

## Comparison of Carbon Storage Measurement Methods on Agroforestry Systems in Sakon Nakhon Province, Northeast Thailand

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### ABSTRACT

The current global climate has changed dramatically. One of the main causes is human activities that contribute to the emission of large amounts of carbon dioxide (CO<sub>2</sub>) from reserve areas into the atmosphere, causing global warming. The objective of this research is the comparison of measurement methods of carbon storage on agroforestry systems in Sakon Nakhon Province, northeast Thailand. The research methodologies comprised 1) the transfer of knowledge to farmers who participated in the project and 2) monitoring carbon sequestration with satellite imagery. The overall results concluded that farmers obtained knowledge and understanding of the causes of global warming as well as adjusted toward the changes in the weather and atmosphere. More than 80% of farmers were able to perform measurements themselves, recording the Diameter at Breast Height (DBH) and total height of the trees. The results of biomass measurement were attained by monitoring carbon sequestration in the agroforestry areas and equalled 38,649.48 tonnes of carbon dioxide equivalent (tCO<sub>2</sub>e). The carbon sequestration assessment with satellite imagery was able to assess carbon collection, which was equivalent to 36,343.08 tCO<sub>2</sub>e.

### 1. Introduction

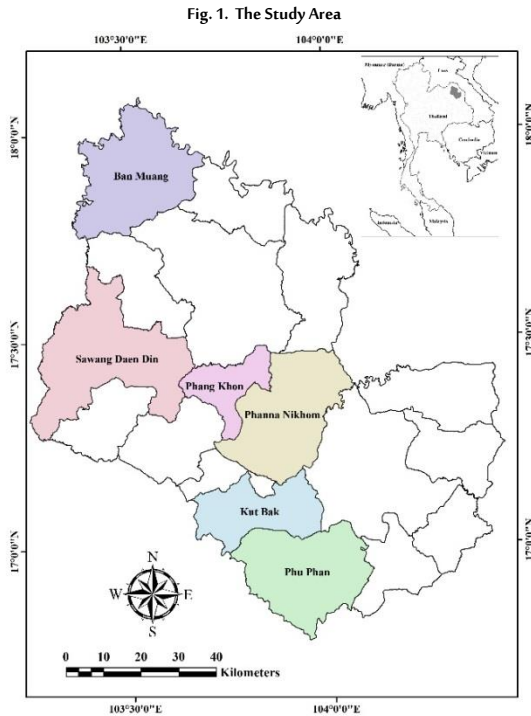
At present, the Earth's climate has drastically changed. The main causes are human activities that have resulted in the release of large amounts of carbon dioxide (CO<sub>2</sub>) emissions from reserve areas into the atmosphere (Pin *et al.*, 2013; Tukimat & Ahmad, 2018). Examples of such activities include fuel combustion, transportation, and manufacturing processes in factories amongst others (Vagen *et al.*, 2017). Additionally, human actions have also resulted in reduced natural carbon reserves. Activities, including forest intrusion, have resulted in the Earth's diminished ability to extract CO<sub>2</sub> from the atmosphere, thus causing an increased amount of surplus CO<sub>2</sub> in the atmosphere (Laosuwan & Uttarak, 2016). Consequently, this leads to the Greenhouse Effect, which causes an increase in temperature giving rise to 'global warming' (Oregon, 2017). This is because CO<sub>2</sub> absorbs heat radiation from the sun and the ground (Nabuurs, 2007; Lee *et al.*, 2009; Bravo *et al.*, 2017). Carbon is an element that comprises a main component of living organisms and is also significant in balancing global ecosystems (Senpaseuth *et al.*, 2009). Carbon is stored in different reserves such as land-based sources, water sources, in the atmosphere, and in living organisms (Lal, 2004). Moreover, carbon also exists in nature in all three forms of solid, liquid, and gas (Liebig *et al.*, 2010). Most natural carbon will be stored in plants in the form of a hydrocarbon compound, which is a component in plant tissue. Regarding sustainable solutions to the global warming issue, one method is to store excess carbon from the atmosphere in living organisms through activities such as planting trees (Englin & Callaway, 1995). This is because trees play a significant role in the sink or absorption of CO<sub>2</sub> (Spracklen *et al.*, 2015; Ounkerd *et al.*, 2015; Bradford & Bell, 2017). The photosynthesis process conducted in the leaves of the trees helps absorb CO<sub>2</sub> and sink it into different parts of the tree such as the stem, branch, leaves and roots as biomass (Ogawa *et al.*, 1965). Thus, planting trees will help in the reduction of CO<sub>2</sub> from the atmosphere, which in turn can help solve the global warming issue (Uttarak & Laosuwan, 2018).

