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*Full Length Research Paper*

# Sunlight environment for vanilla planifolia cultivated by agroforestry system in East Kalimantan

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**The suitable sunlight environment for cultivation of vanilla by agroforestry in an equatorial region was investigated. The cultivation required shade, and the canopies of crop trees and support trees performed that function. Enough shade by the canopies of these trees kept the sunlight intensity on vanilla colony lower than 30klx. The thick crop-tree-canopies and thin support-trees-canopies kept it lower than 50klx, except the invasion of occasional 50-150klx. Although support-tree-canopies in the plantation style without crop trees reduced it below 60klx, an invasion of 60-200klx was frequently reached. Sunlight below 50klx maintained the vanilla leaves at a healthy green color. Invasion higher than 100 klx*h/day of the integration sunlight intensity changed it to a yellow color or red color. Even though the flowering of a vanilla plant required strong sunlight by shade release, in the equatorial region, this invasion was excessive. In order to prevent disturbance and to promote flowering, 100klx*h/day was considered to be the suitable upper limit in shade release work. And it was thought that such a sunlight environment was controllable by pruning the support trees under thick crop-tree-canopies.**

**Key words:** Agroforestry, vanilla, cultivation, equatorial region, sunlight environment, sunlight intensity, shade control, pruning, support trees, color of leaves, disturbance.

## INTRODUCTION

Vanilla is worthy as an agricultural product in a tropical or subtropical area, and it is cultivated in various area of the world. The main production area are subject to a monsoon climate where both a rainy season and dry season exist. Almost none of those districts possess a tropical rain forest climate. However, in East Kalimantan, Indonesia, in an equatorial belt, although it is subject to awet tropical climate, there is an agroforestry site which produces vanilla. Here, a moderate level of production is performed by local farmers (Kitai 2015). Vanilla cultivation by agroforestry under a wet tropical wet climate is considered to be a rare and very interesting instance.

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Anilkumar (2004), Hernandez and Lubinsky (2011), and Bianchessi (2012) described the details of the process of a vanilla plantation. In various cultural works which they advocate, shading and its release plays an important role. This is because the vanilla plant needs shade for growth and needs strong sunlight for fruit bearing. It is possible for that activity to be performed by attachment and removal of butter muslin in a plantation with a facility. In a style without a facility, support trees for hanging vanilla vine are planted. Branches and leaves of support trees provide the shade effect to vanilla. Pruning which removes branches performs shade release. In the vanilla cultivation without a facility, sunlight environment is controlled by such operation. In agroforestry, not only support trees but crop trees have the shade effect, and that control work is complicated.
It is thought that the property of sunlight in east Kalimantan

under the equator differs from it in the vanilla producing districts away from the equator. A risk will be expected if the removal of shade for the fruit bearing is carried out like a common vanilla producing district. In spite of it, the farmer actually produces by trial and error in east Kalimantan. There is no measured value standard here. Actually, many vanilla leaves discolored terribly are observed in this farmland. In order to improve the productivity of vanilla in this region, the understanding about suitable sunlight environment is required.

There are some reports which show examples of measuring the sunlight environment in agroforestry sites. Mialet-Serra et al. (2001) shows the result of measuring the sunlight environment in the field of the agroforestry in Ivory Coast and Vanuatu. Fang et al. (2005) and Zhang et al. (2014) shows it in China, and Varella et al. (2011) shows it in New Zealand.

Each of these districts is distant from the equator. And most of them do not belong to tropical areas. The serial measuring of light intensity in the field became easy about ten years ago. However, informational for an equatorial region has hardly yet been provided.

Relative light intensity (%) is used as a shade standard in common vanilla cultivation(Hernandez and Lubinsky, 2011; Bianchessi, 2012). However, the sunlight intensity of whole sky under an equator which is a fractional denominator is the highest on the earth theoretically. The relative value used in other regions is inapplicable here.

Therefore, the actual sunlight environment in that field was measured in this study. The shade regulation for the vanilla cultivation in agroforestry is performed by the treatment of the branches and leaves of trees. Sunlight environment changes with combinations of the existence of pruning in a crop tree and a support tree. The diurnal change of the euphotic intensity of a vanilla was measured for such every combination.

## MATERIALS AND METHODS

### Study site

Figure 1 show the study site in Kecamatan Tenggarong Seberang Kabupaten Kutai Kartanegara Propinsi Kalimantan Timur near Samarinda, Indonesia.This is located at 0 degrees 3 minutes south, directly under the equator, and is subject to a tropical rain forest climate. The original vegetation was a virgin tropical rainforest with many giant trees of Dipterocarpaceae.

In this region, the primary forest was clear cut for export timber to various countries in the 1970s.After that, open cut mining of coal has been active. At other sites, farmland has also been developed actively. However, although developed, some farmers could not maintain their land, and some farmland came to be neglected.

Around 1975, local residents and a landowner began the challenge of developing the farmland. And although it was small-scale farmland, they maintained the production of the agricultural. They started vanilla cultivation in small-scale plantation in 1995. Their cultivation management came to be performed by Agroforestry System in the 2000s.

In this agroforestry system, the vanilla was introduced as a cash crop, Gliricida sepium was used for its support tree, and one kind of Agarwood or Tectona grandis was chosen as a crop tree. This field had about 2,400 m2 of plantation style land, and about 10,000 m2 of agroforestry style land, and the investigation was conducted in these plots. In the plantation style area without a facility, vanilla colonies accompanied by a support tree have been arranged at 1x1 m or 2x2 m, and there was no harvest tree here (Figure 2). In the agroforestry style area, the vanilla colonies accompanied by a support tree have been arranged at 3x3 m or 5x5 m, and the harvest tree has been equally arranged in the middle of each of these (Figure 3).

Paying attention to the plantation style plot arranged at 2 m x 2 m, and the agroforestry style plot arranged at 5 m x 5 m, these were chosen as the main subjects of an investigation of sunlight environment. In the agroforestry plot, Agarwood i.e.Gaharu (Aquilaria spp) was used as a crop tree. An investigation was conducted in reference to the other tree.

### Measurement

In order to know the sunlight environment, light quantum and illumination were measured.

Data logger LI1400 made from LI-COR and Quantum Sensors LI-190SA was used for measurement of the light quantum, i.e. photosynthetically active radiation quantity (PAR). Three sensors were always used, and these were horizontally installed so that the sunlight might be measured from a perpendicular direction. The average of the three measured values was used for analysis. In this measuring, the unitary was set toμmol / m2s, and the interval was set to 1 minute.

HOBO Pendant Temperature/Light Data Logger 64K made from Onset were used for measurement of illumination. These instruments were hung vertically. In order to measure dispersion light, the installation required that the sensor inclination be horizontal, and that it not receive sunlight directly. In this measurement, the units were set to lx, and the interval was set to 1 minute.

PAR was used for the frequency for the sunlight environment measurement by a plant ecology, etc., in recent years. However, there was financial difficulty in preparing an adequate number of instrumentals for multipoint measurement. Compared with the instrument for a PAR measurement, the lux measuring device is easy to come to hand, and was thus used for the luminous-flux-density measuring. Although the conversion between mutually different PAR and lux had the senseless nature of the measuring, in this measuring, the near relationship of the value of both at same time to the sunlight of an equatorial belt was needed.

