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Intensifying of reflected radiation under oil palm canopy and its effect on growth and production of soybean

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Abstract. The main problem of cultivating soybeans under the stands of oil palm plantations in the low intensity of solar radiation. The aim of this study was to analyze the effect of reflective mulch application on the growth, physiology, and production of soybeans cultivated as intercropping under oil palm plantation stands. The study was carried out at Cimarga Banten Indonesia using a two-factor randomized nested design with three replications. The treatments consist of two factors, viz different age of oil palm stands and types of reflected mulches. The use of reflective mulch would increasing albedo, as well as in intensifying reflected radiation of land surface by 29% for organic mulch and by 49% for inorganic mulch. The application of organic and inorganic reflective mulches could increase the interception of solar radiation by soybean plants and had positive effects on height, stem diameter, leaf area index, biomass, and radiation use efficiency. The use of organic reflective mulch increased the amount of relative leaf chlorophyll in shaded conditions and the amount of chlorophyll in the upper, middle and lower position leaves. Organic and inorganic reflective mulches had a significant effect on increasing the number of fill pods, production, and weight of 100 soybean grains.

1. Introduction

Soybeans are very popular as a plant-based protein source for Indonesian people as shown by National soybean needs that have exceeded 2.5 million tons per year and are projected to an annual increase of 2.10% [1]. The government imported about 86.95% of soybeans to meet domestic needs [2]. Therefore, there are continual efforts to increase national soybean production through increasing productivity and expanding planting areas (extensification) [3]. Improvement of cultivation systems and the application of appropriate, economical and efficient technologies are expected to increase production per unit area. On the other hands, extensification is limited by land availability. Thus, the utilization of sub-optimal (marginal) lands such as land under oil palm stands offers alternative through intercropping systems. However, there were reports that planting crops under oil palm stands could have a negative impact on oil palm growth and production [4]. But, according to [5] the oil palm intercropping system with legumes did not inhibit the rate of growth and development of oil palm, it even accelerating the growth of oil palm, especially the young plants that have not yet produced.

The main constraints for utilizing land under the stands are low light intensity, high soil acidity and the threat of drought [6]. In general, the low light intensity will affect the growth and yield of plants [7]. Soybean production is significantly reduced if the light intensity falls below 30% of normal conditions both in the rainy and dry seasons [8]. Thus low light intensity could be considered as sub-optimal environment condition and acts as an abiotic stressor for soybean crops.

Efforts to improve production on land under the stands can be achieved through improving potential yields, the adaptation of plants to abiotic and biotic stresses, as well as physiology-based cultivation techniques or plant ecophysiology [6]. Microclimate modification under the stands also important in order to create the optimum abiotic environment around plants for its growth and

development. These modifications can be in the form of setting up a cultivation system, land processing, using certain materials, and constructing permanent construction such as greenhouses. The application of plant microclimate modification must consider the principles of effectiveness, efficiency, and economic value for its sustainable application. Based on these principles, the efforts to increase the amount of radiation reaching crops under oil palm stands can be carried out by improving routine oil palm leaves pruning, and the application of reflective mulch on the land surface. Pruning reduces radiation intercepted by oil palm leaves, while reflective mulch increase surface albedo or the reflection capability of solar radiation on a surface under the stands.

Reflective mulch is a material able to reflect solar radiation and its ability in reflecting light is determined by the value of the albedo [10]. The use of reflective mulch can improve photosynthetically active radiation/PAR [11]. The incoming solar radiation on the leaves will affect the distribution of chlorophyll. The presence of radiation that reaches the bottom of the leaf causes chlorophyll translocation so the absorption of light for photosynthesis becomes higher [12]. Reflective mulch applications in soybean cultivation under 50% shade will increase photosynthesis rates by 15% to 44% and increase production by 63% compared to controls [13].

The purpose of this study was to analyze the effect of inorganic and organic reflective mulch applications on the growth, physiology, and production of soybeans cultivated as intercrops under the stands of oil palm plantations.

