Leaf Area Index (LAI) in different type of agroforestry systems based on hemispherical photographs in Cidanau Watershed

Rahmi Nur Khairiah1,2*, Yudi Setiawan1,2, Lilik Budi Prasetyo1 and Prita Ayu Permatasari2
1 Department of Forest Resource Conservation and Ecotourism, Faculty of Forestry, Bogor Agricultural University, Kampus IPB Dramaga, Bogor, Indonesia
2 Center for Environmental Research, Bogor Agricultural University, PPLH Building 2nd-4th Floor, Jl. Lingkar Akademik, Kampus IPB Dramaga, Bogor, Indonesia

E-mail: rahmi.khairiah@apps.ipb.ac.id

Abstract. Ecological functions of agroforestry systems have perceived benefit to people around Cidanau Watershed, especially in the protection of water quality. The main causes of the problems encountered in the Cidanau Watershed are associated with the human factors, especially encroachment and conversion of forest into farmland. The encroachment has made most forest in Cidanau Watershed become bare land. To preserve the ecological function of agroforestry systems in Cidanau Watershed, monitoring of the condition of the vegetation canopy in agroforestry systems is really needed. High intensity thinning of crown density due to deforestation can change stand leaf area index dramatically. By knowing LAI, we can assess the condition of the vegetation canopy in agroforestry systems. LAI in this research was obtained from Hemispherical Photographs analysis using the threshold method in HemiView Canopy Analysis Software. Our research results indicate that there are six types of agroforestry in Cidanau Watershed i.e. Sengon Agroforestry, Clove Agroforestry, Melinjo Agroforestry, Chocolate Agroforestry, Coffee Agroforestry, and Complex Agroforestry. Several factors potentially contribute to variations in the value of LAI in different types of agroforestry. The simple assumptions about differences ranges of LAI values on six types of agroforestry is closely related to leaf area and plant population density.

1. Introduction
Agroforestry system is an intensified land use system for swidden agriculture in Indonesia. It is adaptation of shifting cultivation due to high pressure of population in Java. Java is the most populous island in Indonesia. The population density of Java Island is expected to increase from 1,068 per sq. km. in 2010 to 1,304 per sq. km. in 2035 [1]. Kosuke et. al., (2013) [2] explain that increasing population density necessitates the shortening of fallow period in a shifting cultivation cycle. If the fallow period is too short, the forest will end up becoming degraded lands. Classical literature on forest ecology suggests that human intervention threatens the balance of nature of forest ecology. For example, Mikesell, (1960) [3] suggests that the major causes of deforestation have been and continue to be: domestic and industrial consumption of wood, burning to clear land for cultivation, and destruction of palatable plants by livestock. Even in modern literature, major causes of deforestation
are believed to include population pressure inducing forest conversion into agricultural land and the demand for fuelwood, development project, logging and forest concession and fire loss [4, 5].

Cidanau Watershed is the only water resources for nearly 100 industries which are operating in Cilegon [6]. Ecological functions of agroforestry systems have perceived benefit to people around Cidanau Watershed, especially in the protection of water quality. The main causes of the problems encountered in the Cidanau Watershed are associated with the human factors, especially encroachment and conversion of forest into farmland. However, opportunities felling of trees in Cidanau Watershed very high. The encroachment has made most forest in Cidanau Watershed become bare land. However, the society as a whole bears the cost of lost biodiversity, global warming, smoke pollution and the degradation of water resources. The condition of seriously damaged watersheds will be a challenge to conserve. To preserve the ecological function of agroforestry systems in Cidanau Watershed, monitoring of the condition of the vegetation canopy in agroforestry systems is really needed.