From past to present studies, several different types of research have

studied the amount of carbon sequestration in forest areas using field surveys (Liaghat & Balasundram, 2010). In general, the amount of carbon within trees produces a direct correlation to the biomass value, which is the total mass of all components of the tree (stems, branches, leaves, and roots). For this reason, anatomy characteristics of trees such as their height, stem size, and the width of branches, could all be used to evaluate the amount of carbon sequestration in trees along with allometric equations, which are relational equations between the biomass and structural characteristics of trees (Vicharnakorn *et al.*, 2014). While a field survey will likely provide accurate information on the structures and shapes, this method requires expert and trained personnel to carry it out. Additionally, if the area is covered with dense plant species and is located further away from a community, a field survey would be inconvenient, thus it could result in faulty data (Uttarak *et al.*, 2017).

At present, advanced remote sensing technology with satellite imagery such as Landsat, Terra/Modis, and THEOS, has been developed and applied to the data from satellites to study the structural characteristics and density of plant species in the Earth's forests (Jundang *et al.*, 2010; Robinson *et al.*, 2013; Laosuwan & Uttarak, 2014). This data can be used to evaluate biomass along with allometric equations to calculate the amount of carbon sequestration occurring in the forests (Xu *et al.*, 2010; Zhang *et al.*, 2019). The objective of this research is to integrate participation for farmers in tree measurement and carbon sequestration assessments using satellite imagery. The research area comprised 1,433,824m<sup>2</sup> of agroforestry areas, owned by 64 farmers. The aim was for the study to serve as a prototype method for research projects aimed at finding solutions to global warming. This is achieved by integrating participation between researchers, educational institutions and participating farmers in the development of potential applications of such cooperation to other agroforestry areas throughout Thailand.

The agroforestry area surveyed was 1,433,824m<sup>2</sup>, from 64 farmers who were chosen to participate in the project. They were members of the Inpang community network (Fig. 1) located in Sakon Nakhon Province, Northeast Thailand.



The principal area for the project is scattered throughout six districts of Sakon Nakhon Province, that is: Ban Muang, Sawang Daen Din, Phang Khon, Phanna Nikhom, Phu Phan and Kut Bak.

## 2. Materials and Methods

The key method included the transfer of a knowledge base concerning the causes of global warming and climate variation, and the subsequent impact on the changes in weather and atmosphere. It also included operational training for farmers focused on techniques for collecting carbon from the biomass of trees. The details of the activities were as follows:

### 2.1. Transfer of Knowledge Base:

The research project included hosting of a training session to transfer knowledge on the solutions to the consequences of global warming. The skills and knowledge transferred is maintained through the participation of farmers in the sustainable and systematic management of forest resources. The transfer of knowledge was completed in a lecture format by a speaker presenting on the causes and severity of the changes in weather and atmosphere, as well as that of global warming. It also included information about the severe impacts from the variations in climate on the forestry and agriculture sectors, as well as the necessary adjustments in light of such changes. Furthermore, the researcher evaluated this transfer of knowledge through questionnaires, by setting up evaluation criteria: farmers who participated in the training must demonstrate more than 80 per cent knowledge acquisition and understanding of the transferred knowledge base in order to pass the training.