2. Material and Methods
The study was conducted at the PTPN VIII oil palm plantation in the Lebak Cimarga, Banten Province from January to July 2018. Analysis of the samples was carried out at the Integrated Laboratory of GFM-FMIPA IPB and Integrated and Micro Engineering Laboratory Department of AGH-FAPERTA IPB.

2.1 Testing of reflective mulch albedo
The albedo was measured from 4 types of reflectors and 2 types of land cover types as controls. The material used in this testing includes metallic plastic mulch, black silver plastic mulch, rice husk, and dried oil palm leaves. The controls were open land and short grass. The testing we did by measuring the intensity of the incoming radiation and reflected radiation by the material at the same time using 2 unit solarimeter tubes and calibrated with the SR03-type pyranometer. Measurements were made by placing a solarimeter-1 tube in an open field with a sensor facing upward to obtain the intensity of incoming radiation, while reflected radiation is measured by a tube solarimeter-2 with a censor facing the surface of the land or reflective mulch. The tube solarimeter-2 sensor for the measurement of reflected radiation was set at a height of 30 cm, 60 cm, and 120 cm.

2.2 Reflective mulch application in soybean cultivation under oil palm stands.
The materials used in this testing are anjasmoro variety soybean seeds, inorganic and organic reflective mulch (the best albedo material test results). The tools used are measuring instrument, digital calipers, tube solarimeter, chlorophyll meter SPAD-502plus, oven, seed counter, and digital scales. This study uses a randomized two-factor nested design with three replications. The first factor is the age group of oil palm (S) which consists of control (S0; open land), age 4 years (S1), 5 years (S2) and 8 years (S3). The second factor is the use of reflective mulch consisting of three levels, namely without reflective/control mulch (R0), inorganic reflective mulch (R1), and organic reflective mulch (R2). The data were analyzed by variance and tested with Duncan's Multiple Range Test (DMRT) at 95% confidence level using the SPSS 21.5 program.

Interception of solar radiation is the difference between the intensity of radiation received above the canopy (Qo; MJ m^{-2}) and under the crop canopy (Q; MJ m^{-2}). According to [9], interception of radiation can be calculated using Beer Law, Qint is Qo x (1-exp (-k x LAI)), LAI is (Ld/Lh) x P and k is ln(Q/Qo)/LAI. Value k is extinction coefficient, P is total population, LAI is the leaf area index, Lh is land area (m^2), Ld is leaf area (m^2). The results of interception of radiation are used to calculate the

radiation use efficiency (RUE; g MJ^{-1}), value with the following equation RUE is dw/Qint, where dw is addition of plant biomass (g m^{-2}) and Qint is the interception of global solar radiation (MJ m^{-2}).

The observation of agronomic parameters is plant height, stem diameter, LAI, and biomass. The production parameters were measured using a purposive sampling method, including the number of fill pods, number of empty pods, productivity (ton ha^{-1}), and seed weight of 100 points (g).

3. Result and discussion

3.1 Albedo, radiation interception, and radiation use efficiency

Generally, inorganic mulch has a higher albedo than organic mulch and control as presented in Figure 1. Based on a significant test of a 95% confidence interval within inorganic and organic reflective mulch that there was no significant difference in albedo. The black and silver plastic mulch are representing inorganic reflective mulch (49%) and dried oil palm leaves representing organic reflective mulch (29%). Final selection of the reflective mulch is determined by the ability to reflect radiation, the cost and the availability of the materials around oil palm plantations area.
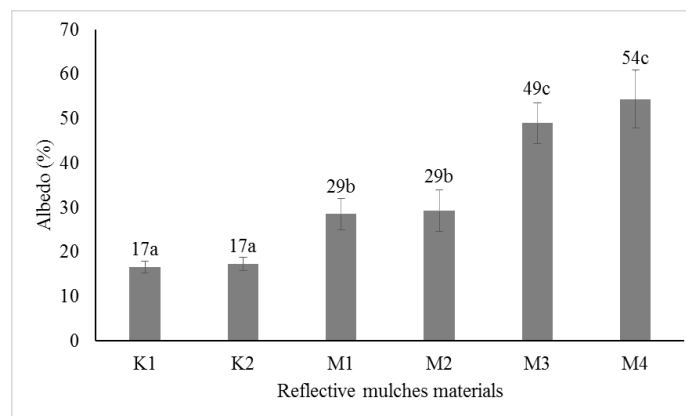

Figure 1. The albedo of several types of reflective mulch and control. K1: open land /control-1, K2: short grass / control-2, M1: dry oil palm leaf, M2: dry rice husk, M3: black silver plastic mulch, M4: metallic plastic mulch. The bar with the same letter describes it is no significant different at *P<5%*.

