

## Development of Prototype Project for Carbon Storage and Greenhouse Gas Emission Reduction from Thailand's Agricultural Sector (Pembangunan Projek Prototip untuk Penyimpanan Karbon dan Pengurangan Pelepasan Gas Rumah Hijau daripada Sektor Pertanian di Thailand)

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### ABSTRACT

*At present, the world is facing many crises. One of the major crises is the climate change problem or the greenhouse effect caused by carbon dioxide that is released into the atmosphere. This is ranked as the main cause of global warming. The purpose of this research was to develop a prototype project for carbon storage and GHG emissions reduction from the agricultural sector according to T-VER methods developed for Thailand. The research methods were to calculate the carbon storage of trees and the GHG emissions reduction according to the T-VER-METH-AGR-02. The results of the project implementation can summarize the amount of GHG in the whole study area of 115,520 m<sup>2</sup> as follows; The carbon storage from the yearly project implementation was at 69.54 tCO<sub>2</sub>e/y and the carbon storage within 7 years of the project implementation was at 486.78 tCO<sub>2</sub>e. The GHG emissions reduction from the yearly project implementation was at 0.307 tCO<sub>2</sub>e/y and the GHG emissions reduction within 7 years of the project implementation was at 2.149 tCO<sub>2</sub>e. The calculation of the amount of carbon storage and GHG emissions from the activities during the project lifetime was found at 488.93 tCO<sub>2</sub>e. In addition, orchard owners can use this research-based approach to calculate the carbon storage of trees and the GHG emissions reduction in their orchards and to prepare for the carbon offset process from voluntary sector under the T-VER.*

*Keywords: Agriculture sector; carbon storage; GHG emissions reduction; T-VER*

### ABSTRAK

*Pada masa ini, dunia sedang menghadapi banyak krisis. Salah satu krisis utama adalah masalah perubahan iklim atau kesan rumah hijau yang disebabkan oleh karbon dioksida yang dilepaskan ke atmosfera. Ia merupakan penyebab utama pemanasan global. Tujuan penyelidikan ini diadakan adalah untuk membangunkan satu projek prototip bagi penyimpanan karbon serta pengurangan pelepasan GHG daripada sektor pertanian mengikut metod T-VER yang dibangunkan untuk Thailand. Kaedah penyelidikan ini adalah untuk menghitung penyimpanan karbon oleh pokok dan pengurangan pelepasan GHG mengikut T-VER-METH-AGR-02. Keputusan daripada pelaksanaan projek ini boleh merumuskan jumlah GHG dalam keseluruhan kawasan kajian iaitu 115,520 m<sup>2</sup> seperti berikut; penyimpanan karbon daripada pelaksanaan projek tahunan ialah pada 69.54 tCO<sub>2</sub>e/y dan penyimpanan karbon dalam tempoh 7 tahun dari pelaksanaan projek ialah pada 486.78 tCO<sub>2</sub>e, pengurangan pengeluaran GHG daripada pelaksanaan projek tahunan ialah pada 0.307 tCO<sub>2</sub>e/y dan pengurangan pengeluaran GHG dalam tempoh 7 tahun pelaksanaan projek adalah pada 2.149 tCO<sub>2</sub>e. Pengiraan jumlah penyimpanan karbon dan pengeluaran GHG daripada aktiviti sepanjang tempoh projek ialah pada 488.93 tCO<sub>2</sub>e. Di samping itu, para pemilik kebun boleh menggunakan pendekatan berasaskan penyelidikan ini untuk menghitung penyimpanan karbon oleh pokok dan pengurangan pengeluaran GHG di dalam kebun mereka serta menyediakan proses ofset karbon daripada sektor sukarela di bawah T-VER.*

*Kata kunci: Pengurangan pengeluaran GHG; penyimpanan karbon; sektor pertanian; T-VER*

### INTRODUCTION

The problems of global warming and climate change have been progressively severe and increasingly affecting worldwide (He 2017; Jordan et al. 2014; Laosuwan & Uttaruk 2016). From the study of Intergovernmental Panel on Climate Change (IPCC 2007), the organization that is responsible for providing scientific information to United Nations Framework Convention on Climate Change (UNFCCC 2009), reported that the average global surface temperature is currently about 0.8°C higher than

100 years ago. Also, there is the evidence that clearly ensures that the global temperature is related to the amount of CO<sub>2</sub> in the atmosphere. Throughout the past 650,000 years, the world's atmosphere never had the amount of CO<sub>2</sub> exceeding 300 ppm (part per million). But now, the world's atmosphere had CO<sub>2</sub> concentration up to 380 ppm (UNFCCC 2009). At present, human activities, especially the uses of fossil fuel, accelerating greenhouse gas (GHG) emissions, such as CO<sub>2</sub>, methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) into the atmosphere. These activities are increasing

the amounts of these gases dramatically (IEA 2011; IPCC 2014). At any rate, IPCC has stated about the danger from the global climate change that has already begun and might be caused by GHG emissions. Therefore, it is necessary to find out methods to reduce GHG emissions (FAO 2015) and the potential climate change in the future.

The agriculture sector plays a complex role in global warming (Boonsang & Arunpraparat 2011; Burney et al. 2010; Johnson et al. 2005; Samek et al. 2011; Tubiello et al. 2013) by being both a source of GHG emissions and carbon sequestration (Adani et al. 2017; FAO 2010; Paustian et al. 1997; Ruesch & Gibbs 2008). Agricultural activities contribute to significant GHG emissions, such as emissions of CH<sub>4</sub> and N<sub>2</sub>O from rice farming, nitrogen fertilization, organic fertilizer production, and livestock (Barsotti et al. 2013; IPCC 2007; Lal 2004). Carbon sequestration in agricultural areas is caused by carbon storage in plants and soils that is similar to carbon storage in forest areas (Uttaruk & Laosuwan 2016). But the durations of storage and ecological disturbance are different (Uttaruk & Laosuwan 2018). Although the potential for reducing greenhouse gases in the agriculture sector is not quite distinctly effective as other manufacturing sectors, however, agricultural areas can help reduce greenhouse gases and capture carbon in plants and soils as well (Liebig et al. 2010; Sainju 2015; Santika et al. 2017). While other manufacturing sectors, particularly industries, could not reduce existing greenhouse gases in the atmosphere. For these reasons, the use of agricultural areas as a source of carbon sequestration and GHG emissions reduction is highly potential and very interesting, especially in Thailand which has more than 243,730.814 km<sup>2</sup> of agricultural areas (Land Development Department 2016).