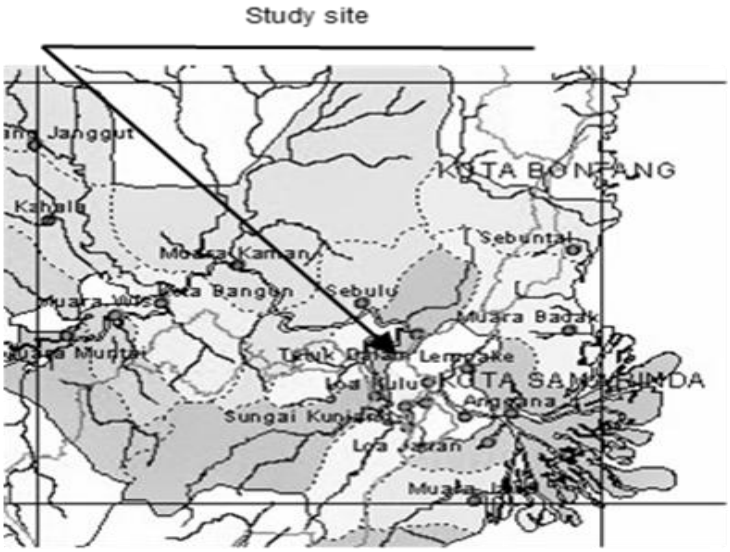


Figure 1. Map of study site

Figure 2. Plantation style site where the vanilla colony was arranged by 2 x2 m

Figure 3. Agroforestry style site where the vanilla colony was arranged by 5 x5 m

Whole sky sunlight was measured on the point without the shading in this investigation plot. One set with three sensors of LI1800 and two sets of HOBO were used, and it was measured. The measurements were carried outin the period described below: 2006-12-24/2006-12-25, 2008-8-26/2008-8-27, 2008-9-4/2008-9-5, 2009-3-8/2009-3-10, 2009-3-18/2009-3-19, 2009-3-23/2009-3-26,and 2009-8-28/2009-8-29.

The sunlight intensity on vanilla leaves were measured at the plantation style plot and agroforestry style plot. In the plantation plot, the difference between the shading conditions by the thickness or thinness of a support tree canopy was measured. In the agroforestry plot, the difference in the environment of the type of combination of the shading by the harvest tree and support tree was measured. Only HOBO was used for this measurement. The measuring devices were put on the top of a support tree, and were put on the vanilla colony top, its east-side surface, the west-side surface and the internal. These were carried out in the period described below:

2007-6-4/2007-6-12, 2008-3-7/2008-3-22, 2008-3-23/2008-4-7, 2008-8-15/2008-9-4, 2009-2-26/2009-3-19, 2009-3-22/2009-3-29, and 2009-8-26/2009-9-2. At these measurements, the shading condition of the support tree and crop tree was investigated (Table 1).
Together with those sunlight measuring, the health of the vanilla colony was observed, and the condition of the vine or leaf of vanilla was investigated as a health indicator. The color classification was used for the index, and it showed each stage in the process in which a vanilla colony declines from health. The item was set as overall green, partial yellow, overall yellow, partial red.

## RESULTS AND DISCUSSION

### Sunlight Quantum (PAR)and Illuminance

Figure 4 shows the sunlight quantum in the investigation plot. This means the photosynthetically active radiation quantity by light flux with a wavelength of 400-700 nm. In this figure, all the measured values in various seasons were plot¬ted for every time for one day. The line on the figure shows the theoretical value under the whole sky on the equator. The value actually acquired by weather change such as clear sky, clouded sky, fog, or rain was various for every time. For this reason, in this figure, the points were distributed over the territory inside that line, and filled the line.
Some territories, over which points are not distributed, were recognized along the line. There is one around 12:00, and it was influenced by the clouds which the radiant heat of the morning clear sky made. There are others around 10:00 and around 16:00, and these were influenced by the shadow of a structure, tree, and microtopography.
According to this measured value and theoretical value, the maximum photosynthetically active radiationquantity at the investigation plot is 2550 (μmol / s･m2) on meridian transit, and that time was 12:36.
Figure 5 shows the relation between a sunlight quantum and illuminance. These two pairs of measurement were performed at the same time in the investigation plot. Although the PAR meter and the illuminometer were used, the difference in accuracy was observed among these. The response of the illuminometer was low compared with the PAR meter, and measured value had a scatter. About the relation between both, although the correlation coefficient R2 was low at 0.6178, the regression y=87.871x was obtained. However, expedient guidance that about 1/90 of a value of illumination was equivalent to a value of photosynthetically active radiation quantity, was obtained from the regression.
The vanilla colonies cultivated at the investigation site were under various sunlight environments according to disposition of the vegetation for every plot, and the process of work activities. Then, in order to know such an environment clearly, the sunlight illuminance was measured in the various positions there.
Table 1 shows the outline of those measurements. The items in this table were the number, the term, the plot, the position, the shade of the crop trees, the shade of a support tree, and the sunlight illuminance in meridian transit.
In the table, whether a tree canopy is thin or thick is estimated, and they were shown as a shading effect. When Agarwood was young, the canopy was thin and there was almost no shading effect. When the branch of support or a harvest tree grew, the canopy was thick and gave the shade to the vanilla. By the pruning of trees, the canopy became thin and the shading effect diminished.
The item "meri value" in Table 1 meant the sunlight illuminance at meridian transit (klx), and expressed the shading effect of the support trees and crop trees well.
Figure 6shows the whole sky illuminance in the investigation site for every time from 0:00 to 24:00. All the values of 2007-6-4/2007-6-12(01), 2007-6-4/2007-6-12(05), 2009-8-26/2009-9-2(04) indicated as a measurement term in Table 1 were plotted into this figure. The outside line in this figure shows the theoretical maximum of each time of day. However, the reproducibility of this measurement over 170klx, was not good. Compared with the sunlight quantum of Figure 3-1, it has been recognized that the reliability of this measurement in the high end of energy range is not good.
Figure 7 shows the model of the layer structure constituted by the vanilla colony, the support tree, and a crop tree in the agroforestry style site. Here, sunlight energy was absorbed by the crop tree canopy first, next by the support tree canopy, and then arrived at the vanilla colony. On the other hand, in the plantation style site, since the crop tree was lacking, sunlight energy was absorbed by only the support tree canopy before arriving at the vanilla colony.
According to such a layer structure, the condition of the sunlight which reaches a vanilla leaf differed. Furthermore, it changed with growth of a crop tree, the pruning work of the support tree, etc. These various sunlight environments were the target of this measurement.
In vanilla cultivation, the process of repetition of shading and its release is indispensable. Control of the sunlight environment in agroforestry is just an operation of stratification. Therefore, it is important to get to know the sunlight environment under the layered structure in various conditions.

### The sunlight intensity of the plantation style site

Figure 8 shows the measurement result at the plantation style site, when support tree canopy was thick.
The partial figure '08-8-15/'08-9-4 (03) in Figure 6 shows the condition on the top layer of the vanilla colony.

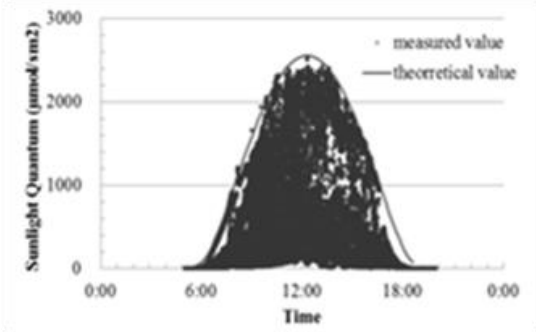


Figure 4. Whole sky sunlight quantum (APR) in all the measured value in the investigation site

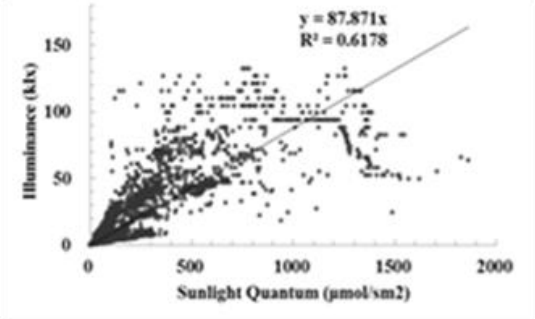


Figure 5. Relation between the sunlight Quantum (APR) and Illuminace in all the measured value in the investigation site

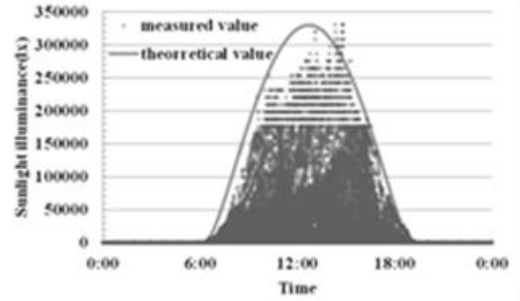


Figure 6. Illuminace in all the measured value in the investigation site

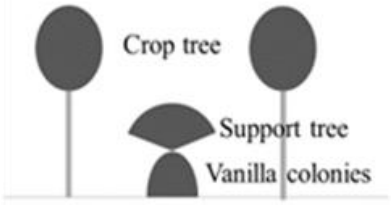


Figure 7. Layered structure model of vanilla colonies, support trees, and crop trees

Here, the "meridian transit illuminance in each measurement" / "meridian transit illuminance of theoretical whole sky sunlight" was named the hypothetical relative illuminance.