The use of reflective mulch in soybean cultivation under oil palm stands increases LAI and will further increase the interception of solar radiation (Figure 2). The increase in LAI will increase leaf extinction coefficient value (k) which causes the decrease amount of radiation transmitted according to Beer Law. The high radiation interception and RUE were influenced by the canopy structure, where the higher the LAI leads to the higher the canopy extinction coefficient [14]. The use of reflective mulch increases the interception of solar radiation and the ability of plants to convert solar energy into biomass through RUE [15].
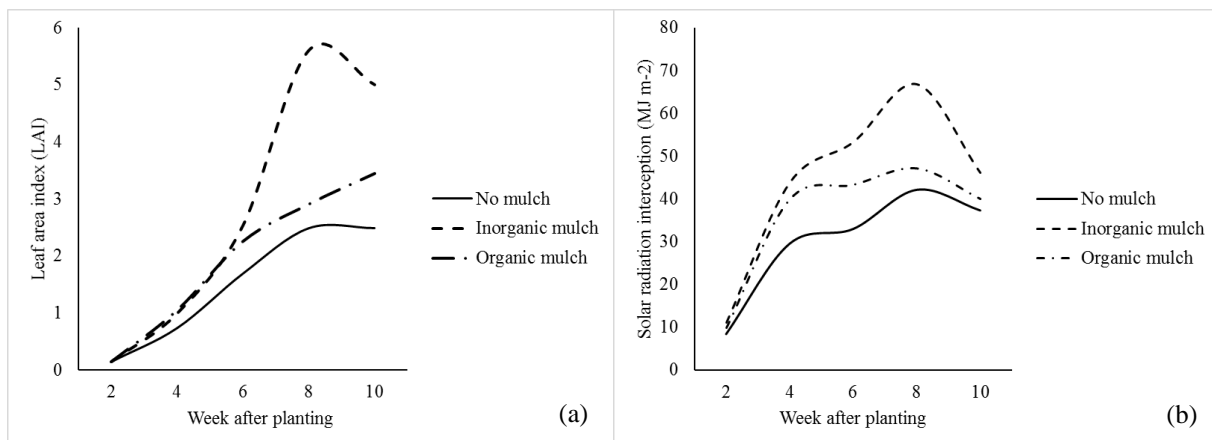
Figure 2. Leaf area index (LAI) of several types of reflective mulch (a) and soybean solar radiation interception on several types of reflective mulch (b).

