SOC_t = SOC_o + (SOC_o - SOC_e) \exp^{(-kt)} \qquad [S3]$$

Where SOC_o is the initial SOC stock (t C/ha) and SOC_e is the SOC stock at equilibrium or at steady state (t C/ha). SOC reaches an equilibrium or steady state after a long period under similar land management, when the rate of C addition equals the rate of SOC loss:

$$SOC_e = A/k \qquad [S4]$$

If the rate of C addition exceeds SOC loss then SOC stock increases and vice versa. Dalal & Mayer (1986) found that the rate of SOC loss was inversely related to the clay content of the soils, so that coarse-textured soils, for example, sandy soils required higher rates of C addition than clay soils to maintain the SOC stock at steady state.

The IPCC default values (Penman *et al*., 2003) for SOC loss upon land use change are expressed as remaining fraction of the original stock. For a change from forest to cropland the default value is 0.69 (31% SOC loss) for dry tropical regions and 0.58 (42% SOC loss) for wet regions. For the change from forest to grassland the default value is 1 (meaning no SOC loss). Similar fraction values were reported by Don *et al*., (2011) although values were higher (0.76 [24%] and 0.68 [32%] for conversion to cropland) and lower for grassland (0.91 [9%], Figure S1). The discrepancy was primarily because Don *et al*. (2011) also adjusted for changes in bulk density and soil depth.

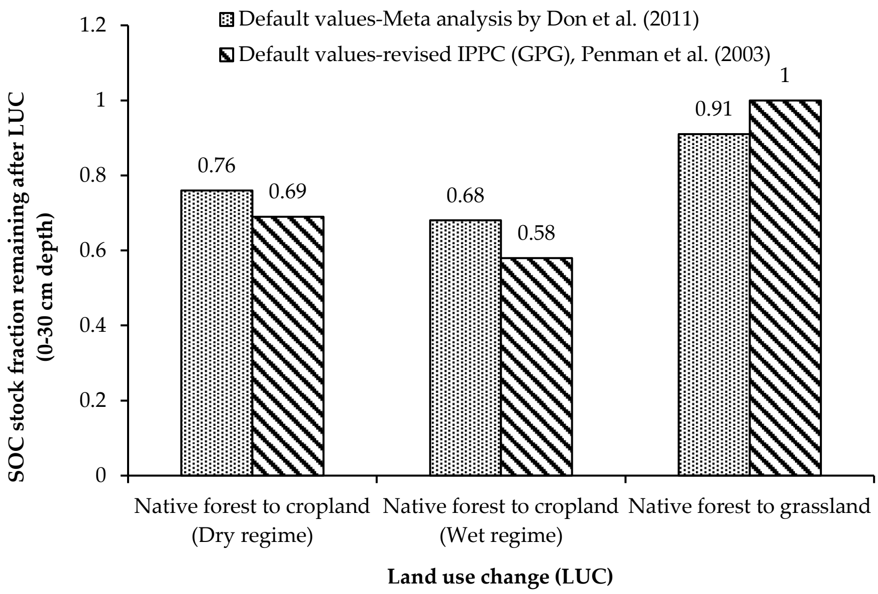

Figure S1. Default values for remaining SOC fraction after land use change from Don *et al*. (2011) and IPCC (Penman *et al*., 2003).

Additional information on SOC stock change and GHG emission fluxes from different land use changes is given in Tables S1- S10 in the Supplementary Information below:

Table S1. Change of SOC stock on conversion of primary forest land in subtropical and tropical (30 º N- 30 º S) regions.

Country	Original Land Use Type	Converted Land Use Type	Age of Converted Land Use Site (years)	SOC Stock of Original Land Use (t C/ha)	SOC Stock of Converted Land Use (t C/ha)	Soil Type/ Comments	Relative Change in SOC Stock (%)	References
South East Asia	Tropical forests	Oil palm plantation	-	Range : 75-225 t/ha	Range : 65-196 t/ha	-	-	Ziegler *et al*., 2012
Indonesia	Primary forest	Oil palm plantation	3	101.8 (t/ha) (0-30 cm)	119.7(t/ha) (0-30 cm)	-	17.6	Ishizuka *et al*., 2005; Powers *et al*., 2011
Brazil, Amazon region	Natural rain forest	Oil palm plantation	4	30.2 (t/ha) (0-30 cm, mass equivalent basis)	33.2 (t/ha) (0-30 cm, mass equivalent basis)	Oxisol	9.9	Frazão *et al*., 2013
Brazil, Amazon region	Natural rain forest	Oil palm plantation	4	25.6 (t/ha) (0-30 cm, normalised for soil clay content)	28.1 (t/ha) (0-30 cm, normalised for soil clay content)	Oxisol	9.8	Frazão *et al*., 2013
Indonesia	Primary forest	Oil palm plantation	5	101.8 (t/ha) (0-30 cm)	40 (t/ha) (0-30 cm)	-	-60.7	Ishizuka *et al*., 2005; Powers *et al*., 2011
Ghana	Native forest	Oil palm plantation	8	Cumulative SOC: 79.3 (t/ha) (0-30 cm)	Cumulative SOC: 65.8 (t/ha) (0-30 cm)	Sandy clay soils and Oxisol	-17	Chiti *et al*., 2014
Brazil, Amazon region	Natural rain forest	Oil palm plantation	8	30.2 (t/ha) (0-30 cm, mass equivalent basis)	22.6 (t/ha) (0-30 cm, mass equivalent basis)	Oxisol	-25.2	Frazão *et al*., 2013
Brazil, Amazon region	Natural rain forest	Oil palm plantation	8	25.6 (t/ha) (0-30 cm, normalised for soil clay content)	25.3 (t/ha) (0-30 cm, normalised for soil clay content)		-1.2	Frazão *et al*., 2013
Brazil	Amazon primary forests	Oil palm plantation (up to 450 cm rooting depth)	9 (preceded with 25 years of crop and fallow period in between the forest conversion)	Estimated: 42.8 (t/ha) (0-30 cm), Reported: 5.7 kg C/m²/ 0.4 m depth) (0-40 cm depth)	Estimated: 23.3 (t/ha) (0-30 cm), Reported: 3.1 kg C/m²/0.4 m depth) (0-40 cm depth)	Typic Kandiudult, with texture of loamy sand in the top soil and sandy clay loam in the deeper layers up to 600 cm	-45.6	Sommer *et al*., 2000

Indonesia	Primary forest	Oil palm plantation	10	43.8 (t/ha) (0-30 cm)	28.4 (t/ha) (0-30 cm)	-	-35.1	van Straaten *et al.*, 2015
Indonesia	Primary forest	Oil palm plantation	10	76.6 (t/ha) (0-30 cm)	64.9 (t/ha) (0-30 cm)	-	-15.3	van Straaten *et al.*, 2015
Indonesia	Primary forest	Oil palm plantation	10	64.5 (t/ha) (0-30 cm)	63.2 (t/ha) (0-30 cm)	-	-2.0	van Straaten *et al.*, 2015
Indonesia	Primary forest	Oil palm plantation	10	82.1 (t/ha) (0-30 cm)	39.6 (t/ha) (0-30 cm)	-	-51.8	van Straaten *et al.*, 2015
Indonesia	Primary forest	Oil palm plantation	10	69.3 (t/ha) (0-30 cm)	57.0 (t/ha) (0-30 cm)	-	-17.8	van Straaten *et al.*, 2015
Cameroon	Primary forest	Oil palm plantation	10	63.1 (t/ha) (0-30 cm)	40.7 (t/ha) (0-30 cm)	-	-35.5	van Straaten *et al.*, 2015
Peru	Primary forest	Oil palm plantation	11	35.6 (t/ha) (0-30 cm)	31.8 (t/ha) (0-30 cm)	-	-10.8	van Straaten *et al.*, 2015
Cameroon	Primary forest	Oil palm plantation	11	63.1 (t/ha) (0-30 cm)	36.2 (t/ha) (0-30 cm)	-	-42.5	van Straaten *et al.*, 2015
Indonesia	Primary forest	Oil palm plantation	12	49.4 (t/ha) (0-30 cm)	35.6 (t/ha) (0-30 cm)	-	-28.0	van Straaten *et al.*, 2015
Indonesia	Primary forest	Oil palm plantation	12	86.2 (t/ha) (0-30 cm)	35.8 (t/ha) (0-30 cm)	-	-58.5	van Straaten *et al.*, 2015
Cameroon	Primary forest	Oil palm plantation	13	63.1 (t/ha) (0-30 cm)	31.2 (t/ha) (0-30 cm)	-	-50.6	van Straaten *et al.*, 2015
Cameroon	Primary forest	Oil palm plantation	13	60.7 (t/ha) (0-30 cm)	46.0 (t/ha) (0-30 cm)	-	-24.2	van Straaten *et al.*, 2015
Indonesia	Primary forest	Oil palm plantation	14	67.9 (t/ha) (0-30 cm)	48.7 (t/ha) (0-30 cm)	-	-28.3	van Straaten *et al.*, 2015
Peru	Primary forest	Oil palm plantation	14	36.7 (t/ha) (0-30 cm)	29.5 (t/ha) (0-30 cm)	-	-19.7	van Straaten *et al.*, 2015
Indonesia	Primary forest	Oil palm plantation	15	101.8 (t/ha) (0-30 cm)	79.1 (t/ha) (0-30 cm)	-	-22.3	Ishizuka *et al.*, 2005
Indonesia	Primary forest	Oil palm plantation	15	43.8 (t/ha) (0-30 cm)	30.3 (t/ha) (0-30 cm)	-	-30.8	van Straaten *et al*. 2015
Indonesia	Primary forest	Oil palm plantation	15	87.0 (t/ha) (0-30 cm)	94.8 (t/ha) (0-30 cm)	-	9.0	van Straaten *et al.*, 2015
Peru	Primary forest	Oil palm plantation	15	50.9 (t/ha) (0-30 cm)	32.5 (t/ha) (0-30 cm)	-	-36.0	van Straaten *et al.*, 2015

