The effectiveness of reflective mulch in the intercropping system between soybean and oil palm: effects on growth, chlorophyll content, and photosynthetic characteristics

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Abstract

This study was conducted to analyze the effectiveness of using reflective mulch under the stands of oil palm plants of several ages on the intensity of solar radiation reflection, growth, chlorophyll content, and photosynthetic characteristics of soybeans. A nested design was used, with the first factor of oil palm age group consisting of open land and land under oil palm stands aged 4, 5, and 8 years. The second factor was the reflective mulch that included land without mulch, land with inorganic reflective mulch, and land with organic reflective mulch. The use of reflective mulch in the soybean–oil palm intercropping system was able to increase the reflection intensity of surface solar radiation, as well as increase the soybean solar radiation interception. The use of inorganic and organic reflective mulch significantly increased the leaf area, specific leaf weight, and soybean stomatal density. Organic reflective mulch led to significant reductions in the amount of chlorophyll A and B content. The photosynthetic rate of soybean in lower leaves was increased significantly. Inorganic reflective mulch resulted in significant reductions in the rate of transpiration, intercellular CO2 concentration, and conductance of soybean stomata in lower leaves. The use of reflective mulch contributed to improved soybean performance under oil palm stands. The use of organic reflective mulch for soybean grown under oil palm stands aged up to 5 years resulted in better growth rates due to the increased intensity of solar radiation reflected from the surface. However, the reflection effect could not meet the needs of soybean solar radiation on land under oil palm stands aged >5 years due to the very low transmission. Therefore, the use of organic reflective mulch is more effective and efficient in the soybean–oil palm intercropping system until the oil palm reaches the age of 5 years.

Key words: Intercropping system, Low light intensity, Microclimate, Morphophysiology

1. Introduction

The use of land under the main crop stands is limited by the low intensity of solar radiation, water availability, low pH, and the presence of weeds (Sopandie et al., 2003). Low radiation intensity is a major limiting factor in the use of land under the plant stands (Sopandie and Trikoesoemaningtyas, 2011; Fiorucci and Fankhauser, 2017), which can occur due to the atmospheric conditions or being under other plant stands and can affect the response, growth, and production of crops (Sopandie et al., 2003; Yang et al., 2015). Plants growing under low light stress conditions could develop metabolic disorders that reduce the rate of photosynthesis, mesophyll conductance, leaf thickness, and carbohydrate synthesis (Chowdhury et al., 1994; Koesmaryono et al., 1998; Sopandie et al., 2003) because of solar radiation, especially because light acts as energy driving the process of photosynthetic, which is a determinant of the growth rate, development, and yield of plants (Jiang et al., 2011; Li et al., 2014). Photosynthesis is an important process for plants, which uses only a portion of the solar radiation that is known as photosynthetic active radiation (PAR) or light, which is one of the physical environmental factors that determine plant production (Yang et al., 2014). Under shading conditions, there are changes in the quantity and quality of light, which can affect the rate of photosynthesis of plants cultivated in the intercropping system as they are limited by low light and shade between similar or different plants (Yang et al., 2017; Yang et al., 2018).

Soybean is a C3 plant that does not require full light, can grow well in the shade or on land with low solar radiation intensity, and can capture N in the atmosphere, which can in turn reduce the input of inorganic fertilizers (Sugimoto et al., 2005; Qin et al., 2013; Yang et al., 2014). Hence, soybean has emerged as one of the crops that is often planted in an intercropping system to increase land-use efficiency and crop yield (Echarte et al., 2011; Lithourgidis et al., 2011; Gong et al., 2014). The production of
soybean decreases significantly when the light intensity is <30% of normal conditions in both rainy and dry seasons (Polthanee et al., 2011). Soybean grown under 50% shade could show 15% decreased production (Mubarak et al., 2017). Soybean plants grown in the intercropping system can be exposed to low light stress due to the presence of shade caused by taller plants (Yang et al., 2014). Therefore, there is a need for efforts to increase light or solar radiation under the main plant stands by modifying the microclimate using reflective mulch. The use of reflectors or reflective mulch can increase the intensity of surface reflection radiation that can be used in the intercropping system (Mubarak et al., 2018).

Land use under oil palm stands has not been optimal despite the fact that it can increase land productivity. Cultivation of soybean under oil palm stands can be profitable economically and have a positive impact on the growth of young oil palms (Putra et al., 2012). The use of land under oil palm stands in the intercropping system has been conducted on oil palm land under the age of 3 years (Putra et al., 2012). The use of oil palm land for more than 3 years requires technology that can prevent the reduction of solar radiation under the stands. Although previous research did not disclose the role of reflective mulch, land use under oil palm stands aged less than 3 years was examined (Putra et al., 2012). Mubarak et al. (2017) investigated the use of inorganic reflective mulch and artificial shade (50% shaded conditions) in soybean plants; however, this approach has not been tested on oil palm plantations. Therefore, modifying the microclimate using reflective mulch under the main plant stands comprises an attempt to increase the intensity of solar radiation reflection that reaches the surface so that it can be used by intercropping plants such as soybeans.

The use of reflective mulch helps in reflecting back the intensity of solar radiation transmitted by the main plant stands to the soybean stands, and it can also prevent the evaporation process and reduce soil temperature (Mubarak et al., 2018). It has been reported that the use of reflective mulch increased soybean production by 17%–34% under non-shaded conditions and by 33%–39% under 50% shaded conditions (Mubarak et al., 2017). This suggests that the use of reflective mulch can increase the reflection of solar radiation from the surface around shaded plantations, consequently having a positive impact on microclimate, photosynthesis, and crop production. Therefore, this study was conducted to investigate the effectiveness of using reflective mulch on the intensity of solar radiation reflection, growth, chlorophyll content, and photosynthetic characteristics of soybean plants grown under oil palm stands of some age groups.

