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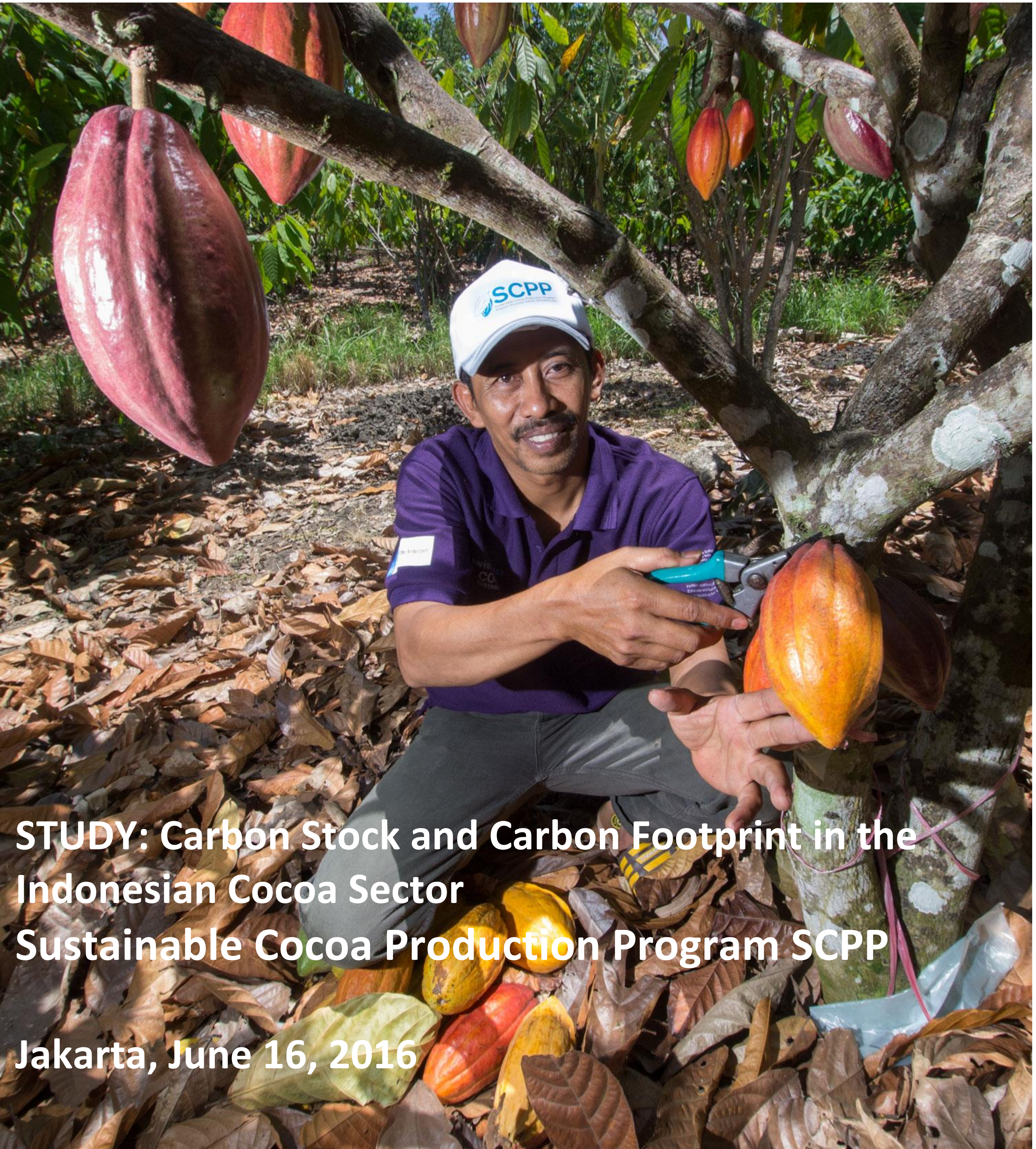

STUDY: Carbon Stock and Carbon Footprint in the Indonesian Cocoa Sector
Sustainable Cocoa Production Program SCPP

Jakarta, June 16, 2016

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SCPP carbon stock and carbon footprint in the Indonesian cocoa sector

Abstract

The Sustainable Cocoa Production Program (SCPP) quantified carbon stocks from four pools: above-ground, below-ground biomass, litter and soil organic carbon in 30 farms of three cocoa shade management systems in West Sulawesi, Indonesia. Each shade management system was selected according to the number of shade tree species moving from the less to the more complex agroforestry system. The carbon footprint was estimated based on 51,620 farmers from the CocoaTrace[1] farm management software, considering only the GHG emitted by the use of fertilizer. The total carbon stock was estimated in average 90.3 t ha^{-1}, in which soil organic carbon (SOC) was the main contributor of carbon stock (55%). Shade trees were the main carbon stock above-ground (75%), compared to 10.9 t C ha^{-1} in cacao trees. Fruit trees were the major shade tree contributor to carbon stock (11.3 8 t ha^{-1}). The annual rate of carbon stock was estimated in 1.5 t ha^{-1} $year^{-1}$ and depending on the future action plan it could increase by 2.1 t ha^{-1} $year^{-1}$ in 2020. Nitrous oxide from fertilizer use contributed to 2.36 t CO_2e t^{-1} cocoa dry beans. The values were different among farmers according their average annual yield and amount of applied fertilizer per ha. Depending on the changing pattern of yield and applied fertilizer continuum, the carbon footprint could get reduced by 30% to 1.73 t CO_2e t^{-1} while the carbon stock could increase by up to 13% to 101.5 t C ha^{-1} in 2020. These results show the lack of knowledge of some farmers on the appropriate use of fertilizer, and the urgent necessity to promote proper fertilizing practices while increasing the carbon stock by good management of shade system and soil.