LAI is defined as one sided is the total area of leaf tissue per unit ground surface area [7]. LAI has emerged as an important quantity for determining the impacts of global environmental change on forests [8] and highly correlated with forest growth and yield [9-11]. LAI is also commonly used as a measure of crop and forest growth and productivity at spatial scales ranging from the plot to the globe [12]. Canopy size determines the productivity of forest stands through its role in radiation interception. Canopy size is often measured as leaf area index, which plays a key role in interception models [13, 14]. High intensity thinning of crown density due to deforestation can change stand leaf area index dramatically. It is also likely that the discontinuous canopy resulting from thinning affects the radiation available to individual trees and may alter the structure of tree crowns and the stand as a whole [15]. By knowing LAI, we can assess the condition of the vegetation canopy in agroforestry systems. The condition of the vegetation canopy LAI would be considered good if the value doesn’t decline drastically. If there is a drastic reduction in LAI, then we can know that a decline in leaf area. To measure the LAI of different type of agroforestry Systems over large areas would require measurements at many different locations. Leaf area estimation can be performed by direct or indirect methods. Direct methods are expensive and complex, since the sampling restricts the amount of measurements to be performed. On the other hand, indirect methods provide non-destructive and reliable results [16]. Hemispherical Photographs was one of the first methods used to indirectly estimate LAI and well established method to optically assess ecological parameters related to plant canopies [17]. The acquisition of high definition photos under the canopy is quickly analyzed by proprietary software, taking as a basis algorithms with the zenith angle, the light attenuation and the contrast between plants and sky. The advantages of using Hemispherical Photographs, including high-resolution images to LAI estimation are discussed by [18-20]. The objective of this research was to describe the characteristics of LAI in Different Type of agroforestry systems based on Hemispherical Photographs.

2. Data and methods

2.1. Study area

Cidanau Watershed is located in Serang District and Pandeglang District, Banten Province, Indonesia (06°07’30”-06°18’00”S and 105°49’00”-106°04’00”E). Cidanau Watershed cover an area of 22,620 Ha, which encompasses 999.29 Ha area of Pandeglang District and 21,620.71 Ha area of Serang District. Cidanau Watershed has the various topographical condition, from 0% up to 135%.

2.2. Data collection

Field observation was carried out to collect The Hemispherical Photographs data, names of plant species (ranging from samplings, pole, and tree) and ground control points (GCP). Sample points were then placed based on the 10 classes of stand density types, under the stratified random sampling
method. In total, 140 plots were used for sampling, distribution of sample points can be seen in Figure 2.

Each observation plots represented one measurement plot of which Huang et. al., (2006) [40] suggested that measurement plot which used a 30 meter x 30-meter resolution image should take a dimension of 50 meters x 50 meters. Going forward, estimating LAI will be done using Landsat Imagine, so as to the size of the sample plot, adapted to the size of the pixels on the Landsat data. The data collection was conducted on the structure of tree species growing stakes, poles, and trees with a trunk diameter ≥ 1.5 cm [41]. Tree type identification was conducted by observing the characteristics of each species through generative organs such as fruit and flower seeds or vegetative parts such as stems and leaves.

Hemispherical Photographs data collection was conducted by using a DSLR camera with a fisheye lens. Hemispherical Photographs was conducted at the midpoint of the plot with the camera facing upwards on a tripod with a height of ± 1.5 meters to avoid shrubs blocking the view and monitor the camera facing towards the north compass [21]. The camera can be raised or lowered to the proper height. In the case of the camera is very close to the ground, it is possible to squat or even lie to get out of the field of view lens [22]. Then the camera is positioned correctly and leveled before the photo was taken. The proper position for taking photos that include location horizontally and has a flat field, while the camera orientation refers to the rotation of the camera relative to the north, it is adjusted so that magnetic north is straight to the top of the image [23].

2.3. LAI calculation
LAI in this research was obtained from Hemispherical Photographs (figure 3) analysis using the threshold method in HemiView Canopy Analysis Software [6]. The threshold was increased or decreased until a match of classification result figure and the original figure was found, and so a clear boundary of the canopy covered area and open area was obtained. High quality figures with a clear boundary between canopy covered area and open area are needed to minimize subjectivity of this method [22]. The LAI estimated by the inversion process may not be an exact measure of the LAI of the real canopy, even if that could be measured accurately. However, an ideal canopy with the LAI estimated will behave in a very similar way to the real canopy as far as radiation interception is concerned.
Agroforestry is planted with a mixture of many species of trees but may be dominated by one species, e.g. bamboo, in which case it is named after this species, so the name is bamboo agroforestry [2]. Analysis of the type of agroforestry was conducted by quantifying a number of major crops in each plot. Each type of agroforestry reflects the dominant plant that assembles which in this study accounted more than 80% stands on the land. If there is no major crops then it is will described as a Complex Agroforestry. Complex Agroforestry is defined as forest structures planted and managed by farmers for the production of various forest and agricultural products on the same piece of land [24]. Complex Agroforestry Systems in intimately association with a high number of components (trees, lianas, herbs), and either primary or secondary forests are Able to sustain both biodiversity conservation and farmers' economic needs [25].