2. Materials and Methods

2.1 Time and location

This study was conducted during January–July 2018 in the oil palm plantation of PTPN VIII Bantarjaya Cimarga Lebak, Banten-Indonesia, located at an altitude of 102 m above sea level and distributed in four different locations. Data collection of each variable was carried out in March until June 2018. The coordinates of the four locations are 1) location of open land/control (6°28′28.62″S 106°14′8.34″E), 2) location of 4-year-old oil palm trees (6°28′35.52″S 106°14′2.58″E), 3) location of 5-year-old oil palm trees (6°29′13.02″S 106°13′44.34″E), and 4) location of 8-year-old oil palm trees (6°27′38.64″S 106°14′15.9″E). These research sites are located in one area within a radius of 5 km and have a uniform soil type of latosol. The preparation of meteorological instrumentation and data processing were conducted at the Agrometeorology Laboratory of the Department of Geophysics and Meteorology, IPB University. Plant samples were analyzed at the Integrated and Micro Engineering Laboratory of the Department of Agronomy and Horticulture, IPB University, Bogor. The weather conditions during the study are presented in Figure 1.

2.2 Methods

The following materials were used in this study: soybean seeds of anjasmoro variety, inorganic reflective mulch (black silver plastic mulch), organic reflective mulch (dry oil palm leaves), manure, chemical fertilizers, including urea (45% N), SP-36 (39% P₂O₅), and KCl (60% K₂O), and dolomite and comost enriched with plant growth-promoting rhizobacteria (Rhizobium sp., Bacillus sp., Pseudomonas sp., and Azospirillum sp.). A two-factor nested design (a development of the randomized block design) with three replications was used. The first factor was the oil palm age group that consisted of control (open land; 0% shade; 100% transmission of solar radiation), 4-year-old oil palm (55.2% shade; 44.8% transmission of solar radiation), 5-year-old oil palm (59.4% shade; 40.6% transmission

![Fig. 1. Temperature, relative humidity, precipitation (a), and solar radiation during the measurements (b).](image-url)
of solar radiation), and 8-year-old oil palm (74.9% shade; 25.1% transmission of solar radiation). The age of the oil palm used in this study was adjusted to the age of the available oil palms at the research location. The second factor was the use of reflective mulch covering three levels, namely without reflective mulch (control), inorganic reflective mulch, and organic reflective mulch. The nested design was used because of the presence of one factor (oil palm age) that cannot be repeated in each group. Oil palms were planted in the research location using a spacing of 9 m × 9 m × 9 m or a population of 143 plants per hectare. Soybean plants were planted under the oil palm stands by making plots of 9 m × 4 m size. The soybean spacing was 40 cm × 12.5 cm with a population of 40 plants m⁻² or 1440 plants per plot. Data were analyzed using variance and evaluated using Duncan’s multiple range test at 95% confidence level. Statistical analysis was conducted using the Statistical Tool for Agricultural Research (STAR) 2.0.1 (http://bibi.irri.org/products), and the results were also checked by manual calculations.

The intensity of reflection of surface solar radiation (MJ m⁻²) was measured using 2 units of tube solarimeters (double sensors) that were installed at a height of 30 and 120 cm, respectively. The tube solarimeter is the recommended tool for measuring solar radiation under the stands (Szeicz et al., 1964). The tube solarimeter used in this study was produced from an assembly from the Instrumentation Laboratory of IPB University, which is calibrated with a pyranometer (pyranometer type-SR03I, Hukseflux Thermal Sensors, The Netherlands).

Solar radiation interception (Qint; MJ m⁻²); Qint is believed to use Beer’s law (Equation 1), where Qo is the radiation above the canopy, k is the light extinction coefficient (Equation 3), P is the total population, LAI is the leaf area index (Equation 2), Lh is the land area (cm²), Ld is the leaf area (cm²). It is the radiation intensity received in the canopy, and Io is the radiation intensity received by the crown (Handoko et al., 1994).

\[ Q_{\text{int}} = Q_0 \times (1 - \exp(-k \times \text{LAI})) \]  

\[ \text{LAI} = P \times \frac{L_h}{L_d} \]  

\[ k = \frac{\ln (\tau)}{\text{LAI}} \]  

Photosynthetic characteristics, including the rate of photosynthesis, transpiration, intercellular CO₂ concentration, and conductance of soybean stomata, were measured using LI-COR 6400XT (Li-Cor Bioscience Inc., Lincoln, NE, USA) at the peak of the vegetative phase (5 weeks after planting). PAR was conditioned in between 997.38 and 1003.95 µmol m⁻² s⁻¹ (average of 1000.38 µmol m⁻² s⁻¹), the concentration of CO₂ was maintained at 367.13–423.66 µmol mol⁻¹ (average of 389.92 µmol mol⁻¹), temperature was maintained at 25.4°C–27.4°C (average of 26.3°C), and the relative humidity was maintained at 42.3%–51.0% (average of 47.9%). Measurements were made on each plot with 3 randomly determined plant samples. Leaf measurements included the upper and lower leaf position groups of soybean stands.