Cultivation of plants under the stands causes the low radiation availability and it will have an impact on the low amount of radiation that will be converted into biomass. The use of reflective mulch can significantly increase soybean biomass and RUE in Figure 3. Soybean biomass which had reflective mulch application is higher than biomass without the application of reflective mulch (reflector). This has an impact on increasing the value of RUE in soybeans. Based on the gradient of interception of solar radiation on biomass, RUE soybeans for control plants (without reflective mulch) is 2.44 g MJ^{-1}, inorganic reflective mulch is 3.07 g MJ^{-1} and organic reflective mulch is 2.90 g MJ^{-1}. The RUE values are strongly influenced by population size, spacing ([16] and type of soybean cultivars [17].
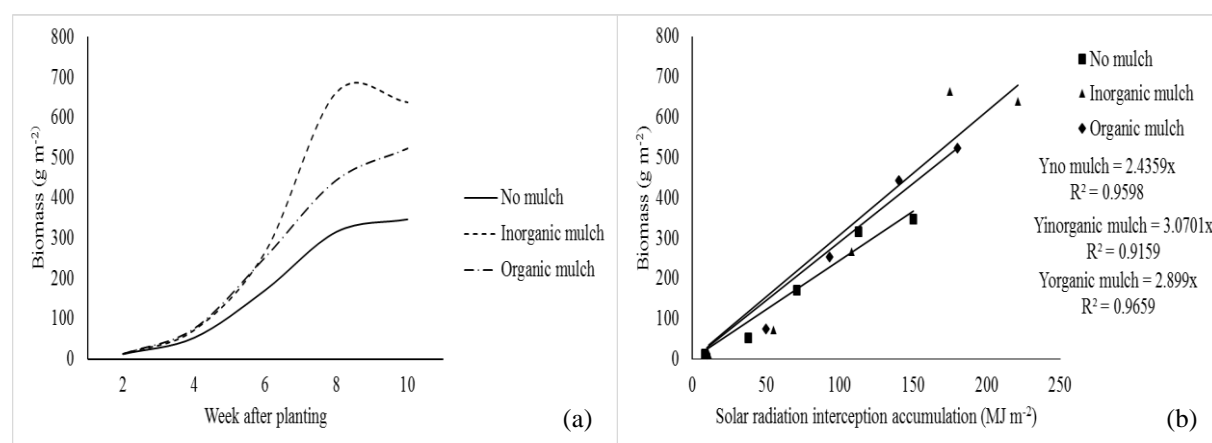

Figure 3. Biomass of soybean crops under several types of reflective mulch (a), Radiation use efficiency (RUE) on several types of reflective mulch (b).

3.2 Soybean growth and chlorophyll
Soybean growth is observed using parameters of stem height and diameter. Figure 4 presents the increase in height and stem diameter of soybeans from the age of 2 weeks after planting (WAP) to 10 WAP under the oil palm stand which is applied inorganic and organic reflective mulch. Plant height from 2 WAP to 5 WAP between mulch species did not show a significant difference, but when it

entered 6 WAP that the height of soybean with reflective mulches was higher than the control (Figure 4a). The low intensity of solar radiation received by plants will cause root growth disorders and etiolation symptoms as indicated by stem length increment [18]. Based on a significant test at a 95% confidence interval, there was no significant difference between inorganic reflective mulch and organic reflective mulch, but it was significantly different from the control. According to [19] increasing height in shaded plants is one response to increasing RUE and increasing the amount of light that can be absorbed.

The diameter of the soybean stem which using the reflective mulch is higher than the control since 3 WAP. The diameter of the soybean stem using the inorganic reflector produced the highest diameter of 3.9 mm, followed by organic reflective mulch with a diameter of 3.5 mm, while the control diameter was only 2.8 mm (Figure 4b). Based on the significance test on the 95% confidence interval, the stem diameter of soybean using inorganic reflectors was not significantly different from the organic reflector, but it was significantly different from the control. The value of the stem diameter is the indicator of the robustness of the stem. The results of this study showed that the use of reflective mulch increases the stem diameter of soybeans which implies that the soybean stem is not easy to fall down.
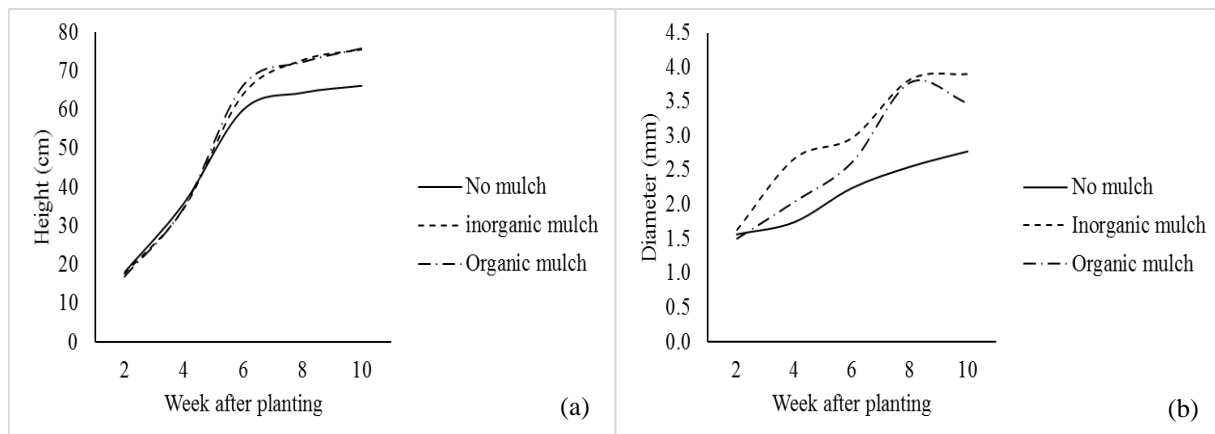