3. Result and discussion

Agroforestry system combining forestry component (woody plants) to the agricultural component (or non-wood plant). Woody plants intended long rotation (tree crops) and non-timber plants of this type of seasonal crops (annual crops). The advantage of agroforestry systems that was felt by the farmers is agroforestry systems have composition of diverse plants and can be used by the owner (farmer) at any time in accordance with the wishes of the owner. Cidanau Watershed is the only water resources for nearly 100 industries which are operating in Cilegon [6]. Ecological functions of agroforestry systems have perceived benefit to people around Cidanau Watershed, especially in the protection of water quality. The role of the community in the upstream felt very important to communities downstream. Water quality protection requires a multi sectoral approach are integral in the management of Cidanau Watershed. Rivers through agricultural land is often not overgrown vegetation on the banks of rivers and streams zone of surface water containing excessive fertilizer and pesticide. Agroforestry system, can be said to be like a forest buffer on the river bank, it is very effective in reducing water pollution from agricultural activities. One of the efforts for soil preservation or soil erosion control is by means of vegetative, i.e. planting forestry plants, planting a cover cropland and planting crops is parallel to contour lines, planting crops in the strip, planting crops in rotation, and mulching or plant biomass utilization [26].

A total of 20,091 trees from 79 species were recorded in the 140 survey plots, there are: Akasia (Acacia auriculiformis A. Cunn. ex Benth.), Angsana (Pterocarpus indicus Willd.), Asam Jawa (Tamarindus indica L.), Asam Kranji (Dialium indum L.), Bacang (Mangifera foetida Lour), Balsa (Ochroma pyramidale), Bayur (Pterospermum javanicum Jungh.), Belimbing Wuluh (Averrhoa bilimbi L), Bisbul (Diospyros blancoi A. DC.), Bungur (Lagerstroemia loudonii T.& B), Cempedak (Artocarpus integer), Clove (Syzygium aromaticum (L.) Merr. & L. M. Perry), Dadap Merah (Erythrina cristagalli L.), Duku (Lansium domesticum Corr), Durian (Durio zibethinus Murr), Flamboyan (Delonix regia), Gamal (Gliricidia maculata), Gandaria (Bovea macrophylla Griff.), Huru Sengon with LAI value 1.0  Sengon Agroforestry with LAI value 1.5  Cloves Agroforestry with LAI value 1.8  Cloves Agroforestry with LAI value 2.3  Melinjo Agroforestry with LAI value 2.6  Melinjo Agroforestry with LAI value 2.8  Cacao Agroforestry with LAI value 2.9  Cacao Agroforestry with LAI value 3.1