Observations of the number, length, and width of stomata were made by sampling the leaf stomata using a replica technique and then placing it on a glass preparation. The results of the stomata replica were observed under a microscope (type BX41, Olympus, Japan) at a magnification of 10 × 40 and a field of view of 0.19625 mm². Observations were made at the peak vegetative phase. The results of stomatal photographs were analyzed using the ImageJ 1.50 g software (Rasband, W.S., ImageJ, U. S. National Institutes of Health, Bethesda, Maryland, USA, https://imagej.nih.gov/ij/, 1997–2018).

Leaf thickness (µm) was observed in the peak vegetative phase using the third leaf sample. The preparation of the leaves to be sampled was performed using microtome slices. The best slices were then measured for their thickness using a trinocular microscope equipped with the DP2-BSW Imaging software application. The chlorophyll content was analyzed using a UV-VIS spectrophotometer at the Analytical Laboratory of the Department of Agronomy and Horticulture, Faculty of Agriculture, IPB University, Bogor. Leaf area was measured using a scanner and then analyzed using the ImageJ 1.50 g software.

The specific leaf weight (SLW; mg cm⁻²) indicates the level of leaf thickness calculated using the following equation: SLW = leaf dry weight/leaf area (Ma et al., 1995). The specific leaf area (SLA; cm² mg⁻¹) indicates the amount of plant tissue used for photosynthesis per unit of leaf tissue (Chowdhury et al., 2016). SLA is the ratio of leaf area to leaf dry weight, or SLA = leaf area/leaf dry weight.

3. Results

3.1 The intensity of reflection and interception of solar radiation

The intensity of reflection of solar radiation from the reflective mulch became lesser with the increase in age of the oil palms due to lower transmission of radiation to the land surface (Fig. 2a). The use of inorganic and organic reflective mulch in the oil palm–soybean intercropping system was able to significantly increase the intensity of solar radiation reflected from the surface (p < 0.05) both on open land and under the oil palm stands aged 4, 5, and 8 years. The intensity of solar radiation reflection using inorganic reflective mulch was significantly higher than that using organic reflective mulch and that without using mulch (p < 0.05). On open land, the intensities of solar radiation reflection with the use of inorganic and organic reflective mulch and without the use of reflective mulch were 68.3, 45.1, and 27.6 MJ m⁻², respectively. On the land with oil palm stands aged below 4 years, the intensities of solar radiation reflection with the use of inorganic and organic reflective mulch and without the use of reflective mulch were 32.7, 19.7, and 12.6 MJ m⁻², respectively. In the 5-year-old oil palm fields, the respective intensities of solar radiation reflection were 36.3, 20.4, and 12.6 MJ m⁻². In the oil palm fields aged 8 years, the respective solar radiation reflection intensities were 25.2, 15.5, and 9.8 MJ m⁻².

The use of reflective mulch on open land increased the intensity of radiation reflection compared with the use of inorganic and organic reflective mulch by 147% and 63%, respectively. On lands with oil palm stands aged 4, 5, and 8 years, the intensity of solar radiation reflection with the use
of inorganic and organic reflective mulch was increased by 169% and 59%, respectively. Inorganic reflective mulch had the maximum ability to reflect solar radiation (40.6 MJ m⁻²), which was significantly different \( (p < 0.05) \) from that of organic reflective mulch (25.2 MJ m⁻²) and on land without the use of mulch (15.7 MJ m⁻²) (Fig. 2b). The use of reflective mulch increased the average reflection radiation \( \text{Qint}_\text{global} \) combined in open land and under oil palm stands by 159% with the use of inorganic reflective mulch and by 61% with the use of organic reflective mulch.

The interception of solar radiation in soybean plants increased with the age of the plants (Fig. 3a), which is the average value of solar radiation interception of soybean plants on open land with oil palm stands aged 4, 5, and 8 years. This increase reached the highest point at the 6th week after planting and then decreased until the end of the growing season. Figure 3a also shows the results of the analysis of total radiation interception, which is the accumulation of global radiation interception and interception of solar radiation reflected from the reflective mulch surface. These results indicate that inorganic and organic reflective mulch significantly contributed to the increase in total soybean interception. The use of reflective mulch could increase the interception of soybean radiation from the beginning to the end of plant growth.

Solar radiation interception of soybean plants grown under oil palm stands was decreased; however, the use of reflective mulch tended to increase the solar radiation interception significantly \( (p < 0.05) \) in each age group of oil palm (Fig. 3b). In the open fields, the use of reflective mulch increased the solar radiation interception by 39% with the use of inorganic reflective mulch and by 14% with the use of organic reflective mulch, considering the land without the use of reflective mulch as the baseline.

The mean solar radiation interception of soybean plants grown under oil palm stands increased with the use of reflective mulch. Inorganic reflective mulch increased the radiation interception by 30%, and organic reflective mulch increased it by 26%.

Note: Numbers followed by different letters in each group show significant differences \( (p < 0.05) \) based on Duncan’s multiple range test at \( \alpha = 5\% \)

Fig. 2. (a) The intensity of reflection of surface solar radiation using reflective mulch on open land and land under oil palm stands aged 4, 5, and 8 years, (b) The average intensity of reflection of solar radiation using inorganic and organic reflective mulch and without mulch/control.