From the recent implementation of the Clean Development Mechanism (CDM) project in Thailand, there

were many obstacles, such as high transaction costs, strict operating regulations, document, proposal and project verification, GHG emissions reduction, delays in project registration, carbon credits as well as Certified Emission Reductions (CERS) that tended to decrease significantly. As a result, the development of the CDM project had been hold or abandoned by those who have already started the project and those who were developing new projects (TGO 2013). For Thailand, the Thailand Greenhouse Gas Management Organization (TGO) has its main missions to support the implementation for climate change, particularly GHG emissions reduction. Thus, the Thailand Voluntary Emission Reduction Program (T-VER) has been developed (Dransfeld et al. 2015; ICAP 2017; Kittisompun 2014; Lohsomboon 2014; TGO 2015;) with following objectives: To promote participation in the voluntary emission reduction in the country, to encourage domestic carbon markets to accommodate future carbon credit trading, and to urge all sectors to get ready to the mission of GHG emissions reduction. This implementation aimed to support and encourage all sectors to participate in the voluntary emission reduction in the country, particularly in forestry and the agricultural sector, which play an important role in climate change. It contributed to reducing GHG emissions through activities for greenhouse gas storage as well as producing benefits for economics, society and environments.

#### OBJECTIVE

The main objective of this study was to develop a prototype project for carbon sequestration and GHG emissions reduction from the agricultural sector. The study areas selected were orchards in Sang Kho sub district, Phu Phan district, Sakon Nakhon province in northeast Thailand (Figure 1).

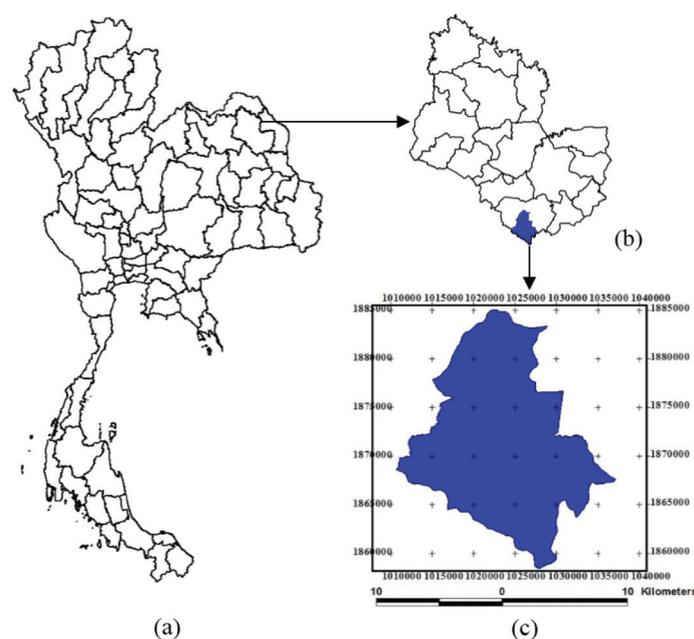


FIGURE 1. The study area

The carbon storage of trees and the GHG emissions reduction was calculated according to T-VER-METH-AGR-02 methods (TGO 2014). The expected results were approaches and good practice for various sectors in Thailand to be used as a guideline for developing the T-VER project and to implement greenhouse gas reduction activities, which will result in a long-term reduction of the overall GHG emissions in Thailand and lead to sustainable development of the country in the future onwards (TGO 2015, 2014, 2013).

## MATERIALS AND METHODS

To achieve the objectives of the prototype project that focuses on main issues based on the scope of the study of the voluntary emission reduction for carbon storage in the orchards, this research will be carried out under T-VER methods. The procedures and implementation details are as follows;

### SITE SELECTION AND PREPARATION OF AGRICULTURISTS BEFORE PARTICIPATING IN THE PROJECT

The meeting was held to clarify the objectives and details of the project to provide information to 12 orchard owners (agriculturists) who were interested and want to participate in the project voluntarily. Then, the training workshop on climate change knowledge and participation of agriculturists who were working in the orchards on climate change were organized. The purposes were to help the interested agriculturists understand the causes of climate change, effects of climate change on global and local levels, including economics, society, environments, health and roles of the orchard agriculturists on mitigation of global climate change.

After the application of interested agriculturists who were interested to participate in the project, the researchers had mutually surveyed the area for planting fruit trees, collected data and verified qualifications in order to meet the requirements of the T-VER-TOOL-FOR/ AGR-01 methods consisting of surveys of the baseline and historical data of the area, the uses of fertilizers and soil amendments during the project implementation by using a data survey form. Then, all people involved had conducted training about techniques of surveying plant data, measuring biological data of plants in plots, sampling a sample from plots at least 1% of the plot area to evaluate the amount of carbon storage in several parts of trees by making 20 × 20 meter-sized sample plots in a total of 13 plots, measuring heights of trees at 1.30 meters and recording names, sizes and heights of trees.

### CALCULATION OF THE AMOUNTS OF SEQUESTRATION AND GHG EMISSIONS REDUCTION

Based on the research implementation, the calculation of carbon storage of trees and the GHG emissions reduction was calculated according to T-VER-METH-AGR-02 methods, the analysis of aboveground biomass of trees had used the allometric equation developed for local plants in

Thailand. There were 13 kinds of fruits planted in the study area including Santol (*Sandoricum koetjape* Burm.); Jack Fruit (*Artocarpus heterophyllus* Lam.); Sugar Apple (*Annona squamosa* L.); Tamarind (*Tamarindus indica* L.); Indian Gooseberry (*Phyllanthus emblica* L.); Lime (*Citrus aurantifolia* Swing.); Marian Plum (*Bouea macrophylla* Griffith.); Burmese Grape (*Baccaurea ramiflora* Lour.); Longan (*Dimocarpus longen* Lour.); Lychee (*Litchi chinensis*. Sonn.); Pomelo (*Citrus maxima* Merr.); Mulberry (*Morus alba* Linn.); Maoberry (*Antidesma thwaitesianum* Mull. Arg.), was used the allometric equation as described in (1) developed by Ogawa et al. (1965). Another kind of fruit was Mango (*Mangifera indica* L.) used the allometric equation as described in (2) developed by Klinhom et al. (2011) and the allometric equation as described in (3) developed by Issaree (1982) to calculate Sapling.

$$\begin{aligned} W_S &= 0.396(D^2H)^{0.933} \\ W_B &= 0.00349(D^2H)^{1.030} \\ W_L &= (28 / (W_S + W_B + 0.025))^{-1} \\ W_T &= W_S + W_B + W_L \end{aligned} \quad (1)$$

$$\begin{aligned} W_S &= 1.525(D^2H)^{0.33604} \\ W_B &= 0.954(D^2H)^{0.50995} \\ W_L &= 0.913(D^2H)^{0.22404} \\ W_T &= W_S + W_B + W_L \end{aligned} \quad (2)$$

$$\begin{aligned} W_S &= 1.525(D^2H)^{0.66513} \\ W_B &= 0.954(D^2H)^{0.58255} \\ W_L &= 0.913(D^2H)^{0.44363} \\ W_T &= W_S + W_B + W_L \end{aligned} \quad (3)$$

where  $W_T$  is the total of tree (kg);  $W_S$  is the weight of the stem (kg);  $W_B$  is the weight of branches (kg);  $W_L$  is the weight of leaves (kg);  $D$  is the diameter at breast height (cm); and  $H$  is the tree height (m).