Program Background

To support the Sustainable Cocoa Production Program (SCPP), Swisscontact has created a wide array of public and private sector partners that add value along the supply chain from inputs to farming to trading to processing to manufacturing. The Program, designed and implemented by Swisscontact, is a large public-private partnership between Swisscontact and the Swiss State Secretariat for Economic Affairs (SECO), the International Fund for Agricultural Development (IFAD), and the Millennium Challenge Account-Indonesia (MCA-I). At national level, SCPP works with the Indonesian Ministry of Home Affairs and on regional level with all provincial and local governments in the selected cocoa producing districts. Private sector partners are Barry Callebaut, BT Cocoa, Cargill Cocoa and Chocolate, Ecom, JB Cocoa, Mars Inc., Mondelēz International, and Nestlé. Within the specific Green Prosperity program component, SCPP works closely together with Vredeseilanden VZW (VECO Indonesia), and the World Cocoa Foundation (WCF) for specific activities.

[1] CocoaTrace is a data management software developed by Swisscontact and PT Koltiva to monitor, collect, manage and evaluate data of cocoa farmers (including certification and mapping). It also serves as a state of art tool to enhance traceability in cocoa value chain.

SCPP consists of a series of targeted training modules that cover good agricultural, financial, business, nutrition, social, and environmental practices together with training on internal systems, traceability, and certification. The program takes a three-dimensional approach to capture the social, environmental, and economic aspects of sustainability, with a special focus on ensuring continuity and the participation of the next generation of cocoa farmers.

Geared toward the reduction of poverty and greenhouse gas emissions in the Indonesian cocoa sector, SCPP includes a focus on 11 of the 17 Sustainable Development Goals and is aimed at increasing the competitiveness of an environmentally responsible and inclusive cocoa value chain. The log frame on which SCPP is based includes 77 indicators correlated to impact, outcomes, and outputs, aligned with the 'triple P' bottom line of People, Planet, and Profit.

The program includes rigorous farm observations and interviews which feed data to www.cocoatrace.com, developed by an Indonesian IT Start-up which then integrate farm and project management systems in order to populate dashboards which allow for farmer identification, producer profiles, farm mapping, and full product traceability. Together, the components of the SCPP system ultimately help ensure a living income for participating farmer families.

Introduction

The rising concentration of greenhouse gases (GHG) in the atmosphere is contributed to a large extent by fossil fuels consumption and the conversion of tropical forest into agricultural and pasture land (Paustian et al., 2000). The latter one is responsible for 17.4% of the global GHG emissions (IPCC, 2007). Indonesia has lost 40% of its forest cover since 1945 with a current rate of about 5,000,000 ha year-1 (FAO, 2010), following the highest annual deforestation rate in primary forest of all tropical countries (Margono et al., 2014).

In Central Sulawesi, palm oil and cocoa cultivation are considered the main drivers of deforestation (Koch, 2009). Oil palm plantations are currently the leading cause of forest destruction in Malaysia and Indonesia, with an estimate of 98% forest loss by 2022 (UNEP, 2007). Cocoa annual production in Indonesia increased by more than 25% from 1980 to 1994 (COPAL, 2008; Juhrbandt et al., 2010), becoming the third largest cocoa producer in the world since 2008 until today (ICCO, 2015). Besides deforestation, one of the main issues of the cocoa boom in 1990 was that many smallholder farmers cultivated this crop without appropriate crop management (poor knowledge or training). This resulted in old poorly managed cacao trees (most have not been replanted since then), which are more prone to pests and diseases. In combination with inappropriate soil management, the cocoa production in Indonesia is far behind its potential, it can be harmful to environment and yield revenues are often not enough for cocoa farmer's needs (SCPP, 2015).

This becomes more relevant, given the recent high demand to produce cocoa in a sustainable manner (Millard, 2011; Waldron et al., 2012), where initiatives like voluntary carbon markets (FAO, 2010b) and certification have started to address the challenge.

SCPP attempts to increase productivity while enhancing the environmental performance through mechanisms such as farmers training on good agricultural and environmental practices, traceability and certification. With being able to quantify the carbon footprint on cocoa farms, the Sustainable Cocoa Production Program (SCPP) will be able to measure its impact thus contribute to reduction of GHG emissions in cocoa sector.

There are two indicators that have been used to measure the impact of commodities such as coffee and cocoa on the climate. The first one is the carbon footprint, which measures the quantity of all GHG emitted per unit of commodity produced and it is measured in CO equivalents: CO_2e (van Rikxoort et al., 2014). The total emissions depend on variables such as use of chemical and organic fertilizer, pesticide, and fossil fuel for transport and farm operations (van Rikxoort et al., 2014). The second indicator is the carbon stock of a particular land use system, which is always compared with the natural system i.e. primary or secondary forest and is measured in t ha^{-1}. There are sufficient studies showing that cocoa cultivated in agroforestry systems sequesters considerable high amount of carbon (Kumar and Nair, 2011). This amount varies among different agroforestry systems for instance coffee, cocoa, and rubber from 12 to 228 t ha^{-1} (Dixon, 1995; Albrecht and Kandji, 2003; Montagnini and Nair, 2004; Nair et al., 2009) and depends on the shade management system; shade tree density and species; percentage of shade coverage among others. For instance, rustic shade would have higher carbon stock compared to mixed shade or specialized shade.