Note: Numbers followed by different letters in each group show significant differences \( (p < 0.05) \) based on Duncan’s multiple range test at \( \alpha = 5\% \)

Fig. 3. (a) Mean solar radiation interception from global radiation (dotted line) and mean solar radiation interception from total radiation (solid line) with the use of different types of reflective mulch during growth, (b) Total interception of soybean solar radiation on open land and land under oil palm stands using reflective mulch.
3.2 Growth of soybean

3.2.1 Leaf area

Soybean leaf area decreased with increasing oil palm stand age but increased with the use of reflective mulch (Tables 1 and 2 and Fig. 4). The soybean plants on the open land and under oil palm stands aged 4 years showed a significantly greater leaf area ($p < 0.05$) than that of soybean plants grown under oil palm stands aged 5 and 8 years (Table 1 and Fig. 4a). The average leaf area values of soybeans grown on open land and under oil palm fields aged 4, 5, and 8 years were 756.71, 724.80, 461.82, and 146.82 cm$^2$, respectively. The use of reflective mulch was able to significantly increase the soybean leaf area ($p < 0.05$) from 4 MST, especially with the use of inorganic reflective mulch (Table 2 and Fig. 4b) with an average leaf area of 714.08 cm$^2$, followed by 491.38 cm$^2$ with the use of organic reflective mulch and 378.35 cm$^2$ in the control or without the use of reflective mulch.

3.2.2 Leaf thickness

Soybean leaf thickness decreased significantly ($p < 0.05$) in the 8-year-old oil palm group, but there was no significant difference ($p > 0.05$) between soybean leaf thickness grown on open land and under the 4- and 5-year-old oil palm stands (Table 1). As shown in Table 2, the use of reflective mulch did not significantly affect the thickness of soybean leaves ($p > 0.05$). This result indicates that the role of inorganic and organic reflective mulch does not contribute to soybean leaf thickness.

3.2.3 Specific leaf weight

The value of soybean SLW decreased along with the increase in shade due to the increasing age of the oil palm, except at age 5 years (Table 1). The highest SLW value was found in soybean

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### Table 1. Leaf area, leaf thickness, density, length, and width of soybean leaf stomata under oil palm stands of different age groups.

| Variable                      | Under oil palm canopy | 4 years | 5 years | 8 years |
|-------------------------------|-----------------------|---------|---------|---------|
|                               | Open land             |         |         |         |
| Leaf area (cm$^2$)            | 756.71 c              | 724.80 c| 461.82 b| 146.82 a|
| Leaf thickness (µm)           | 125.63 b              | 117.03 ab| 131.84 b| 103.97 a|
| Specific leaf weight/SLW (mg cm$^{-2}$) | 12.13 c              | 8.78 b  | 11.36 c | 5.67 a  |
| Stomatal density (unit mm$^{-2}$) | 292.52 b              | 235.54 b| 211.73 ab| 134.35 a|
| Stomatal length (nm)          | 15.70 a               | 16.95 a | 16.69 a | 20.23 b |
| Stomatal width (nm)           | 9.75 a                | 10.90 b | 10.44 ab| 11.15 b |
| Stomatal area (nm$^2$)        | 153.63 a              | 184.95 bc| 172.09 b| 195.39 c|

Note: Numbers followed by different letters on the same line show significant differences ($p < 0.05$) based on Duncan’s multiple range test at $\alpha = 5$

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### Table 2. Leaf area, leaf thickness, density, length, and width of soybean leaf stomata using reflective mulch.

| Variable                      | Reflective mulches |
|-------------------------------|--------------------|
|                               | No mulch | Inorganic | Organic |
| Leaf area (cm$^2$)            | 378.35 a       | 714.08 b  | 491.38 a|
| Leaf thickness (µm)           | 120.59 a       | 118.99 a | 119.28 a|
| Specific leaf weight/SLW (mg cm$^{-2}$) | 8.85 ab       | 8.73 a    | 10.79 b |
| Stomatal density (unit mm$^{-2}$) | 180.48 a     | 259.15 b | 213.00 b|
| Stomatal length (nm)          | 18.19 a        | 16.84 a  | 17.13 a |
| Stomatal width (nm)           | 10.94 b        | 10.67 ab | 10.06 a |
| Stomatal area (nm$^2$)        | 176.58 a       | 178.66 a | 171.95 a|

Note: Numbers followed by different letters on the same line show significant differences ($p < 0.05$) based on Duncan’s multiple range test at $\alpha = 5$

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![Fig. 4](image-url) (a) Weekly distribution of soybean leaf area on land under oil palm stands of different age groups, and (b) Weekly distribution of soybean leaf area using reflective mulch.
plants grown on open land, which was not significantly different \((p > 0.05)\) compared to that of soybean plants grown under 5-year-old oil palm stands, but it was significantly different \((p < 0.05)\) from the SLW value of soybean plants grown under 4- and 8-year-old oil palm stands. The use of reflective mulch did not significantly influence the SLW value \((p > 0.05)\); however, the type of reflective mulch (inorganic and organic) had a significant influence on the SLW value \((p < 0.05)\) (Table 2).

### 3.2.4 Stomatal density

The stomatal density of soybean was lower with lower solar radiation reaching the surface of the soybean plant due to the increasing age of oil palm as the main crop (Table 1 and Fig. 5). There was a significant decrease in soybean stomatal density \((p < 0.05)\) in the plants grown under 8-year-old oil palm stands, but that of soybean plants grown on open land and under 4- and 5-year-old oil palm stands was not significantly different \((p > 0.05)\). The use of reflective mulch in soybean cultivation on open land and under oil palm plantations could significantly increase leaf stomatal densities \((p < 0.05)\). The maximum stomatal density of 259.15 mm\(^2\) was found with the use of inorganic reflective mulch, which was significantly different \((p < 0.05)\) compared to that with the use of organic reflective mulch (213.00 mm\(^2\)) and on land without the use of reflective mulch (180.48 mm\(^2\)) (Table 2).