Cameroon	Primary forest	Oil palm plantation	15	60.7 (t/ha) (0-30 cm)	44.5 (t/ha) (0-30 cm)	-	-26.7	van Straaten *et al*., 2015
Nigeria	Natural rain forest	Oil palm plantation	16	Estimated: 40.2 (t/ha) (0-30 cm), Reported: 13.4 (t/ha) (0-10 cm)	Estimated: 24.9 (t/ha) (0-30 cm), Reported: 8.3 (t/ha) (0-10 cm)	Oxisol	-38.1	Aweto 1995
Indonesia	Primary forest	Oil palm plantation	16	67.9 (t/ha) (0-30 cm)	39.0 (t/ha) (0-30 cm)	-	-42.6	van Straaten *et al*., 2015
Peru	Primary forest	Oil palm plantation	17	37.9 (t/ha) (0-30 cm)	22.2 (t/ha) (0-30 cm)	-	-41.6	van Straaten *et al*., 2015
Indonesia	Primary forest	Oil palm plantation	19	59.8 (t/ha) (0-30 cm)	36.2 (t/ha) (0-30 cm)	-	-39.5	van Straaten *et al*., 2015
Peru	Primary forest	Oil palm plantation	20	45.5 (t/ha) (0-30 cm)	32.8 (t/ha) (0-30 cm)	-	-28.0	van Straaten *et al*, 2015
Indonesia	Primary forest	Oil palm plantation	22	51.4 (t/ha) (0-30 cm)	40.2 (t/ha) (0-30 cm)	-	-21.8	van Straaten *et al*., 2015
Brazil	Native Atlantic rainforest	Oil palm plantation	23	48.5 ± 3.3 (t/ha) (0-30 cm, equivalent mass adjusted)	34.3 ± 2.7 (t/ha) (0-30 cm, equivalent mass adjusted)	Oxisol	-29.3	Frazão *et al*., 2014
Brazil, Amazon region	Natural rain forest	Oil palm plantation	25	30.2 ± 3.4 (t/ha) (0-30 cm, equivalent mass adjusted)	22.7± 1.4 (t/ha) (0-30 cm, equivalent mass adjusted)	Oxisol	-24.8	Frazão *et al*., 2013
Brazil, Amazon region	Natural rain forest	Oil palm plantation	25	25.6 (t/ha) (0-30 cm, normalised for soil clay content)	30.3 (t/ha) (0-30 cm, normalised for soil clay content)	Oxisol	18.3	Frazão *et al*., 2013
Indonesia	Primary forest	Oil palm plantation	25	53.63 ± 15.98 (t/ha) (0-30 cm, time averaged stock)	51.85 ± 18.95 (t/ha) (0-30 cm, time averaged stock)	Ultisols, Inceptisols, Spodosols, Oxisols and Entisols	-3.2	Khasanah *et al*., 2015
Ghana	Native forest	Oil palm plantation	25	Cumulative SOC: 79.3 (t/ha) (0-30 cm)	Cumulative SOC: 57.3 (t/ha) (0-30 cm)	Sandy clay soils and Oxisol	-27.7	Chiti *et al*., 2014
Indonesia	Primary forest	Oil palm plantation	25	76.6 (t/ha) (0-30 cm)	46.5 (t/ha) (0-30 cm)	-	-39.3	van Straaten *et al*., 2015

Brazil	Native Atlantic rainforest	Oil palm plantation	34	48.5 ± 3.3 (t/ha) (0-30 cm, equivalent mass adjusted)	61.1 (t/ha) (0-30 cm, equivalent mass adjusted)	Oxisol	26	Frazão *et al*., 2014
South East Asia	Tropical forests	Rubber plantation	-	Range: 75-225 t/ha	Range: 65-196 t/ha	-	-	Ziegler *et al*., 2012
Ghana	Native forest	Rubber Plantation	5	Cumulative SOC: 79.3 (t/ha) (0-30 cm)	Cumulative SOC: 64.4 (t/ha) (0-30 cm)	Sandy clay soils and Oxisol	-18.79	Chiti *et al*., 2014
Indonesia	Primary forest	Rubber plantation	5-9	155.4 (t/ha) (0-30 cm)	138.5 (t/ha) (0-30 cm)	-	-10.9	Ishizuka *et al*., 2005
Ghana	Native forest	Rubber Plantation	10	Cumulative SOC: 79.3 (t/ha) (0-30 cm)	Cumulative SOC: 57.5 (t/ha) (0-30 cm)	Sandy clay soils and Oxisol	-27.5	Chiti *et al*., 2014
Indonesia	Primary forest	Rubber plantation	10	45.5 (t/ha) (0-30 cm)	46.3 (t/ha) (0-30 cm)	-	1.8	van Straaten *et al*., 2015
Indonesia	Primary forest	Rubber plantation	10	43.8 (t/ha) (0-30 cm)	50.8 (t/ha) (0-30 cm)	-	16.0	van Straaten *et al*., 2015
Indonesia	Primary forest	Rubber plantation	10	82.1 (t/ha) (0-30 cm)	45.7 (t/ha) (0-30 cm)	-	-44.3	van Straaten *et al*., 2015
Indonesia	Primary forest	Rubber plantation	10	61.4 (t/ha) (0-30 cm)	61.7 (t/ha) (0-30 cm)	-	0.6	van Straaten *et al*., 2015
Indonesia	Primary forest	Rubber plantation	10	67.9 (t/ha) (0-30 cm)	65.3 (t/ha) (0-30 cm)	-	-3.8	van Straaten *et al*., 2015
Indonesia	Primary forest	Rubber plantation	11	53.9 (t/ha) (0-30 cm)	37.6 (t/ha) (0-30 cm)	-	-30.2	van Straaten *et al*., 2015
Indonesia	Primary forest	Rubber plantation	11.5	105 (t/ha) (0-30 cm)	55.7 (t/ha) (0-30 cm)	-	-46.9	van Straaten *et al*., 2015
Indonesia	Primary forest	Rubber plantation	13	69.3 (t/ha) (0-30 cm)	38.7 (t/ha) (0-30 cm)	-	-44.1	van Straaten *et al*., 2015
Indonesia	Primary forest	Rubber plantation	13.5	86.2 (t/ha) (0-30 cm)	55.5 (t/ha) (0-30 cm)	-	-35.6	van Straaten *et al*., 2015
Ghana	Native forest	Rubber Plantation	14	Cumulative SOC: 79.3 (t/ha) (0-30 cm)	Cumulative SOC: 55 (t/ha) (0-30 cm)	Sandy clay soils and Oxisol	-30.6	Chiti *et al*., 2014
Nigeria	Natural rain forest	Rubber plantation	14	Estimated: 40.2 (t/ha) (0-30 cm), Reported:	Estimated: 24.6 (t/ha) (0-30 cm), Reported:	Oxisol	-38.8	Aweto, 1995

				13.4 (t/ha) (0-10 cm)	8.2 (t/ha) (0-10 cm)			
Indonesia	Primary forest	Rubber plantation	>10	101.8 (t/ha) (0-30 cm)	51.5 (t/ha) (0-30 cm)	-	-49.4	Ishizuka *et al*., 2005
Indonesia	Primary forest	Rubber plantation	> 10	101.8 (t/ha) (0-30 cm)	87.6 (t/ha) (0-30 cm)	-	-13.9	Ishizuka *et al*., 2005
Indonesia	Primary forest	Rubber plantation	15	49.9 (t/ha) (0-30 cm)	57.2 (t/ha) (0-30 cm)	-	14.6	van Straaten *et al*., 2015
Indonesia	Primary forest	Rubber plantation	17	53.9 (t/ha) (0-30 cm)	66.4 (t/ha) (0-30 cm)	-	23.2	van Straaten *et al*., 2015
Indonesia	Primary forest	Rubber plantation	10-19	101.8 (t/ha) (0-30 cm)	130.6 (t/ha) (0-30 cm)	-	28.3	Ishizuka *et al*., 2005
Indonesia	Primary forest	Rubber plantation	10-19	101.8 (t/ha) (0-30 cm)	101.1 (t/ha) (0-30 cm)	-	-0.7	Ishizuka *et al*., 2005
Cameroon	Primary forest	Rubber plantation	20	35.9 (t/ha) (0-30 cm)	29.6 (t/ha) (0-30 cm)	-	-17.5	van Straaten *et al*., 2015
Indonesia	Primary forest	Rubber plantation	25	74.4 (t/ha) (0-30 cm)	186.9 (t/ha) (0-30 cm)	-	151.1	van Straaten *et al*., 2015
Indonesia	Primary forest	Rubber plantation	27.5	49.9 (t/ha) (0-30 cm)	50.7 (t/ha) (0-30 cm)	-	1.5	van Straaten *et al*., 2015
Indonesia	Primary forest	Rubber plantation	28	67.9 (t/ha) (0-30 cm)	47.4 (t/ha) (0-30 cm)	-	-30.2	van Straaten *et al*., 2015
Southwest China	Seasonal rain forest	Rubber Plantation	>30	Estimated: 130.1 t/ha (0-30 cm, assuming a default BD of 1.45 g/cm^3), Reported: 29.9 ± 1.1 (g/kg) (0-10 cm)	Estimated: 98.31 t/ha (0-30 cm, assuming a default BD of 1.45 g/cm^3), Reported: 22.6 ± 1.3 (g/kg) (0-10 cm)	Lateritic soil (texture: Sandy clay loam)	-24.4	Zhang *et al*., 2013
Indonesia	Primary forest	Rubber plantation	30	43.8 (t/ha) (0-30 cm)	44.6 (t/ha) (0-30 cm)	-	1.9	van Straaten *et al*., 2015
Indonesia	Primary forest	Rubber plantation	20-39	101.8 (t/ha) (0-30 cm)	94.1 (t/ha) (0-30 cm)	-	-7.6	Ishizuka *et al*., 2005
Cameroon	Primary forest	Rubber plantation	40	82.9 (t/ha) (0-30 cm)	47.5 (t/ha) (0-30 cm)	-	-42.7	van Straaten *et al*., 2015
Cameroon	Primary forest	Rubber plantation	45	35.9 (t/ha) (0-30 cm)	27.6 (t/ha) (0-30 cm)	-	-23.2	van Straaten *et al*., 2015

Ghana	Native forest	Rubber Plantation	49	Cumulative SOC: 79.3 (t/ha) (0-30 cm)	Cumulative SOC: 48.1 (t/ha) (0-30 cm)	Sandy clay soils and Oxisol	-39.3	Chiti *et al*., 2014
India, Inceptisol	Primary forest	Rubber plantation	50	76.5 (t/ha) (0-30 cm)	57.0 (t/ha) (0-30 cm)	-	-25.5	Saha *et al*., 2010
Cameroon	Primary forest	Rubber plantation	50	82.9 (t/ha) (0-30 cm)	53.7 (t/ha) (0-30 cm)	-	-35.2	van Straaten *et al*., 2015
Cameroon	Primary forest	Rubber plantation	50	82.9 (t/ha) (0-30 cm)	27.3 (t/ha) (0-30 cm)	-	-67.1	van Straaten *et al*., 2015
Cameroon	Primary forest	Rubber plantation	55	35.9 (t/ha) (0-30 cm)	29.3 (t/ha) (0-30 cm)	-	-18.5	van Straaten *et al*., 2015
South East Asia	Tropical forests	Secondary logged-over forests	-	Range: 75-225 t/ha	Range: 68-205 t/ha	-		Ziegler *et al*., 2012
South East Asia	Tropical forests	Tree and orchard plantations	-	Range: 75-225 t/ha	Range: 65-196 t/ha	-		Ziegler *et al*., 2012
Meta-data analysis (26 countries, mostly from Australia, Brazil, China and USA) *No significant difference between tropical and temperate regions	Natural forests	Plantation forests (mostly from Coniferous and arboreal tress, excluding sp. of fruit trees, shrubs, rubber and coffee trees)	Mean: 30 (range: 4-80 years)	Estimated: 38.6 (t/ha) (0-30 cm), Reported: 128.8 ± 13.7 t/ha (0-100 cm)	Estimated: 31.2 (t/ha) (0-30 cm), Reported: 103.9 ± 10.1 t/ha (0-100 cm)	-	-19.2	Liao *et al*., 2010
Brazil	Amazon primary forests	Secondary woodland vegetation	12	Estimated: 42.8 (t/ha) (0-30 cm), Reported: 5.7 kg C/m^2 /depth) (0-0.4m depth)	Estimated: 33.0 (t/ha) (0-30 cm), Reported: 4.4 kg C/m^2 /depth) (0-0.4m depth)	Typic Kandiudult, with texture of loamy sand in the top soil and sandy clay loam in the deeper layers up to 600 cm	-22.9	Sommer *et al*., 2000