The meridian transit illuminance was about 50 klx, and the hypothetical relative illuminance was 15%. The measurements for'07-6-4/'07-6-12(04),'07-6-4/'07-6-12(06),'08-8-15/'08-9-4 (02), '09-08-26/'09-9-2(01), '09-08-26/'09-9-2(02), '09-08-26/'09-9-2(03) in Table 1 without a figure was similar to this.

The partial figure for '08-3-23/'08-4-7(06) shows the condition on the east side of the colony. Although the

**Table 1.** The outline of sunlight illuminance measurement.

| No. | Term(sno.) | style by | plot | measuring position | shading by | | sunlight | | invation time (h) | color of colony | note |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | crop trees | suport trees | eridian (klx) | nvertion (klx) | | | |
| 1 | 2007-6-4/2007-6-12(01) | - | - | whole sky | - | - | 350 | - | - | - | |
| 2 | 2007-6-4/2007-6-12(02) | plantaion | A | colony top | - | thin | 50 | 150 | 2.0 | overall yellow | |
| 3 | 2007-6-4/2007-6-12(03) | plantaion | A | colony top | - | thin | 50 | 150 | 1.0 | overall yellow | |
| 4 | 2007-6-4/2007-6-12(04) | plantaion | A | colony top | - | thick | 40 | 0 | 0.0 | overall green | |
| 5 | 2007-6-4/2007-6-12(05) | - | - | whole sky | - | - | 330 | - | - | - | |
| 6 | 2007-6-4/2007-6-12(06) | plantaion | A | colony top | - | thick | 50 | 0 | 0.0 | overall green | |
| 7 | 2008-3-7/2008-3-22(01) | plantaion | A | east side | - | thick | 50 | 150 | 1.5 | overall yellow | |
| 8 | 2008-3-7/2008-3-22(02) | agroforestry | C | west side | thick | thick | 30 | 80 | 0.5 | overall green | dark spot |
| 9 | 2008-3-7/2008-3-22(03) | agroforestry | C | west side | thin | thin | 70 | 175 | 2.5 | overall yellow | bright spot |
| 10 | 2008-3-7/2008-3-22(04) | agroforestry | D | west side | thick | thin | 40 | 145 | 2.0 | overall yellow | |
| 11 | 2008-3-7/2008-3-22(05) | plantaion | B | west side | - | thin | 70 | 200 | 4.0 | partial red | bright spot |
| 12 | 2008-3-7/2008-3-22(06) | agroforestry | D | colony top | thick | thick | 40 | 60 | 0.2 | overall green | |
| 13 | 2008-3-7/2008-3-22(07) | plantaion | B | colony top | - | thin | 50 | 180 | 4.0 | overall yellow | |
| 14 | 2008-3-7/2008-3-22(08) | plantaion | B | east side | - | thin | 70 | 230 | 4.0 | partial red | |
| 15 | 2008-3-7/2008-3-22(09) | plantaion | A | west side | - | thick | 50 | 75 | 1.0 | overall green | |
| 16 | 2008-3-23/2008-4-7(01) | agroforestry | C | support top | thin | - | 70 | 230 | 4.5 | - | |
| 17 | 2008-3-23/2008-4-7(02) | agroforestry | D | colony top | thick | thin | 50 | 80 | 0.2 | overall green | |
| 18 | 2008-3-23/2008-4-7(03) | agroforestry | D | colony top | thick | thick | 30 | 50 | 0.1 | overall green | |
| 19 | 2008-3-23/2008-4-7(04) | agroforestry | C | colony top | thin | thin | 50 | 150 | 3.0 | overall yellow | expose |
| 20 | 2008-3-23/2008-4-7(05) | agroforestry | D | north side | thick | thick | 40 | 0 | 0.0 | overall green | |
| 21 | 2008-3-23/2008-4-7(06) | plantaion | B | east side | - | thick | 40 | 140 | 2.5 | partial yellow | |
| 22 | 2008-3-23/2008-4-7(07) | agroforestry | D | south side | thick | thick | 30 | 0 | 0.0 | overall green | |
| 23 | 2008-3-23/2008-4-7(08) | agroforestry | D | colony top | thick | thick | 30 | 0 | 0.0 | overall green | |
| 24 | 2008-3-23/2008-4-7(09) | agroforestry | D | colony top | thick | thin | 70 | 140 | 2.5 | overall yellow | expose |
| 25 | 2008-8-15/2008-9-4(01) | agroforestry | D | support top | thin | - | 60 | 140 | 3.5 | - | |
| 26 | 2008-8-15/2008-9-4(02) | plantaion | B | colony top | - | thick | 50 | 0 | 0.0 | overall green | |
| 27 | 2008-8-15/2008-9-4(03) | plantaion | B | colony top | - | thick | 50 | 0 | 0.0 | overall green | |
| 28 | 2008-8-15/2008-9-4(04) | agroforestry | C | east side | thick | thin | 60 | 120 | 2.0 | overall yellow | expose |
| 29 | 2008-8-15/2008-9-4(05) | agroforestry | C | colony top | thick | thin | 60 | 0 | 0.0 | overall green | |
| 30 | 2008-8-15/2008-9-4(06) | agroforestry | C | east side | thick | thin | 60 | 120 | 2.0 | overall yellow | expose |
| 31 | 2008-8-15/2008-9-4(07) | agroforestry | C | west side | thick | thick | 25 | 50 | 0.1 | overall green | |
| 32 | 2008-8-15/2008-9-4(08) | agroforestry | C | colony top | thin | thick | 50 | 190 | 3.0 | partial yellow | |
| 33 | 2008-8-15/2008-9-4(09) | agroforestry | D | west side | thin | thin | 50 | 175 | 4.0 | partial yellow | |
| 34 | 2008-8-15/2008-9-4(10) | agroforestry | D | colony top | thin | thick | 70 | 0 | 0.0 | overall green | |
| 35 | 2009-2-26/2009-3-19(01) | agroforestry | D | west side | thick | thin | 40 | 140 | 1.5 | partial yellow | |
| 36 | 2009-2-26/2009-3-19(02) | plantaion | B | west side | - | thick | 50 | 0 | 0.0 | overall green | |
| 37 | 2009-2-26/2009-3-19(03) | agroforestry | C | colony top | thick | thick | 40 | 0 | 0.0 | overall green | |
| 38 | 2009-2-26/2009-3-19(04) | agroforestry | C | west side | thin | thick | 40 | 170 | 3.0 | partial yellow | |
| 39 | 2009-2-26/2009-3-19(05) | agroforestry | D | support top | thin | - | 70 | 180 | 4.0 | - | |
| 40 | 2009-2-26/2009-3-19(06) | agroforestry | D | east side | thin | thin | 60 | 120 | 4.0 | overall yellow | |
| 41 | 2009-2-26/2009-3-19(07) | agroforestry | D | colony top | thin | thick | 60 | 150 | 2.5 | overall yellow | |
| 42 | 2009-2-26/2009-3-19(08) | agroforestry | D | colony top | thin | thick | 40 | 0 | 0.0 | overall green | |
| 43 | 2009-2-26/2009-3-19(09) | agroforestry | D | colony top | thick | thick | 40 | 0 | 0.0 | overall green | |
| 44 | 2009-2-26/2009-3-19(10) | agroforestry | D | east side | thick | thick | 25 | 120 | 0.4 | overall green | |
| 45 | 2009-3-22/2009-3-29(01) | plantaion | B | west side | - | thick | 50 | 120 | 1.5 | partial yellow | |
| 46 | 2009-3-22/2009-3-29(02) | plantaion | B | east side | - | thick | 50 | 150 | 3.0 | partial yellow | |
| 47 | 2009-3-22/2009-3-29(03) | plantaion | B | inside | - | thick | 40 | 0 | 0.0 | overall green | |
| 48 | 2009-3-22/2009-3-29(04) | plantaion | B | core | - | thick | 25 | 0 | 0.0 | overall green | |
| 49 | 2009-3-22/2009-3-29(05) | agroforestry | D | colony top | thin | thick | 20 | 0 | 0.0 | overall green | |
| 50 | 2009-3-22/2009-3-29(06) | agroforestry | D | colony top | thick | thick | 40 | 0 | 0.0 | overall green | |
| 51 | 2009-3-22/2009-3-29(07) | agroforestry | D | core | thick | thick | 15 | 0 | 0.0 | overall green | |
| 52 | 2009-3-22/2009-3-29(08) | agroforestry | D | inside | thick | thick | 20 | 0 | 0.0 | overall green | |
| 53 | 2009-3-22/2009-3-29(09) | agroforestry | D | east side | thick | thick | 30 | 0 | 0.0 | overall green | |
| 54 | 2009-3-22/2009-3-29(10) | agroforestry | D | support top | thick | - | 30 | 150 | 4.0 | - | |
| 55 | 2009-8-26/2009-9-2(01) | plantaion | A | colony top | - | thick | 40 | 0 | 0.0 | overall green | |
| 56 | 2009-8-26/2009-9-2(02) | plantaion | A | colony top | - | thick | 40 | 0 | 0.0 | overall green | |
| 57 | 2009-8-26/2009-9-2(03) | plantaion | A | colony top | - | thick | 50 | 0 | 0.0 | overall green | |
| 58 | 2009-8-26/2009-9-2(04) | - | - | whole sky | - | - | 270 | - | - | - | |
| 59 | 2009-8-26/2009-9-2(05) | agroforestry | D | colony top | thin | thick | 50 | 0 | 0.0 | overall green | |
| 60 | 2009-8-26/2009-9-2(06) | agroforestry | D | west side | thick | thin | 50 | 80 | 3.0 | partial yellow | |
| 61 | 2009-8-26/2009-9-2(07) | agroforestry | D | support top | thin | - | 70 | 125 | 3.0 | - | |
| 62 | 2009-8-26/2009-9-2(08) | agroforestry | D | west side | thick | thick | 40 | 80 | 1.0 | overall green | |
| 63 | 2009-8-26/2009-9-2(09) | agroforestry | D | support top | thin | - | 80 | 180 | 3.0 | - | |
| 64 | 2009-8-26/2009-9-2(10) | agroforestry | D | west side | thick | thick | 25 | 65 | 1.5 | overall green | |