Figure 4. The height of soybean in several types of reflective mulch (a), Soybean stem diameter in several types of reflective mulch (b).

Figure 5a presents the amount of relative chlorophyll of soybean leaves using several types of reflective mulch under shade conditions. In conditions without the shade that the amount of soybean chlorophyll leaves is higher than the shaded plants. This occurs both in controls and soybean plants using reflective mulch. The highest increase of the amount of soybean chlorophyll using the application of organic reflective mulch was significantly different based on the significant test on the 95% confidence interval compared to the inorganic reflective mulch treatment and control. Whereas in shaded conditions the use of reflectors is relatively able to increase the amount of soybean leaf chlorophyll. The high amount of relative leaf chlorophyll of soybeans on organic reflective mulch treatment is estimated due to the presence of mulch weathering which plays a role in improving soil physical and chemical properties by increasing nutrient uptake and the amount of leaf chlorophyll. This indicates that the use of organic reflective mulch will contribute significantly to yield and biomass in the cultivation of soybeans under oil palm stands.

Figure 5b presents the amount of soybean leaf chlorophyll using reflective mulch in several leaf positions. The use of reflectors can increase the amount of leaf chlorophyll in the upper, middle and lower leaves. Organic reflective mulch contributes the highest to the amount of chlorophyll in all leaf positions, followed by inorganic reflective mulch and without reflective mulch/control. This shows that the use of reflective mulch will increase the amount of soybean chlorophyll in the stands of oil

palm plantations. The amount of chlorophyll in soybean leaves besides being determined by the presence of shade is also influenced by the position of the leaves. In general, the position of the upper part of the leaf will have the highest amount of leaf chlorophyll, further decreasing in the position of leaves in the middle and lower leaves. The same thing was conveyed by [20] who observed leaf chlorophyll relative to the greenish index of leaves in three parts of the plant, namely the upper, middle and lower leaves, and it was known that the lower the leaf chlorophyll content diminished.

The high content of leaf chlorophyll will increase the ability of plants to meet solar energy needs to be converted into chemical energy [21]. The chlorophyll content is one of the parameters that play a role in supporting the efficiency of light capture of soybean plants which have implications for the production of biomass. Shaded plants will experience a decrease in the amount of chlorophyll in the leaves, and interfere with photosynthetic activity due to decreased mesophyll conductance [22-23].
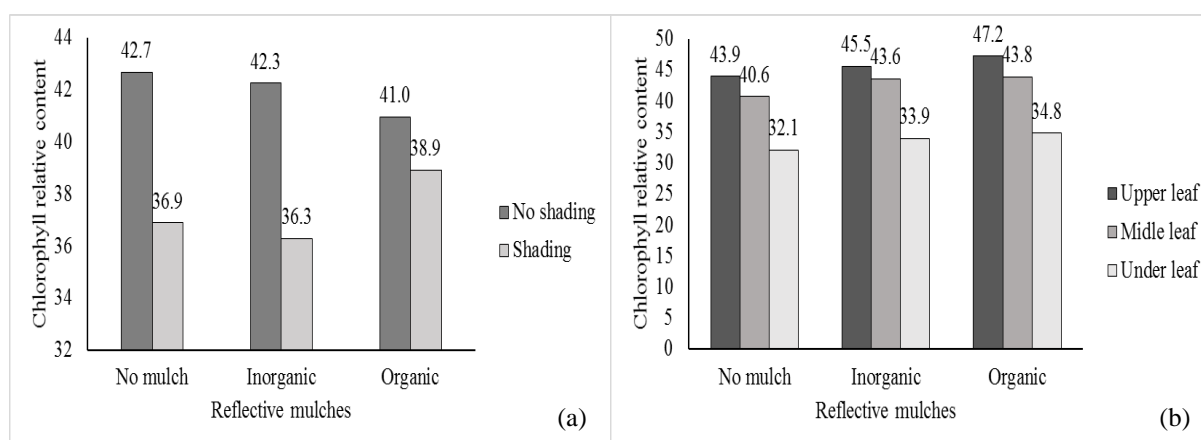