### 2.2. Operational Training:

As part of this research project, operational training was also given by the speaker of the project, focusing on techniques for carbon collection from the biomass of trees. The aim was for farmers who participated in the operational training to obtain knowledge and understanding of the survey planning process, techniques for tree measurement, the use of the Global Positioning System (GPS) and a

systematic method for recording and storing survey data. For operational training, the researcher also used questionnaires to evaluate the observations of the farmers. Similarly, the researcher set up the evaluation criteria that farmers who participated in the training must demonstrate more than 80 per cent knowledge acquisition and understanding of the transferred knowledge base in order to pass the training.

### 2.3. Collection and Data Analysis from Field Survey:

#### 2.3.1. Survey and Data Collection

The researcher surveyed and collected basic data from 64 participants, consisting of their name and address, the size of their agroforestry area, age of the planted tree (year of planting), as well as a 20-year history of the land usage. The data was considered in accordance with the conditions that the agroforestry area must be operated by a juristic person and shall not be a forest or denuded forest area from 31<sup>st</sup> December 1989 onward. It should also consist of a legitimate land title deed.

#### 2.3.2. Tree Measurement

Within the agroforestry area in this project, tree measurement was based on stratified random sampling. This was because the agroforestry area consists of several plant species with varying ages. Therefore, the creation of a permanent plot would need to cover the area without any bias. In this research project, farmers were asked to create a permanent plot and record data on tree measurement, consisting of a sample permanent plot with a size of 25x25m for purposes of surveying the trees. It should also include a sample permanent plot with a size of 10x10m within the bounds of the 25x25m plot, for a total of 1 plot in order to survey saplings. A sample permanent plot with a size of 1x1m for a total of five plots within the bounds of the 25x25m plot was also included for means of surveying seedlings. Farmers that participated in the project were required to measure trees with a size of Diameter at Breast Height (DBH) that was higher or equivalent to 4.5cm. The height of the tree needed to be higher or equivalent to 1.30m from the ground upwards, measurable through the use of a clinometer. Following that, farmers needed to record tree names and details from the measurement survey in a form, and all 64 of them were required to submit that form to the research team, who inserted details such as common names, scientific names, names of species, and different plant types.

#### 2.3.3. Area Measurement

The total agroforestry area from the permanent plots of 64 participants (codes from SK01 to SK64) in this research project was measured using GPS to give the respective geographical locations on the Earth's surface. The locations were then transferred from GPS to a program of geographic information systems, and data was adjusted for accuracy.

#### 2.3.4. Data Analysis

For the analysis of Above Ground Biomass (AGB) in this research, the allometric equation for agroforestry plants was used. The allometric equation in equation 1 was redeveloped to suit the use of AGB analysis of agroforestry plants at a local level, especially in the north-eastern area of Thailand.

$$\begin{aligned}
 W_s &= 0.0389(D^2H)^{0.9417} \\
 W_B &= 0.0678(D^2H)^{0.6618} \\
 W_L &= 0.0084(D^2H)^{0.7660} \\
 W_T &= W_s + W_B + W_L
 \end{aligned}
 \tag{1}$$

Where:

- $W_T$  = Total weight of the tree (kg)
- $W_S$  = Weight of the stem (kg)
- $W_B$  = Weight of the branches (kg)
- $W_L$  = Weight of the leaves (kg)
- $D$  = Diameter at Breast Height (DBH) (cm)
- $H$  = Tree height (m)

**2.4. Carbon Sequestration with Satellite Imagery**

According to the theory, carbon sequestration of biomass can be monitored using two parallel methods. Firstly, analysis can be conducted through a field survey to measure biomass from plant tissue, as mentioned above. Secondly, analysis can be conducted through the use of satellite imagery. Both methods would need to evaluate the biomass before converting it into carbon. For this research, the researcher evaluated biomass through data analysis from the Landsat-8 OLI satellite using two images (to be able to cover the entirety of the area). Those images were Path 127 Rows 48 and Path 128 Rows 48, recorded on 2<sup>nd</sup> December 2018. Following that, the evaluated results of biomass were calculated for carbon sequestration in the agroforestry areas of the farmers who participated in this project.

