Spectral radiation of tree leaves in Bogor Agricultural University campus

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Abstract. Every anthropogenic activities that use fossil fuels will produce pollutants such as greenhouse gases. CO$_2$ with other greenhouse gases increase urban air temperatures through the greenhouse effect. The aims of this study are to measure spectral radiation of several species of trees leaves in Bogor Agricultural University Campus and determine types of trees that are effective in absorbing CO$_2$. Data was statistically analyzed based on the order of spectral radiation value. Meanwhile, grouping the ability of species to absorb CO$_2$ was done based on normal curve distribution. Spectral radiation value is inversely proportional to the ability of plants to absorb CO$_2$. The tree species classified as having a high ability to absorb CO$_2$ is *Tamrindus indica*, *Adenanthera pavoniana*, *Samanea saman*, and *Ceiba pentandra* whereas the species classified as low capacity in absorbing CO$_2$ is *Annona murricata*, *Pterocarpus indicus*, *Acacia mangium*, and *Canangium odoratum*, the rest classified as having moderate capability.

1. Introduction

Every anthropogenic activities that use fossil fuels will produce pollutants such as greenhouse gases, one of that is carbon dioxide (CO$_2$). Anthropogenic activities will be increased to the center of the city. Many modern cities in the world and including Indonesia can not escape from those kind of problem. CO$_2$ with other greenhouse increase urban air temperatures through the greenhouse effect. CO$_2$ can increase the temperature of the air by absorbing near-infrared wave [1], so it becomes important to note as the greatest contribution in increasing air temperature [2].

One of the way to tackle the problem is developing urban forests and other forms of green open space. In urban forest and other forms of green open space generally planted by trees. Different types of tree has primary function of each, such as a shade, fruit producing, windbreaker, good-sided view, CO$_2$ absorber, reduce the noise, etc. Trees that have a primary function in sinking CO$_2$ is needed to reduce the greenhouse effect and decrease the air temperature. Therefore it is necessary to do research on plants (in this case is a tree) that are effective in absorbing CO$_2$. Several studies that had been conducted to estimate the ability to absorb CO$_2$ on some tree species are as follows, [3][4][5][6][7][8]. Most of these studies using carbohydrate analysis and light response curve to estimate the ability of trees to absorb CO$_2$ but very few of them use the information about spectral radiation of tree leaves.

Predicting the ability of plants to absorb CO$_2$ by using the value of its spectral radiation is a new approach. Spectral radiation is the amount of energy emitted per unit surface area of thermal emitting objects. These predictions are not directly related with the ability of photosynthesis of a plant species. If it compared with other methods, this method does not require a long time and the results can be quickly obtained.
2. Objectives and Benefit
The purpose of this study is to measure the spectral radiation value on some types of trees leaves in Bogor Agricultural University campus based on its using that has been widely planted in Bogor city and determine the types of trees that are effective in absorbing CO$_2$ based on the spectral radiation. The results of this study can be used as the basis for choosing the type of tree that is effective in absorbing CO$_2$.

3. Methods

3.1. Location and Time
Research and data collection was conducted in Bogor Agricultural University (IPB) campus and LAPAN Rancabungur, Bogor on June 16th, 2016.

3.2. Tools and Materials
Equipment used were Handheld 2 Spectroradiometer, software HH2 Sync, Icebox, labels, pole, styrofoam, and stationery. Styrofoam was formed in 45° of angle from research object. The materials used were ice cubes.

3.3. Research Object
Research object were leaf samples from twenty five of tree species which exist in Bogor Agricultural University campus. Selection of tree species referred to [3][9]. The selected trees were the trees that had been widely planted in Bogor city, the location was not too far apart and the leaves and branches still reachable by a pole.

3.4. Type of Collected Data
Type of collected data in this study were only primary data. Primary data were obtained from value of spectral radiation from each leaf sample. Spectral radiation value is in range of 325-1075 nm.

3.5. Collecting Data

3.5.1. Literature study
Literature study is an activity related to any literature review, showing tree species that has been widely planted in Bogor city and those kind of trees were exist in IPB Darmaga campus.

3.5.2. Collecting Spectral Radiation Value
There are 3 leaves were taken from each tree species of twenty five selected trees. It were the fifth leaves from of the end of the branch. All leaves were taken in the morning and kept on ice box during the trip to LAPAN. Measurement of spectral radiation value by using Handheld 2 Spectroradiometer from 12:20 to 13:00 pm. Before measuring spectral radiation value on each leaf, Handheld 2 Spectroradiometer need to be calibrated by using white reference. Measurement of the spectral radiation value was done by placing the Handheld 2 Spectroradiometer on each leaf in 45° angle with the distance from the tool to the leaf as far as 4 cm. Collecting spectral radiation value of small leaf (length and width <2 cm) was to be stacked and for the leaf with the length and width more than 2 cm was not stacked. Handheld 2 Spectroradiometer was placed in side of styrofoam to remain static while capturing spectral radiation value. It would automatically capture leaf spectral radiation value. Spectral radiation value stored in a text document format (.txt). Before doing the method of collecting spectral radiation value as described above, it has been carried out trial and error in order to get spectral radiation value accurately.