Brazil	Amazon primary forests	Secondary woodland vegetation	40	Estimated: 42.8 (t/ha) (0-30 cm), Reported: 5.7 kg C/m^2 /depth) (0-0.4m depth)	Estimated: 37.5 (t/ha) (0-30 cm), Reported: 5.0 kg C/m^2 /depth) (0-0.4m depth)	Typic Kandiudult, with texture of loamy sand in the top soil and sandy clay loam in the deeper layers 600 cm	-12.4	Sommer *et al*., 2000
Ghana	Native forest	Mixed tree plantation	36	Cumulative SOC: 79.3 (t/ha) (0-30 cm)	Cumulative SOC: 66.6 (t/ha) (0-30 cm)	Sandy clay soils and Oxisol	-16.0	Chiti *et al*., 2014
Ghana	Native forest	Mixed tree plantation	49	Cumulative SOC: 79.3 (t/ha) (0-30 cm)	Cumulative SOC: 68.5 (t/ha) (0-30 cm)	Sandy clay soils and Oxisol	-13.6	Chiti *et al*,. 2014
Indonesia	Tropical forest	Perennial tree plantation	50	Estimated: 128.3 (t/ha) (0-30 cm)	Estimated: 113.2 (t/ha) (0-30 cm)	Mineral soils (Inceptisol, Oxisol and Ultisol)	-11.8	Van Noordwijk *et al*., 1997
Brazil	Native Atlantic forest	Broadleaf tree plantation	34	Cumulative SOC: 42.7 (t/ha) (0-30 cm)	Cumulative SOC: 25.7 (t/ha) (0-30 cm)	Oxisols	-39.8	Cook *et al*.,2013
Nigeria	Natural rain forest	Teak plantation	25	Estimated: 40.2 (t/ha) (0-30 cm), Reported: 13.4 (t/ha) (0-10 cm)	Estimated: 33.6 (t/ha) (0-30 cm), Reported: 11.2 (t/ha) (0-10 cm)	Alfisol	-16.4	Aweto, 1995
Nigeria	Natural rain forest	Gmelina plantation	15	Estimated: 40.2 (t/ha) (0-30 cm), Reported: 13.4 (t/ha) (0-10 cm)	Estimated: 35.7(t/ha) (0-30 cm), Reported: 11.9 (t/ha) (0-10 cm)	Alfisol	-11.2	Aweto, 1995
Nigeria	Natural rain forest	Cashew plantation	20	Estimated: 40.2 (t/ha) (0-30 cm), Reported: 13.4 (t/ha) (0-10 cm)	Estimated: 29.4 (t/ha) (0-30 cm), Reported: 9.8 (t/ha) (0-10 cm)	Alfisol	-26.9	Aweto, 1995
Nigeria	Natural rain forest	Coffee plantation	20	Estimated: 40.2 (t/ha) (0-30 cm), Reported: 13.4 (t/ha)	Estimated: 23.7 (t/ha) (0-30 cm), Reported: 7.9 (t/ha)	Alfisol	-41.0	Aweto, 1995

				(0-10 cm)	(0-10 cm)			
Brazil	Amazon primary forests	Passion fruit plantation (up to 2.5 m rooting depth)	2.5 (preceded with 25 years of crop and fallow period in between the forest conversion)	Estimated: 42.8 (t/ha) (0-30 cm), Reported: 5.7 kg C/m² /0.4 m depth) (0-40 cm depth)	Estimated: 31.5 (t/ha) (0-30 cm), Reported: 4.2 kg C/m² /0.4 m depth) (0-40 cm depth)	Typic Kandiudult, with texture of loamy sand in the top soil and sandy clay loam in the deeper layers up to 600 cm	-26.4	Sommer *et al*., 2000
Cameroon	Primary forest	Cacao plantation	20	41.5 (t/ha) (0-30 cm)	31.5 (t/ha) (0-30 cm)	-	-24.1	van Straaten *et al*. 2015
Cameroon	Primary forest	Cacao plantation	20	35.9 (t/ha) (0-30 cm)	20.9 (t/ha) (0-30 cm)	-	-41.7	van Straaten *et al*., 2015
Cameroon	Primary forest	Cacao plantation	24	60.7 (t/ha) (0-30 cm)	44.9 (t/ha) (0-30 cm)	-	-26.0	van Straaten *et al*., 2015
Cameroon	Primary forest	Cacao plantation	24	60.7 (t/ha) (0-30 cm)	43.5 (t/ha) (0-30 cm)	-	-28.4	van Straaten *et al*., 2015
Cameroon	Primary forest	Cacao plantation	27.5	82.9 (t/ha) (0-30 cm)	38.0 (t/ha) (0-30 cm)	-	-54.2	van Straaten *et al*., 2015
Cameroon	Primary forest	Cacao plantation	30	35.9 (t/ha) (0-30 cm)	40.2 (t/ha) (0-30 cm)	-	11.9	van Straaten *et al*., 2015
Cameroon	Primary forest	Cacao plantation	40	51.2 (t/ha) (0-30 cm)	42.5 (t/ha) (0-30 cm)	-	-17.1	van Straaten *et al*., 2015
Cameroon	Primary forest	Cacao plantation	50	82.9 (t/ha) (0-30 cm)	41.6 (t/ha) (0-30 cm)	-	-49.8	van Straaten *et al*., 2015
Cameroon	Primary forest	Cacao plantation	65	51.2(t/ha) (0-30 cm)	43.3 (t/ha) (0-30 cm)	-	-15.5	van Straaten *et al*., 2015
Cameroon	Primary forest	Cacao plantation	80	63.1 (t/ha) (0-30 cm)	30.3 (t/ha) (0-30 cm)	-	-51.9	van Straaten *et al*., 2015
Cameroon	Primary forest	Cacao plantation	100	63.1 (t/ha) (0-30 cm)	37.8 (t/ha) (0-30 cm)	-	-40.0	van Straaten *et al*., 2015
South East Asia	Tropical forests	Pasture /Grasslands/ shrublands	-	Range: 75-225 t/ha	Range: 66-198 t/ha	-		Ziegler *et al*., 2012
Brazil	Native Atlantic forest	Pasture	2-12	72.3 ± 8.3 (t/ha) (0-30 cm)	59.5 ± 8.7 (t/ha) (0-30 cm)	-	-17.7	Assad *et al*., 2013

Brazil	Native Atlantic forest	Pasture	34	Cumulative SOC: 42.7 (t/ha) (0-30 cm)	Cumulative SOC: 23.5 (t/ha) (0-30 cm)	Oxisols	-45.0	Cook *et al.*, 2013
Brazil	Native Atlantic forest	Pasture grass (Cerrado)	30	58.03 (t/ha) (0-30 cm)	44.4 (t/ha) (0-30 cm)	Anionic Acrudox, Typic Hapludox, Typic Rhodudalf, Typic Kandiudult, Rhodic Hapludox	-23.5	Franco *et al.*, 2015
Brazil, Amazon region	Tropical forests	Pasture grass (productive and degraded)	15	Estimated: 63.0 (t/ha) (0-30 cm) Reported: 42.0 (t/ha) (0-20 cm) under equilibrium landscape	Estimated: 52.4 (t/ha) (0-30 cm) Reported: 34.9 (t/ha) (0-20 cm) under equilibrium landscape	Ultisol, Oxisols	-16.8	Fearnside and Barbosa, 1998
Australia, Queensland	Native vegetation (Tree *spp.* of *Acacia, Casuarina* and *Eucalyptus*)	Perennial pasture	23	67.7 (t/ha) (0-30 cm)	58.3 (t/ha) (0-30 cm)	Vertisol, Luvisol	-13.9	Dalal *et al.*, 2013
Indonesia,	Tropical rainforest, Sumatra region	Grassland	10-33	Estimated: 63.3 (t/ha) (0-30 cm) Reported: 84.4 (t/ha) (0-40 cm)	Estimated: 33.5 (t/ha) (0-30 cm) Reported: 44.6 (t/ha) (0-40 cm)	Acrisol	-47.1	Woomer *et al.*, 2000, van der Kamp *et al.*, 2009
Ecuadorian Andes	Tropical montane forests	Pasture and mixed pasture	15	95.55 (t/ha) (0-30 cm)	84.35 (t/ha) (0-30 cm)	Andic humitropep	-11.7	Rhoades *et al.*, 2000
Indonesia	Tropical forest	Grassland	50	Estimated: 128.3 (t/ha) (0-30 cm)	Estimated: 103.7 (t/ha) (0-30 cm)	Mineral soils (Inceptisol, Oxisol and Ultisol)	-19.2	Van Noordwijk *et al.*, 1997
Hawaii	Tropical forests	Pasture	90	Estimated: 93.2 (t/ha) (0-30 cm)	Estimated: 107.5 (t/ha) (0-30 cm)	Volcanic ash soils	+15.3	Osher *et al.*, 2003

				Reported C: 31.07 (kg C/m^2 / 1m depth) for low rainfall, 2500 mm/yr, zone	Reported C: 35.83 (kg C/m^2 / 1m depth) for low rainfall, 2500 mm/yr, zone			
South East Asia	Tropical forests	Croplands (permanent)	-	Range: 75-225 t/ha	Range: 53-158 t/ha	-		Ziegler *et al*., 2012
South East Asia	Tropical forests	Short fallow and swidden agriculture	-	Range: 75-225 t/ha	Range: 59-178 t/ha	-		Ziegler *et al*., 2012
Brazil, Amazon region	Tropical forests	Agro-farmland	15	Estimated: 63.0 (t/ha) (0-30 cm) Reported: 42.0 (t/ha) (0-20 cm) under equilibrium landscape	Estimated: 41.0 (t/ha) (0-30 cm) Reported: 27.3 (t/ha) (0-20 cm) under equilibrium landscape	Ultisol, Oxisols	-34.9	Fearnside and Barbosa, 1998
Mexico	Tropical evergreen forest	Crop land (Sugarcane)	20- 50	Estimated: 199.5 (t/ha) (0-30 cm) Reported: 133 ± 9 (t/ha) (0-20 cm)	Estimated: 179.7 (t/ha) (0-30 cm) Reported: 119.77 ± 5.2 (t/ha) (0-20 cm)	Clayey Rendzina	-9.9	Anaya and Huber-Sannwald, 2015
Hawaii	Tropical forests	Crop land (Sugarcane)	50	Estimated: 93.2 (t/ha) (0-30 cm) Reported C: 31.07 (kg C/m^2 /1m depth) for low rainfall, 2500 mm/yr, zone	Estimated: 69.4 (t/ha) (0-30 cm) Reported C: 23.14 (kg C/m^2 /1m depth) for low rainfall, 2500 mm/yr, zone	Volcanic ash soils	-25.5	Osher *et al*., 2003
Ecuadorian Andes	Tropical montane forests	Crop land (sugarcane)	50	95.6 (t/ha) (0-30 cm)	72.9 (t/ha) (0-30 cm)	Andic humitropept	-23.7	Rhoades *et al*., 2000
Australia, Queensland	Native vegetation (Tree *spp.* of *Acacia,*	Cereal Cropland	23	67.7 (t/ha) (0-30 cm)	44.9 (t/ha) (0-30 cm)	Vertisol, Luvisol	-33.7	Dalal *et al*., 2013

	Casuarina and *Eucalyptus*)							
Thailand	Dry evergreen forest	Cropland (Maize)	10	105.4 (t/ha) (0-30 cm)	54 (t/ha) (0-30 cm)	Alfisol	-48.8	Jaiarree *et al*., 2011
Indonesia	Tropical forest	Upland crop	50	Estimated: 128.3 (t/ha) (0-30 cm)	Estimated: 117.1 (t/ha) (0-30 cm)	Mineral soils (Inceptisol, Oxisol and Ultisol)	-8.7	Van Noordwijk *et al*., 1997
Brazil	Amazon primary forests	Traditional slash and burn agriculture (crop and fallow)	1.75 (various crops aged 21 months, preceded with 4-10 years of fallow period)	Estimated: 42.8 (t/ha) (0-30 cm), Reported: 5.7 kg C/m^2 /depth) (0-0.4m depth)	Estimated: 39.8 (t/ha) (0-30 cm), Reported: 5.3 kg C/m^2 /depth) (0-0.4m depth)	Typic Kandiudult, with texture of loamy sand in the top soil and sandy clay loam in the deeper layers up to 600 cm	-7.0	Sommer *et al*., 2000
Brazil	Native Atlantic forest	Crop-livestock	2-12	72.3 ± 8.3 (t/ha) (0-30 cm)	61.1 ± 5.5 (t/ha) (0-30 cm)	-	-15.5	Assad *et al*., 2013

Note: Relative change in SOC stock (%) values with (-) signs indicate source of soil C / emission due to converted land use / loss of soil C from the original land use type / release of CO_2 in to the atmosphere.