Figure 5. The amount of soybean chlorophyll in shaded and not shaded condition (a), the amount of soybean chlorophyll in several leaf positions (b). Upper leaf: leaves in the upper position of the canopy, middle leaf: leaves in the middle position of the canopy, and under leaf: leaves in the lower position of the canopy.

3.3 Productivity and quality of soybeans

The productivity and quality parameters analyzed in this study are the number of fill and empty pods, 100-grain seed weight and productivity per unit land area. The number of soybean fill pods on the land without mulch/control application is 16.03 pods, which is the lowest compared to the land that is applied inorganic reflective mulch (30.43 pods) and pods of organic reflective mulch (30.33). The application of inorganic or organic reflective mulch in soybean cultivation under oil palm plantation stands significantly increases the number of fill pods almost twice. The number of fill pods between soybeans that are applied inorganic and organic reflective mulch does not show any significant differences. The number of empty pods did not show a significant difference between control and land with the application of both reflective mulches (Table 1).

The weight of the 100-grain seed is one of the indicators of the soybean quality. The use of organic reflective mulch was able to produce the highest 100-grain seed weight which reached 16.57 g, inorganic reflective mulch reached 16.10 g and the lowest was control with 12.70 g. Based on a significant analysis of the test on the 95% confidence interval of 100-grain seed weights between organic and inorganic reflective mulch was not significantly different, but significantly different from the control. The use of reflective mulch can improve the quality of soybeans cultivated under oil palm plantation stands.

Table 1 presents the highest soybean productivity found in the application of organic reflective mulch which reached 2.29 ton ha^{-1}. This result was not significantly different from the production in inorganic reflective mulch application of 2.23 ton ha^{-1}, but it is significantly different from controls

which produced only 1.60 ton ha^{-1}. This shows that the use of reflective mulch contributes significantly to increase the productivity of soybeans under the stands of oil palm plantations. Plant shade can inhibit solar radiation that comes to the stands below, this causes the intercepted radiation to be reduced so that there is a decrease in forage production due to a decrease in the percentage of dry matter in plants [24]. Plants that lack light will experience a decline in physiological processes so that plant growth is not optimal and causes plant productivity to decline. In addition, the effect also has an impact on the chemical content present in plant productivity [25].

Table 1. The yield of soybeans under the oil palm canopy in several types of reflective mulch.

Yield variables	No reflective mulch	Inorganic reflective mulch	Organic reflective mulch
Number of fill pods	16.03a ± 1.17	30.43b ± 10.91	30.33b ± 10.87
Number of empty pods	0.89b ± 0.48	1.05b ± 0.57	0.44a ± 0.37
Weight of 100 grains (g)	12.70a ± 8.48	16.10b ± 1.64	16.57b ± 1.45
Production (ton ha^{-1})	1.60a ± 0.59	2.23b ± 1.42	2.29b ± 1.82

The letters in each row followed by the same letter showed no significant difference based on DMRT at $\alpha = 5$ %

4. Conclusion
The application of organic and inorganic reflective mulches increase interception of solar radiation of soybean and have positive effects on height, stem diameter, leaf area index, biomass, and radiation use efficiency. Organic reflective mulch increases the amount of relative soybean chlorophyll in shaded conditions and the amount of soybean chlorophyll in leaves in the upper, middle and lowers positions of the canopy. Organic and inorganic reflective mulches had significant effects on increasing the number of fill pods, the weight of 100 seeds, and production of soybean.

Acknowledgment

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