### 3.2.5 Length, width, and area of stomata

The length, width, and area of soybean stomata tended to increase significantly \((p < 0.05)\) with increasing age of oil palm stands (Table 1). In general, the use of reflective mulch, both inorganic and organic, did not affect the length, width, and area of soybean stomata. The average length of soybean leaf stomata was 18.19 mm in open land, 16.84 mm with the use of inorganic reflective mulch, and 17.13 mm with the use of organic reflective mulch. The average width of soybean leaf stomata was 10.94 mm without the use of reflective mulch, 10.67 mm with the use of inorganic reflective mulch, and 10.06 mm with the use of organic reflective mulch. The average area of soybean leaf stomata on land was 176.58 mm\(^2\) without the use of reflective mulch, 178.66 mm\(^2\) with the use of inorganic reflective mulch, and 171.95 mm\(^2\) with the use of organic reflective mulch.

### 3.3 Soybean leaf chlorophyll

The content of chlorophyll A, chlorophyll B, and chlorophyll A/B ratio did not differ significantly \((p > 0.05)\) in soybean plants grown on open land and under oil palm stands aged 4 and 5 years, but they were significantly different \((p < 0.05)\) in soybean plants grown under oil palms aged 8 years (Fig. 6a). The content of chlorophyll A, chlorophyll B, and chlorophyll A/B ratios in soybean leaves planted under 8-year-old oil palm stands...
were lower than those in soybean leaves planted under oil palm stands of other age groups due to the low transmission of solar radiation reaching the surface, which was approximately 25.1% due to large shade (74.9%).

The use of organic reflective mulch significantly reduced the content of chlorophyll A and chlorophyll B ($p < 0.05$) compared with the use of inorganic reflective mulch and without the use of reflective mulch; however, the use of reflective mulch had no significant ($p > 0.05$) impact on the chlorophyll A/B ratio (Fig. 6b). The average chlorophyll A content was decreased from 3.06 to 2.62 mg g$^{-1}$ with the use of inorganic reflective mulch and to 2.33 mg g$^{-1}$ with the use of organic reflective mulch. Similar result was observed for chlorophyll B content, whose average value decreased to 1.53 mg g$^{-1}$ in the oil palm fields without the use of reflective mulch and to 1.29 and 1.14 mg g$^{-1}$, respectively, with the use of inorganic and organic reflective mulch.

### 3.4 Photosynthetic characteristics

#### 3.4.1 Photosynthesis rate

Photosynthesis rate measurements were conducted on the upper and lower leaf groups. The rate of photosynthesis in the upper leaf group of soybean plants was decreased significantly in the oil palm fields aged 8 years ($p < 0.05$); it was also decreased significantly ($p < 0.05$) in the lower leaf group of soybean plants grown under 5-year-old oil palm stands (Table 3).

The use of reflective mulch resulted in a significant impact on the increase in the rate of photosynthesis in the lower leaves of soybean plants ($p < 0.05$), but it did not cause a significant difference ($p > 0.05$) in the upper leaf group (Table 4). However, the rate of photosynthesis with the use of inorganic and organic reflective mulch showed no significant difference ($p > 0.05$) (Table 4). The average rates of photosynthesis of the top leaves of soybean plants cultivated without the use of mulch and with the use of inorganic and organic reflective mulch were 31.72, 33.13, and 33.91 mmol CO$_2$ m$^{-2}$ s$^{-1}$, respectively. The average rates of photosynthesis of the lower leaves of soybean plants cultivated without mulch and with the use of inorganic and organic reflective mulch were 20.89, 23.64, and 24.74 mmol CO$_2$ m$^{-2}$ s$^{-1}$, respectively. This result suggests that the use of reflective mulch significantly contributed to the increase in the rate of photosynthesis only in the lower leaves of soybeans planted under the canopy.

#### 3.4.2 Transpiration rate

The rate of transpiration in the upper leaves of soybean plants grown under oil palm stands aged 5 years was significantly different ($p < 0.05$) from that of soybean plants grown on open land and under 4- and 8-year-old oil palm stands (Table 3). The transpiration rate of the upper leaves of soybean plants decreased with the increasing age of the oil palm until the age of 5 years and increased again under oil palm stands aged 8 years. The average transpiration rates of the upper leaves of soybean plants grown on open land and under oil palm stands aged 4, 5,

### Table 3. Photosynthetic characteristics of soybean leaves under oil palm stands of different age groups.

| Photosynthetic characteristics | Leaf position | Under oil palm canopy |
|-------------------------------|--------------|-----------------------|
|                               | Open land    | 4 years | 5 years | 8 years |
| Photosynthetic rate (µmol CO$_2$ m$^{-2}$ s$^{-1}$) | Upper | 35.52 b | 36.03 b | 35.24 b | 24.88 a |
|                               | Lower | 27.20 b | 26.87 b | 20.49 a | 17.81 a |
| Transpiration rate (mmol H$_2$O m$^{-2}$ s$^{-1}$) | Upper | 11.74 b | 10.92 ab | 9.56 a | 11.99 b |
|                               | Lower | 11.58 a | 10.98 a | 9.80 a | 9.68 a |
| Intercellular CO$_2$ concentration (µmol CO$_2$ m$^{-2}$ s$^{-1}$) | Upper | 316.01 a | 310.11 a | 311.84 a | 331.72 a |
|                               | Lower | 333.59 ab | 331.71 ab | 347.56 b | 320.48 a |
| Stomatal conductance (mol H$_2$O m$^{-2}$ s$^{-1}$) | Upper | 0.92 a | 0.90 a | 0.98 a | 0.86 a |
|                               | Lower | 0.90 b | 0.91 b | 0.98 b | 0.80 a |

Note: Numbers followed by different letters on the same line show significant differences ($p < 0.05$) based on Duncan’s multiple range test at $\alpha = 5\%$.