Table S2. Change of SOC stock on conversion of secondary forest land in subtropical and tropical (30 º N- 30 º S) regions.

Country	Original land use type	Converted land use type	Age of converted land use site (years)	SOC stock of original land use (t C/ha)	SOC stock of converted land use (t C/ha)	Soil type / comments	Relative change in SOC stock (%)	References
South East Asia	Secondary logged-over forests	Oil palm plantation	-	Range: 68-205 t/ha	Range: 65-196 t/ha	-		Ziegler *et al*., 2012
Brazil, eastern Amazon	Secondary forest	Oil palm plantation	2.5	42.6 (t/ha) (0-30 cm)	55.1 (t/ha) (0-30 cm)	* oil palm agroforestry with low sp. diversity	29.3	de Carvalho *et al*., 2014
Brazil, eastern Amazon	Secondary forest	Oil palm plantation	2.5	42.6 (t/ha) (0-30 cm)	52.6 (t/ha) (0-30 cm)	* oil palm agroforestry with high sp. diversity	23.5	de Carvalho *et al*., 2014
Brazil	Mixed secondary forest/ Agroforestry spontaneous system	Oil palm plantation	34	44 ± 5.2 (t/ha) (0-30 cm, equivalent mass adjusted)	61.1 ± 9.6 (t/ha) (0-30 cm, equivalent mass adjusted)	Oxisol, *older plantation	+ 38.9	Frazão *et al*., 2014
Papua New Guinea	Secondary forests	Oil palm *(management practices with high fertiliser inputs, non-burning)	25	Estimated: 93.24 (t/ha) , (0-30 cm) (using means of 4.2 % C, BD: 0.74 g/cm^3), Reported: 6.17 % Total C, 0-5 cm, BD=0.69 g/cm^3; 2.18 % Total C, 10-15 cm, BD=0.79 g/cm^3	Estimated: 114.57(t/ha), (0-30 cm) (using means of 5.7% C, BD: 0.67 g/cm^3) Reported: 8.14 % Total C, 0-5 cm, BD=0.61 g/cm^3; 3.23% Total C, 10-15 cm, BD=0.72 g/cm^3	Sandy volcanic ash soils	+ 22.9	Nelson *et al*., 2014
Brazil,	Mixed secondary forest/ Agroforestry spontaneous system	Oil palm plantation	23	44 ± 5.2 (t/ha) (0-30 cm, equivalent mass adjusted)	34.3 ± 2.7 (t/ha) (0-30 cm, equivalent mass adjusted)	Oxisol	-22.0	Frazão *et al*., 2014

Indonesia	Secondary rainforest	Oil palm plantation	14	58.15 ± 3.1 (t/ha) (0-30 cm) (mean of Harapan and Bukit regions)	47.55 ± 5.5 (t/ha) (0-30 cm) (mean of Harapan and Bukit regions)	Lowland mineral soils	-18.2 (SOC content decreased up to 62 % overall in converted oil palm)	Guillaume *et al*., 2015
Malaysia	Secondary logged forest	Oil palm estates	8-17	Estimated: 87.3 t/ha (0-30 cm) , Reported: 33.1 ± 14.8 (g/kg, TC) (0-10 cm, BD 0.88 g/mL)	Estimated: 85.2 t/ha (0-30 cm) , Reported: 31.6 ± 12.6 (g/kg, TC) (0-10 cm, BD 0.90 g/mL)	Typic Dysrudepts	-2.4	Tanaka *et al*., 2009
Brazil	Secondary woodland vegetation (12 years old)	Oil palm plantation (up to 4.5 m rooting depth)	9 (preceded with 25 years of crop and fallow period in between the forest conversion)	Estimated: 33.0 (t/ha) (0-30 cm), Reported: 4.4 kg C/m^2/depth) (0-0.4m deep)	Estimated: 23.3 (t/ha) (0-30 cm), Reported: 3.1 kg C/m^2/depth) (0-0.4m deep)	Typic Kandiudult, with texture of loamy sand in the top soil and sandy clay loam in the deeper layers up to 600 cm	-29.4	Sommer *et al*., 2000
Brazil	Secondary woodland vegetation (40 years old)	Oil palm plantation (up to 4.5 m rooting depth)	9 (preceded with 25 years of crop and fallow period in between the forest conversion)	Estimated: 37.5 (t/ha) (0-30 cm), Reported: 5.0 kg C/m^2/depth) (0-0.4m deep)	Estimated: 23.3 (t/ha) (0-30 cm), Reported: 3.1 kg C/m^2/depth) (0-0.4m deep)	Typic Kandiudult, with texture of loamy sand in the top soil and sandy clay loam in the deeper layers up to 600 cm	-37.9	Sommer *et al*., 2000
Ghana	Secondary forests	Oil palm plantation	8	Cumulative SOC: 67.6 (t/ha) (0-30 cm)	Cumulative SOC: 65.8 (t/ha) (0-30 cm)	Sandy clay soils and Oxisol	-2.7	Chiti *et al*., 2014
Ghana	Secondary forests	Oil palm plantation	25	Cumulative SOC: 67.6 (t/ha) (0-30 cm)	Cumulative SOC: 57.3 (t/ha) (0-30 cm)	Sandy clay soils and Oxisol	-15.2	Chiti *et al*., 2014

South East Asia	Secondary logged-over forests	Rubber plantation	-	Range: 68-205 t/ha	Range: 65-196 t/ha	-		Ziegler *et al*., 2012
Indonesia	Secondary rainforest	Rubber plantation (jungle and plantation rubber)	10 - 42	54.3 ± 4.3 (t/ha) (0-30 cm) (Harapan region)	45.7 ± 2.4 (t/ha) (0-30 cm) (Harapan region)	Lowland mineral soils	-15.8 (SOC content decreased up to 70 % overall in converted rubber)	Guillaume *et al*. 2015
Malaysia	Secondary logged forest	Rubber farms	2-60	Estimated: 87.3 t/ha (0-30 cm), Reported: 33.1 ± 14.8 (g/kg, TC) (0-10 cm, BD 0.88 g/mL)	Estimated: 80.1 t/ha (0-30 cm), Reported: 30.7 ± 9.3 (g/kg, TC) (0-10 cm, BD 0.87 g/mL)	Typic Dysrudepts	-8.2	Tanaka *et al*. 2009
Brazil, Amazon region	Secondary forests	Rubber plantation	7	67.5 (t/ha) (0-30 cm)	59.4 ± 0.5 (t/ha) (0-30 cm)	Xanthic Ferrasol	-12	Schroth *et al*., 2002
Ghana	Secondary forests	Rubber Plantation	5	Cumulative SOC: 67.6 (t/ha) (0-30 cm)	Cumulative SOC: 64.4 (t/ha) (0-30 cm)	Sandy clay soils and Oxisol	- 4.7	Chiti *et al*., 2014
Ghana	Secondary forests	Rubber Plantation	10	Cumulative SOC: 67.6 (t/ha) (0-30 cm)	Cumulative SOC: 57.5 (t/ha) (0-30 cm)	Sandy clay soils and Oxisol	-14.9	Chiti *et al*., 2014
Ghana	Secondary forests	Rubber Plantation	14	Cumulative SOC: 67.6 (t/ha) (0-30 cm)	Cumulative SOC: 55.0 (t/ha) (0-30 cm)	Sandy clay soils and Oxisol	-18.6	Chiti *et al*., 2014
Ghana	Secondary forests	Rubber Plantation	49	Cumulative SOC: 67.6 (t/ha) (0-30 cm)	Cumulative SOC: 48.1 (t/ha) (0-30 cm)	Sandy clay soils and Oxisol	-28.8	Chiti *et al*., 2014
Tropical China	Secondary forests	Rubber plantation	46	82.8 ± 2.1 (t/ha) (0-30 cm)	60.1 ± 1.8 (t/ha) (0-30 cm)	Ferrasol	-27.4	de Blecourt *et al*., 2013
South East Asia	Secondary logged-over forests	Orchard and tree plantation	-	Range: 68-205 t/ha	Range: 65-196 t/ha	-		Ziegler *et al*., 2012

Ghana	Secondary forest	Mixed tree plantation	49	Cumulative SOC: 67.6 (t/ha) (0-30 cm)	Cumulative SOC: 68.5 (t/ha) (0-30 cm)	Sandy clay soils and Oxisol	+1.3	Chiti *et al*., 2014
Indonesia	Secondary forest	Perennial tree plantation	50	Estimated: 132.5 (t/ha) (0-30 cm)	Estimated: 113.2 (t/ha) (0-30 cm)	Mineral soils (Inceptisol, Oxisol and Ultisol)	-14.6	Van Noordwijk *et al*., 1997
Brazil, Amazon region	Secondary forests	Monoculture tree plantation (Citrus, Peach palm, etc.)	7	Estimated: 67.5(t/ha) (0-30 cm), Reported: 22.5 ± 1.3 (t/ha) (0-10 cm)	Estimated: 59.4 (t/ha) (0-30 cm), Reported: 19.8 ± 0.5 (t/ha) (0-10 cm)	Xanthic Ferrazol	-12	Schroth *et al*., 2002
Ghana	Secondary forest	Mixed tree plantation	36	Cumulative SOC: 67.6 (t/ha) (0-30 cm)	Cumulative SOC: 66.6 (t/ha) (0-30 cm)	Sandy clay soils and Oxisol	-1.5	Chiti *et al*., 2014
Malaysia	Secondary logged forest	Pepper farms	1-22	Estimated: 87.3 t/ha (0-30 cm) Reported: 33.1 ± 14.8 (g/kg, TC) (0-10 cm, BD 0.88 g/mL)	Estimated: 75.9 t/ha (0-30 cm) Reported: 25 ± 10.6 (g/kg, TC) (0-10 cm, BD 1.01 g/mL)	Typic Dysrudepts	-13.1	Tanaka *et al*., 2009
Brazil	Secondary woodland vegetation (12 years old)	Passion fruit plantation (up to 2.5 m rooting depth)	2.5 (preceded with 25 years of crop and fallow period in between the forest conversion)	Estimated: 33.0 (t/ha) (0-30 cm), Reported: 4.4 kg C/m²/depth) (0-0.4m deep)	Estimated: 31.5 (t/ha) (0-30 cm), Reported: 4.2 kg C/m²/depth) (0-0.4m deep)	Typic Kandiudult, with texture of loamy sand in the top soil and sandy clay loam in the deeper layers up to 600 cm	-4.5	Sommer *et al*., 2000
South East Asia	Secondary logged-over forests	Grassland/ pasture/ shrubland	-	Range: 68-205 t/ha	Range: 66-198 t/ha	-		Ziegler *et al*., 2012
Indonesia	Secondary forests, after deforestation (Eat	Grassland	10-12	29.9 ± 5.1 (t/ha) (0-30 cm)	36.9 ± 9.8 (t/ha) (0-30 cm)	Typic Paleudults, Typic Hapludults	+ 23.4	Yonekura *et al*., 2010