In the process of data analysis from the satellite, the researcher took data from the Landsat-8 OLI satellite to analyse using digital image processing as follows:

- Correcting the value of Top of Atmosphere (ToA) reflectance of Landsat-8 OLI to reduce errors in the energy reflected from objects on the Earth’s surfaces to the data recorder, from the surrounding environment whilst recording. That included the weather, topography, temperature and angle of incidence using equation 2 (Yale University, 2019).

$$L_{\lambda} = M_{\lambda} * Q_{cal} + A_{\lambda} \tag{2}$$

Where:

- $L_{\lambda}$  = Top of Atmosphere spectral radiance [W/(m<sup>2</sup> sr μm)]
- $M_{\lambda}$  = Band specific multiplicative rescaling factor (Table 1)
- $Q_{cal}$  = OLI image
- $A_{\lambda}$  = Band specific additive rescaling factor (Table 1)

Table 1. Rescaling factor (Yale University, 2019)

| Rescaling factor | Band 10  | Band 11  |
|------------------|----------|----------|
| $M_{\lambda}$    | 0.000342 | 0.000342 |
| $A_{\lambda}$    | 0.1      | 0.1      |

- Analysis of vegetation index with the Modified Soil-adjusted Vegetation Index-2 (MSAVI-2) referred from equation 3 (Qi *et al.*, 1994).

$$MSAVI-2 = \frac{2 * NIR + 1 - \sqrt{(2 * NIR + 1)^2 - 8 * (NIR - RED)}}{2} \tag{3}$$

Where:

- RED = The Red band reflectance of Landsat 8 (band 4, 0.64 – 0.67 μm and resolution 30 m)
- NIR = The Near Infrared band (band 5, 0.85-0.88 μm and resolution 30 m)
- The MSAVI-2 evaluation results will be taken from step 2 to convert them into Fractional Vegetation Cover (FVC), illustrated in equation 4 (Camacho *et al.*, 2013; Laosuwan & Uttaruk, 2014; Jia *et al.*, 2016). The analysis of FVC will adjust the details of the data to

further analyse the relationships in line with the field-surveyed carbon.

$$FVC = \frac{(VI - VI_{open})}{(VI_{canopy} - VI_{open})} * 100 \tag{4}$$

Where:

- FVC = Tree canopy fractional cover
- VI = Vegetation index
- $VI_{open}$  = Vegetation index of open areas
- $VI_{canopy}$  = Vegetation index of tree canopy

**3. Results and Discussion**

**3.1. Results from Transfer of Knowledge Base and Operational Training:**

For general information, it was found that 91 participants were interested in participating in the lecture from speakers. That figure can be divided into 77 males and 14 females aged between 25–80 years. Over 94 per cent of the participants’ occupation was farmer, though the remaining 6 per cent included occupations such as carpenters, basket makers, and maids.

3.1.1. Results from Transfer of Knowledge Base

The results from the evaluation on the questionnaire found that 7 per cent of those who participated in the lecture still lacked understanding of 1) the causes and severity of conditions from the changes in weather and atmosphere as well as global warming, and 2) the relief in severity from the changes in weather and atmosphere in forestry and agricultural sectors, as well as adjustment as a result of this change. About 93 per cent gained an understanding of these topics after the lecture. The group of participants that possessed understanding can be separated based on their knowledge and understanding; 27 per cent obtained knowledge, understanding, and the ability to explain details on topic 1) and topic 2). Another 73 per cent obtained an understanding of topic 1) but were unable to explain the details in topic 2).

3.1.2. Results from Operational Training

The results from the knowledge and ability training in tree measurement found that 64 farmers were able to measure the growth (diameter) and height of the trees as well as record measurement data on a record form. From a group of participants that possessed understanding, it was found that 12 per cent of them used a tool to measure the growth of a tree. About 47 per cent used approximation and another 41 per cent did not give feedback. For the measurement of tree height, it was found that 7 per cent of participants in the operational training could measure using a tool and another 57 per cent used approximation. The remaining 36 per cent did not specify their measurement method.