### Table 4. The photosynthetic characteristics of soybean leaves without the use of mulch and with the use of inorganic and organic reflective mulch.

| Photosynthetic characteristics | Leaf position | Reflective mulches |
|-------------------------------|--------------|-------------------|
|                               |              | No mulch | Inorganic | Organic |
| Photosynthetic rate (µmol CO$_2$ m$^{-2}$ s$^{-1}$) | Upper | 31.72 a | 33.13 a | 33.91 a |
|                               | Lower | 20.89 a | 23.64 b | 24.74 b |
| Transpiration rate (mmol H$_2$O m$^{-2}$ s$^{-1}$) | Upper | 11.44 a | 10.25 a | 11.48 a |
|                               | Lower | 11.56 b | 9.33 a | 10.64 ab |
| Intercellular CO$_2$ concentration (µmol CO$_2$ m$^{-2}$ s$^{-1}$) | Upper | 322.73 a | 308.48 a | 321.05 a |
|                               | Lower | 348.76 b | 320.41 a | 330.84 ab |
| Stomatal conductance (mol H$_2$O m$^{-2}$ s$^{-1}$) | Upper | 0.93 a | 0.83 a | 0.98 a |
|                               | Lower | 0.96 b | 0.75 a | 0.91 b |

Note: Numbers followed by different letters on the same line show significant differences ($p < 0.05$) based on Duncan’s multiple range test at $\alpha = 5\%$.
and 8 years were 11.74, 10.92, 9.56, and 11.99 mmol H$_2$O, respectively. Different results were found for the lower leaf group of soybean plants. The age of oil palm stands had no significant influence ($p > 0.05$) on the transpiration rate in the lower leaves of soybean plants compared with the control (open land).

The use of reflective mulch had no significant effect ($p > 0.05$) on the transpiration rate of the upper soybean leaf group (Table 4). The average transpiration rate of upper soybean leaves on land was 11.44 mmol H$_2$O m$^{-2}$ s$^{-1}$ without the use of reflective mulch, 10.25 mmol H$_2$O m$^{-2}$ s$^{-1}$ with the use of inorganic reflective mulch, and 11.48 mmol H$_2$O m$^{-2}$ s$^{-1}$ with the use of organic reflective mulch. In the lower leaf group, there was a significant decrease in the transpiration rate ($p < 0.05$) with the use of inorganic reflective mulch, but the transpiration rate was not significant ($p > 0.05$) with the use of organic reflective mulch (Table 4). The average transpiration rate of lower soybean leaves on land was 11.56 mmol H$_2$O m$^{-2}$ s$^{-1}$ without the use of reflective mulch, 9.33 mmol H$_2$O m$^{-2}$ s$^{-1}$ with the use of inorganic reflective mulch, and 10.64 mmol H$_2$O m$^{-2}$ s$^{-1}$ with the use of organic reflective mulch.

3.4.3 Intracellular CO$_2$ concentration

The age of oil palm stands had no significant influence ($p > 0.05$) on the intracellular CO$_2$ concentration in both the upper and lower leaf groups of soybean plants (Table 3). The average intracellular CO$_2$ concentrations in the upper leaves of soybean plants grown on open land and under oil palm stands aged 4, 5, and 8 years were 316.01, 310.11, 311.84, and 331.72 µmol CO$_2$ m$^{-2}$ s$^{-1}$, respectively. In the lower leaves of soybean plants, the respective average intracellular CO$_2$ concentrations were 333.59, 331.71, 347.56, and 320.48 µmol CO$_2$ m$^{-2}$ s$^{-1}$.

The use of reflective mulch did not affect the intracellular CO$_2$ concentration in the upper leaves of soybean plants ($p > 0.05$), but the use of inorganic reflective mulch significantly reduced the intracellular CO$_2$ concentration ($p < 0.05$) in the lower leaves (Table 4). The use of organic reflective mulch had no significant effect ($p > 0.05$) on the intracellular CO$_2$ concentration. The average intracellular CO$_2$ concentrations of the upper soybean leaves without the use of mulch and with the use of inorganic and organic reflective mulch were 322.73, 308.48, and 321.05 µmol CO$_2$ m$^{-2}$ s$^{-1}$, respectively. The respective average intracellular CO$_2$ concentrations of the lower soybean leaves were 348.76, 320.41, and 330.84 µmol CO$_2$ m$^{-2}$ s$^{-1}$.

3.4.4 Stomatal conductance

The age of oil palm stands had no significant impact on the stomatal conductance of the upper leaves of soybean plants ($p > 0.05$), as well as the lower leaves of soybean plants cultivated under oil palm stands until the age of 5 years. However, in the lower leaves of soybean plants grown under 8-years-old oil palm stands, the stomatal conductance was decreased significantly ($p < 0.05$) (Table 3). The average stomatal conductance values of soybean plants grown on open land and under oil palm stands aged 4, 5, and 8 years were 0.92, 0.90, 0.98, and 0.86 mol H$_2$O m$^{-2}$ s$^{-1}$, respectively. The average rootstock stomatal conductance values of soybean plants grown on open land and under oil palm stands aged 4, 5, and 8 years were 0.90, 0.91, 0.98, and 0.80 mol H$_2$O m$^{-2}$ s$^{-1}$, respectively.