	Kalimantan, Borneo)							
Indonesia,	Secondary forests, Kalimantan region	Grasslands	4 years after burning	Estimated: 29.2 (t/ha) (0-30 cm), Reported: 38.98 (t/ha) (0-40 cm)	Estimated: 27.1(t/ha) (0-30 cm), Reported: 36.19 (t/ha) (0-40 cm)	Acrisol	-7.2	van der Kamp *et al*., 2009
Indonesia,	Secondary forests	Grassland	10-33	Estimated: 64.1 (t/ha) (0-30 cm), Reported: 85.4 (t/ha) (0-40 cm)	Estimated: 33.45 (t/ha) (0-30 cm), Reported: 44.6 (t/ha) (0-40 cm)	Acrisol	-47.8	Woomer *et al*. 2000, van der Kamp *et al*., 2009
Indonesia	Secondary forest	Grassland	50	Estimated: 132.5 (t/ha) (0-30 cm)	Estimated: 103.7(t/ha) (0-30 cm)	Mineral soils (Inceptisol, Oxisol and Ultisol)	-21.7	Van Noordwijk *et al*., 1997
Australia (Queensland)	Rangeland (Mixed trees of Eucalyptus and Acacia spp.)	Grassland	11-31 years	31.0 (t/ha) (0-30 cm)	28.53 (t/ha) (0-30 cm)	Kandosols, Vertosols, Sodosols	-8.0	Harms *et al*., 2005
South East Asia	Secondary logged-over forests	Short fallow and swiddening agriculture	-	Range: 68-205 t/ha	Range: 59-178 t/ha	-		Ziegler *et al*., 2012
South East Asia	Secondary logged-over forests	Crop land (permanent)	-	Range: 68-205 t/ha	Range: 66-198 t/ha	-		Ziegler *et al*., 2012
Brazil, Amazon region	Secondary forests	Agriculture (shifting, slash and burn) and fallow land	7	Estimated: 67.5(t/ha) (0-30 cm), Reported: 22.5 ± 1.3 (t/ha) (0-10 cm)	Estimated: 51.6 (t/ha) (0-30 cm), Reported: 17.2 ± 1.6 (t/ha) (0-10 cm)	Xanthic Ferrazol	-23.6	Schroth *et al*., 2002
Indonesia	Secondary forest	Upland crop	50	Estimated: 132.5 (t/ha) (0-30 cm)	Estimated: 117.1 (t/ha) (0-30 cm)	Mineral soils (Inceptisol, Oxisol and Ultisol)	-11.6	Van Noordwijk *et al*., 1997

Bangladesh	Reforested land/ secondary forest	Upland crops (Mustard, Sugarcane, Cotton, Rice)	12	Estimated: 45.3 (t/ha) (0-30 cm) Reported: 12.8 (g/kg, TOC) (BD 1.18 g/mL)	Estimated: 30.6 (t/ha) (0-30 cm) Reported: 7.4 (g/kg, TOC) (BD 1.38 g/mL)	Typic, Paleustult (flat upland fine loamy or clayey soils)	-32.5	Islam and Weil, 2000

Note: Relative change in SOC stock (%) values with (-) signs indicate source of soil C / emission due to converted land use / loss of soil C from the original land use type / release of CO_2 in to the atmosphere.

Table S3. Change of SOC stock on conversion of pasture and grassland in subtropical and tropical (30 º N- 30 º S) regions.

Country	Original land use type	Converted land use type	Age of converted land use site (years)	SOC stock of original land use (t C/ha)	SOC stock of converted land use (t C/ha)	Soil type / comments	Relative change in SOC stock (%)	References
South East Asia	Pasture /Grasslands/ shrublands	Oil palm plantation	-	Range: 66-198 t/ha	Range: 65-196 t/ha	-		Ziegler *et al*., 2012
Papua New Guinea	Grasslands	Oil palm	25	Estimated: 21.4 (t/ha) (0-30 cm) Reported: 10.7 (kg/m^2) (depth: 1.5 m, BD 1.0 g/cm^3)	Estimated: 24.0 (t/ha) (0-30 cm) Reported: 12.0 (kg/m^2) (depth: 1.5 m, BD 1.0 g/cm^3)	Vitrands	+12.1	Goodrick *et al*., 2015
Brazil, Amazon region	Permanent pasture (55 years)	Oil palm plantation	25	38.5 ± 4 (t/ha) (0-30 cm, mass equivalent basis)	22.7 ± 1.4 (t/ha) (0-30 cm, mass equivalent basis)	Oxisol	-41.0	Frazão *et al*., 2013
Papua New Guinea	Grasslands *(management practices with regular burning sites)	Oil palm *(management practices with high fertiliser inputs, non-burning)	25	Estimated: 125.5 (t/ha) (0-30 cm), Reported: 5.1 % C, BD: 0.82 g/cm^3, 0-5 cm deep)	Estimated: 117.7 (t/ha) (0-30 cm), Reported: 4.67 % C, BD: 0.84 g/cm^3, 0-5 cm deep)	Sandy volcanic ash soils	-6.2	Nelson *et al*., 2014
South East Asia	Pasture /Grasslands/ shrublands	Rubber plantation	-	Range: 66-198 t/ha	Range: 65-196 t/ha	-		Ziegler *et al*., 2012
Tropical China	Grasslands	Rubber plantation (immature, before tapping, <8 years, but the site had rubber for >40 years)	40	Estimated: 47.9 t/ha, (0-30 cm), assuming a default BD of 1.45 g/cm^3), Reported: 11 ± 1 (g/kg) (0-20 cm)	Estimated: 47.9 t/ha, (0-30 cm), assuming a default BD of 1.45 g/cm^3), Reported: 11 ± 1 (g/kg) (0-20 cm)	Oxisol	0.0	Zhang *et al*., 2007
Tropical China	Grasslands	Rubber plantation (mature, after	40	Estimated: 47.85 t/ha, (0-30 cm),	Estimated: 36.1 t/ha, (0-30 cm),	Oxisol	-24.6	Zhang *et al*., 2007

		tapping, >8 years, but the site had rubber for >40 years)		assuming a default BD of 1.45 g/cm³), Reported: 11 ± 1 (g/kg) (0-20 cm)	assuming a default BD of 1.45 g/cm³), Reported: 8.3 ± 0.4 (g/kg) (0-20 cm)			
South East Asia	Pasture /Grasslands/ shrublands	Secondary/logged over forests	-	Range: 66-198 t/ha	Range: 68-205 t/ha	-		Ziegler *et al*., 2012
South East Asia	Pasture /Grasslands/ shrublands	Orchard and tree plantations	-	Range: 66-198 t/ha	Range: 65-196 t/ha	-		Ziegler *et al*., 2012
Brazil, Amazon region	Pasture (productive and degraded)	Secondary forests	15	Estimated: 52.4 t/ha, (0-30 cm), Reported: 34.9 (t/ha) (0-20 cm) under equilibrium landscape	Estimated: 58.7 t/ha, (0-30 cm), Reported: 39.1 (t/ha) (0-20 cm) under equilibrium landscape	Ultisol, Oxisols	+12	Fearnside and Barbosa, 1998
Panama	Tropical Pasture grass	Tree Plantations (Teak)	5	Estimated: 64 (t/ha) (0-30 cm), Reported: 6.4 kg/m² (0-30 cm)	Estimated: 77 (t/ha) (0-30 cm), Reported: 7.7 kg/m² (0-30 cm)	Typic Tropudalf, Aquic Tropudalfs	+ 20.3	Potvin *et al*., 2004
Brazil	Pasture	Broadleaf tree plantation	34	Cumulative SOC: 28.0 (t/ha) (0-30 cm)	Cumulative SOC: 25.7 (t/ha) (0-30 cm)	Oxisols	-8.2	Cook *et al*., 2013
Costa Rica	Pasture grass	Tree plantations (*Vochysia*)	4-10	100.2 ± 1.9 (t/ha) (0-30 cm)	85.3 ± 1.4 (t/ha) (0-30 cm)	Tropohumults, Dystropepts, and Dystrandepts	- 14.9	Powers, 2004
South East Asia	Pasture /Grasslands/ shrublands	Short fallow and swiddening agriculture	-	Range: 66-198 t/ha	Range: 59-178 t/ha	-		Ziegler *et al*., 2012
South East Asia	Pasture /Grasslands/ shrublands	Croplands (permanent)	-	Range: 66-198 t/ha	Range: 53-158 t/ha			Ziegler *et al*., 2012
Brazil	Pasture grass (Cerrado)	Crop land (Sugarcane)	5-20	0.4 t/ha/yr (rate of SOC stock lost from native forest to pasture grass)	0.25 t/ha/yr (rate of SOC stock lost from pasture to crop land)	Anionic Acrudox, Typic Hapludox, Typic Rhodudalf,	-37.5	Franco *et al*., 2015

						Typic Kandiudult, Rhodic Hapludox		
Hawaii	Pasture	Crop land (Sugarcane)	50	Estimated: 107.5 (t/ha) (0-30 cm) Reported C: 35.83 (kg C /m^2/m depth) low rainfall, 2500 mm/yr, zone	Estimated: 69.4 (t/ha) (0-30 cm) Reported C: 23.14 (kg C /m^2/m depth) low rainfall, 2500 mm/yr, zone	Volcanic ash soils	-35.4	Osher *et al*., 2003
Brazil	Native forest	Crop land (Sugarcane, burned managed land)	8	Estimated: 128.0 (t/ha) (0-30 cm) Reported C: 47.95 g/kg cumulative C for 0-20 cm, BD mean=0.89 g/cm^3, 0-30 cm depth)	Estimated: 106.46 (t/ha) (0-30 cm) Reported C: 31.97 g/kg cumulative C for 0-20 cm, BD mean=1.11 g/cm^3, 0-30 cm depth)	Clayey Oxisols	-16.8	Galdos *et al*., 2009
Ecuadorian Andes	Pasture and mixed pasture	Crop land (sugarcane)	50	84.35 (t/ha) (0-30 cm)	72.9 (t/ha) (0-30 cm)	Andic humitropep	-13.6	Rhoades *et al*., 2000
Costa Rica	Pasture grass	Crop lands (Pineapple)	1.5-10	89.9 ± 1.7 (t/ha) (0-30 cm)	73.8 ± 1.1 (t/ha) (0-30 cm)	Tropohumults, Dystropepts, and Dystrandepts	- 17.9	Powers, 2004

Table S4. Change of SOC stock on conversion of cropland in subtropical and tropical (30 º N- 30 º S) regions.