**3.2. Results from Data Analysis of Field Survey:**

The analysis of carbon collection, in the form of biomass with plants in the agroforestry system, used analysis to measure the growth of each species using equation 1. For the calculation of carbon collection, data from a field survey in the agroforestry area of the 64 farmers who participated in the project, with a total area equivalent to 1,433,824m<sup>2</sup>, was input into the equation. The analysis of biomass was then converted into carbon in biomass. The result from the carbon sequestration in the agroforestry gave a measurement of 10,540.77 tCO<sub>2</sub>, which can be calculated to give 38,649.48 tCO<sub>2</sub>e. Additionally, the agroforestry plot that was able to collect the

highest amount of carbon was reference SK 22. Carbon equivalent to 790.42 tCO<sub>2</sub> or 2,898.20 tCO<sub>2</sub>e was collected. The agroforestry plot that was able to collect the lowest amount of carbon was reference SK 06. It collected the carbon equivalent to 1.53 tCO<sub>2</sub> or 5.26 tCO<sub>2</sub>e. These results are displayed in Table 2.

Table 2. Carbon Sequestration in the Agroforestry Area from Field Survey

| Code           | Agriculture Area (m <sup>2</sup> ) | Forest Area (m <sup>2</sup> ) | Carbon (tCO <sub>2</sub> ) | Carbon (tCO <sub>2</sub> e) |
|----------------|------------------------------------|-------------------------------|----------------------------|-----------------------------|
| SK 01 to SK 64 | 1,911,600                          | 1,433,824                     | 10,540.77                  | 38,649.48                   |
| MAX (SK 22)    | 50.00                              | 45.76                         | 743.36                     | 2,725.65                    |
| MIN (SK 06)    | 5.00                               | 0.63                          | 1.53                       | 5.62                        |

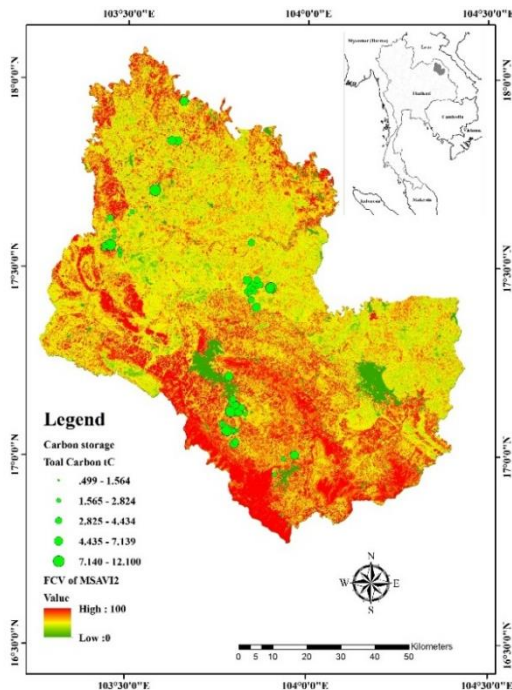
### 3.3. Results of Carbon Sequestration with Satellite Imagery:

The carbon sequestration with satellite imagery was conducted using the method and steps previously mentioned in section 2.4. The analysis of FVC came from data of the Landsat-8 OLI satellite. This analysis was then used to find the relationship with the quantity of field-surveyed carbon, which equalled a correlation analysis of  $Y = 0.0260e^{0.067X}$  and had the Coefficient of Determination that was equal to r<sup>2</sup>, or a value of 0.95. Therefore, when using the correlation analysis to calculate the carbon sequestration in the agroforestry area from the total area of 1,433,824 m<sup>2</sup>, it was found that the amount of carbon collected was equal to 9,991.74 tCO<sub>2</sub> or 36,343.08 tCO<sub>2</sub>e. The analysis results of carbon sequestration using satellite imagery are displayed in Table 3 and Figure 2.