shade of this support tree was thick, the strong sunlight of 60-130klx had continued and reached there from 8:00 to 11:00. The measurement for '08-3-7/'08-3-22(01) in Table 1 without a figure was similar to this.

The partial figure for '09-2-26/'09-3-719(02) shows the condition on the west side. The invading sunlight of 60-70 klx weaker than the east side, was recognized from 14:00 to 17:00.The measurement for '08-3-7/'08-3-22(09)in Table 1 without a figure was similar.

Thus, sunlight reached the east-side surface and west-side surface of the vanilla colony directly. This type of invasive sunlight was not observed at the colony top. When excluding such an invasion, the fundamental diurnal change of the sunlight intensity on the west side

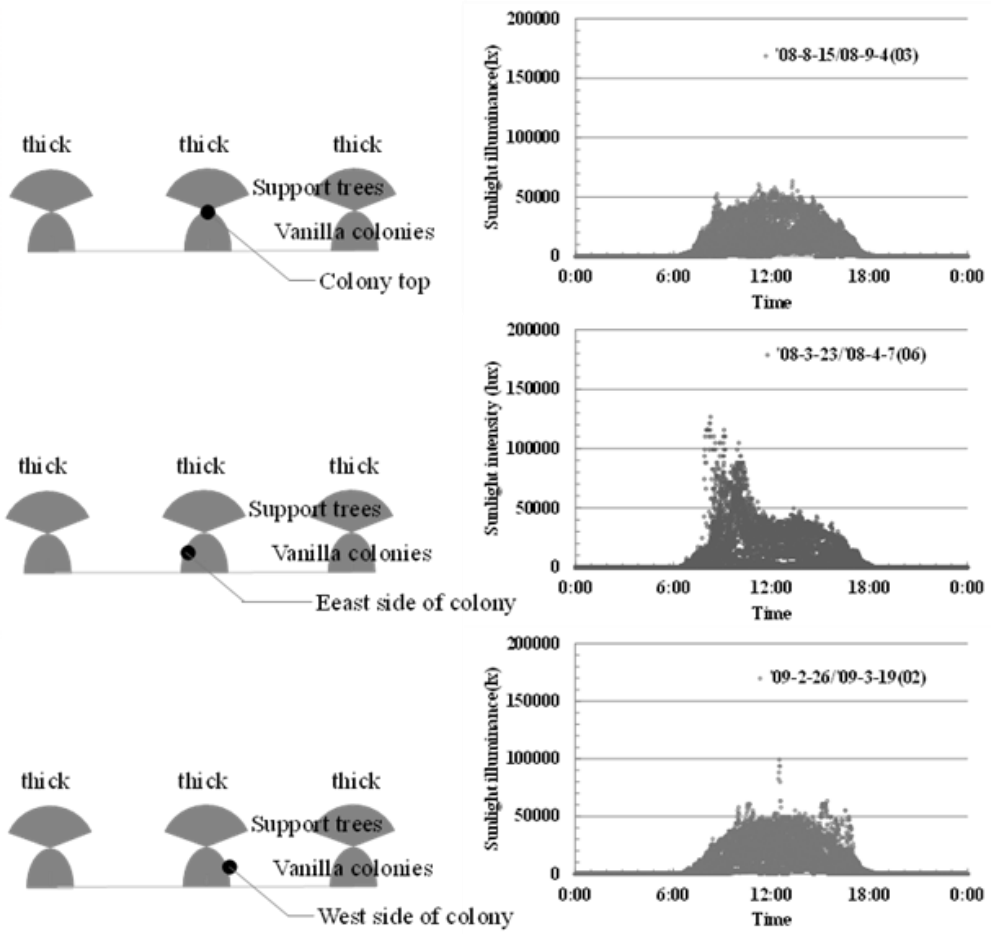


**Figure 8.** Shade effect of support trees with the thick canopy in the Plantation style site.

and the east side of the colony was almost the same as the top part. The meridian transit illuminance was about 50klx. The hypothetical relative illuminance was 15%.

There are gaps between each support tree. Sunlight invaded from there, and strong sunlight reached both sides of the colony there. With solar movement, irradiation occurred on the east side in the morning, and occurred on the west side in the afternoon. On the other hand, in the colony top part, the shading effect of the support tree was sufficient.

Figure 9 shows the measuring result at the plantation style site, when the support tree canopy was thin.

The partial figure for '08-3-7/'08-3-22(07) shows the condition on the top part of the colony of vanilla. Here, for the maintenance work activities to the support trees, the branches extended to the zenith were kept and others were cut. The shade effect with the branches and leaves from 11:00 to 15:00 was recognized. The meridian transit illuminance was about 60klx. The hypothetical relative illuminance was 18%. However, strong sunlight of 60-160klxreached the top part of colony from 9:00 to 11:00, and 15:00-17:00, and vanilla was exposed to this energy. The measurements of'07-6-4/'07-6-12(02) and '07-6-4/'07-6-12(03),without a figure were similar.

The partial figure for '08-3-7/'08-3-22(08) shows the condition on the east side of the colony. Strong sunlight of 60-220klx reached this point continuously from 7:00 to 12:00. The partial figure for '08-3-7/'08-3-22(05) shows the condition on the west side, and the strong sunlight of 60-220 (klx) reached at 13:00 to 17:00. The sunlight on the east side and the west side reached the colony without being interrupted by the support tree canopy, and was almost equivalent to whole sky sunlight.

When excluding that invasion, the fundamental diurnal change in the three part figures of Figure 9 was almost the same. Then the meridian transit illuminance was about 50klx, and the hypothetical relative illuminance of the meridian transit illuminance were 15%.