Methodology

The baseline study area was located in Mamuju (02˚55' S 118˚52' E - 02˚22'S 119˚12' E), West Sulawesi, Indonesia. The field work was carried out during the month of November 2015 in SCPP active areas. The region is classified as humid tropical forest according to Holdridge (1987) with mean temperature of 28˚C and mean annual rainfall of 2,674 mm. In Mamuju, the driest months occur from June to September, while the rainiest are from December to March (Government data Mamuju, 2010).

Based on CocoaTrace farm information, 30 cocoa farms located in different districts of Mamuju were selected (Fig. 1). Among the 30 farms, three shade management systems were identified as follows:

- First system: one or two shade trees species including fruit trees combined with coconut or legume trees.
- Second system: three or more shade species including coconut, *Gliricidia* (gamal), and fruit trees.
- Third system: more than four shade tree species including timber trees.

SCPP made inventories of land and management in semi-structured interviews with the farmers (Annex 1). For every farm, the data related to cocoa stand characteristics, productivity, agrochemical use, waste and land use management, and transportation were recorded.

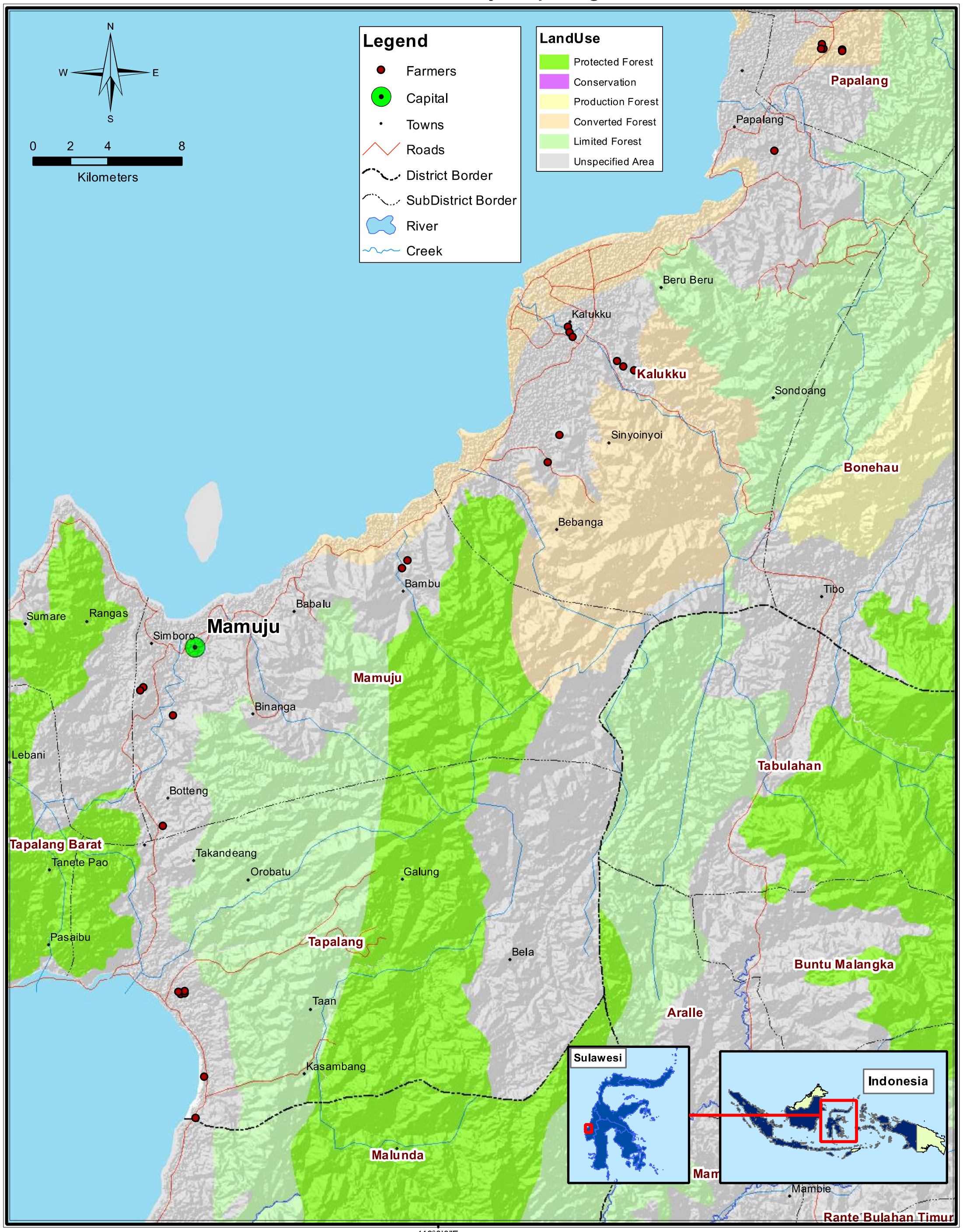

Figure 1. Location of the study area with the 30 selected farms.