Figure 3. Hemispherical photographs in different type of agroforestry systems

![Hemispherical photographs in different type of agroforestry systems](image-url)
(Macaranga rhizinoides (Blume) Muell Arg.), Jambu Air (Eugenia aquea Burm.F.), Jambu Batu (Psidium guajava L.), Jarak Pagar (Jatropha curcas L.), Jati (Tectona grandis L.f.), Jati Putih (Gmelina arborea Roxb.), Jengkol (Archidendron jiringa (Jack) L.C.Nielsen.), Jeruk lemo (Citrus amblycarpa (Hassk.) Ochse), Cacao (Theobroma cacao L.), Kamboja (Plumeria acuminata Ait), Karet (Hevea brasiliensis Muell. Arg), Karet Kebo (Ficus elastica Roxb. ex Hornem), Kayu Afrika (Maesopsis eminii Engl.), Kayu Manis (Cinnamomum burmannii (Nees &Th. Nees)), Kayu Pedang (Oroxylum indicum (L.) Vent.), Kapci (Sandoricum koetjape (Burm.F.) Merr), Kedondong (Spondias dulcis), Kedoya (Dysoxylum gaudichaudianum (A.Juss.) Miq.), Kelapa (Cocos nucifera L.), Kembang Sepatu (Hibiscus rosa-sinensis L.), Kemiri (Aleurites moluccana (L.) Wild), Kenanga (Cananga odorata (Lamk.) Hook.), Kenari (Canarium indicum), Kepuh (Sterculia foetida L.), Kersen (Muntingia calabura L.), Keruing (Diptocarpus cornutus Dyer), Coffee (Coffee arabica L.), Laban (Vitex pubescens Vahl.), Mahoni Daun Besar (Swietenia macrophylla King.), Mahoni Daun Kecil (Swietenia mahagoni (L.) Jacq.), Maja (Aegle marmelos (L.) Corr), Mangga (Mangifera indica L.), Manggis (Garcinia mangostana L.), Manglid (Magnolia Blumei Prantl.), Mareme (Glochidion borneense Boer.), Melinjo (Gnetum gnomon L.), Mengkudu (Morinda citrifolia L.), Meranti Tembaga (Shorea leprosula Miq.), Mindi (Melia azedarach L.), Nangka (Artocarpus heterophyllus Lam), Pachira (Pachira affinis Decne), Pala (Myristica fragrans Houtt), Palem Jawa (Ceratolobus glaucescens), Papaya (Carica papaya L.), Petai (Parkia speciosa Hassk), Pinang (Areca catechu L.), Pisang (Musa paradisiaca), Pulai (Alstonia scholaris R. Br.), Pulus (Laporatea stimulans (Lf) Gaud), Rambutan (Nephelium lappaceum L.), Randu (Ceiba pentandra L. Gaertn), Sagu (Metroxylon sagu Roth), Salam (Syzygium polyanthum Vahl), Sawo Duren (Chrysophyllum cainito L.), Sawo Kelic (Milanika kauki Dub), Sengon (Paraserianthes falcatoria (L.) Nielsen), Singkong (Manihot esculenta Crantz), Sukun (Artocarpus communis Forst), Tanjung (Mimusops elengi L.), Waru Gunung (Hibiscus macrophyllus Roxb. ex Hornem). These plants are grown there and there are growing naturally in farmers’ fields. Clove (Syzygium aromaticum (L.), Cacao (Theobroma cacao L.), Melinjo (Gnetum gnomon L.) dan Sengon (Paraserianthes falcatoria (L.) Nielsen) are booming because of their good price in the markets. Even on smaller farms with a priority on crop production, planting tree with high economic value on boundaries away from crops or at low densities seems to be an attractive option to enhance income.

Turner et. al., (1999) [27] has conducted research on various types of tropical forest vegetation and crop areas (gardens) with a calculation method directly in the field. The study involved three National Science Foundation Long Term Ecological Research sites differing widely in vegetation physiognomy, climate, and topography. Vegetation types at the three sites included grassland, shrubland, hardwood forest, and conifer forest. At each site, measurements of LAI were made at a number of plots with locations determined by the Global Positioning System (GPS). Furthermore, another study shows that the in situ measurements for LAI in evergreen broadleaf forest in East Africa vary between 3.95 and 7.4 [28]. Global averages from ground measurements of tropical evergreen broadleaf forests around 4.9 [29] and Aragao et. al., (2005) [30] measured slightly lower LAI values for the Amazonian evergreen broadleaf forest between 3.25 and 5.1.

| Number | Vegetation Types          | Number of Samples | Estimation Method of LAI | Ranges of LAI |
|--------|---------------------------|-------------------|--------------------------|---------------|
| 1      | Burned grassland          | 6                 | Clipping                 | 2.5-6.3       |
| 2      | Unburned grassland        | 7                 | Clipping                 | 2.5-3.2       |
| 3      | Broadleaf forest          | 14                | Litterfall               | 4.4-8.4       |
| 4      | Conifer forest - Young    | 10                | Litterfall               | 1.4-3.9       |
| 5      | Shrub-land                | 3                 | Plant Cover              | 1.0-3.3       |
| 6      | Conifer Forests - Young   | 6                 | Sapwood Area             | 5.3-9.6       |
| 7      | Conifer Forests - Old     | 7                 | Sapwood Area             | 7.9-13.0      |