3.6. Processing and Data Analysis

3.6.1. Selected Spectral Radiation Value
The value of spectral radiation was modified from .txt to Ms. Excel format. It were not all of wavelengths of spectral radiation values were used, only red and blue wavelength of sunlight as the most effective wavelength to perform photosynthesis [10][11]. Red wavelengths (450-520 nm) and blue (630-690 nm) based on by [12] (Table 1.)

| Band   | Wavelength (µm) | Resolution (m) |
|--------|-----------------|----------------|
| Blue   | 0.45 - 0.52     | 30             |
| Red    | 0.63 - 0.69     | 30             |

Table 1. Characteristics of the sensor on Landsat TM, ETM +

Spectral radiation value of tree leaf from one tree species were averaged. Spectral radiation value obtained from averaging the value of nine repetition. Leaf spectral radiation value of twenty-five species of trees are sorted from smallest to largest. Tree species that has the lowest spectral radiation value is a species of tree that has the highest CO$_2$ absorption ability due to spectral radiation value is inversely proportional to the ability of photosynthesis. Spectral radiation value is only inform in sorting the ability of photosynthesis and absorbing CO$_2$ of plant species, from the largest to the lowest level, but can not provide a picture of how the mass of CO$_2$ absorbed per time unit.

3.6.2. Grouping Spectral Radiation Value

Grouping spectral radiation values are divided into classifications of low, medium, and high. The ability of photosynthesis is inversely proportional to the value of the spectral radiation. Once all types of trees leafe has grouped its spectral radiation values and relate it with photosynthetich ability, the type of tree that is effective in absorbing CO$_2$ can be directly determined. Grouping spectral radiation values using a simple statistical calculation based on the normal distribution curve. Twenty-five species of trees that have been determined the spectral radiation value of its leaf were calculated its standard deviation (Sd), mean, mean-Sd, and mean+Sd. Furthermore, spectral radiation value that included in low classification is if $X < \text{Mean - Sd}$, high if $X > \text{Mean - Sd}$, and moderate if spectral radiation value is between $X < \text{Mean-Sd}$ and $X > \text{Mean - Sd}$.

3.6.2.1. Calculation of mean

$$\mu = \frac{\sum x_i}{N}$$

(1)

3.6.2.2. Calculation of standard deviation (Sd)

$$\sigma = \sqrt{\frac{\sum x_i^2 - \left(\frac{\sum x_i}{N}\right)^2}{N}}$$

(2)

3.6.2.3. Calculation of mean - Sd

$$\mu = \frac{\sum x_i}{N} - \sigma \sqrt{\frac{\sum x_i^2 - \left(\frac{\sum x_i}{N}\right)^2}{N}}$$

(3)

3.6.2.4. Calculation of mean + Sd

$$\mu = \frac{\sum x_i}{N} + \sigma \sqrt{\frac{\sum x_i^2 - \left(\frac{\sum x_i}{N}\right)^2}{N}}$$

(4)
4. Results and Discussion

4.1. Spectral Radiation Value

Spectral radiation values that can be captured by Handheld 2 Spectroradiometer has range of 325-1075 nm. It can not be directly processed by using Ms. Excel. HH 2 Sync software can convert the data spectral radiation value into .txt format and further processed by using Ms. Excel. Spectral radiation value of 25 types of tree leaves can be seen in Figure 1.

![Figure 1. Spectral radiation value of 25 types of tree leaves](image_url)

Image above only shows distribution of spectral radiation value of each type of leaf, but it has not shown how the pattern spectral radiation value itself clearly on blue and red wavelength. Although the data is only focused on those kind of wavelength, it does not mean a wavelength of 325-1075 nm has no value. Figure 2 shows an example pattern of spectral radiation value of saga leaf (*Adenanthera pavoniana*) on 325-1075 nm wavelength as well as Figure 3 and Figure 4 shows the pattern of spectral radiation value of light wavelength that is used for photosynthesis (400-700 nm) on trembesi (*Samanea saman*) and Angsana (*Pterocarpus indicus*).
Related with spectral radiation value which is mentioned above will be further described by the following literature. Spectral radiation value is a reflection of the sun's radiation, so it applied the principle of light reflection. Solar radiation that comes and touches a surface can be reflected, absorbed or transmitted. Light reflected by an object called the reflectance / reflection, whereas the absorbance / absorption is light absorbed by an object located at a particular wavelength. Each different objects reflect and absorb different wavelengths.