In this environment where the canopy was pruned by the work activities of shading control, it was recognized that very strong sunlight more than 100 klx irradiates almost all the surfaces of a vanilla colony in a definite time zone.

As well as the case where the canopy of a support tree is thick, this irradiation occurred on the east side in the morning, and occurred on the west side in the afternoon. However, the intensity was violently high. In the top part of colony, the shading effect with several

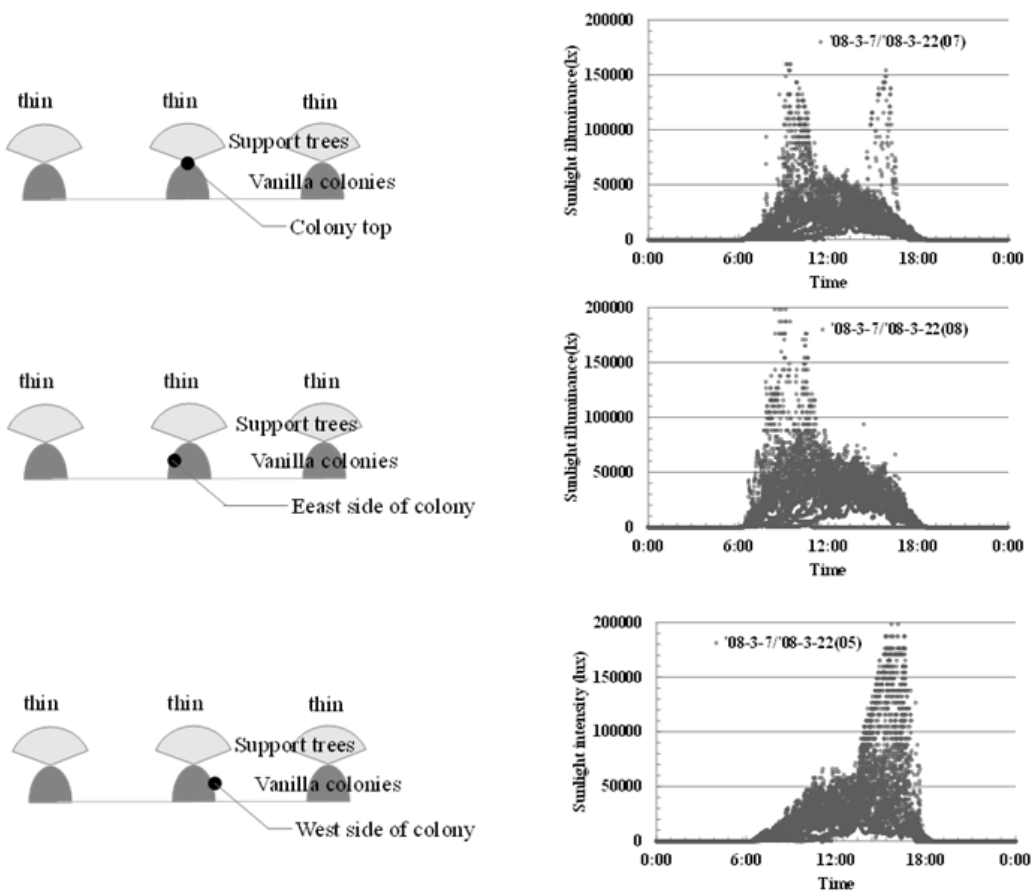


**Figure 9.** The shade effect of the support trees with the thin canopies in Plantation style site.

branches extended to the zenith was only before or after meridian transit time

**The sunlight intensity of the agroforestry style site**

Since the shading effect of the crop tree was added, the sunlight environment in the agroforestry style plot was more complicated than the plantation style.

Figure 10 shows the measurement result at the agroforestry style site, when both the canopies of the crop tree and support tree were thick.

The partial figure for '08-3-23/'08-4-7(08) in this figure shows the condition for the top part of vanilla colony. Although not shown here, measurements '09-2-26/'09-3-19(03),'09-2-26/'09-3-19(09), '08-3-23/'08-4-7(03) and '08-3-7/'08-3-22(06) in Table 1 were similar to this. The meridian transit illuminance of them was about 30-40klx. The hypothetical relative illuminance of them was 9-12%. When the shade effect by the crop trees and support trees functioned fully, and direct sunlight to the colony surface was not recognized.

The partial figure '09-8-26/'09-9-2(10) shows the condition on the vanilla colony east side. The partial figure for '09-2-26/'09-3-19(10) was the result in the west side. The measurements'08-3-7/'08-3-22(02), '08-3-7/'08-3-22(04), '08-8-15/'08-9-4(07), '09-2-26/'09-3-19(01), '09-8-26/'09-9-2(08) were similar to this.

On the east side from 8:00 to 17:00, an illuminance 30-60klx higher than other time zones was recognized. In the west side at 15:00 from 17:00, an illuminance of 30-120klx was recognized. Those meridian transit illuminances were about 30klx, and the hypothetical relative illuminance was 9%.

Even if it was the layer structure formed by both crop tree canopies and support tree canopies, it was recognized that a sunlight reached the colony surface of the east-side and west-side through a small gap.

The partial figure for '08-3-23/'08-4-7(07) shows the condition on the south side of vanilla colony. The measurement '08-3-23/'08-4-7(05) in Table1 without a figure is the result on the north side, and it was similar to the south side. Those meridian transit illuminances were about 30klx, and the hypothetical relative illuminance was 9%. In the vernal equinox season, there was no irradiation of sunlight from the north side or on the south, and measured value was low.

Figure 11 shows the measurement result at the agroforestry style site, when the canopies of the crop trees were thin. These were the measurements from when the agarwood was young, and that tree height is low. The condition on the defoliation of a teak was also assessed under the same conditions.

The condition of the thin crop tree canopies and thick support tree canopies resembled the sunlight environment