LAI in our research was obtained from Hemispherical Photographs by using the threshold method in HemiView Canopy Analysis Software. Each one plot represented by a Hemispherical Photographs
which is then analyzed into one LAI value. Thus, in this study we have 140 LAI values are grouped into several types of agroforestry systems based on the calculation of plant components in the plot. Once grouped, we describe a range of values LAI on any type of agroforestry systems.

Our research results indicate that there are six types of agroforestry in Cidanau Watershed i.e. Sengon Agroforestry, Clove Agroforestry, Melinjo Agroforestry, Chocolate Agroforestry, Coffee Agroforestry, and Complex Agroforestry. Complex agroforestry is a dominant type of agroforestry in Cidanau Watershed, this is because the types of crops in agroforestry is very diverse. Complex Agroforestry consists of 11-36 plant species, so the ranges bound of the LAI value is very difficult to observe. LAI Ranges values in Coffee Agroforestry can not be known, this is because only one number of samples have been found. As can be seen in Table 2, LAI interval of Sengon Agroforestry (1.0 -1.5), Cloves Agroforestry (1.8 -2.3), Melinjo Agroforestry (2.6 -2.8), Cacao Agroforestry (2.9-3.1), and the Complex Agroforestry (1.0-5.3). This range value showed minimum and maximum range of LAI values forming fairly open to very dense canopy in six types of agroforestry in Cidanau Watershed. These results can be used to monitor vegetation conditions based on the value of LAI in Cidanau Watershed.

### Table 2. Ranges of LAI in different type of agroforestry

| Number | Agroforestry Type         | Number of Samples | Estimation Method of LAI                      | Ranges of LAI |
|--------|---------------------------|-------------------|-----------------------------------------------|-------------|
| 1      | Sengon Agroforestry       | 4                 | Hemispherical Photographs Analysis            | 1.0-1.5     |
| 2      | Cloves Agroforestry       | 5                 | Hemispherical Photographs Analysis            | 1.8-2.3     |
| 3      | Melinjo Agroforestry      | 6                 | Hemispherical Photographs Analysis            | 2.6-2.8     |
| 4      | Cacao Agroforestry        | 5                 | Hemispherical Photographs Analysis            | 2.9-3.1     |
| 5      | Coffee Agroforestry       | 1                 | Hemispherical Photographs Analysis            | 2.5         |
| 6      | Complex Agroforestry      | 119               | Hemispherical Photographs Analysis            | 1.0-5.3     |

Several factors potentially contribute to variations in the value of LAI in different types of agroforestry. The simple assumptions about differences ranges of LAI values on six types of agroforestry is closely related to leaf area and plant population density. However, additional research needs to to prove the relationship between LAI values in any type of agroforestry system with leaf area and plant population density. At the leaf level, these include influences associated with variation in leaf pigments, leaf internal structure, and the orientation of the leaf relative to solar radiation [32-35]. At the multi tree scale, heterogeneity in tree height and the number and size of tree gaps influences reflectance [36-39].

### 4. Conclusion

The results of this study showed that six types of agroforestry system applied in Cidanau Watershed by farmers. LAI ranges value of five agroforestry types has been obtained, namely Sengon Agroforestry (1.0-1.5), Cloves Agroforestry (1.8-2.3), Melinjo Agroforestry (2.6-2.8), Cacao Agroforestry (2.9-3.1), and Complex Agroforestry (1.0-5.3). Several factors potentially contribute to variations in the value of LAI in different types of agroforestry. The simple assumptions about differences ranges of LAI values on six types of agroforestry is closely related to leaf area and plant population density. However, additional research needs to to prove the relationship between LAI values in any type of agroforestry system with leaf area and plant population density.