The activities of greenhouse gas storage and emissions (Table 1) used for the calculation in this study were: the calculation of greenhouse gas stored/reduced from the baseline including the calculations of greenhouse gas storage under the baseline and GHG emissions under the baseline (baseline is the case of greenhouse gas emission in normal conditions, in the event that no greenhouse gas emission reduction project has been implemented), and the calculation of GHG emissions stored/reduced from the project implementation including the calculation of greenhouse gas stored/reduced from the project

TABLE 1. Greenhouse gas storage and emissions activities used in the calculation

	Emissions /storage	Types of Greenhouse Gases	Details
Greenhouse gas storage under base line	Above Ground Biomass: ABG	CO <sub>2</sub>	Calculated from the amount of biomass of trees stored above the ground, such as the stems, branches and leaves
	Below Ground Biomass: BLG	CO <sub>2</sub>	Calculated from the biomass of underground (root)
Greenhouse gas storage above base line	Direct N <sub>2</sub> O emissions from fertilizer application	N <sub>2</sub> O	Calculated from the amount of fertilizer and organic fertilizer used in cultivation
	N <sub>2</sub> O emissions from evaporation in the form of NH <sub>3</sub> and NO <sub>x</sub>	N <sub>2</sub> O	Calculated from the amount of fertilizer and organic fertilizer used in cultivation
	N <sub>2</sub> O emissions from leaching through the soil	N <sub>2</sub> O	Calculated from the amount of fertilizer and organic fertilizer used in cultivation
	CO <sub>2</sub> emissions from using urea fertilizer	CO <sub>2</sub>	Calculated from the amount of fertilizer and organic fertilizer used in cultivation
	CO <sub>2</sub> emissions from the use of lime and dolomite	CO <sub>2</sub>	Calculated from the consumption of lime and dolomite
	CO <sub>2</sub> emissions from burning fossil fuels	CO <sub>2</sub>	Calculated from the consumption of fossil fuels
Greenhouse gas storage from project implementation	Above Ground Biomass: ABG	CO <sub>2</sub>	Calculated from the amount of biomass of trees stored above the ground, such as the stems, branches and leaves
	Below Ground Biomass: BLG	CO <sub>2</sub>	Calculated from the biomass of underground (root)
Greenhouse gas emission from project implementation	Direct N <sub>2</sub> O emissions from fertilizer application	N <sub>2</sub> O	Calculated from the amount of fertilizer and organic fertilizer used in cultivation
	N <sub>2</sub> O emissions from evaporation in the form of NH <sub>3</sub> and NO <sub>x</sub>	N <sub>2</sub> O	Calculated from the amount of fertilizer and organic fertilizer used in cultivation
	N <sub>2</sub> O emissions from leaching through the soil	N <sub>2</sub> O	Calculated from the amount of fertilizer and organic fertilizer used in cultivation
	CO <sub>2</sub> emissions from using urea fertilizer	CO <sub>2</sub>	Calculated from the amount of fertilizer and organic fertilizer used in cultivation
	CO <sub>2</sub> emissions from the use of lime and dolomite	CO <sub>2</sub>	Calculated from the consumption of lime and dolomite
	CO <sub>2</sub> emissions from burning fossil fuels	CO <sub>2</sub>	Calculated from the consumption of fossil fuels

implementation and the calculation of GHG emissions from the project implementation. According to the T-VER-METH-AGR-02 methods, there was no leakage emission calculation.

#### CALCULATION OF THE AMOUNTS OF GREENHOUSE GASES STORED /REDUCED FROM THE BASELINE

The calculation of carbon sequestration under the baseline was conducted according to the calculation of carbon sequestration of trees (T-VER-METH-AGR-02) as shown in (4). For the calculations of Above Ground Biomass (ABG) and Below Ground Biomass (BLG) were conducted from (5) to (8), respectively.

Calculation of carbon sequestration under the baseline.

$$C_{TT_0} = C_{ABG_0} + C_{BLG_0} \quad (4)$$

where  $C_{TT_0}$  is the amount of carbon storage of the project area in the baseline (tCO<sub>2</sub>/y);  $C_{ABG_0}$  is the amount of carbon storage above ground in baseline case (tCO<sub>2</sub>/y); and  $C_{BLG_0}$  is the amount of carbon storage below ground in baseline case (tCO<sub>2</sub>/y).

ABG Calculation

$$AGB = W_S + W_B + W_L \quad (5)$$

BGB Calculation

$$BFB = AGB * R \quad (6)$$

where  $R$  is the stem and root biomass ratio was 0.27 (IPCC 2006).

Calculation of carbon content in biomass

$$C_{AGB} = AGB * CF \quad (7)$$

$$C_{BGB} = BGB * CF \quad (8)$$

where  $CF$  is the carbon fraction is 0.47 (IPCC 2006).

Calculation of GHG emissions from the baseline

$$C_{BSL} = NBL + CBL + FBL \quad (9)$$

where  $C_{BSL}$  is the amount of GHG emissions under base line (tCO<sub>2</sub>e/y);  $NBL$  is the N<sub>2</sub>O emissions from fertilizer application (tCO<sub>2</sub>e/y);  $CBL$  is the CO<sub>2</sub> emissions from fertilizer application (tCO<sub>2</sub>e/y); and  $FBL$  is the emission CO<sub>2</sub> from burning fossil fuels.

Calculation of N<sub>2</sub>O emissions from fertilizer use in agriculture.

$$NBL = NBL_{DR} + NBL_{IDR} \quad (10)$$

where  $NBL$  is the N<sub>2</sub>O emissions from fertilizer application (tCO<sub>2</sub>e/y);  $NBL_{DR}$  is the N<sub>2</sub>O direct emissions (calculated) (tCO<sub>2</sub>e/y); and  $NBL_{IDR}$  is the Indirect N<sub>2</sub>O emissions (calculated) (tCO<sub>2</sub>e/y).