The results shown in Table 4 indicate that the stomatal conductance value in the upper leaves was not affected by the use of reflective mulch ($p < 0.05$); in contrast, the lower leaves showed a significant decrease in the stomatal conductance value with the use of inorganic reflective mulch ($p < 0.05$), but not with the use of organic reflective mulch ($p > 0.05$). The average stomatal conductance values in the upper soybean leaves were 0.93 mol H$_2$O m$^{-2}$ s$^{-1}$ without the use of reflective mulch, 0.83 mol H$_2$O m$^{-2}$ s$^{-1}$ with the use of inorganic reflective mulch, and 0.98 mol H$_2$O m$^{-2}$ s$^{-1}$ with the use of organic reflective mulch. In the lower soybean leaves, the respective average stomatal conductance values were 0.96, 0.75, and 0.91 mol H$_2$O m$^{-2}$ s$^{-1}$.

3.5 Yield of soybean

The use of organic reflective mulch could yield the maximum weight of 16.57 g of soybean seeds of 100 grains, and the use of inorganic reflective mulch yielded a weight of 16.10 g, whereas the lowest weight of 12.70 g was produced on the land without the use of reflective mulch (Table 5). The use of inorganic and organic reflective mulch could significantly increase the weight of soybean seeds by 100 grains ($p < 0.05$). However, there was no difference in the weight of 100 soybean grains between the use of the reflective mulch types ($p > 0.05$). The use of reflective mulch significantly increased the soybean productivity ($p < 0.05$), but there was no difference between the types of reflective mulch ($p > 0.05$). The productivities of soybeans without the use of reflective mulch and with the use of inorganic and organic reflective mulch were 134.99, 190.15, and 195.59 g m$^{-2}$, respectively.

Based on location of planting, the weights of 100-grain soybeans grown on open land and under 4- and 5-year-old oil palm stands were not different ($p < 0.05$), the values being 17.51, 16.66, and 16.88 g, respectively. However, in the land of 8-year-old oil palm stands, there was a significant reduction in the weight of 9.44 g of 100 grains of soybean seeds ($p < 0.05$). Soybean productivity was decreased significantly ($p < 0.05$) when compared between the open land and oil palm stands aged 4, 5, and 8 years, with the productivity values being 335.04, 214.89, 125.92, and 18.45 g m$^{-2}$, respectively (Table 5).

**Table 5. Yield of soybeans under the oil palm canopy with the use of different types of reflective mulch.**

| Factors | Weight of 100 grains (g) | Productivity (g m$^{-2}$) |
|---------|-------------------------|---------------------------|
| Reflective mulches: | | |
| No reflector | 12.70 a | 134.99 a |
| Inorganic | 16.10 b | 190.15 b |
| Organic | 16.57 b | 195.59 b |
| Under oil palm canopy: | | |
| Open land | 17.51 b | 335.04 d |
| 4 years | 16.66 b | 214.89 e |
| 5 years | 16.88 b | 125.92 b |
| 8 years | 9.44 a | 18.45 a |

Note: Numbers followed by different letters on the same column show significant differences ($p < 0.05$) based on Duncan’s multiple range test at α = 5%
4. Discussion

The use of reflective mulch under oil palm stands was able to increase the reflection intensity of solar radiation. The reflective ability of solar radiation with the use of inorganic reflective mulch has been reported to be higher than that with the use of organic reflective mulch due to the high albedo value produced by the inorganic reflective mulch material (Hidayat et al., 2019). This study showed that the increasing age of oil palm stands resulted in lesser transmission of solar radiation to the surface of the land, so that the reflection intensity of solar radiation that is reflected by the reflective mulch is lower, and vice versa. The changes in the intensity of solar radiation reflection are also influenced by the age of the soybean plant (Hidayat et al., 2020), the angle of incidence of radiation, the level of atmospheric brightness, wind, stand structure, the type of plant, and the leaf size area (Ross, 1975; Mubarak et al., 2018). The intensity of the reflection of solar radiation from the land surface will be lower along with the increase in soybean LAI and the light extinction coefficient of the stand (Hidayat et al., 2019). When radiation transmits through a stand, there will be a decrease in its amount and also an uneven distribution (Hidayat et al., 2020).

The use of reflective mulch under oil palm stands could increase the interception of solar radiation. The amount of solar radiation intercepted by plants is determined by the magnitude of the intensity of solar radiation reaching the plant surface, cultivation techniques, and plant species (Koemayono and Sabaruddin, 2005). The response of soybean plants to low light stress (shade) reflects a change in morphological characteristics, chlorophyll content, and photosynthetic characteristics (Gong et al., 2014; Su et al., 2014; Yang et al., 2014).

An oil palm stand aged >5 years is no longer effective for planting soybeans as an intercrop as it could decrease the morphological quality of soybean, which would affect the performance and productivity of soybean. The decline in morphophysiological quality indicates the response of soybean plants to low light intensity grown under an 8-year-old oil palm stand due to the high percentage of shade that causes the soybean leaves to become thinner. Pantilu et al. (2012) reported that soybeans can adapt to an environment of low solar radiation conditions by increasing the length and width of their stomata to increase the rate of photosynthesis.

The increase in the content of chlorophyll A and chlorophyll B of soybeans with the increasing age of oil palm stands (up to 5 years) is due to the very low transmission of solar radiation to the surface, which was approximately 25.1% due to large shading (74.9%). The increase in the content of chlorophyll A and chlorophyll B in soybeans grown under oil palm stands was accompanied by a decrease in the rate of photosynthesis. This is believed to be due to low PAR (Song and Li, 2016; Fan et al., 2019), increased soybean ability to capture and use solar radiation (Zhang et al., 2016), increased protein levels associated with the process of chlorophyll formation (Fan et al., 2019), thus increasing the amount of chlorophyll per unit leaf area (Sulistyowati et al., 2016), and energy deficiency for the process of carbon assimilation in the dark reaction (Su et al., 2014). Fan et al. (2019) also reported that soybean plants grown in the shade experienced an increase in light capture efficiency on PSII, but the ability of electron transport from PSII to PSI was decreased.