Carbon stock methodology

SCPP estimated the above-ground biomass of wood and litter; below-ground biomass and soil organic carbon (SOC). Tree sampling was based on the methodology of Rügnitz et al. (2009) in plot of 50 x 20 m, where every tree with DBH more than 10 cm was recorded at 1.3 m above the soil surface. The sample included 30 cacao trees at 30 cm above the soil surface (Fig. 2). The program recorded data of species, *height, DBH and* age (Annex 2). The appropriate allometric equations were applied (Table 1) to convert DBH and height into tree biomass (Holdridge, 1987). Wood density was extracted from the global ICRAF data base of wood density (Kind et al., 2015) and converted biomass to carbon using the factor 0.47 (IPCC, 2006).
To estimate the annual rate per year, the carbon stock was divided per the age of each shade tree. The average age of shade trees is 13 years old with the average DBH of 22.1 cm.

Table 1. The allometric equations used to calculate above-ground biomass

Tree type	Allometric equation	Reference
Cocoa	Log B = (−1.684 + 2.158 * Log (DBH30) + 0.892 * Log(H))	(CATIE, unpublished)
Fruit trees	Log B = (−1.11 + 2.64 * Log(DBH))	(CATIE, unpublished)
Palms	B=4.5+7.7*H	(Frangi and Lugo, 1985)
Coconut	B= ((π /4) *(DBH*0.5) ^2) *H*0.4	(Hairiah et al. 2001)
Banana	$B=0.030*DBH^{2.13}$	(Van Noordwijk et al. 2002)
Other shade trees	B= 0.050 9*(WD*((DBH)^2) *H) ^0.916))	(Chave et al. 2005)

DBH (Diameter at Breast Height)
WD (Wood density) ICRAF data base
H (Height)

Inside the main sampling plot, subplots of 10 m x 25 m were established to measure SOC and bulk density. Square frames of 0.25 m^2 (50 cm x 50 cm) were established to determine litter biomass (Fig. 2). To estimate litter, the whole fresh weight was recorded of the four samples in the square frame and the subsample of fresh weight of 200 g. In the laboratory the subsamples were dried and weighted again. Below-ground biomass was estimated based on above-ground biomass *(*Cairns et al. 1997) by following formula.

$$B = \exp [-1.0587 + 0.8836 * \ln (\text{Above-ground biomass})]$$

SOC was determined by four soil disturbed samples taken at two depths which were 0-10 cm and 0-20 cm on each subplot. Furthermore, SOC was examined by one sample of undisturbed soil at the same two depths on metal rings of 2.5 cm radius and 5 cm height (Fig. 2). The samples were analyzed by laboratory of Assessment Institute for Agricultural Technology, South Sulawesi to obtain percentage of SOC on each depth and the weight of the undisturbed sample to calculate bulk density.

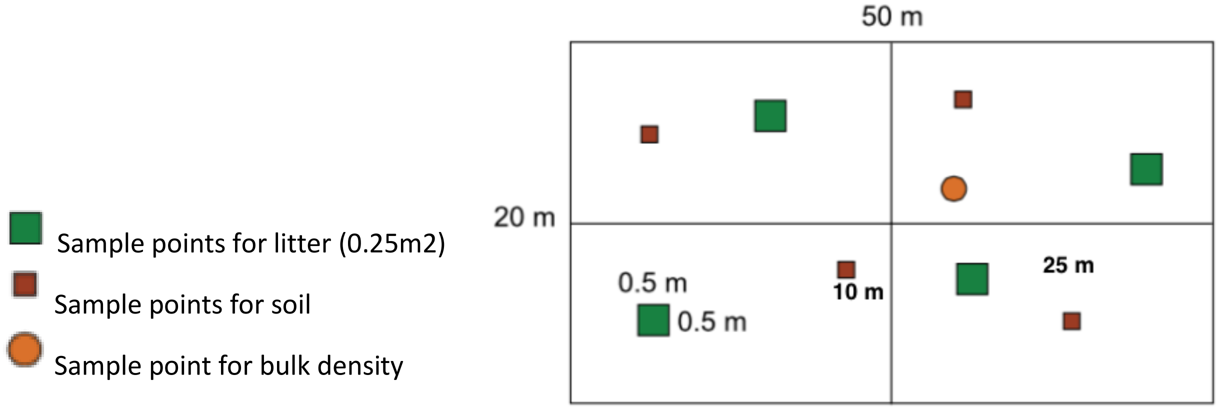

Figure 2. Sketch adapted from Poveda et al. (2013). Sampling design on carbon stock assessment.

Estimation of GHG emissions

To measure GHG emissions, SCPP currently uses the tool of UNFCCC/CCNUCC "Estimation of direct nitrous oxide emission from nitrogen fertilization" allowing for estimating direct nitrous oxide emission from applying nitrogenous fertilizer within SCPP boundary, for baseline and post line estimation. To compare two different methodologies, both using the farmer data from CocoaTrace database, The Cool Farm Tool (CFT) was used in this study. This tool is a GHG calculator, which estimates emissions at farm level depending on site and management activities. It also has the advantage to calculate GHG emissions on different case scenarios to explore mitigation options. In comparison to current SCPP methodology using the default emissions factor used by 2006 IPCC Guidelines, The CFT uses the scientific research and different factors are taking into account of N_2O emission measurements such as climate, crop type, fertilizer type, application rate, mode and timing of application, soil organic and carbon content, soil nitrogen content, pH, texture and drainage, measurement technique and frequency, and length of the measurement period.