N<sub>2</sub>O direct emissions (calculated)

$$NBL_{DR} = [(F_{SN,i} + F_{ON,i}) \times EF_2] \times \frac{44}{28} \times GWP_{N_2O} \quad (11)$$

where  $NBL_{DR}$  is the N<sub>2</sub>O direct emissions (calculated) (tCO<sub>2</sub>e/y);  $F_{SN,i}$  is the N<sub>2</sub>O chemical fertilizer type (tN<sub>2</sub>O/year);  $F_{ON,i}$  is the N<sub>2</sub>O from Organic Fertilizer type (tN<sub>2</sub>O/year);  $EF_2$  is the GHG emissions factor (Set to 0.01);  $GWP_{N_2O}$  is the Global Warming Potential for N<sub>2</sub>O (set to 298).

Indirect N<sub>2</sub>O emissions (calculated)

$$\begin{aligned} NBL_{IDR} &= [(F_{SN,i} + F_{ON,i}) \times EF_2] \times \frac{44}{28} \times GWP_{N_2O} \\ N_2O_{(v),i} &= [(F_{SN,i} \times frac_{NH_3-NO_x,1}) + (F_{ON,i} \times frac_{NH_3-NO_x,2})] \times EF_3 \\ N_2O_{(L),i} &= (F_{SN,i} + F_{ON,i}) \times frac_{leach} \times EF_4 \end{aligned} \quad (12)$$

where  $NBL_{IDR}$  is the Indirect N<sub>2</sub>O emissions (calculated) (tCO<sub>2</sub>e/y);  $N_2O_{(v),i}$  is the N<sub>2</sub>O emissions from evaporation in NH<sub>3</sub> + NO<sub>x</sub> of fertilizer type (tN<sub>2</sub>O/y);  $N_2O_{(L),i}$  is the N<sub>2</sub>O emission from soil permeability of fertilizer type  $i$  (tN<sub>2</sub>O/y);  $GWP_{N_2O}$  is the Global Warming Potential for N<sub>2</sub>O (set to 298);  $F_{SN,i}$  is the N<sub>2</sub>O content from chemical fertilizer type  $i$  (tN<sub>2</sub>O/y);  $F_{ON,i}$  is the N<sub>2</sub>O content of organic fertilizer type  $i$  (tN<sub>2</sub>O/y);  $F_{SN,i} \times frac_{NH_3-NO_x,1}$  is the

percentage of chemical fertilizer evaporation in NH<sub>3</sub> + NO<sub>x</sub> (set to 0.1);  $F_{ON,i} \times frac_{NH_3-NO_x,2}$  is the proportion of volatile organic compounds in NH<sub>3</sub> + NO<sub>x</sub> (set to 0.2);  $frac_{leach}$  is the proportion of leaching fertilizer (set to 0.3);  $EF_3$  is the GHG emissions factor (set to 0.01); and  $EF_4$  is the GHG emissions factor (set to 0.0075).

Calculation of CO<sub>2</sub> emissions from the uses of urea fertilizer and lime in the agricultural sector

$$CBL = CBL_{UR} + CBL_{LS} \quad (13)$$

where  $CBL$  is the CO<sub>2</sub> emissions from urea and mortar use (tCO<sub>2</sub>/y);  $CBL_{UR}$  is the CO<sub>2</sub> emissions from Urea Fertilizer (t/year); and  $CBL_{LS}$  is the CO<sub>2</sub> emissions from the use of cement (Tons per year).

Calculation of GHG emissions under the baseline was CO<sub>2</sub> emissions from fossil fuel combustion from the uses of machines for fertilizer applications.

$$FBL = \sum_{i=1}^n Fuel_{i,0} \times EF_i \quad (14)$$

$$Fuel_{i,0} = FC_{Fuel,i} \times NCV_{Fuel,i} \times 10^{-3}$$

where  $FBL$  is the CO<sub>2</sub> emissions from burning fossil fuels (tCO<sub>2</sub>/y);  $Fuel_{i,0}$  is the energy consumption of fuels type  $i$  in base line year (MJ);  $EF_i$  is the coefficient of GHG emissions of type (as determined by TGO);  $FC_{Fuel,i,0}$  is the energy consumption of fuels type  $i$  in base line year (units per year);  $NCV_{Fuel,i}$  is the net heating value of fuel type  $i$  (MJ per unit).

#### CALCULATION OF THE AMOUNTS OF GREENHOUSE GASES STORED /REDUCED FROM THE PROJECT IMPLEMENTATION

The calculation of carbon sequestration from the project implementation was conducted according to the method of calculating the carbon storage of trees T-VER-METH-AGR-02 as described in (15). In addition, T-VER-METH-AGR-02 had specified that the duration of the project implementation must be at least 7 years or over.

Calculation of carbon sequestration from the project implementation.

$$C_{TT_t} = C_{ABG_t} + C_{BLG_t} \quad (15)$$

where  $C_{TT_t}$  is the total carbon capture quantity of project area from Project Implementation in year (tCO<sub>2</sub>/y);  $C_{ABG_t}$  is the amount of ABG from project implementation in year (tCO<sub>2</sub>/y);  $C_{BLG_t}$  is the amount of BLG from project implementation in year (tCO<sub>2</sub>/y); and  $t$  is the year in which evaluation was conducted.

The calculation of the GHG emissions from the project implementation according to the T-VER-METH-AGR-02 methods was conducted by using (16). The calculation of N<sub>2</sub>O emissions from the uses of fertilizers in the agricultural sector was calculated by using (17) to (19). The calculation of CO<sub>2</sub> emissions from the uses of urea

fertilizers and lime in the agricultural sector was calculated by using (20). And the calculation of CO<sub>2</sub> emissions from fossil fuel combustion and the uses of machines in fertilizer applications was calculated by using (21).

GHG emissions from the project implementation

$$C_{PROJ} = NPE + CPE + FPE \quad (16)$$

where  $C_{PROJ}$  is the amount of GHG emissions from the project (tCO<sub>2</sub>/y);  $NPE$  is the N<sub>2</sub>O emission from fertilizer application (tCO<sub>2</sub>/y);  $CPE$  is the CO<sub>2</sub> emissions from fertilizer application (tCO<sub>2</sub>/y); and  $FPE$  is the CO<sub>2</sub> emission from burning fossil fuels (tCO<sub>2</sub>/y).