The content of chlorophyll A and chlorophyll B in the lower part of soybean leaves decreased with the use of reflective mulch, and the rate of photosynthesis in soybean plants was increased. This is because the lower leaves of soybeans are more dominant in utilizing the intensity of solar radiation generated by the reflective mulch, whereas the upper leaves use more of the global radiation intensity. This is because the ability of reflective mulch reflection becomes higher when it is closer to the mulch surface (Hidayat et al., 2019). The decrease in chlorophyll content accompanied by the increase in the photosynthetic rate observed in this study was consistent with previous studies conducted by Su et al. (2014), Yao et al. (2017), Yang et al. (2018), and Fan et al. (2019). However, several other studies have demonstrated contradictory results, where a positive correlation was observed between chlorophyll content and the rate of photosynthesis (Marchiori et al., 2014; Khalid et al., 2019). This shows that differences still exist in the results of studies related to the response of soybean plants grown under shade to chlorophyll content and the rate of photosynthesis. An earlier study confirmed that the use of reflective mulch can also improve the quality of the physical environment toward better temperature and soil moisture content conditions, which are more conducive to the growth of soybean plants (Hidayat et al., 2019).

The photosynthetic rate of plants grown under shade is lower than that of plants grown under normal light conditions (Marchiori et al., 2014); however, the use of reflective mulch can overcome the problem of low intensity of solar radiation under shade. Solar radiation is known to play a vital role in the process of plant growth and development (Fiorucci and Fankhauser, 2017). The photosynthetic rate of plants, including soybeans, will increase with increase in LAI, interception, and efficiency of solar radiation use (Nagasuga, 2019), which was confirmed in the present study. The use of reflective mulch also had an impact changes in other photosynthetic characteristics, i.e., the rate of transpiration, intercellular CO2 concentration, and stomatal conductance. These results are supported by a study conducted by Khalid et al. (2019) who demonstrated that the shade and stage of plant development significantly affected the rate of transpiration. The intercellular CO2 concentration indicates the availability of CO2 for the process of assimilation (Tominaga et al., 2018). A decrease in intercellular CO2 concentration can result in inhibition of the process of photosynthesis, consequently reducing plant production (Kelly et al., 2016). Under stressful conditions, the stomatal conductance of plants decreases (Davies and Flore, 1986), and consequently, the rate of photosynthesis and transpiration will also decrease (Nagy and Galiba, 1995; Bertolde et al., 2012).

A novel finding of this study was that the application of reflective mulch contributed to increasing the surface solar radiation reflective intensity, which led to the increase in the photosynthetic rate, especially in the lower leaves, and the productivity of soybeans. However, soybean productivity was decreased with the increasing age of oil palm stands, which was due to the lower intensity of solar radiation under the oil palm stands. Based on the soybean yield data, the land under
oil palm stands until the age of 5 years can still be used for soybean cultivation using reflective mulch. This is a novel finding because till date, soybean cultivation under oil palm stands without using reflective mulch was done only until the age of 3 years. The use of reflective mulch is highly effective in improving the quality of the physical environment, especially in increasing the intensity of reflection of solar radiation and soybean morphophysiology under oil palm stands aged <5 years, and has an impact on increasing soybean productivity. The use of organic reflective mulch for soybean cultivation is recommended for use under oil palm stands based on several factors, i.e., the ease of obtaining raw materials (a byproduct of gardens), low price, easy decomposition, and the ability to add nutrients. This makes organic reflective mulch superior to inorganic reflective mulch both economically and environmentally. Moreover, the use of organic reflective mulch increases the process of water infiltration either from precipitation or irrigation, so that the availability of groundwater is better maintained, especially in areas with low rainfall. The use of land under oil palm stands is effective only until the age of ≤5 years, because after 5 years of age, the productivity of soybeans would decrease dramatically despite the use of reflective mulch.

This study was conducted during only one planting season, known as the transitional season (at the end of the rainy season and the beginning of the dry season). This is a part of a strategy to minimize the limitations of the physical environment under oil palm plantations, especially the intensity of solar radiation and low water availability. Hence, we do not recommend that soybeans be planted in the rainy season or the dry season. In the rainy season, the intensity of solar radiation under the stands is so low that the use of reflective mulch is not effective. Similarly, if soybeans are planted in the dry season, the availability of water becomes a major limiting factor, which is because oil palm stands are planted in dry land.

5. Conclusion

Reflective mulch is effective in increasing the reflection intensity of solar radiation by 169% with the use of inorganic reflective mulch and by 59% with the use of organic reflective mulch in the soybean–oil palm intercropping system. The interception of soybean solar radiation under oil palm stands increased by 30% with the use of inorganic reflective mulch and by 26% with the use of organic reflective mulch. Reflective mulch could improve the growth performance of soybeans by significantly increasing the rate of photosynthesis, especially in the lower leaves, from 20.89 μmol CO₂ m⁻² s⁻¹ in the control to 23.64 μmol CO₂ m⁻² s⁻¹ with the use of inorganic reflective mulch and to 24.74 μmol CO₂ m⁻² s⁻¹ with the use of organic reflective mulch. Organic reflective mulch or oil palm dry leaves can create a conducive microclimate under the main crop stand; hence, it is recommended for use in intensive soybean cultivation under oil palm stands aged ≤5 years.

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