In total, 51,620 farms with annual yield ranging from 10 to more than 2,000 kg ha^{-1} were analyzed using CFT and data from CocoaTrace database. Variables on climate, crop type, fertilizer type, application rate, mode and timing of application, soil organic content, soil nitrogen content, pH, texture and drainage were included. Four groups were identified: farmers with annual yield 10-500 kg ha^{-1}; farmers with annual yield 500-1,000 kg ha^{-1}; farmers with annual yield 1,000-2,000 kg ha^{-1} and farmers with annual yield more than 2,000 kg ha^{-1}. Regarding to those variables the best and worst case scenario was calculated for each group.

Results and Discussion

General information

The results on carbon stock are based on the 30 farms sampled in West Sulawesi whereas the carbon footprint results cover data from all SCPP areas of 51,620 farms. Cocoa production is one of the main activities of the farmers analyzed in the study. The farm area ranges from 0.1 to 18.5 ha (average of 1.02 ha) with mean tree density of 783 trees ha^{-1}. The stand age of cacao trees differs from 2 to 34 years. Yield varies from 10 to 3,600 kg ha^{-1} $year^{-1}$ with average of 517 kg ha^{-1} per year. The highest yield was found on stand ages between 10 and 20 years and tree density of 620 to 900 trees ha^{-1}.

The CocoaTrace data indicate that the dose of applied fertilizer and pesticide varies greatly among farmers. Chemical fertilizer is used by 59.4% farmers. Among them around 42.2% utilize urea as their main fertilizer combined with NPK (41.6%), ZA (6.1%) and some (7.4%) apply organic fertilizers (manure, compost or cocoa husks). Large amount of farmers spray pesticides (75.7%). The most widely used are herbicides (77.3%) with the active ingredient of Glyphosate (66.5%) and/or Paraquat dichloride (44.8%). Insecticides are used by 66.8% with wide use of Lambda cyhalothrin (31.6%) and Cypermethrin (38.7%). Fungicides are the least used by the farmers (26.8%) and mostly include copper oxide (45.8%). Many of the previous pesticides are banned or in the watch list by various certification labels. Majority of the farmers use motorbikes for transportation.

Stand inventory

As mentioned earlier, stand inventory and carbon stock was based on 30 surveyed farms in West Sulawesi. Three shade management systems were identified according to the number of shade tree species as explained in the methodology. The first one had one or two shade tree species, but was not limited to coconut or *Gliricidia*. Different combinations were found including fruit trees combined with coconut or legume trees for a total of 10 species. The second system consists of three to four shade tree species including palms and timber trees with a total of 15 species. The third system included more than four shade trees up to 6 species including all the previous with a total of 20 species (Table 2).

Table 2. Stand inventory of cacao and shade trees in the three shade management systems (n=30)

Average	Shade management 1	Shade management 2	Shade management 3
Number of farms	10	9	11
Area (ha)	0.9	1.2	1
Total number of shade tree species	11	16	20
Shade tree species	2	3	5
Age cocoa (years)	15	20	21
Shade tree density (tree ha^{-1})	106	107	144
Altitude (m)	32.9	83	50
Slope (%)	4	8	12
Cocoa yield (kg ha^{-1} yr^{-1})	1241	1378	1189
Cocoa density (tree ha^{-1})	768	800	781

In total 24 shade tree species were identified. Fruit trees such as durian, langsat and mango (*Durio zibethinus*, *Lansium parasiticum, Mangifera indica*) contributed in higher proportion (33%) followed by banana (*Musa acuminate*, 23.2%), leguminous trees (*Leucaena leucocephala*, *Gliricidia sepium*, 16.2%) and coconut (*Cocos nucifera*, 14%). Although banana is used as shade tree for young cocoa and local consumption, it is an evergreen perennial herb. Because of this, banana would not contribute significantly in terms of carbon stock. In respect with the DBH classes the 54.7% corresponded to 10-20 cm, 24% to 20-30 cm, 13.7% to 30-40 cm, and 7.5% to more than 40 cm.

Carbon stock

Soil organic carbon (SOC) was the main contributor to the total carbon stock by 55% (Fig. 3). It is considered one of the main contributors to carbon stock, because the SOC maintain stable over time (Nair et al., 2009). Scientists reflect only the reduction of SOC during conversion of primary forest to cropland, reporting values up to 70% within 10 or more years after conversion (Lugo and Brown, 1993; Guo and Gifford, 2002; Murty et al., 2002).

SOC did not differ significantly between the shade management systems, supporting the hypothesis it might be determined by the initial conditions of the plot rather than the cultivation systems (Table 3). Furthermore, some authors have found that SOC may increase significantly on the first ten years of the cocoa agroforestry systems (Beer et al., 1990; Albrecht and Kandji, 2003; Isaac et al., 2005), since the shade trees add organic matter to the soil, recycle nutrients, and increase soil fertility among others.