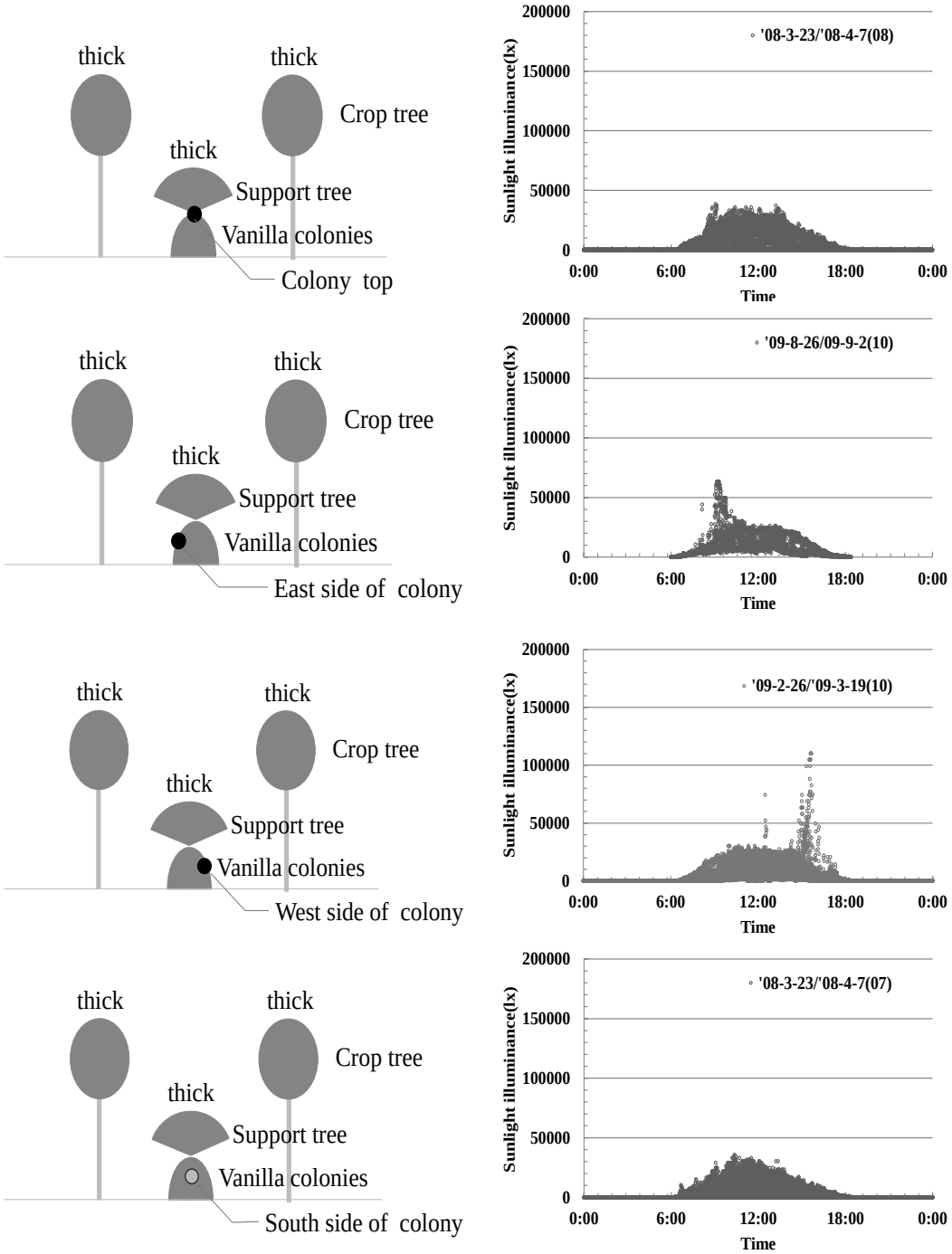


**Figure 10.** Shade effect of the thick canopies of crop tree and thick canopies of support tree in the agroforestry site.

in the plantation which shown in the partial figure of ’08-3-7/’08-3-22(05) in Figure 7. Even if the crop tree canopy in the agroforestry plot was thin, it turned out that it had a shading effect. The invasion of strong sunlight was observed in the east-and-west side of the colony as well as the plantation.

The partial figure for '08-8-15/'08-9-4(08) shows the condition on the top part of colony, when the crop tree canopies and support tree canopies were thin. Strong sunlight of 50-190klx reached the colony continuously from8:00 to 12:00. And strong sunlight of 40-140klx momentarily reached the colony several times between 15:00 and 16:00. The illuminance was restricted by the thin shade of the support tree from 12:00 to 15:00. The meridian transit illuminance was about 50(klx). The hypothetical relative illuminance was 15%.The partial

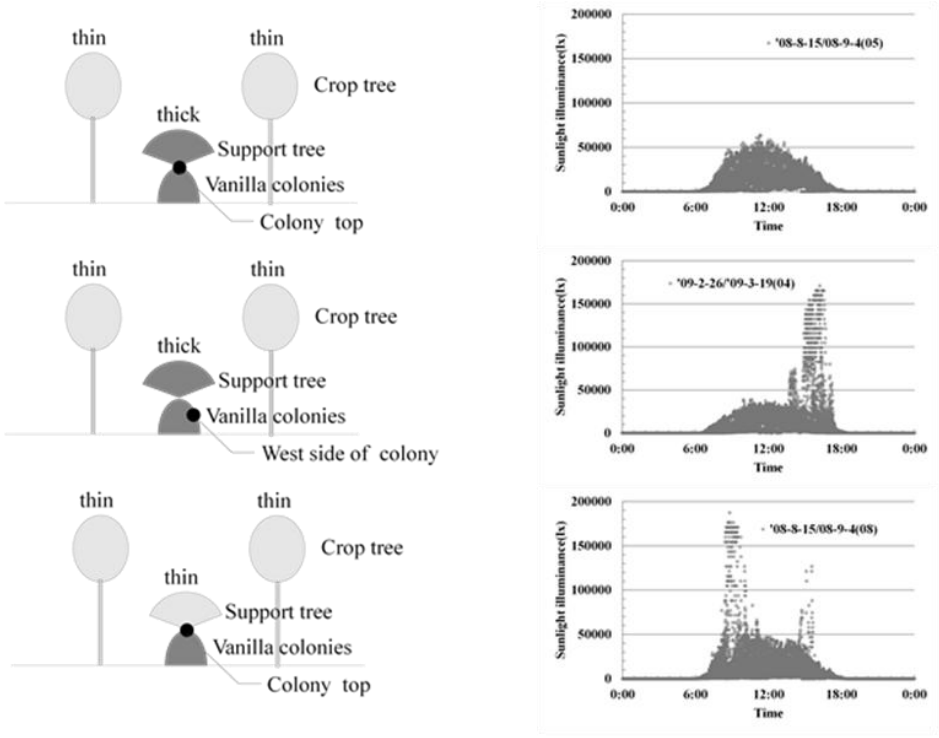


Figure11. Shade effect by the thin canopies of crop trees in the agroforestry site

figure for '08-8-15/'08-9-4(05) in this figure shows the condition on the top part of colony, when the crop tree canopies were thin and the support tree canopies were thick. The meridian transit illuminance was about 60klx. The hypothetical relative illuminance was 18%.It was the same as illuminance as the measurement for 08-8-15/'08-9-4(03) when the support tree canopy was thick in the plantation style site. And the measurement for '08-8-15/'08-9-4(10) in Table 1 without figure was similar.

Although these resembled the sunlight environment in the plantation, which the partial figure of ’08-3-23/’08-4-7 in Figure 7 shows, the illuminance was lower. Furthermore, here it was recognized that the thin crop tree canopy has some shading effect. Measurements '09-2-26/'09-3-19(01), ’09-8-26/’09-9-2(08) and ’08-3-7/’08-3-22(04) in Table 1 without a figure were similar to those in Figure 11.

Figure 12 shows the measurement result at the agroforestry style site, when the crop tree canopies were thick and the support tree canopies were thin.

The partial figure for '08-3-23/'08-4-7(09) shows the condition on the top part of colony. Measurement '08-3-23/'08-4-7(02) in Table 1 without a figure was similar. It was recognized that strong sunlight of 60-130klxinvaded between 9:00 and 12:00. These things indicated that the shading effects of the thick crop tree canopies were low in the light path from the zenith to the vanilla colony.

The partial figure for ’09-8-26/’09-9-2(06) shows the condition on the colony west side in the agroforestry plot, when the crop tree canopies were thick and support trees canopies were thin. Strong sunlight of 50-80klx repeatedly and momentarily invadedfrom14:00 to 16:00. The measurement '08-3-23/'08-4-7(04) in the agroforestry style site was similar.

In the diurnal change on the top part and sides,when those invasions of sunlight were excluded, the meridian transit illuminance was about 50klx, and the hypothetical relative illuminance was 15%. Although the invasion of strong sunlight from the side was observed, compared with the thin canopies of support trees in the plantation, the illuminance was low.

Figure 13shows the conditionon the top of colony in the agroforestry style site, when the crop trees canopies were thin and the support tree canopies were thick.This meridian transit illuminance was about 40klx, and the hypothetical relative illuminance was 13%.This environment was almost equal to the case of the thick canopies of support trees in the plantation shown in Figure 6, ‘08-8-15/’08-9-4(03).In this environment, the thin crop tree canopy had influence, and the illuminance at the agroforestry site was lower than the plantation.

Figure 14 shows the measurement resulton the inside of the colonyin the agroforestry style site,

The partial figure for '09-3-22/'09-3-29(08) shows the condition on the west side of a colony when the canopiesof crop trees and support trees were very thick.There was no invasion of sunlight;the shading function was perfect. This meridian transit illuminance was about 25klx, and the hypothetical relative illuminance was 8%.