Country	Original land use type	Converted land use type	Age of converted land use site (years)	SOC stock of original land use (t C/ha)	SOC stock of converted land use (t C/ha)	Soil type / comments	Relative change in SOC stock (%)	References
South East Asia	Crop lands	Oil palm plantation	-	Range: 53-158 t/ha	Range: 65-196 t/ha	-		Ziegler *et al*., 2012
South East Asia	Crop lands	Rubber plantation	-	Range : 53-158 t/ha	Range : 65-196 t/ha	-		Ziegler *et al*., 2012
South East Asia	Crop lands	Orchard and tree plantation	-	Range : 53-158 t/ha	Range: 65-196 t/ha	-		Ziegler *et al*., 2012
Brazil, Amazon region	Agriculture and farmland	Secondary forests	15	Estimated: 40.9 (t/ha) (0-30 cm) Reported: 27.3 (t/ha) (0-20 cm) under equilibrium landscape	Estimated: 55.2 (t/ha) (0-30 cm) Reported: 36.8 (t/ha) (0-20 cm) under equilibrium landscape	Ultisol, Oxisols	+ 35.0	Fearnside and Barbosa, 1998
Colombia	Crop land (Annual, reduced tillage, medium input)	Oil palm plantation	20	33.1 (t/ha) (0-30 cm)	69.0 (t/ha) (0-30 cm)	Mineral soils, *model data calculated based on IPCC IPCC 2006, input management	+ 108.5	Castanheira *et al*., 2014
Malaysia	Swidden cultivation of upland rice	Oil palm plantation	15	Estimated: 60.0 (t/ha) (0-30 cm) Reported: 40.0 (t/ha) (0-20 cm) Fixed depth approach	Estimated: 35.3 (t/ha) (0-30 cm) Reported: 23.5 (t/ha) (0-20 cm) Fixed depth approach	Ultisol * Fixed depth approach	-41.2	Bruun *et al*., 2013
Malaysia	Swidden cultivation of upland rice	Oil palm plantation	15	Estimated: 70.1 (t/ha) (0-30 cm) Reported: 46.7 (t/ha) (0-20 cm)	Estimated: 34.7(t/ha) (0-30 cm) Reported: 23.1 (t/ha) (0-20 cm)	Ultisol * equivalent soil mass approach	-50.5	Bruun *et al*., 2013

				equivalent soil mass approach	equivalent soil mass approach			
Malaysia	Swidden cultivation of upland rice	Oil palm plantation	3-8	Estimated: 60.0 (t/ha) (0-30 cm) Reported: 40.0 (t/ha) (0-20 cm) Fixed depth approach	Estimated: 58.2 (t/ha) (0-30 cm) Reported: 38.8 (t/ha) (0-20 cm) Fixed depth approach	Ultisol * Fixed depth approach	-3.0	Bruun *et al*., 2013
Malaysia	Swidden cultivation of upland rice	Oil palm plantation	3-8	Estimated: 70.1 (t/ha) (0-30 cm) Reported: 46.7 (t/ha) (0-20 cm) equivalent soil mass approach	Estimated: 58.2 (t/ha) (0-30 cm) Reported: 38.8 (t/ha) (0-20 cm) equivalent soil mass approach	Ultisol * equivalent soil mass approach	-17	Bruun *et al*., 2013
Brazil	Traditional slash and burn agriculture, swiddening (25 years of permanent use with various crops and fallow periods)	Oil palm plantation (up to 4.5 m rooting depth)	9 (fallow and traditional cropping of rice, cotton, cassava)	Estimated: 39.8 (t/ha) (0-30 cm) Reported: 5.3 (kg C /m^2/depth) (0-0.4m depth)	Estimated: 23.3 (t/ha) (0-30 cm), Reported: 3.1 (kg C /m^2/depth) (0-0.4m depth)	Typic Kandiudult, with texture of loamy sand in the top soil and sandy clay loam in the deeper layers up to 600 cm	-41.5	Sommer *et al*., 2000

Table S5. Annual N_2O fluxes in primary forests and in the associated land use change in subtropical and tropical (30 º N- 30 º S) regions.

Country	**Original land use - Vegetation type**	**Changed land use – Vegetation type**	**Mean Annual Rainfall (mm)**	**Mean Annual Temperature (°C)**	**Original land use : Measured N_2O flux (ng/ µg N_2O-N /cm² /h) or Estimated N_2O flux (kg N_2O /ha/ yr)**	**Changed land use : Measured N_2O flux (ng/ µg N_2O-N /cm² /h) or Estimated N_2O flux (kg N_2O /ha/ yr)**	**Soil type / Comments**	**References**
China	Primary rainforest	Secondary forest	1530	21.8	0.5–24.5 (6 ± 0.1) µg N_2O -N /m² /h; 0.83 kg N_2O /ha/ yr	1.1–28.5 (7.3 ± 0.7) µg N_2O -N /m² /h; 1.01 kg N_2O /ha/ yr	Lateritic soils	Werner *et al.*, 2006
Indonesia	Primary rainforest	Secondary/ logged over forest	2060 (Total annual rainfall, 1997-1998)	-	Plot- P1: 0.91µg N_2O -N /m² /h; P1, P2: 0.13, 0.39 kg N_2O /ha/ yr Mean: 0.26 kg N_2O /ha/ yr	Mean of L1, L2: 4.24µg N_2O -N /m² /h ; 0.58 kg N_2O /ha/ yr	Ultisols (infertile, acidic soils)	Ishizuka *et al.*, 2002
Indonesia	Primary rainforest	Rubber	2060 (Total annual rainfall, 1997-1998)	-	Plot- P1: 0.91µg N_2O -N /m² /h; P1, P2: 0.13-0.39 kg N_2O /ha/ yr Mean: 0.26 kg N_2O /ha/ yr	0.45 µg N_2O -N /m² /h ; 0.06 kg N_2O /ha/ yr	Ultisols (infertile, acidic soils)	Ishizuka *et al.*, 2002
China	Primary rainforest	Rubber plantation	1530	21.8	0.5–24.5 (6 ± 0.1) µg N_2O -N /m² /h; 0.83 kg N_2O /ha/ yr	0.4–6.5 (4.1 ± 0.5) µg N_2O -N /m² /h; 0.57 kg N_2O /ha/ yr	Lateritic soils	Werner *et al.*, 2006
Brazil	Rainforest	Active pasture	1850	25	2.43 kg N_2O -N /ha/ yr; 4.09 kg N_2O /ha/ yr	0.25 kg N_2O -N /ha/ yr; 0.42 kg N_2O /ha/ yr	Latosols, Oxisol	Verchot *et al.*, 1999
Brazil	Rainforest	Degraded pasture	1850	25	2.43 kg N_2O -N /ha/ yr; 4.09 kg N_2O /ha/ yr	0.06 kg N_2O -N /ha/ yr; 0.10 kg N_2O /ha/ yr	Latosols, Oxisol	Verchot *et al.*, 1999
Mexico	Deciduous forest	Pasture	748	24.9	0.5–0.7 (mean, 0.6) kg N_2O -N /ha/ yr; 0.94	0.5–0.7 (mean, 0.6) kg N_2O -N /ha/ yr; 0.94	Entisols	Garcia-Mendez *et al.*, 1991

					kg N_2O /ha/ yr	kg N_2O /ha/ yr		
Brazil, Amazon region	Humid tropical forest	Pasture (>3 years)	2200	25.6	1.9 kg N_2O -N /ha/ yr; 2.99 kg N_2O /ha/ yr	1.4 kg N_2O -N /ha/ yr ; 2.2 kg N_2O /ha/ yr	Ultisol (the soil contributes 1/5th of total land cover in Brazilian Amazon)	Melillo *et al*., 2001
Brazil, Amazon region	Humid tropical forest	Pasture (first 2 years)	2200	25.6	1.9 kg N_2O -N /ha/ yr; 2.99 kg N_2O /ha/ yr	5.0 kg N_2O -N /ha/ yr; 7.86 kg N_2O /ha/ yr	Ultisol *higher emission occurs only in younger pasture	Melillo *et al*., 2001
Malaysia	Montane rainforest	Crop land (cabbage)	2085, 3285	10.7-23.9	0.05–8 (log-normal mean, 0.63) ng N_2O /cm^2 /h; 0.87 kg N_2O /ha/ yr	10.69 ng N_2O /cm^2 /h; 14.76 kg N_2O /ha/ yr	Oxisol, inceptisol,	Hall *et al*., 2004
Australia, Queensland	Native vegetation (Tree *spp.* of *Acacia, Casuarina* and *Eucalyptus*)	Perennial pasture (23years)	720	19.8	-	0.4 kg N_2O -N /ha/ yr; 0.63 kg N_2O /ha/ yr	Vertisol, Luvisol	Dalal *et al*., 2013
Australia, Queensland	Native vegetation (Tree *spp.* of *Acacia, Casuarina* and *Eucalyptus*)	Cereal cropland (23years)	720	19.8	-	8.5 kg N_2O -N /ha/ yr; 13.36 kg N_2O /ha/ yr	Vertisol, Luvisol	Dalal *et al*., 2013
Costa Rica	Lowland rainforest		3962	25.8	6.7–23.3 (12.4 ± 2.2) g N_2O -N /ha/d; 7.11 kg N_2O /ha/ yr	-	Ultisol	Liu *et al*., 2000
Australia (Kauri creek)	Moist rainforest	-	1594	20.9	4.36 kg N_2O -N /ha/ yr; 6.85 kg N_2O /ha/ yr	-	Ustochrept (Sandy clay loam)	Kiese and Butterbach-Bahl, 2002
Congo	Rainforest	-	1400	-	0.17–20.6 ng N_2O-N cm^2 /h (2.9 kg N_2O-N /ha/ yr); 4.56 kg N_2O /ha/ yr	-	Oxisols	Serca *et al*., 1994
Kenya	Moist rainforest	-	1662	20.4	2.6 ± 1.2 kg N_2O-N /ha/yr; 4.09 kg N_2O /ha/ yr	-	Luvisols, Lixisols, Cambisols	Werner *et al*, 2007

Brazil	Amazon humid rainforest	-	2000	25	1.5 ± 0.2 kg N_2O-N /ha/ yr; 2.36 kg N_2O /ha/ yr	-	Oxisol	Davidson *et al.*, 2004
Brazil	Amazon humid rainforest	-	2000	26	1.9 kg N_2O -N /ha/ yr; 2.99 kg N_2O /ha/ yr	-	Ultisol	Melillo *et al.*, 2001
USA	Tropical montane rainforest	-	2200-4050	16	–0.2–1.8 (mean, 0.8) ng N_2O -N /cm² /h; 1.1 kg N_2O /ha/ yr		Andisols, inceptisol	Holtgrieve *et al.*, 2006

Table S6. Annual CH_4 fluxes in primary forests and following land use change in subtropical and tropical (30 º N- 30 º S) regions.