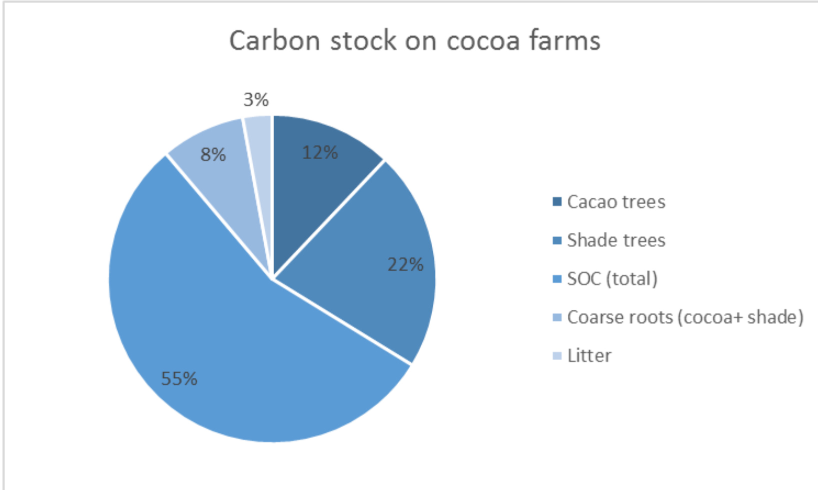

Figure 3. Carbon stock average (%) on cocoa farms in West Sulawesi

Table 3. Carbon stock average (t ha^{-1}) of cacao trees and shade trees in the three shade management systems (n=30)

Average	Shade management 1	Shade management 2	Shade management 3	Average
Cacao trees	10.7	11.3	10.5	10.9
Shade trees	16.1	21.4	21.3	19.6
SOC (0-10 cm)	32.4	27.6	24.7	28.2
SOC (10-20cm)	23.2	20.7	20.5	21.5
SOC (total)	55.6	48.3	45.2	49.7
Coarse roots (cocoa+ shade)	6.6	8.1	7.8	7.5
Litter	2.5	2.3	2.9	2.6
Total	91.5	91.4	87.7	90.3

Carbon above-ground was the second highest contributor to total carbon stock (34%, Fig. 3), and it was lower in the first system, while the second and third system did not differ significantly, despite the difference in tree density (Table 4). This could be explained by the high number of banana shade trees present in the third system. In general, the shade trees of the study area have a carbon stock rate of 1.5 t ha^{-1} $year^{-1}$. Timber trees did not contribute in higher proportion to the carbon stock mainly by the low tree density and DBH. It is recommended to increase number of trees with DBH classes from 30-40 cm and more than 40 cm. If the number of large trees increases in 56 trees ha^{-1}, the carbon stock would increase up to 40% with carbon stock rate of 2.1 t ha^{-1} $year^{-1}$. Fruit trees were the most diverse group (50% of the total tree species) with the highest DBH values and the highest carbon stock (Table 4). Legume trees such as *Leucaena* *leucocephala* and *Gliricidia sepium* had small DBH values since they are used as forage to feed the cattle. It is suggested to increase the number of legume trees to improve food security, carbon stock and nitrogen fixation, which could lead to a reduction of chemical fertilizer use thus carbon footprint.

Table 4. Carbon stock average considering the shade tree typology (n=30)

Shade trees type	Fruit tree	Banana	Coconut	Areca Palm	Timber	Others	Total
Carbon stock (t ha^{-1})	11.3	0.2	5.9	0.2	0.4	1.6	19.7

The total above-ground carbon stock in cacao and shade trees is 30 t ha^{-1}, which is still quite low if compared with other cocoa areas in other countries. For instance, Somarriba et al. (2013) recorded an average of 49.2 t ha^{-1} with 866 tree density between five countries in Central America, including specialized, productive and mixed shade management systems, which are comparable to our systems. Schroth et al. (2014) reported on rustic shade systems in Brazil have carbon stock around 69 t ha^{-1}, with cacao tree density of 872 and annual yield of 275 kg ha^{-1}. In this case, only trees with DBH equal or higher than 30 cm were considered. Rustic shade system is focus in the increment of carbon sequestration rather than yield. Other studies are included in Table 5 and show variability of the results depending on methodology and farm and soil condition and management.

Table 5. Carbon stock in different cocoa agroforestry systems.

Country	Source	C stock (Mg ha^{-1})	Tree density (cocoa + shade)
Cameroon	Norgrove and Hauser (2013)	166.8	1477
Costa Rica	Bustillos	52.7	1071
Indonesia	Leuschner et al. 2013	31.7	1360
Bolivia	Jacobi et al. 2014	73.3	921

Deforestation of primary and secondary forest to grow cocoa must be avoided to maintain SOC, nutrient recycling, soil fertility, and reduce GHG emissions. For instance, van Noordwijk et al. (1997) reported in Sumatra soil lost in upper soil (15 cm) of about 10 Mg C ha^{-1} after the conversion of primary forest to slash-and-burn fields. On the other hand, the use of organic fertilizer and appropriate waste management would increase carbon sequestration besides the reduction of nitrous oxide emissions. For example, the use of cocoa pod husks, pruning waste, and litter as compost, could maximize the nutrient use for the cacao tree besides helping to rehabilitate the soil. The cocoa husks can be fragmented and buried into the ground around all the cocoa area (CSP, 2013). Another alternative would be using the shade trees pruning (*Gliricidia, Leucaena*), grasses and pod husks to feed the animals, while using the manure of animals for compost and biogas to produce energy (CSP, 2013).