Reflectance or reflection has no units or expressed in percent while spectral radiation value has range between 0 and 1, the unit is W cm$^{-2}$ nm$^{-1}$ sr$^{-1}$. Spectral radiation value indicates how much power per square centimeter per steradian per nanometer of sunlight reflected by the leaves, so based on the value, it can be seen how well the ability of type of tree leaves in using the energy of solar radiation for photosynthesis. The greater spectral radiation value leaves on blue and red wave the less solar radiation energy that is used for photosynthesis. Figure 5 shows the spectral reflectance characteristics of green plants leaf. Spectral radiation value in Figure 3 and Figure 4 are accordance with what is stated by [13]. Spectral reflectance of green leaf tend to be high on the wave of green (520-600 nm) and low in red and blue wave. It shows that the blue and red wave are light wave which is effectively used for photosynthesis.
Related to spectral radiation, solar light is a form of radiation that can be reflected, absorbed, or transmitted. Radiation can be defined as the energy emitted in the form of particles or wave. Radiation consists of several kinds, and every kind of radiation has a wavelength of each. In term of the mass, the radiation can be divided into electromagnetic radiation and particle radiation. Electromagnetic radiation is radiation that has no mass. This radiation consists of radio wave, microwave, infrared, visible light, X-rays, gamma rays and cosmic rays. Radiation particle is radiation in the form of particles that have a mass, such as beta particles, alpha and neutron. In the process of photosynthesis, chlorophyll have very important role because it can absorb the sun light that is form of electromagnetic radiation in visible spectrum.

4.2. The Order of Spectral Radiatation Value
It is called as PAR (photosytetically active radiation) in photosynthesis which is known as effective wavelengths for photosynthesis ranged between 400-700 nm. The wavelength range of 400-700 nm is called visible light. As explained earlier the wave of blue and red is the most effective sunlight wavelength in photosynthesis process. Thus the calculation of spectral radiation value focused on the visible light. Once spectral radiation value of all the leaves were known then the spectral radiation values are sorted from the smallest to the largest. The order of the spectral radiation values on blue and red wave are shown in Figure 6 and Figure 7.
4.3. Grouping Spectral Radiation Value

Grouping spectral radiation value based on normal distribution curve. Normal curve can only be made if the calculation of standard deviation, mean, min, and max are known. Figure 8 and Figure 9 shows the normal curve value of spectral radiation blue and red wave. The next stage was spectral radiation value of blue and red wave were averaged for classifying overall of spectral radiation value as a reference in grouping capability of types of trees leaf in absorbing CO$_2$ and the result was made as normal curve (Figure 10).
4.4. Relation between Spectral Radiation Value and CO$_2$ Absorption

The leaf has a pigment molecule that has a light absorption characteristic of each. There are two major types of pigment contained in leaf, they are chlorophyll and carotenoids. Compounds of chlorophyll found in green plants is divided into two, they are chlorophyll-a and chlorophyll-b. Chlorophyll plays an important role in the process of photosynthesis and it is the main light-absorbing pigment found in thylakoid membranes [11]. Carotenoids are compounds that give red and orange on fruits, algae, microorganisms, vegetables and crustacean outer frame such as shrimp. Carotenoids that are found in
nature are very numerous. Carotenoids also play an important role in photosynthesis and the absorption of oxygen for the survival of plants. Each spectrum shows the difference wavelength absorbed by any pigment. The light spectrum that can effectively absorbed by chlorophyll-a and chlorophyll-b are the red and blue.

Leaf as the main photosynthesis organ also functioned as the light receiver [18]. [19] suggested that photosynthesis does not depend on the total energy of light, but the number of photons or quanta absorbed. Photons are packets of energy that is fragmented, each having a specific wavelength. The characteristic of light as well as a wave have an effective wavelength for photosynthesis ranged between 400-700 nm. Therefore wavelengths between 400-700 nm is also called radiation for photosynthesis or photosynthetically active radiation (PAR). Campbell et al. [11] stated that the absorption spectrum of chloroplast pigments provide guidance on the relative effectiveness of various wavelengths to drive photosynthesis, because light can work only if it is absorbed in the chloroplast. Another fact mentioned that the speed of carbon change in the form of inorganic (CO\textsubscript{2}) into organic matter (glucose) in net primary productivity (NPP) is influenced by the availability and intensity of photosynthetically active radiation (PAR) and the distribution of pigment photoactive and light efficiency absorbed [20].