Country	**Original land use - Vegetation type**	**Changed land use – Vegetation type**	**Mean Annual Rainfall (mm)**	**Mean Annual Temperature (°C)**	**Original land use : Measured CH_4 flux (ng/ µg CH_4-C /cm²/h) or Estimated CH_4 flux (kg CH_4/ha/yr)**	**Changed land use : Measured CH_4 flux (ng/ µg CH_4-C /cm²/h) or Estimated CH_4 flux (kg CH_4/ha/yr)**	**Soil type / Comments**	**References**
China	Primary forest	Secondary forest	1530	21.8	–52.3 to –4.3 (–29.5 ± 0.3) µg CH_4-C /m² /h; -3.45 kg CH_4/ha/yr	–0.4 to -44.5 (–25.6 ± 1.3) µg CH_4-C /m² /h ; -2.99 kg CH_4/ha/yr	Lateritic soils	Werner *et al*., 2006
Indonesia	Primary rainforest	Secondary/ logged over forest	2060 (Total annual rainfall, 1997-1998)	-	-9.05 µg CH_4-C /m² /h; -1.06 kg CH_4 /ha/yr	-13.26 µg CH_4-C /m² /h; -1.55 kg CH_4/ha/yr	Ultisols (infertile, acidic soils)	Ishizuka *et al*., 2002
Indonesia	Primary rainforest	Oil palm plantation	2060 (Total annual rainfall, 1997-1998)	-	-9.05 µg CH_4-C /m²/h; -1.06 kg CH_4/ha/yr	-6.23µg CH_4-C /m²/h; -0.73 kg CH_4/ha/yr	Ultisols (infertile, acidic soils)	Ishizuka *et al*., 2002
Indonesia	Primary rainforest	Rubber	2060 (Total annual rainfall, 1997-1998)	-	-9.05 µg CH_4-C /m²/h; -1.06 kg CH_4/ha/yr	-2.37 µg CH_4-C /m² /h; -0.28 kg CH_4/ha/yr	Ultisols (infertile, acidic soils)	Ishizuka *et al*., 2002
China	Primary forest	Rubber plantation	1530	21.8	–52.3 to –4.3 (–29.5 ± 0.3) µg CH_4-C /m² /h; -3.45 kg CH_4/ha/yr	–16 to 1.7 (–5.7 ± 0.5) µg CH_4-C /m² /h ; -0.67 kg CH_4/ha/yr	Lateritic soils	Werner *et al*., 2006
Thailand	Dry evergreen forest	Tree plantation (*Acacia spp*.)	-	-	–4.4 to –0.2 (–2.3) mg CH_4/m² /d; -8.39 kg CH_4/ha/yr	–5.6 to 2.7 (–1.45) mg CH_4/m² /d; -5.29 kg CH_4/ha/yr	Sandy clay loam	Knief *et al*., 2005
India	Seasonally dry tropical forest	Irrigated rice	800	-	–3.98 g CH_4/m²/yr; -39.80 kg CH_4/ha/yr	9.45 g CH_4/m²/yr; 94.5 kg CH_4/ha/yr	Ultisols, Inceptisol	Singh *et al*., 1998
Nepal	Montane forest	Irrigated rice (Khet)	4390	12	–3.0 to –54.4 (–22.8) µg CH_4/m² /h; -2 kg CH_4/ha/yr	0.5 to 267 (53.0) µg CH_4/m² /h; 4.65 kg CH_4/ha/yr	-	Awasthi *et al*., 2005
India	Seasonally dry tropical forest	Dryland rice	800	-	–3.98 g CH_4-C /m² /yr; -39.80 kg CH_4/ha/yr	-2.12 g CH_4-C /m²/yr; -21.2 kg CH_4/ha/yr	Ultisols, Inceptisol	Singh *et al*., 1998
Nepal	Montane forest	Grazing land	4390	12	–3.0 to –54.4 (–22.8) µg CH_4/m² /h;	0.3 to 74.1 (–14.0) µg CH_4/m² /h;	-	Awasthi *et al*., 2005

					-2 kg CH_4 /ha/yr	-1.23 kg CH_4 /ha/yr		
Nepal	Montane forest	Rainfed maize and millet system (Bari)	4390	12	–3.0 to –54.4 (–22.8) μg CH_4 /m² /h; -2 kg CH_4 /ha/yr	0.7 to 30.4 (-2.6) μg CH_4 /m² /h; -0.23 kg CH_4 /ha/yr	-	Awasthi *et al*., 2005
Thailand	Dry evergreen forest	Crop land (Corn field)	-	-	–4.4 to –0.2 (–2.3) mg CH_4 /m² /d; -8.39 kg CH_4 /ha/yr	–1.4 to 1.4 mg CH_4 /m² /d; 0 kg CH_4 /ha/yr	Sandy clay loam	Knief *et al*., 2005
Brazil	Primary forest	Active pasture	1850	-	–2.1 kg CH_4 /ha/yr	–1.3 kg /ha/yr	Latosols, Oxisols	Verchot *et al*., 2000
Brazil	Primary forest	Degraded pasture	1850	-	–2.1 kg CH_4 /ha/yr	–3.1 kg CH_4 /ha/yr	Latosols, Oxisols	Verchot *et al*., 2000
Brazil	Amazon humid rainforest	-	2000	25	–5.3 ± 1.0 kg CH_4 /ha/yr	-	Oxisols	Davidson *et al*., 2004
Brazil	Rainforest	-	-	-	–0.36 to –1.1 (–0.73) mg CH_4 /m² /d; -2.66 kg CH_4 /ha/yr	-	-	Silver *et al*., 2005
Kenya	Rainforest	-	1662	20.4	-38.9 to -88.1 (–56.4 ± 0.8) μg CH_4-C /m² /h; -4.8 ± 0.7 kg CH_4-C /ha/yr; -6.59 kg CH_4 /ha/yr	-	Luvisols, Lixisols, Cambisols	Werner *et al*., 2007

Table S7. Annual N_2O fluxes in secondary forests and following land use change in subtropical and tropical (30 º N- 30 º S) regions.

Country	**Original land use - Vegetation type**	**Changed land use – Vegetation type**	**Mean Annual Rainfall (mm)**	**Mean Annual Temperature (°C)**	**Original land use : Measured N_2O flux (ng/ µg N_2O-N /cm² /h) or Estimated N_2O flux (kg N_2O /ha /yr)**	**Changed land use : Measured N_2O flux (ng/ µg N_2O-N /cm² /h) or Estimated N_2O flux (kg N_2O /ha /yr)**	**Soil type / Comments**	**References**
Indonesia	Logged over, secondary forests	Young Oil palm plantation (<10 years old)	2112- 2798	25	9.3 (2.52 – 23.6) µg N_2O -N /m²/h (0.81 kg N_2O -N /ha/yr); 1.28 kg N_2O /ha/yr	17.25 (7.68-28.83)µg N_2O -N /m²/h (1.50 kg N_2O -N /ha/yr); 2.38 kg N_2O /ha/yr	Udult, Entosol, Ultisol	Ishizuka *et al.*, 2005
Indonesia	Logged over, secondary forests	Old Oil palm plantation (>10 years old)	2112- 2798	25	9.3 (2.52 – 23.6) µg N_2O -N /m²/h (0.81 kg N_2O -N /ha/yr); 1.28 kg N_2O /ha/yr	2.7 (1.14-4.26)µg N_2O -N /m²/h (0.23 kg N_2O -N /ha/yr); 0.37 kg N_2O /ha/yr	Ultisol, Inceptisol	Ishizuka *et al.*, 2005
Indonesia	Logged over, secondary forests	Cinnamon plantation	2112 - 2798	25	9.3 (2.52 – 23.6) µg N_2O - N /m²/h (0.81 kg N_2O -N /ha/yr); 1.28 kg N_2O /ha/yr	5.89 (1.27-12.88) µg N_2O-N /m²/h (0.51 kg N_2O -N /ha/yr); 0.81 kg N_2O /ha/yr	Andisols	Ishizuka *et al.*, 2005
Indonesia	Secondary/ logged over forest	Rubber	2060 (Total annual rainfall, 1997-1998)	-	Mean of L1, L2: 4.24µg N_2O -N /m²/h ; 0.58 kg N_2O /ha/yr	0.45µg N_2O -N /m²/h; 0.06 kg N_2O /ha/yr	Ultisols (infertile, acidic soils)	Ishizuka *et al.*, 2002
Indonesia	Logged over, secondary forests	Young Rubber plantation (<10 years old)	2112- 2798	25	9.3 (2.52 – 23.6) µg N_2O -N /m²/h (0.81 kg N_2O -N /ha/yr); 1.28 kg N_2O /ha/yr	2.16 (1.19-3.13)µg N_2O -N /m²/h (0.19 kg N_2O -N /ha/yr); 0.30 kg N_2O /ha/yr	Andisol, Entosol	Ishizuka *et al.*, 2005
China	Secondary rainforest	Rubber plantation	1530	21.8	1.1–28.5 (7.3 ± 0.7) µg N_2O -N /m²/h; 1.01 kg N_2O /ha/yr	0.4–6.5 (4.1 ± 0.5) µg N_2O -N /m²/h; 0.57 kg N_2O /ha/yr	Lateritic soils	Werner *et al.*, 2006

Indonesia	Logged over, secondary forests	Old Rubber plantation (>10 years old)	2112 -2798	25	9.3 (2.52 – 23.6) μg N_2O -N /m²/h (0.81 kg N_2O -N /ha/yr); 1.28 kg N_2O /ha/yr	20.57 (1.62 - 55.82) μg N_2O -N /m²/h (1.79 kg N_2O -N /ha/yr); 2.84 kg N_2O /ha/yr	Andisol, Udult, Ultisol	Ishizuka *et al*., 2005
Indonesia	Logged over, secondary forests	Grasslands	2112 -2798	25	9.3 (2.52 – 23.6) μg N_2O -N /m²/h (0.81 kg N_2O -N /ha/yr); 1.28 kg N_2O /ha/yr	1.39 (0.13-3.39)μg N_2O -N /m²/h (0.12 kg N_2O -N /ha/yr); 0.19 kg N_2O /ha/yr	Ultisols, Andisol	Ishizuka *et al*., 2005
Brazil	Secondary forest	Active pasture	1850	25	0.94 kg N_2O -N /ha/yr; 1.48 kg N_2O /ha/yr	0.25 kg N_2O -N /ha/yr; 0.39 kg N_2O /ha/yr	Latosols, Oxisol	Verchot *et al*., 1999
Brazil	Secondary forest	Degraded pasture	1850	25	0.94 kg N_2O -N /ha/yr; 1.48 kg N_2O /ha/yr	0.06 kg N_2O -N /ha/yr; 0.09 kg N_2O /ha/yr	Latosols, Oxisol	Verchot *et al*., 1999
Costa Rica	Secondary upland forest	Cropped land (Corn)	3962	25.8	1.46 – 1.62 (1.54) ng N_2O -N /m²/h ; 0.21 g N_2O /ha/yr	2.11 – 5.76 (3.94) ng N_2O -N /m²/h ; 0.54 g N_2O /ha/yr	Clay soil (Dystropept) and loamy soil (Eutropept)	Weitz *et al*., 1998

Table S8. Annual CH_4 fluxes in secondary forests and following land use change in subtropical and tropical (30 º N- 30 º S) regions.