Carbon footprint

The emissions were categorized in four groups according to the annual yield and amount of applied fertilizer (Urea, NPK, TSP) with a total of 51,620 farmers. The values were classified as best and worst scenario depending on the soil properties found in the study (Table 6). About 52.3% of farmers with yield between 10-500 kg ha^{-1} apply on average 0.5 kg ha^{-1} of fertilizer per kg of cocoa bean produced, while the 1.1% of farmers with yield more than 2,000 kg ha^{-1} apply on average 0.17 kg per kg of cocoa beans produced. Because of this dosage, the value of average GHG emissions in the first group is higher compared to the fourth group (4.03 and 0.9 CO_2e t^{-1} respectively). The average carbon footprint resulted in 2.36 t CO_2e t^{-1} of cocoa. When applied to average SCPP farm with yield of 517 kg ha^{-1} and a size of 1.02 ha, there is 1.2 t CO_2e emitted annually on each farm.

Only 7.4% of the farmers use compost as organic fertilizer. These farmers contribute to a low carbon footprint by the reduction of CO_2 and N_2O released to the atmosphere, and also by the sequestration of carbon in the soil (depending on the time frame they have used it) that can offset the emissions, creating an overall net decrease on the farm's emissions. Using organic fertilizer not just emits less, but has a benefit on sequestering carbon in the soil and enhancing soil fertility.

Table 6. GHG emissions average from applied fertilizer (n=51,620) according to annual yield.

Area (Ha)	Yield group	SOM* (%)	Soil texture	Soil drainage	pH	Yield (kg ha^1)	Fert (kg ha^1)	Farmer (%)**	Fertilizer (t CO_2e t^{-1})***
1.2	1	>1.72	Medium	Good	4-5.5	305.6	157.5	52.3	2.34
1.2	1	1.72- 5.19	Coarse	Poor	5.6-7.3	305.6	157.5	52.3	5.72
1.1	2	>1.72	Medium	Good	4-5.5	687.8	305.4	36.9	1.81
1.1	2	1.72- 5.19	Coarse	Poor	5.6-7.3	687.8	305.4	36.9	4.19
1.0	3	>1.72	Medium	Good	4-5.5	1273.3	377.2	9.7	0.93
1.0	3	1.72- 5.19	Coarse	Poor	5.6- 7.3	1273.3	377.2	9.7	2.12
0.5	4	>1.72	Medium	Good	4-5.5	2396.9	413.2	1.1	0.54
0.5	4	1.72- 5.19	Coarse	Poor	5.6- 7.3	2396.9	413.2	1.1	1.24

* Soil organic matter (SOM)
**The percentage of farmers with specified yield and fertilizer
*** GHG emissions of 1 t of applied fertilizer per 1 t of produced dry cocoa bean

If the 10% of farmers with lower yields (305.6 kg ha[1]) switch to higher yields the carbon footprint would get reduced by 0.3 kg CO_2e t^{-1} (Table 6). However, if the amount of applied fertilizer gets reduced by 0.2 t per kg of cocoa bean produced, the emissions would get reduced from 2 to 1.3 t CO_2e t^{-1} in the best case scenario. Additionally, in the worst scenario, the emissions would get reduced from 4.8 to 2.8 CO_2e t^{-1} (Table 7). The chemical fertilizer in amount of 0.2 t could be replaced by adding organic fertilizer. In this case, the carbon footprint would increase only by 0.3 kg CO_2e t^{-1}. In conclusion, the more efficient application of fertilizer, combined with organic fertilizer and higher yields would result in a lower carbon footprint.

Table 7. Total GHG emissions (t CO_2e t^{-1}) from applied fertilizer (n=51,620) according to annual yield and percentage of farmers

t CO_2e t^{-1*}	Chemical Fertilizer	Compost	Farmers increase yield in 10%	Farmers reduce fertilizer dose on average 0.2 t ha[1]	Replace with compost on average 0.2 t ha[1]
Best soil parameters	2	0.58	1.7	1.3	0.3
Worst soil parameters	4.8	0.65	4.1	2.8	0.4

* Unit of GHG emissions: 1 t of applied fertilizer per 1 t of produced dry cocoa bean

Fertilizer application to the soil releases carbon dioxide (CO_2) and nitrous oxide (N_2O). N_2O is the main contributor to the total GHG emissions, due to its global warming potential around 298. It means that 1 kg of N_2O is almost 300 times more than 1 kg of CO_2. Consequently, N_2O has the ability to remain in the atmosphere 114 years before being sunk or destroyed by chemical reactions (IPCC, 2007b). As mentioned before, using pod husks as compost would also sequester carbon in the soil (see more details in section carbon stock under Results).

SCPP Baseline

Carbon stock and carbon footprint are two separate and largely independent measures of climate impact. The climate benefits of high standing carbon stocks in a land use system are not captured in the carbon footprint which measures carbon flows between the production system and its environment (van Rixkoort, 2014). Therefore, SCPP decided to use and measure the two values separately.

As per SCPP target, decreasing emissions and increasing carbon sequestration by 30% in 2020 will end in a change of carbon stock from 90.3 to 101.5 t C ha-1 and from 2.36 to 1.73 t CO2e ha-1 in the carbon footprint (Table 8). The following table shows the net emissions on each year. It is important to realize that this projection will might happened only if the appropriate recommendations are followed.

Table 8. Projections of carbon footprint reduction (%) according to SCPP 2020 KPI planning

	2015	2016	2017	2018	2019	2020	Total
Reduction (%) in t CO_2e emission by the cocoa sector	**0**	**10**	**15**	**20**	**25**	**30**	**30**
GHG emissions (t CO2e/t) from use of agri-inputs	2.36	2.24	2.13	2.02	1.92	1.73	1.73
Carbon sequestration (t C/ha) in cocoa farms by appropriate shade management systems	90.3	92.4	94.6	96.9	99.3	101.5	101.5

Further recommendations

Where to grow cocoa?