Calculation of N<sub>2</sub>O emissions from the uses of fertilizers in the agricultural sector

$$NPE = NPE_{DR} + NPE_{IDR} \quad (17)$$

where  $NPE$  = N<sub>2</sub>O emission from fertilizer application (tCO<sub>2</sub>e/y);  $NPE_{DR}$  = N<sub>2</sub>O direct emissions (calculated) (tCO<sub>2</sub>e/y);  $NPE_{IDR}$  = Indirect N<sub>2</sub>O emissions (calculated) (tCO<sub>2</sub>e/y)

- N<sub>2</sub>O direct emissions (calculated)

$$NPL_{DR} = [(F_{SN,i} + F_{ON,i}) \times EF_2] \times 44/28 \times GWP_{N_2O} \quad (18)$$

where  $NPL_{DR}$  is the N<sub>2</sub>O direct emissions (calculated) (tCO<sub>2</sub>e/y);  $F_{SN,i}$  is the N<sub>2</sub>O chemical fertilizer type  $i$  (tN<sub>2</sub>O/y);  $F_{ON,i}$  is the N<sub>2</sub>O from Organic Fertilizer type  $i$  (tN<sub>2</sub>O/y);  $EF_2$  is the GHG emissions factor (Set to 0.01);  $GWP_{N_2O}$  is the Global Warming Potential for N<sub>2</sub>O (set to 298).

- Indirect N<sub>2</sub>O emissions (calculated)

$$\begin{aligned} NPL_{IDR} &= (N_2O_{(v),i} + N_2O_{(L),i}) \times 44 / 28 \times GWP_{N_2O} \\ N_2O_{(v),i} &= (F_{SN,i} \times frac_{NH_3-NO_x,1}) + (F_{ON,i} \times frac_{NH_3-NO_x,2}) \times EF_3 \\ N_2O_{(L),i} &= (F_{SN,i} + F_{ON,i}) \times frac_{leach} \times EF_4 \end{aligned} \quad (19)$$

where  $NPL_{IDR}$  is the indirect N<sub>2</sub>O emissions (calculated) (tCO<sub>2</sub>e/y);  $N_2O_{(v),i}$  is the Global Warming Potential for N<sub>2</sub>O (set to 298);  $N_2O_{(L),i}$  is the N<sub>2</sub>O content from chemical fertilizer type  $i$  (tN<sub>2</sub>O/y);  $F_{ON,i}$  is the N<sub>2</sub>O content of organic fertilizer type  $i$  (tN<sub>2</sub>O/y);  $frac_{NH_3-NP_x,1}$  is the percentage of chemical fertilizer evaporation in NH<sub>3</sub> + NO<sub>x</sub> form (set to 0.1);  $frac_{NH_3-NO_x,2}$  is the proportion of volatile organic compounds in NH<sub>3</sub> + Nox (set to 0.2);  $frac_{leach}$  is the proportion of leaching fertilizer (set to 0.3);  $EF_3$  is the GHG emissions factor (set to 0.01); and  $EF_4$  is the GHG emissions factor (set to 0.0075).

Calculation of CO<sub>2</sub> emissions from the uses of urea fertilizer and lime in the agricultural sector

$$CPL = CPL_{UR} + CPL_{LS} \quad (20)$$

where  $CPL$  is the CO<sub>2</sub> emissions from urea and mortar use (tCO<sub>2</sub>/y);  $CPL_{UR}$  is the CO<sub>2</sub> emissions from Urea Fertilizer (t/y); and  $CPL_{LS}$  is the CO<sub>2</sub> emissions from the use of cement (t/y).

Calculation of GHG emissions under the baseline was CO<sub>2</sub> emissions from fossil fuel combustion from the uses of machines for fertilizer applications.

$$FPE = \sum_{i=1}^n Fuel_{i,0} \times EF_i \quad (21)$$

$$Fuel_{i,0} = FC_{Fuel_{i,0}} \times NCV_{Fuel,i} \times 10^{-3}$$

where  $FPE$  is the CO<sub>2</sub> emissions from burning fossil fuels (tCO<sub>2</sub>/y);  $Fuel_{i,0}$  is the energy consumption of fuels type in base line year (MJ);  $EF_i$  is the coefficient of GHG emissions of type  $i$  (as determined by TGO);  $FC_{Fuel_{i,0}}$  is the energy consumption of fuels type  $i$  in base line year (units per year); and  $NCV_{Fuel,i}$  is the net heating value of fuel type  $i$  (MJ per unit).

#### CALCULATION OF THE TOTAL AMOUNT OF GREENHOUSE GASES FROM THE PROJECT IMPLEMENTATION

The total greenhouse gases from the project implementation can be calculated by using (22).

$$C_{ORC} = (C_{TT_t} - C_{TT_0}) + (C_{BSL} - C_{Proj}) - C_{LEAK} \quad (22)$$

where  $C_{ORC}$  is the total GHG emissions from the project (tCO<sub>2</sub>/y);  $C_{TT_t}$  is the total carbon capture capacity of the project area from Project implementation in year (tCO<sub>2</sub>/y);  $C_{TT_0}$  is the total carbon stock of the project area under the base line (tCO<sub>2</sub>/y);  $C_{BSL}$  is the GHG emissions under the base line (tCO<sub>2</sub>e/y);  $C_{Proj}$  is the amount of GHG emissions from the project (tCO<sub>2</sub>e/y); and  $C_{LEAK}$  is the amount of GHG emissions from leakage (tCO<sub>2</sub>e/y).

## RESULTS AND DISCUSSION

### SITE SELECTION AND PREPARATION OF AGRICULTURISTS BEFORE PARTICIPATING IN THE PROJECT

For the results of area selection and preparation of agriculturists before participating the project, there were agriculturists in Sang Kho sub district, Phu Phan district, Sakon Nakhon province in northeast Thailand, who grew fruit trees and were interested to participate in the project in a total of 12 people. There were orchard areas in this project in a total of 115,520 m<sup>2</sup> with 14 kinds of fruit trees classified to be mixed cultures plating area of 105,600 m<sup>2</sup>, *Dimocarpus longan* Lour planting area of 9,920 m<sup>2</sup>, and *Annona squamosa* L. plantation area of 1,600 m<sup>2</sup>. For the survey results of the uses of fertilizers and soil improvements during the project implementation by

interviewing agriculturists who participated in the project, there were the uses of urea fertilizers with formula 46-0-0, constant formula 15-15-15, compound formula 16-8-8, and organic fertilizers. In addition, the agriculturists sometimes used lime-based soil amendments as well.

#### CALCULATION RESULTS OF GREENHOUSE GASES STORED/ REDUCED FROM THE BASELINE

Calculation results of greenhouse gas storage under the baseline: The calculation of greenhouse gas storage under the baseline from the accumulation in biomass form of fruit trees with the allometric equation could be found the greenhouse gas storage in the baseline of 1,569.63 tCO<sub>2</sub>e /y. The details are shown in Table 2.