Country	Original land use - Vegetation type	Changed land use – Vegetation type	Mean Annual Rainfall (mm)	Mean Annual Temperature (°C)	Original land use : Measured CH_4 flux (ng/ µg CH_4-C /cm² /h) or Estimated CH_4 flux (kg CH_4 /ha/yr)	Changed land use : Measured CH_4 flux (ng/ µg CH_4-C /cm² /h) or Estimated CH_4 flux (kg CH_4 /ha/yr)	Soil type / Comments	References
Indonesia	Logged over, secondary forests	Old Oil palm plantation (>10 years old)	2112- 2798	25	–0.7 (-0.27 to – 1.27) mg CH_4-C /m²/d; -3.53 kg CH_4 /ha/yr	-0.75 mg CH_4-C /m²/d; -3.78 kg CH_4 /ha/yr	Ultisol, Inceptisol	Ishizuka *et al*., 2005
Indonesia	Logged over, secondary forests	Young Oil palm plantation (<10 years old)	2112- 2798	25	–0.7 (-0.27 to – 1.27) mg CH_4-C /m²/d; -3.53 kg CH_4 /ha/yr	-0.30 mg CH_4-C /m²/d; -1.51 kg CH_4 /ha/yr	Udult, Entosol, Ultisol	Ishizuka *et al*., 2005
Indonesia	Secondary/ logged over forest	Oil palm plantation	2060 (Total annual rainfall, 1997-1998)	-	-13.26 µg CH_4-C /m²/h; -1.55 kg CH_4 /ha/yr	-6.23µg CH_4-C /m²/h; -0.73 kg CH_4 /ha/yr	Ultisols (infertile, acidic soils)	Ishizuka *et al*., 2002
Indonesia	Logged over, secondary forests	Cinnamon plantation	2112 - 2798	25	–0.7 (-0.27 to – 1.27) mg CH_4-C /m²/d; -3.53 kg CH_4 /ha/yr	-0.65 mg CH_4-C /m²/d; -3.28 kg CH_4 /ha/yr	Andisols	Ishizuka *et al*., 2005
China	Secondary rainforest	Rubber plantation	1530	21.8	–0.4 to -44.5 (–25.6 ± 1.3) µg CH_4-C /m²/h; -2.99 kg CH_4 /ha/yr	–16 to 1.7 (–5.7 ± 0.5) µg CH_4-C /m²/h; -0.67 kg CH_4 /ha/yr	Lateritic soils	Werner *et al*., 2006
Indonesia	Secondary/ logged over forest	Rubber	2060 (Total annual rainfall, 1997-1998)	-	-13.26 µg CH_4-C /m²/h; -1.55 kg CH_4 /ha/yr	-2.37 µg CH_4-C /m²/h; -0.28 kg CH_4 /ha/yr	Ultisols (infertile, acidic soils)	Ishizuka *et al*., 2002
Indonesia	Logged over, secondary forests	Old Rubber plantation (>10 years old)	2112 -2798	25	–0.7 (-0.27 to – 1.27) mg CH_4-C /m²/d; -3.53 kg CH_4 /ha/yr	0.01 mg CH_4-C /m²/d; -0.05 kg CH_4 /ha/yr	Andisol, Udult, Ultisol	Ishizuka *et al*., 2005
Indonesia	Logged over, secondary forests	Young Rubber plantation (<10 years old)	2112- 2798	25	–0.7 (-0.27 to – 1.27) mg CH_4-C /m²/d; -3.53 kg CH_4 /ha/yr	-0.51 mg CH_4-C /m²/d; -2.57 kg CH_4 /ha/yr	Andisol, Entosol	Ishizuka *et al*., 2005

Indonesia	Logged over, secondary forests	Grasslands	2112 -2798	25	–0.7 (-0.27 to – 1.27) mg CH_4-C /m²/d; -3.53 kg CH_4 /ha/yr	-0.37 mg CH_4-C /m²/d; -1.87 kg CH_4 /ha/yr	Ultisols, Andisol	Ishizuka *et al*., 2005
Brazil	Secondary forest	Active pasture	1850	-	–1.0 kg CH_4 /ha/yr	–1.3 kg CH_4 /ha/yr	Latosols, Oxisols	Verchot *et al*., 2000
Brazil	Secondary forest	Degraded pasture	1850	-	–1.0 kg CH_4 /ha/yr	–3.1 kg CH_4 /ha/yr	Latosols, Oxisols	Verchot *et al*., 2000
Costa Rica	Secondary upland forest	Crop land (Corn)	3962	25.8	–0.94 to –0.98 (mean, –0.96) mg CH_4 /m²/d; -3.5 kg CH_4 /ha/yr	–0.36 to –0.49 (mean, –0.43) mg CH_4 /m²/d; -1.57 kg CH_4 /ha/yr	Clay soil (Dystropept), loamy soil (Eutropept)	Weitz *et al*., 1998

Table S9. Annual N_2O fluxes in natural savannah and following land use change in subtropical and tropical (30 º N- 30 º S) regions.

Country	Original land use - Vegetation type	Changed land use – Vegetation type	Mean Annual Rainfall (mm)	Mean Annual Temperature (°C)	Original land use : Measured N_2O flux (ng/ µg N_2O-N /cm² /h) or Estimated N_2O flux (kg N_2O /ha/yr)	Changed land use : Measured N_2O flux (ng/ µg N_2O-N /cm² /h) or Estimated N_2O flux (kg N_2O /ha/yr)	Soil type / Comments	References
Australia, Queensland	Perennial pasture (23years)	Cereal cropland (23years)	720	19.8	0.4 kg N_2O -N /ha/yr; 0.63 kg N_2O /ha/yr	8.5 kg N_2O -N /ha/yr; 13.36 kg N_2O /ha/yr	Vertisol, Luvisol	Dalal *et al*., 2013
West Africa	Savannah	Crop land* (Sorgham, cotton, peanut) dry region	926	29.5	0.60 kg N_2O-N /ha/yr; 0.94 kg N_2O /ha/yr	0.20 kg N_2O-N /ha/yr; 0.31 kg N_2O /ha/yr	Oxisols (N trace gas flux could be observed only over short time, <15 years; N limitation and dry region could contribute less emission	Brummer *et al*., 2008
Venezuela	Open tree savanna, 30–50% canopy cover	Cultivated pasture, herbaceous savanna	1057	27.3	Median 0.019 mg N_2O -N /m² /d; 0.11 kg N_2O /ha/yr	0.24 ± 0.22 (wet), 0.14 ± 0.23 (dry), overall mean, 0.19 mg N_2O -N /m² /d; 1.09 kg N_2O /ha/yr	Ultisol, sandy loam	Castaldi *et al*., 2004
Venezuela	Woodland savanna, 50–80% canopy cover	Cultivated pasture, herbaceous savanna	1057	27.3	Median 0.051 mg N_2O -N/m² /d; 0.29 kg N_2O /ha/yr	0.24 ± 0.22 (wet), 0.14 ± 0.23 (dry), overall mean, 0.19 mg N_2O -N /m² /d; 1.09 kg N_2O /ha/yr	Ultisol, sandy loam,	Castaldi *et al*., 2004
Global-Savanna	Savanna- Global		-	-	Median flux 0.32 mg N_2O /m² /d; 1.17 kg N_2O /ha/yr	1.17	-	Castaldi *et al*., 2006
South Africa	Semi-arid savanna	-	625	-	Wet, 0.19, dry, 0.09 (mean,	-	Sandy soil	Scholes *et al*., 1997

					0.14) mg N_2O -N /m² /d; 0.80 kg N_2O /ha/yr			
Zimbabwe	Miombo woodland savanna	-	760–840	15–21	497 (burned), 422 (grass), 249 (protected), overall mean, 389 g N_2O-N /ha/yr; 0.61 kg N_2O /ha/yr	-	Sandy-clay,	Rees *et al*., 2006
Australia -global	Grassland/pasture	-	-	-	0.4–1.4 (log-normal mean, 0.75) kg N_2O -N /ha/yr; 1.18 kg N_2O /ha/yr	-	-	Galbally *et al*., 1992
Puerto Rico	Pasture	-	1120–1930	23–26	16.9 μg N_2O -N /m²/h ; 2.33 kg N_2O /ha/yr	-	Vertisol, Oxisol, Ultisol	Mosier and Delgado, 1997
Brazil	Pastures 25 and 60 years	--	2000	25	2 (wet, 25 year pasture) and 3 (60 year pasture), dry 0; overall mean, 1.25 ng /cm² /h; 1.10 kg N_2O /ha/yr	-	Oxisol	Wick *et al*., 2005
Brazil	Cerrado savanna	-	1500		<0.6 ng N_2O -N /cm² /h; 0.82 kg N_2O /ha/yr			Pinto *et al*., 2002

Table S10. Annual CH_4 fluxes in natural savannah and following land use change in subtropical and tropical (30 º N- 30 º S) regions.

Country	Original land use - Vegetation type	Changed land use – Vegetation type	Mean Annual Rainfall (mm)	Mean Annual Temperature (°C)	Original land use : Measured CH_4 flux (ng/ µg CH_4-C /cm²/h) or Estimated CH_4 flux (kg CH_4 /ha/ yr)	Changed land use : Measured CH_4 flux (ng/ µg CH_4-C /cm²/h) or Estimated CH_4 flux (kg CH_4 /ha/ yr)	Soil type / Comments	References
Ghana	Savannas	-	100–1500	24–30	–9 µg CH_4-C /cm²/h; –0.79 kg CH_4 /ha/ yr	-	-	Prieme and Christensen, 1999
Brazil	Cerrado (savanna)	-	1100–1600	16–25	–8.33 to –15.1 (mean, –11.72) ng CH_4-C /m²/s; –4.92 kg CH_4 /ha/ yr	-		Anderson and Poth, 1998
Brazil	Active pasture	-	1850	-	–1.3 kg CH_4 /ha/ yr; –1.30 kg CH_4 /ha/ yr	-	-	Verchot *et al*., 2000
Brazil	Degraded pasture	-	1850	-	–3.1 kg CH_4 /ha/ yr; –3.1 kg CH_4 /ha/ yr	-	-	Verchot *et al*., 2000
Brazil	Pastures, 25 and 60 years	-	2000	-	4 (wet season, 25 years pasture), 0 (60 years pasture) mg CH_4 /m²/d (overall, negligible)	--	-	Wick *et al*., 2005
Costa Rica	Traditional pasture	-	3962	25.8	Annual flux, –1 to 8.4 (weighted mean, 0.69 mg CH_4 /m²/d); 2.52 kg CH_4 /ha/ yr	-	Loamy Andisol	Veldkamp *et al*., 2001
Puerto Rico	Pasture	-	1120–1930	23–26	–5.8 µg CH_4-C /m²/h ; -0.68 kg CH_4 /ha/ yr	-	Vertisol, oxisol, ultisol	Mosier and Delgado, 1997
Venezuela	Permanent pasture	-	1057	27.3	–0.05 ± 0.06 mg CH_4 /m²/d; -0.18 kg CH_4 /ha/ yr	-	Ultisol, sandy loam	Castaldi *et al*., 2004
Venezuela	Open tree savanna	-	1057	27.3	0.19 ± 0.05 mg CH_4 /m²/d; 0.69 kg CH_4 /ha/ yr	-	Ultisol, sandy loam	Castaldi *et al*., 2004
Venezuela	Woodland savanna	-	1057	27.3	–0.08 ± 0.05 mg CH_4 /m²/d; -0.29 kg CH_4 /ha/ yr	-	Ultisol, sandy loam	Castaldi *et al*., 2004
Global for savanna	Savanna – global	-	-	-	–22.9 to 3.15 (median flux, –0.48) mg CH_4 /m²/d; -1.75 kg CH_4 /ha/ yr	-	-	Castaldi *et al*., 2006

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