To reach the desirable goals, it is mandatory to avoid the conversion of primary and secondary forest to grow cocoa. Instead, cocoa could be grown in fallow land and in old cocoa farms, by rehabilitation and replanting techniques. Fallow land rehabilitation will restore some of the high biomass and SOC lost when forest was first converted. Selecting loamy soils and avoiding pure clay soils to grow cocoa is also important. Loamy soils increase soil moisture and have good drainage, which reduces GHG emissions. Any burn activity to clear land has to be avoided too. Burning releases high amount of CO_2 and does not allow organic matter to decompose, which decreases SOC. Determining other clearing methods improves soil fertility and structure. Mulching is another clearing method, which would increase soil organic matter and reduce erosion (Teusch and Hoffman, 2005). Avoiding high slopes to grow cocoa (>25%) and in areas with slopes higher than 10% increase shade tree density and maintain terracing to prevent soil erosion is crucial. Farm maintenance such as regular pruning of cacao and shade trees, routine weeding as many times as necessary to reduce nutrient competition with cacao trees, and removal of diseased pods are critical to keep the farm healthy and productive. These practices would enhance cacao and shade tree growth and carbon sequestration.

Carbon footprint measurement

SCPP tested two methodologies of GHG emissions estimation with very different results. The UNFCCC/CCNUCC approach is a simple tool to be embedded in agriculture programs' monitoring systems. As the majority of the CO2eq is emitted by use of fertilizers, the data on its use are enough to measure the progress in time. However, for more complex studies, the Cool Farm Tool, including more details on farm and area condition might be more accurate. This would mean much more resources involved thus it is less suitable for programs working with large amount of smallholder farmers in different areas due to unavailability of some data such as soil quality. Therefore, SCPP continues using the first tool and might test more methods in the future.

Above-ground biomass: Shade trees

Productive shade trees such as fruit trees and legumes that can increase carbon stock while improving food security are recommended. Legume trees are able to provide other ecosystem services such as nitrogen fixation, which could reduce the amount of applied chemical fertilizer. Natural regeneration of native species is also highly recommended to increase carbon stock. Shade trees with deep roots have shown to also enhance SOC and below-ground biomass. Shade trees with large and cylindrical trunks like mahogany (*Swietenia macrophylla*) would enhance above-ground carbon, while small canopies with light foliage such as *Albizia* sp., would allow light to go through without compromising cocoa yield (Somarriba et al. 2013). Shade trees with DBH lower than 10 cm when mature should be avoided, because the carbon store is insignificant, and the percentage of DBH class 10-20 cm (54.7%) should be reduced and the DBH > 30 cm (21%) increased respectively. A high density of shade trees provide a micro-environment when extreme changes of rainfall and temperature occur, by buffering humidity and soil moisture availability and by enhancing soil organism activity (Martius et al. 2004; Siles et al. 2010). See the section of carbon stock under results for specific recommendations.

Fertilizer

Reducing the variety and dose of applied fertilizer is recommended. Some farmers apply up to four different types of fertilizers, including urea, NPK, ZA and TSP (1.3%) where a relatively high amount is then depleted to the soil. Many farmers utilize fertilizers inefficiently, often believing it can replace the benefits of organic matter and adding more fertilizer means higher yields. The right composition (organic and inorganic), dosage, time and place is crucial to achieve good results while conserving the soil and decrease carbon footprint. Therefore to increase the farmers' knowledge on this topic is a key. Furthermore, specific cocoa fertilizer might solve part of the issue. For example, in Ghana it was found that NPK (0-18-23) was the most appropriate fertilizer and farmers are encouraged to use only this one (Asare et al., 2013). See the section of Carbon footprint under results for specific recommendations.

Fieldwork recommendations

Due to large variability of cocoa farms and regions in Indonesia, more studies in more areas are needed to estimate the carbon stock. The following systems should be assessed in the other regions of Indonesia (Table 9). The distance between sample plots must be as far as needed depending on the study area and sample size, to capture as much diversity as possible. During the fieldwork it is very important to check the accuracy of the following data: number of cacao trees per ha; distance between cacao trees; area of cocoa farm/garden/plot, and age of the cacao trees. In case that a shade tree cannot be identified, a leave sample must be taken to herbarium for further identification. Dead wood should be included in future carbon studies.

Table 9. System of cocoa carbon stock and carbon footprint assessment for future studies.

Topography	Production systems		Characteristics and shade trees
	Clones	Hybrids	
Lowland	3x3 cacao trees = ~1100 trees		1. Full sun 2. Acidic-clay based soils 3. Maybe drainage
	4x3 cacao trees = ~900 trees		1. Coconut at 10x10 = ~100/ha 2. Acidic clay-based soils 3. Maybe drainage
		4x4 cacao trees = ~625 trees	Variety of fruit trees, sometimes coconut
Slopes	3x3 cacao trees = ~1100 trees		1. Random mixed shade species of varying intensity 2. Poor drainage/contouring/soil erosion control
		4x4 cacao trees = ~625 trees	1. Random mixed shade species of varying intensity 2. Poor drainage/contouring/soil erosion control

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