Calculation results of GHG emissions under the baseline: The calculation results of the amount of GHG emissions from fertilizer applications in the baseline according to the equation for calculating GHG emissions in the baseline

were as follows. The GHG emissions in the project area in N<sub>2</sub>O form were at tCO<sub>2</sub>e/y with direct emissions of 2.035 tCO<sub>2</sub>e/y and indirect emission of 0.459 tCO<sub>2</sub>e/y. The total GHG emission in the form of N<sub>2</sub>O was 2.493 tCO<sub>2</sub>e/y. The amount of GHG emissions in CO<sub>2</sub> form from the uses of urea fertilizers and soil amendments were at 0.308 tCO<sub>2</sub>e/y. The total GHG emissions from the uses of urea fertilizers and soil amendments in the baseline were equivalent to 2.801 tCO<sub>2</sub>e/y. The details are shown in Table 3.

Calculating GHG emissions from the project implementation: The survey results of the uses of fertilizers and soil improvements during the project implementation by interview data of the agriculturists who participated in the project found the uses of urea fertilizer with formula 46-0-0, constant formula fertilizer 15-15-15, compound fertilizer 16-8-8 and organic fertilizers without soil amendments. The calculation results of GHG emissions from fertilizer applications in the project were as follows.

TABLE 2. Indicates the amount of GHG emissions from the plants in fruit tree plots from the baseline

Code	GHG storage volume from the sample plots (t CO <sub>2</sub> e)		C <sub>TT0</sub> (tCO <sub>2</sub> e)	Sample Plots	Size of plot (m <sup>2</sup> )	CO <sub>2</sub> density (tons/m <sup>2</sup> )	Participating areas (m <sup>2</sup> )	GHG storage capacity of the project area (tCO <sub>2</sub> e)
	AGB	BGB						
IN03001	6.93	1.87	8.80	2	800	28,864	11,840	130.60
IN03002	4.12	1.11	5.23	1	400	33,488	7,200	93.39
IN03003	7.48	2.02	9.50	3	1,200	20,816	20,480	162.13
IN03004	1.09	0.29	1.38	1	400	8,832	2,720	9.10
IN03005	0.17	0.05	0.22	1	400	4,720	6,560	3.64
IN03006	6.22	1.68	7.90	2	800	25,312	1,600	15.74
IN03007	13.69	3.70	17.39	3	1,200	37,136	20,000	289.08
IN03008	1.28	0.34	1.62	1	400	14,368	3,520	14.52
IN03009	4.34	1.17	5.52	2	800	17,776	8,960	61.60
IN03010	17.47	4.72	22.19	3	1,200	47,904	19,360	357.61
IN03011	16.67	4.50	21.17	2	800	67,984	8,160	217.97
IN03012	20.03	5.41	25.44	2	800	81,648	6,720	214.24
sum	99.49	26.86	126.35	23	9,280	388,848	117,120	1,569.03

TABLE 3. Calculation results of the amount of GHG emissions from the baseline

Code	N <sub>2</sub> O (tCO <sub>2</sub> e y <sup>-1</sup> )			CO <sub>2</sub> (tCO <sub>2</sub> e)	sum (tCO <sub>2</sub> e y <sup>-1</sup> )
	direct	indirect	sum		
IN03001	0.084	0.019	0.103	0.000	0.103
IN03002	0.063	0.014	0.077	0.000	0.078
IN03003	0.755	0.170	0.926	0.000	0.926
IN03004	0.032	0.007	0.039	0.031	0.071
IN03005	0.010	0.002	0.012	0.000	0.012
IN03006	0.084	0.019	0.104	0.000	0.104
IN03007	0.313	0.070	0.383	0.276	0.659
IN03008	0.020	0.005	0.025	0.000	0.025
IN03009	0.507	0.114	0.621	0.000	0.621
IN03010	0.006	0.001	0.008	0.000	0.008
IN03011	0.003	0.001	0.003	0.000	0.003
IN03012	0.157	0.035	0.193	0.000	0.193
sum	2.035	0.459	2.493	0.308	2.801

The direct GHG emissions in the project area in N<sub>2</sub>O form were equal to 2.035 tCO<sub>2</sub>e/y and the indirect emissions were equal to 0.458 tCO<sub>2</sub>e/y. The total GHG emissions in N<sub>2</sub>O form were equal to 2.493tCO<sub>2</sub>e/y. The amounts of GHG emissions in CO<sub>2</sub> form from the uses of urea fertilizers of soil amendments were equal to 0.001 tCO<sub>2</sub>e/y. The total amount of GHG emissions from the uses of urea fertilizers of soil amendments in the baseline were at 2.494 tCO<sub>2</sub>e/y. The details are shown in Table 4.

From the calculation of emissions reduction from the project implementation over 7 years, the GHG emissions were reduced from the project averagely 0.307 tCO<sub>2</sub>e per year. The total amount of greenhouse gases reduced during the project implementation period was 2.149 tCO<sub>2</sub>e. The details are shown in Table 5.

#### CALCULATING THE TOTAL AMOUNT OF GREENHOUSE GASES FROM THE PROJECT IMPLEMENTATION

The results of the project implementation of carbon sequestration and GHG emissions reduction from the orchards of the agriculturists in Sang Kho sub district, Phu Phan district, Sakon Nakhon province in northeast Thailand, can summarize the amount of greenhouse

gases from the project implementation as follows: The amount of carbon sequestration from the yearly project implementation was equal to 69.54 tCO<sub>2</sub>e/y. Throughout the 7 years of the project implementation, the amount of carbon sequestration was equal to 486.78 tCO<sub>2</sub> and the amount of emissions reduction from the uses of fertilizers was 0.307 tCO<sub>2</sub>e/y. The total emission reduction throughout the project was equal to 2.149 tCO<sub>2</sub>. The calculation of the amounts of greenhouse gases storage and emissions reduction from the activities during the project implementation period were equal to 488.93 tCO<sub>2</sub>. The details are shown in Table 6.