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References

[1] Ferraris J, Makalew R J, Posselt H and Harahap D P 2015 The 2010–2035 Indonesian Population Projection: Understanding the Causes, Consequences and Policy Options for Population and Development. UNFPA or the Government of Indonesia.

[2] Kosuke M, Mugniesyah S S, Herianto A S and Hiroshi T 2013 Talun-huma, swidden agriculture, and rural economy in West Java, Indonesia Southeast Asian Studies. 2 351–381

[3] Mikesell and Mike W 1960 Deforestation in Northern Morocco Science 132 441-445

[4] World Bank 1990 Indonesia: Sustainable Development of Forests, Land and Water (Washington, D.C.: The World Bank)

[5] World Resources Institute 1991 World Resources 1990-1991 (New York: Oxford University Press)

[6] Khairiah R N, Prasetyo L B, Setiawan Y and Kosmaryandi N 2016 Monitoring model of payment for environmental service (PES) implementation in Cidanau Watershed with stands density approach Procedia Environmental Sciences. 33 269-278

[7] Chen J M and Black T A 1992 Defining leaf area index for non-flat leaves plant Cell Environ. 15 421–429.

[8] Thomas, Sean C and Winner William E 2000 Leaf area index of an old-growth Douglas-fir forest estimated from direct structural measurements in the canopy Canadian Journal of Forest Research. 30 1922-1930

[9] Waring R H 1983 Estimating forest growth and efficiency in relation to canopy leaf area Adv. Ecol. Res. 13 327-354.

[10] Fownes J H and Harrington R A 1990 Modelling growth and optimal rotations of tropical multipurpose trees using unit leaf rate and leaf area index J. Appl. Ecol. 27 888-896.

[11] Harrington R A, Fownes J H, Meinzer F C and Scowcroft P G 1995 Forest growth along a rainfall gradient in Hawaii: Acacia koa stand structure, productivity foliar nutrients, and water and nutrient use efficiencies Oecologia. 102 227-284.

[12] Anonymous 2014 LAI Theory and Practice (New York: Decagon Devices, Inc)

[13] Jarvis P G and Leverenz J 1983 Productivity of temperate, deciduous and evergreen forest. In Encyclopedia of Plant Physiology. New Series, Vol. 12D. Eds. O.L. Lange, P.S. Nobel, C.B. Osmond and H. Ziegler. (Berlin: Springer-Verlag) pp 233–80.

[14] Landsberg J J and Hingston F J 1996 Evaluating a simple radiation/dry matter conversion model using data from Eucalyptus globulus plantations in Western Australia Tree Physiol. 16 801–808.

[15] Medhurst J L and Beadle C L 2001 Crown structure and leaf area index development in thinned and unthinned Eucalyptus nitens plantations Tree Physiology 21 989–999

[16] Brandão and Zonta 2016 Hemispherical photography to estimate biophysical variables of cotton. Rev. bras. eng. agríc. ambient. 20 789-794.

[17] Glatthorn J and Philip B 2014 Standardizing the protocol for hemispherical photographs: accuracy assessment of binarization Algorithms PLoS One. 9 e111924.

[18] Jonckheere I, Fleck S, Nackaerts K, Muys B, Coppin P, Weiss M and Baret F 2004 Review of methods for in situ leaf area index determination. Part I. Theories, sensors and hemispherical photography Agricultural and Forest Meteorology. 121 19-35.

[19] Chianucci F and Cutini A 2012 Digital hemispherical photography for estimating forest canopy properties: Current controversies and opportunities Forest Biogeosciences and Forestry. 5 290-295.

[20] Zhao, F., Strahler, A. H., Schaaf, C. L., Yao, T., Yang, X., Wang, Z., Schull, M. A., Román, M. O., Woodcock, C. E., Olofsson, P., Ni- Meister, W., Jupp, D. L. B., Lovell, J. L., Culvenor, D. S.