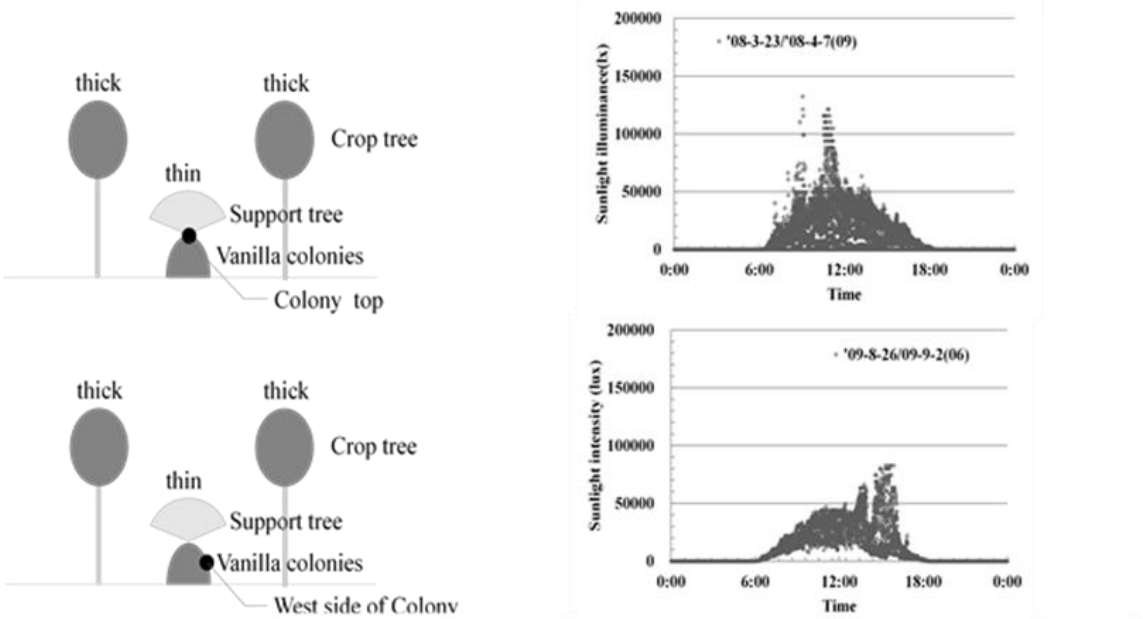


Figure 12. Shade effect by the thick canopies of crop tree and thin canopies of support tree in the agroforestry style site

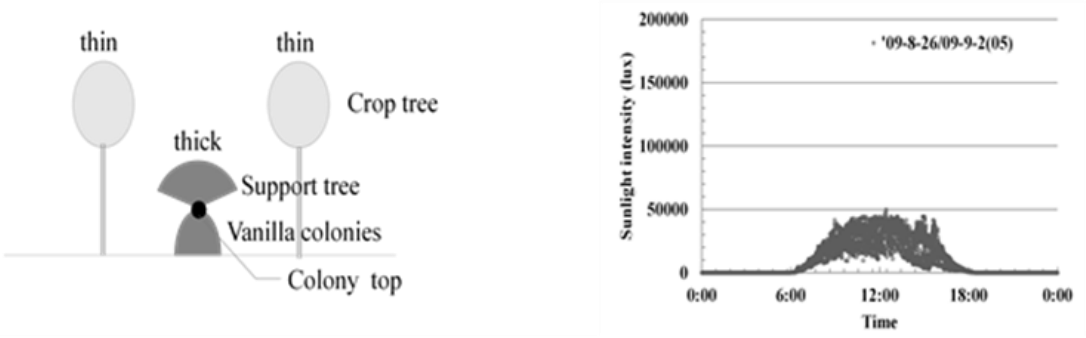


Figure 13. Shade effect of thin crop trees and thick support trees in the plot D

The measurement '09-2-22/'09-3-29(05) in Table 1 without a figure was similar.

The partial figure '09-2-22/'093-29(03)shows the condition on the inside of a colony, when the canopies of the crop trees and support treeswere thin.This meridian transit illuminance was about 40klx, and the hypothetical relative illuminance was 12%.Although those values were slightly high compared with those where the canopy of both crop tree and support tree were thick, the shading function was perfect as well.

**Influence of invasive sunlight on the color of leaves**

Mialet-Serra (2001) showed that the daily maximum whole sky sunlight quantum in an agroforestry of theobroma and a coconut was 2300µmol/s*m² in Vanuatu away from the equator. Varella (2011) showed that it was 2100 µmol/s*m² in the combination of lucerne and radiata pine in New Zealand, a temperate zone. At this study site of ours just under the equator, it was 2550µmol/s*m² higher than those values. It is thought that these differences are based on latitude, and the correspondence to overly strong sunlight is important in an equatorial region.

The usual style vanilla cultivation practiced in a variety of countries avoids such direct sunlight by shade work (Anilkumar, 2004; Hernandez and Lubinsky, 2011; Bianchessi, 2012).Hernandez and Lubinsky (2011) described that 50% shade is appropriate for the growth of vanilla, and that excessive sunlight which burns the leaf or vine will lead to disease. Bianchessi (2012) has advocated that 100% pruning must not be performed even if it is a flowering operation.

These studies indicate that too strong sunlight causes a distu-

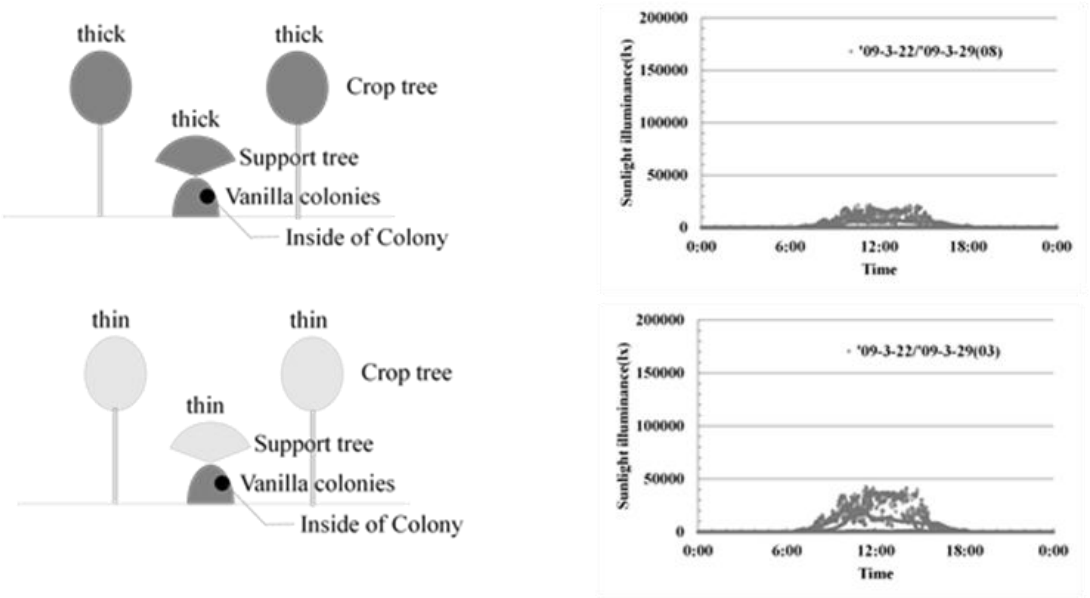


Figure 14. Shade effect of vanilla colony itself under the thick canopy of crop trees and support trees.

urbance to the plant. At our study site, it appeared as a discoloration of a leaf or vine. Figures 15-16 show the difference in the color of leaves by the intensity of sunlight. Different markers for every color classification of leaves in each spot were plotted into these figures.

Figure 15 shows the relationship between the intensities of the meridian transit sunlight intensity and invasion sunlight in all the measuring spots. When invasive sunlight existed, there was a weak positive correlation between meridian transit sunlight intensity and invasive sunlight intensity. At the spot without invasive sunlight, the leaves always remained green overall. Furthermore, with a meridian transit sunlight below 40klx, and invasive sunlight below 120 klx, leaves always remained green overall. For meridian transit sunlight beyond 50klx, and invasive sunlight beyond 120klx, the leaves usually turned yellow or red. It was especially red with a meridian transit sunlight of 70klx, and the invasion sunlight beyond 200klx.

Figure 16 shows the relationship between the invasive sunlight intensity and invasion time in all the measurement areas. A weak positive correlation was found between the invasive sunlight intensity and the invasion time. However, when the invasion time was longer than 1.0hr, leaves were yellow or red. In the case of weak invasive sunlight of 80klx, even for an invasion time of 1.0hr, the leaves remained green overall. This noteworthy line that connects (x= 120, y= 0.5) to (x= 80, y= 1.0) is expressed through the formula; y=-0.02x+3.00.If the coordinate position determined by a sunlight intensity and a time is lower than this line, a leaf will surely remain green overall. And if it is high, it will be thought that a leaf changes to yellow or red.