In photosynthesis, plants utilize solar energy to oxidize water to release O\textsubscript{2}, and reduce CO\textsubscript{2} to form larger carbon compounds, especially sugars [21]. Abiotic factors such as light, temperature, CO\textsubscript{2} concentration, moisture, presence of nutrients have a major effect on net photosynthesis, which in turn affects growth and productivity. The ability of photosynthesis is not only influenced by abiotic factor but also influenced by age and position of leaves in the canopy. Different types or genus has a different rate of photosynthesis. Dahlan [3] refers to various references explained that the rate of leaf photosynthesis of plants is influenced by several factors, namely: air pollutants, leaf health, the availability of ground water and humidity, concentration of CO\textsubscript{2}, sunlight intensity, the growth phase, the location of the leaf, the age of leaves, and different types of plants. Another explanation said that the temperature of the air through a complex scheme also affects photosynthesis [21].

Based on information from the description above it can be concluded that solar radiation plays a role in the ability of leaf photosynthesis. Plants that have a lower spectral radiation value in blue and red light wave (more sunlight energy absorbed) can be interpreted that these plants use the sun's light wave effectively to carry out photosynthesis, so the ability of photosynthesis can is high. Related to that fact it is automatically concluded if the leaf have high photosynthetis ability, CO\textsubscript{2} absorption is also high. Thus the relation between spectral radiation value and the ability of plants to absorb CO\textsubscript{2} is inversely proportional. Table 2, Table 3, and Table 4 shows grouping of spectral radiation value and ability to absorb CO\textsubscript{2} from the 25 types of tree leaf.

| No | Scientific name     | Classification of Spectral radiation value | Classification in absorbing CO\textsubscript{2} |
|----|---------------------|-------------------------------------------|-----------------------------------------------|
| 1  | Tamarindus indica   | Low                                       | High                                          |
| 2  | Adenanthera pavoniana | Low                                       | High                                          |
| 3  | Samanea saman       | Low                                       | High                                          |
| 4  | Ceiba pentandra     | Low                                       | High                                          |
Table 3. Grouping spectral radiation values and the ability to absorb CO$_2$ intermediate classification

| No | Scientific name          | Classification of Spectral radiation value | Classification in absorbing CO$_2$ |
|----|--------------------------|--------------------------------------------|-----------------------------------|
| 5  | Caesalpinia pulcherrima  | Intermediate                               | Intermediate                      |
| 6  | Khaya anthotheca         | Intermediate                               | Intermediate                      |
| 7  | Swietenia mahagoni       | Intermediate                               | Intermediate                      |
| 8  | Nephelium lappaceum      | Intermediate                               | Intermediate                      |
| 9  | Tectona grandis          | Intermediate                               | Intermediate                      |
| 10 | Delonix regia            | Intermediate                               | Intermediate                      |
| 11 | Artocarpus heterophyllus | Intermediate                               | Intermediate                      |
| 12 | Mimusops elengi          | Intermediate                               | Intermediate                      |
| 13 | Swietenia macrophylla    | Intermediate                               | Intermediate                      |
| 14 | Ficus benjamina          | Intermediate                               | Intermediate                      |
| 15 | Manilkora grandisflora   | Intermediate                               | Intermediate                      |
| 16 | Terminalia catappa       | Intermediate                               | Intermediate                      |
| 17 | Felicium decipiens       | Intermediate                               | Intermediate                      |
| 18 | Manilkara kauki          | Intermediate                               | Intermediate                      |
| 19 | Acacia auriculiformis    | Intermediate                               | Intermediate                      |
| 20 | Pometia pinnata          | Intermediate                               | Intermediate                      |
| 21 | Schima wallichii         | Intermediate                               | Intermediate                      |

Table 4. Grouping spectral radiation values and the ability to absorb CO$_2$ high and low classification

| No | Scientific name          | Classification of Spectral radiation value | Classification in absorbing CO$_2$ |
|----|--------------------------|--------------------------------------------|-----------------------------------|
| 22 | Anona muricata           | High                                       | Low                               |
| 23 | Pterocarpus indicus      | High                                       | Low                               |
| 24 | Acacia mangium           | High                                       | Low                               |
| 25 | Canangium odoratum       | High                                       | Low                               |

5. Conclusion
Twenty five types of tree leaves of the research object have a various spectral radiation value. The lowest spectral radiation value is tamarind and the highest is ylang on blue and red wave. Low classification of spectral radiation value is tamarind leaves, sage, tamarind, and cotton. Moderate spectral radiation value is peacock flower, khaya, small leaf mahogany, rambutan, teak, flamboyant, jackfruit, capes, big leaf mahogany, banyan, handkerchiefs, ketapan, sunshade umbrella, sapodilla kecik, Acacia auriculiformis, matoa, and flower. High spectral radiation value is soursop, Angsana, Acacia mangium, and ylang-ylang. Spectral radiation value is inversely proportional to the ability of plants to absorb CO$_2$. So the type of leaves that were classified as having high ability to absorb CO$_2$ is tamarind, saga, tamarind, and cotton while the type of tree leaves were classified as having low ability to absorb CO$_2$ is soursop, Angsana, Acacia mangium, and ylang, the rest classified as having moderate capability.
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