#### CONCLUSION

T-VER is a voluntary greenhouse gas reduction program developed by TGO to encourage and support all sectors to participate in greenhouse gas reduction voluntarily in the country and can bring the amount of GHG emissions reduction called 'carbon credits' to be sold in the voluntary carbon market in the country. Under this research, the researcher had calculated the carbon sequestration of trees and the GHG emissions reduction according to the

TABLE 4. Total amount of GHG emissions from the project implementation

Code	N <sub>2</sub> O (tCO <sub>2</sub> e y <sup>-1</sup> )			CO <sub>2</sub> (tCO <sub>2</sub> e)	sum (tCO <sub>2</sub> e y <sup>-1</sup> )
	direct	indirect	sum		
IN03001	0.084	0.019	0.103	0.000	0.103
IN03002	0.063	0.014	0.077	0.000	0.078
IN03003	0.755	0.170	0.926	0.000	0.926
IN03004	0.032	0.007	0.039	0.000	0.039
IN03005	0.010	0.002	0.012	0.000	0.012
IN03006	0.084	0.019	0.104	0.000	0.104
IN03007	0.313	0.070	0.383	0.001	0.384
IN03008	0.020	0.005	0.025	0.000	0.025
IN03009	0.507	0.114	0.621	0.000	0.621
IN03010	0.006	0.001	0.008	0.000	0.008
IN03011	0.003	0.001	0.003	0.000	0.003
IN03012	0.157	0.035	0.193	0.000	0.193
sum	2.035	0.458	2.493	0.001	2.494

TABLE 5. Estimated amount of GHG emissions reduction from the uses of fertilizers and soil amendments

Years	GHG emissions from the base line (tCO <sub>2</sub> e)	GHG emissions from the project (tCO <sub>2</sub> e)	GHG emissions (tCO <sub>2</sub> e)
1	2.801	2.494	0.307
2	2.801	2.494	0.307
3	2.801	2.494	0.307
4	2.801	2.494	0.307
5	2.801	2.494	0.307
6	2.801	2.494	0.307
7	2.801	2.494	0.307
Sum (tCO <sub>2</sub> e)	19.607	17.458	2.149
Years	7	7	7
(tCO <sub>2</sub> e/y)	2.801	2.494	0.307

TABLE 6. Summarizes the amount of greenhouse gases from the project implementation

year/cycle	GHG storage from baseline (tCO <sub>2</sub> e)	GHG storage from the project (tCO <sub>2</sub> e)	Out-of-project GHG emissions	GHG storage/ GHG emissions
t	1=0	2=1+(t*0.95*area)	3	4=2-1-3
0	1,598.02	0.00	0	0
1	1,598.02	1,667.56	0	69.54
2	1,598.02	1,737.10	0	139.08
3	1,598.02	1,806.64	0	208.62
4	1,598.02	1,876.18	0	278.16
5	1,598.02	1,945.72	0	347.70
6	1,598.02	2,015.26	0	417.24
7	1,598.02	2,084.80	0	486.78
SUM (tCO <sub>2</sub> e)	1,598.02	2,084.80	0	486.78
Years	7	7	7	7
tCO <sub>2</sub> e/y	228.29	297.83	0	69.54

T-VER-METH-AGR-02 methods. For the assessment of the amount of greenhouse gases reduced and/or stored in the agriculture sector (orchards), the calculation was conducted according to academic principles by defining activities of the project in accordance with the method of calculating greenhouse gas reduced and/or stored. There were two types of activities including greenhouse gas capture and GHG emissions reduction. The greenhouse gas capture activities consists of two main parts including capturing carbon in wood from agricultural crops containing wood and capturing carbon in soils. And the GHG emissions reduction activities were such as reducing the use of chemical fertilizers or using appropriate quantities of fertilizers and increasing the use of organic fertilizers for growing crops or garden plants. For the results of the project implementation can summarize the amount of GHG in the whole study area of 115,520 m<sup>2</sup> as follows; The carbon storage from the yearly project implementation was at 69.54 tCO<sub>2</sub>e/y and the carbon storage within 7 years of the project implementation was at 486.78 tCO<sub>2</sub>e. The GHG emissions reduction from the yearly project implementation was at 0.307 tCO<sub>2</sub>e/y and the GHG emissions reduction within 7 years of the project implementation was at 2.149 tCO<sub>2</sub>e. The calculation of the amount of carbon storage and GHG emissions from the activities during the project lifetime was found at 488.93 tCO<sub>2</sub>e. In addition, tree carbon sequestration and GHG emission reductions calculated according to the method of this study must be registered with TGO and within 7 years of the implementation of this project will be monitored by TGO.

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#### REFERENCES

- Adani, A., Holman, I., & Jude S. 2017. Adapting water management to climate change: Institutional involvement, inter-institutional networks and barriers in India. *Global Environmental Change* 44: 144-157.
- Boonsang, S. & Arunpraparat, W. 2011. Estimation of above-ground carbon sequestration of forest using remote sensing techniques in Mae Tuen Wildlife Sanctuary, Tak Province. *Thai Journal of Forestry* 30(3): 14-23.
- Barsotti, J.L., Sainju, U.M., Lenssen, A.W., Montagne, C. & Hatfield, P.G. 2013. Net greenhouse gas emissions affected by sheep grazing in dry land cropping systems. *Soil Science Society of America Journal* 77: 1012-1025.
- Burney, J.A., Davis, S.J. & Lobell, D.B. 2010. Greenhouse gas mitigation by agricultural intensification. *National Academy of Sciences* 107: 12052-12057.
- Dransfeld, B., Kachi, A., Tänzler, D., Hoch, S., Ruthner, L. & Michaelowa, A. 2015. *Synthesis Report: Practicability of Transitioning from CDM to Future Climate Policy Instruments*. [https://www.perspectives.cc/fileadmin/Publications/Practicability\\_of\\_transitioning\\_from\\_CDM\\_to\\_future\\_climate\\_policy\\_instruments\\_Hoch\\_Stephan\\_Michaelowa\\_Axel\\_2015.pdf](https://www.perspectives.cc/fileadmin/Publications/Practicability_of_transitioning_from_CDM_to_future_climate_policy_instruments_Hoch_Stephan_Michaelowa_Axel_2015.pdf).
- FAO. 2015. *Estimating Greenhouse Gas Emissions in Agriculture*. [www.fao.org/3/a-i4260e.pdf](http://www.fao.org/3/a-i4260e.pdf).
- FAO. 2010. *Global Forest Resources Assessment*. [www.fao.org/docrep/013/i1757e/i1757e.pdf](http://www.fao.org/docrep/013/i1757e/i1757e.pdf).
- ICAP. 2014. *Emissions Trading Worldwide*. [https://icapcarbonaction.com/en/?option=com\\_attach&task=download&id=349](https://icapcarbonaction.com/en/?option=com_attach&task=download&id=349).
- IEA. 2011. *World Energy Outlook*. [https://www.iea.org/publications/free\\_publications/publication/WEO2011\\_WEB.pdf](https://www.iea.org/publications/free_publications/publication/WEO2011_WEB.pdf).
- IPCC. 2014. *Climate Change 2014. Mitigation of Climate Change*. [https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/WGIIIAR5\\_SPM\\_TS\\_Volume.pdf](https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/WGIIIAR5_SPM_TS_Volume.pdf).
- IPCC. 2007. *Climate Change 2007: Mitigation*. [https://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4\\_wg3\\_full\\_report.pdf](https://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4_wg3_full_report.pdf).
- IPCC. 2006. *Guidelines for National Greenhouse Gas Inventories*. Vol. 4, Agriculture, forestry and other land use