As a factor which is strongly related to the color of a leaf, the product of the invasive sunlight intensity(klx) and the invasion time(hr) attracted attention. Figure 17 shows the average of those products in each measurement areas according to classification of the color of a leaf.

In the leaves which remained green overall, the average of these products was low compared with the leaves of other colors. In the partial yellow and the overall yellow cases, the difference between them was not recognized in those values. In the partially red cases, the value was the highest. These differences were recognized to a 0.1% level of significance. Accordingly, it was suggested that invasive sunlight of a value lower than 100 klx*hr keeps a leaf overall green. And it is thought that strong sunlight above 100klx*hr changes a leaf to yellow, and still stronger sunlight above 700klx*hr changes it to red color.

Since it was observed that the surface of the vine accompanying the red leaf had an intense wrinkle, it is thought that it will tend to die.

Mialet-Serra (2001), Fang et al. (2005), Zhang et al. (2014) and Varella et al.(2011) investigated in detail the sunlight environment in agroforestry systems. According to them, although crop trees sufficiently decrease the invasive sunlight from the side, the sunlight reduced from the zenith is insufficient. This means that an invasion from the zenith is strong for a vanilla colony located in the center between crop trees. It is also suggested from our measurement result that this tendency is much more remarkable in an equatorial region.

The important function which support trees should perform

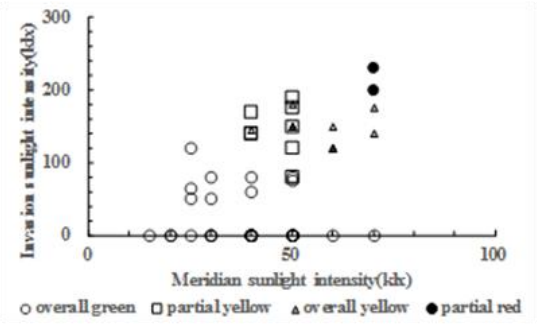


Figure 15. The relationship between the meridian transit sunlight intensity and the invasion sunlight intensity in each measuring spot according to the classification of the color of leaves

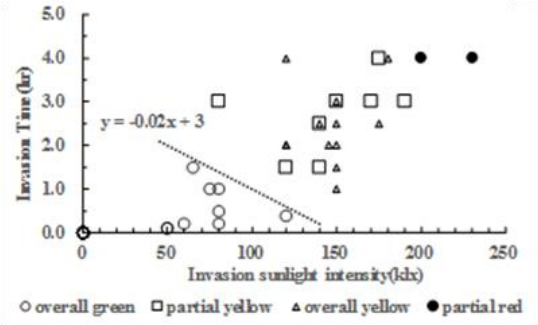


Figure 16. The relationship between the invasion sunlight intensity and the invasion time in each measuring spot according to the classification of the color of leaves

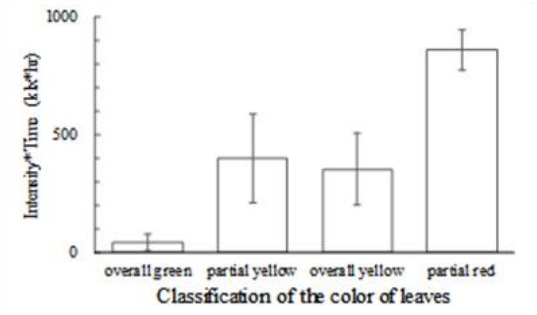


Figure 17. The relationship between the invasion sunlight intensity and the invasion time in each measuring spot according to the classification of the color of leaves

is a shade from this sunlight. In order to control invasive sunlight, it is thought that pruning support trees is most appropriate and an important operation. In this work, control of sunlight suitable for growth or flowering should be performed, maintaining 100klx*hr as the upper limit.

## CONCLUSION

In the equatorial belt, the sunlight measurement distinctly suggested the environmental classification of an agroforestry site. The classification explained the shading condition of the canopy of a support tree and a crop tree for vanilla cultivation. The maximum shading effect by those trees gave an illuminance lower than 30klx to the vanilla colony. Under the thick canopy of a crop tree, and the thin canopy of a support tree, although it was usually below 50 klx, strong sunlight of 50-150 klx sometimes invaded. In the plantation style, a thin canopy of the support tree led to the frequent invasion of intense sunlight of 60-200 klx. It was shown that the shading effect of agroforestry is good compared to the plantation.

When there was no invasive sunlight, sunlight lower than 50 klx kept the vanilla leaves green overall. Since shading is important for the growth of a vanilla vine, it is thought appropriate to set 50 klx as an upper control limit for sunlight. In order to maintain this condition, it is necessary to keep thick the canopy of both a support tree and a crop tree.

When invasion occurred, for the product of the intensity and time, sunlight below 100 klx*h kept the vanilla leaves green overall. This means it is necessary to suppress an invasion of strong sunlight of 100klx within one hour. Furthermore, in this condition, it is necessary for the canopy of a support tree and a crop tree to be thick.

On the other hand, for the flowering of vanilla, strong sunlight is required by release of shading. The removal activities of the branches and leaves of the support trees satisfy this requirement. By this operation, the invasive sunlight beyond 50 klx hits a colony and prompts fruit bearing. According to the irradiation intensity and its time, the color of the vine and leaf changes to a yellow or red color.

At this farmland i.e. investigation place, many fruits of the vanilla plant were observed on such a yellow vine. This means that the intense sunlight prompted fruit bearing. However, fruits were also recognized on overall green vines, and the vine was in perfect health, without withering. Since the vine without a discoloration maintains the health of the vanilla colony, it contributes to sustained production. The discoloration of a vine bearing fruit is the result of too strong irradiation, and it seems that this is an unsuitable condition.

Therefore, in order for a vine bearing fruit be green, it is important to keep shading release below 100klx*h. As for this operation, it is convenient to carry out this mainly on support trees. A containment of the branch extended in the direction of 11:00 to 13:00, and the other removal can build such a sunlight environment. In this case, an agroforestry system is useful, because the canopy of crop trees will surely function as a buffer to excessively strong invasive sunlight from the side from 9:00 to 11:00, and 13:00 to 16:00.The partial figure for "09-8-26 / 09-9-2" in Figure 12 explains this environment.

Based on those standards of sunlight control, it is thought appropriate for a vanilla cultivation on the equatorial belt to perform via an agroforestry system. The key for these operations is the pruning of the support trees which keep 100klx*hat the upper limit. We expect that the information shown by this research will contribute to the development of agroforestry systems.

**ACKNOWLEDGMENT**

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**REFERENCE**

Anilkumar AS (2004). Vanilla cultivation - A profitable agri-based enterprise. Kerala Calling, February 26-30.

Bianchessi P (2012). Vanilla Handbook. Venui Vanilla Co., Vanuatu. 128p.

Fang S, Xu X,Yu X, Li Z(2005). Poplar in wet land agroforestry: a case study of ecological benefits, site productivity, and economics. Wetlands Ecol Manage. 13:93-104.

Hernandes JH, Lubinsky P (2011). Cultivation Systems: Vanilla. New York, US: CRC Press,pp75-95.

Kitai K, Abubakar ML (2015). Agroforestry Management with Vanilla and Agarwood in East Kalimantan. J. Econ. Sustain. Dev. 6(4):12-17.

Mialet-Serra I, Dazat J,Auclair D (2001). Using plant architectural models for estimation of radiation transfer in coconut-based agroforestry system. Agroforest Syst, 53:141-149.

Varella AC, Moot DJ, Pollock KM, Peri PL, Lucas RJ (2011). Do light alfalta responses to cloth and slatted shade represent those measured under an agroforestry system? Agroforest Syst, 81:157173.

Zhang D, Zhang L, Liu J, Han S, Wang Q, Evwes J, Liu J, Werf W, Li L (2014). Plant density affects light interception and yield in cotton grown as companion crop in young jujube plantation. Field Crops Research, 169:132-139.