[21] Djumaher M 2003 Pendugaan leaf area individual dan stands basal area menggunakan Landsat 7 ETM+. Bachelor Thesis (Bogor: Institut Pertanian Bogor)
[22] Rich P M, Wood J, Vieglais D A, Burek K. and Webb N 1999 Hemiview User Manual. United of Kingdom: Delta-T Devices LTD. 106 285–304.
[23] Rich P M 1990 Characterizing plant canopies with hemispherical photographs Remote Sensing Reviews 5 13-29.
[24] De Foresta, H and Michon G 1996 Tree improvement research for agroforestry: A note of caution Agroforestry Forum. 7 8-10.
[25] De Foresta H and Michon G 1994 Agroforest: an original agro-forestry model from smallholder farmers for environmental conservation and sustainable development. In Traditional Technology for Environmental Conservation and Sustainable Development in the Asian-Pacific Region. Japan pp 52-58.
[26] Senoaji G 2012 Pengelolahan lahan dengan sistem agroforestrti oleh masyarakat baduy di banten selatan Bumi lestari. 12 283-293.
[27] Turner D P, Cohen W B, Kennedy R E, Faanacht K S and Brings J M 1999 Relationship Between Leaf Area Individual and Landsat TM Spectral Vegetation Individuals across Three Temperate Zone Sites (New York: Elsevier Science Inc.)
[28] Kraus T 2008 Ground-Based Validation of the MODIS Leaf Area Index Product for East African Rain Forest Ecosystems. Ph.D. Thesis, Friedrich-Alexander (Erlangen: Universität Erlangen-Nürnberg Germany)
[29] Wang Y, ian Y, Zhang Y, El -Saleous N, Knyzakhin Y, Vermote E and Myneni R B 2001 Investigation of product accuracy as a function of input and model uncertainties: Case study with SeaWiFS and MODIS LAI/FPAR algorithm Remote Sens. Environ. 78 299–313.
[30] Aragao L E O C, Shimabukuro Y E, Espirito-Santo F D B and Williams M 2005 Spatial validation of the collection 4 MODIS LAI product in eastern Amazonia. IEEE Trans. Geosci. Remote Sens. 43 2526–2534.
[31] Koesmaryono Y, Haseba T, Sugimoto H and Ito D 1996 Growth and yield of soybean cultivated under different population density with special reference to unusual summer eather in 1994. In Crop research in Asia: Achievements and perspective. Proc. 2nd Asian Crop Sci. Conf. 478-479.
[32] Baret F and Guyot G 1991 Potentials and limits of vegetation indices for LAI and APAR assessment. Remote Sens. Environ. 35 161–173.
[33] Williams D L. 1991 A comparison of spectral reflectance properties at the needle, branch, and canopy level for selected conifer species Remote Sens. Environ. 35 79–93.
[34] Bouman B A 1992 Accuracy of estimating the leaf area index from vegetation indices derived from crop reflectance characteristics, a simulation study. Int. J. Remote Sens. 13 3069–3084
[35] Yoder B J and Waring R H 1994 The normalized difference vegetation index of small Douglas-fir canopies with varying chlorophyll concentrations. Remote Sens. Environ. 49 81–91
[36] Guyot G, Guyon D and Riom J 1989 Factors affecting the spectral response of forest canopies: a review. Geocarta Int. 4 3–18.
[37] Cohen W B and Spies T A 1992 Estimating structural attributes of Douglas-fir/western hemlock forest stands Landsat and SPOT imagery. Remote Sens. Environ. 41 1–17.
[38] Cohen W B, Spies T A and Bradshaw G A 1990 Semivariograms of digital imagery for analysis of conifer canopy structure Remote Sens. Environ. 34 167–178.
[39] Leblon B, Gallant L and Grandberg H 1996 Effects of shadowing types on ground-measured visible and near-infra- red shadow reflectances Remote Sens. Environ. 58 322–328.
[40] Huang D, Yang W, Tan B, Rautiainen M and Zhang P 2006 The importance of measurement errors for deriving accurate reference leaf area index maps for validation of moderate resolution satellite LAI products. J. IEEE Transactions Geoscience and Remote Sensing. 44 1866-1871
[41] Standar Nasional Indonesia 2011 Pengukuran dan Perhitungan Cadangan Karbon-Pengukuran Lapangan untuk Penaksiran Cadangan Karbon Hutan. (Jakarta: Badan Standarisasi Nasional) 25 320–333