- (AFLOLU). Institute for Global Environmental Strategies, Hayama, Japan.
- Issaree, M. 1982. Primary production of plant communities in old clearing areas at Sakaerat Environmental Research Station, Pak Thongchai, Nakhonratchasima. Thesis. Kasetsart University, Thailand (Unpublished).
- Johnson, J.M.F., Reicosky, D.C., Allmaras, R.R., Sauer, T.J., Venterea, R.T. & Dell. C.J. 2005. Greenhouse gas contributions and mitigation potential of agriculture in the central USA. *Soil and Tillage Research* 83(1): 73-94.
- Jordan, Y.C., Ghulam, A. & Chu, M.L. 2014. Assessing the impacts of future urban development patterns and climate changes on total suspended sediment loading in surface waters using geoinformatics. *Journal of Environmental Informatics* 24(2): 65-79.
- Kittisompun, B. 2014. *Thailand Voluntary Emission Reduction (T-VER)*. [https://www.iges.or.jp/files/research/climate-energy/mm/PDF/20141013/S10-3\\_Kittisompun.pdf](https://www.iges.or.jp/files/research/climate-energy/mm/PDF/20141013/S10-3_Kittisompun.pdf).
- Klinhom, U., Laosuwan, T., Uttaruk, P., Junggoth, R., Thamsenanupap, P. & Wongpakam, K. 2011. *Carbon Offset in forest Sector, Final Report Carbon Offset in forest Sector Project*. National Research Council of Thailand. p. 220.
- Lal, R. 2004. Soil carbon sequestration impact on global climate change and food security. *Science* 304: 1623-1627.
- Laosuwan, T & Uttaruk, Y. 2016. Estimating above ground carbon capture using remote sensing technology in small scale agroforestry areas. *Agriculture and Forestry* 62(2): 253-262.
- Land Development Department. 2016. *Strategic of Land Development Department during the 11th National Economic and Social Development Plan*. <http://www. ldd.go.th/www/files/75752.pdf>.
- Liebig, M.A., Tanaka, D.L. & Gross, J.R. 2010. Fallow effects on soil carbon and greenhouse gas flux in Central North Dakota. *Soil Science Society of America Journal* 74: 358-365.
- Lohsomboon, P. 2012. *Establishment of MRV System for TVERs and TVETS in Thailand*. [https://www.iges.or.jp/isap/2012/jp/pdf/25/S4-2\\_4\\_Pongvipa.pdf](https://www.iges.or.jp/isap/2012/jp/pdf/25/S4-2_4_Pongvipa.pdf).
- Ogawa, H., Yoda, K., Oginio, K. & Kira, T. 1965. Comparative ecological studies on three main type of forest vegetation in Thailand II. Plant biomass. *Nature and Life in Southeast Asia* 4: 49-80.
- Paustian, K., Andren, O., Janzen, H., Lal, R., Smith, P., Tian, G., Tiessen, H., Noordwijk, M.V. & Woomer, P. 1997. Agricultural soil as a C sink to offset CO<sub>2</sub> emissions. *Soil Use and Management* 13: 230-244.
- Ruesch, A.S. & Gibbs, H.K. 2008. *New IPCC Tier-1 Global Biomass Carbon Map for the Year 2000*. Carbon Dioxide Information Analysis Center. <http://cdiac.ornl.gov>.
- Samek, J.H., Skole, D.L., Klinhom, U., Butthep, C., Navanugraha, C., Uttaruk, P. & Laosuwan T. 2011. Inpang Carbon Bank in Northeast Thailand: A community effort in carbon trading from agroforestry projects. In *Carbon Sequestration Potential of Agroforestry Systems: Opportunities and Challenges*, edited by Kumar, B.M. & Nair, P.K.R. Springer Science+Business Media B.V. pp. 263-280.
- Santika, T., Meijaard, E., Budiharta, S., Law, E.A., Kusworo, A., Hutabarat, J.A., Indrawan, T.P., Struebig, M., Raharjo, S., Huda, I., Sulhani, Ekaputri, A.D., Trison, S., Stigner, M. & Wilson, K.A. 2017. Community forest management in Indonesia: Avoided deforestation in the context of anthropogenic and climate complexities. *Global Environmental Change* 46: 60-71.
- Sainju, U. 2015. Comparison of net global warming potential and greenhouse gas intensity affected by management practices in two dry land cropping sites. *Journal of Environmental Protection* 6: 1042-1056.
- TGO. 2015. *Thailand Voluntary Emission Reduction Program*. [http:// conference.tgo.or.th/download/tgo\\_or\\_th/seminar/presentation/2014/Mar/2728/06\\_TVER.pdf](http://conference.tgo.or.th/download/tgo_or_th/seminar/presentation/2014/Mar/2728/06_TVER.pdf).
- TGO. 2014. *Carbon Sequestration and Reducing Emission in Orchards*. <http://ghgreduction.tgo.or.th/tver-method/tver-methodology-for-voluntary-greenhouse-gas-reduction/agr/item/479-carbon-sequestration-and-reducing-emission-in-orchards.html>. (In Thai)
- TGO. 2013. *Progress on the Development of a Voluntary Carbon Market in Thailand*. [https://www.iges.or.jp/files/research/climate-energy/mm/PDF/20130904/S5\\_2\\_Sumon.pdf](https://www.iges.or.jp/files/research/climate-energy/mm/PDF/20130904/S5_2_Sumon.pdf).
- Tubiello, F.N., Salvatore, M., Rossi, S., Ferrara, A., Fitton, N. & Smith P. 2013. The FAOSTAT database of greenhouse gas emissions from agriculture. *Environ. Res. Lett.* 8: 015009.
- Uttaruk, Y. & Laosuwan, T. 2018. Community forest for global warming mitigation; the technique for estimation of biomass and above ground carbon storage using remote sensing technology method. *Agriculture and Forestry* 64(3): 47-57.
- Uttaruk, Y. & Laosuwan, T. 2016. Remote sensing based vegetation indices for estimating above ground carbon sequestration in orchards. *Agriculture and Forestry* 62(4): 193-201.
- UNFCCC. 2009. *Fact Sheet: The Need for Mitigation*. [http:// unfccc.int/files/press/backgrounders/application/pdf/press\\_factsh\\_mitigation.pdf](http://unfccc.int/files/press/backgrounders/application/pdf/press_factsh_mitigation.pdf).

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