Table 3. Carbon sequestration in the agroforestry area from satellite imagery

| Code           | Agriculture Area (m <sup>2</sup> ) | Forest Area (m <sup>2</sup> ) | Carbon (tCO <sub>2</sub> ) | Carbon (tCO <sub>2</sub> e) |
|----------------|------------------------------------|-------------------------------|----------------------------|-----------------------------|
| SK 01 to SK 64 | 1,911,600                          | 1,433,824                     | 9,911.74                   | 36,343.08                   |
| MAX (SK 22)    | 50.00                              | 45.76                         | 547.76                     | 2,008.44                    |
| MIN (SK 06)    | 5.00                               | 0.63                          | 1.11                       | 4.06                        |

Figure 2. Illustration of the distribution of the permanent plot and carbon sequestration in the agroforestry area



## 4. Conclusions

The changing weather and atmosphere is a global issue that affects every country in terms of environment, economy, society as well as

health. If there are any measurement conducted to manage the issue, it might affect the development of a country. In order to cope with the situation, Thailand and the global community have ratified their efforts by forging an alliance, according to the Paris agreement under The United Nations Framework Convention on Climate Change (UNFCCC). The alliance is dedicated to creating responsibilities for all parties to conserve our planet. Being part of the alliance means a commitment to limiting increasing temperatures, and an increased ability in the response to consequences of changes in the weather and atmosphere. In the past, the global community has paid significant attention to this issue and tried to come up with different strategies to mitigate the effects of global warming. The promotion of energy-saving, the use of alternative energy, and the conservation as well as expansion of growing forests are among the several approaches suggested or previously implemented. This research has contributed another type of research that could assist in the reduction of global warming through CO<sub>2</sub> sequestration from agroforestry areas. This research used the integration of participation between researchers, educational institutions and farmers, including members of the Inpang community network. They were aware of the situation concerning the changes in the weather and atmosphere, and that such changes could manifest themselves negatively for all people worldwide.

The overall results concluded that farmers obtained knowledge and understanding about the causes of global warming as well as adjustment towards the changes in the weather and atmosphere. More than 80 per cent of farmers were able to measure and record the amounts of carbon in the trees by themselves. The results of carbon measurement by farmers were evaluated by collecting carbon in the agroforestry area, which was found to be equivalent to 38,649.48 tCO<sub>2</sub>e. The carbon sequestration using satellite imagery was analysed through the collection of carbon, which was equivalent to 36,343.08 tCO<sub>2</sub>e. Additionally, the researcher concluded the results for the amount of carbon that could be analysed using data from field surveys compared with data from Landsat-8, using a total of 64 samples of a permanent plot with a Paired Sample T-test. The results displayed statistically significant indifference at a 0.05 level. This indicated that the application of the data from the satellite Landsat-8 OLI was very reliable for estimating above-ground carbon sequestration in the areas of agroforestry in the Inpang community network, Sakon Nakhon Province.

Moreover, the aim was also to encourage farmers to have the determination for sustainable conservation of their respective agroforestry areas. This research also offered an endowment to support activity under the Corporate Social Responsibility (CSR) approach, which was operated under specified conditions to promote the conservation and preservation of the agroforestry area. It was also followed by the amount of collection and increased the quantity of carbon collection in each agroforestry area. Farmers will need to be supported through the process of training in order to acquire the relevant knowledge on changes toward weather and atmosphere, consequences of those changes, and the role of farmers in suppressing the effects of the changes. Farmers should also learn about techniques in the measurement and evaluation of carbon sequestration in their agroforestry area. From the results, it was found that the agroforestry area of 1,433,824m<sup>2</sup> could sequester carbon up to an amount of 38,649.48 tCO<sub>2</sub>e. After calculating the increase in the quantity of carbon collection within a period of one year, that figure was equivalent to 3,864.94 tCO<sub>2</sub>e. Donations were collected into a fund to support sustainable conservation for the agroforestry area, raising a total of 116,055 baht or \$US3,700.

## Bios

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