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# Response of sweet potato yield components to stakes angle and mulch type: Sweet potato cultivation in the Papua highlands

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# Response of sweet potato yield components to stakes angle and mulch type: Sweet potato cultivation in the Papua highlands

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**Abstract.** This study aims to improve the ability of sweet potato plants to obtain photosynthetic active radiation through a combination of stake angle with mulch as a reflector. The experiments were arranged in a separate plot design with three replications. The main plot consisted of Cangkuang variety with 90° stakes and Cangkuang varieties with 60° stakes. The subplots consisted of no mulch, straw mulch, white sand mulch, clear plastic mulch, and black silver plastic mulch. The results showed that the use of mulch as a reflector on both stake angle was able to increase photosynthesis active radiation by 27.84% to 34.63% compared to without mulch at 16.82%, and the optimum leaf area index at the age of 100 DAP was 3.74 to 4.45 at stake angle of 90° and 3.23 to 4.10 at stake angle of 60°. The number of tubers per plant increased and reached the highest of 3.17 and 4.50 in straw mulch, the number of marketable tubers from 51.90% to 59.23% compared to without mulch of 41.97% for stakes angle of 90° and 44.67% to 65.83% compared without mulch of 32.47% for stakes angle of 60°.

## 1. Introduction

Sweet potato (*Ipomoea batatas* L.) is one of the highest carbohydrate-producing tropical tuber crops and even sweet potato is an important food crop among 15 world food crops [1]. For the Papuan people, especially those living in upland agroecological zones, have traditionally managed sweet potato as the most important agricultural commodity. The importance of the sweet potato plant for the local community because of its role as the main food source where 90% of the people consume sweet potato but also as a source of animal feed, and it is used in traditional ritual events.

The problem with sweet potato in Papua in general is that productivity is still low compared to the potential yield. Sweet potato harvested area in Indonesia reaches 156.667 hectares with a productivity level of 15.2 ton/ha. The harvested area in Papua is 36.091 ha or 23.04% of the harvested area for sweet potatoes in Indonesia with a production of 446.925 ton and a productivity of 12.47 ton/ha [2]. These results can explain that the productivity of sweet potato in Papua is lower than the national average, while the potential for sweet potato production in Indonesia is 30-40 ton/ha.

The limiting factor for the low productivity of sweet potato in the highlands as a center for sweet potato production in Papua is the abiotic stress caused by low average temperatures so that the harvest is long and the lack of sunlight intensity as an energy source for the photosinesis process due to high levels of cloudiness. This is coupled with the genetic trait of the sweet potato plant which has a horizontal leaf morphology, allowing the leaves to shade each other so that only the top layer of the leaf gets full sun. Therefore, it requires the support of specific location cultivation technology, such as the use of adaptive superior varieties, the application of local wisdom such as the use of stakes and enriching solar radiation by using mulch as a reflector to maximize the intensity of solar radiation so as to produce sweet potato production according to its genetic potential.

Sweet potato production technology has been found, but sweet potato cultivation technology related to the use of varieties that are able to capture maximum solar radiation, but also the arrangement of leaf architects from horizontal to erect through the use of stakes and enriching solar radiation through the use of mulch as a reflector in the highlands yet been researched.

The combination of Cangkuang varieties (broad leaves) with a stake angle of 90° was able to increase sweet potato production by 45.3% compared to without using stakes, or from 10.17 to 31.53 t/ha [3]. This result is higher than the sweet potato production achieved by [4] for the Cangkuang variety of 13.28 t/ha. However, the use of mulch as a reflector for enrichment of sunlight in an effort to increase photosynthesis active radiation for sweet potato plants in the highlands has never been studied. The use mulch as reflector can improve photosynthetically active radiation (PAR) because the incoming solar radiation on the leaves will affect the distribution of chlorophyll [5,6]. This research is expected to provide a solution to the limiting factor for the lack of sunlight due to the high level of cloudiness in the Papua highlands. The aim of this study was to improve the ability of plants to obtain active photosynthetic radiation energy through a combination of stakes and mulch as a reflector. The indicators can be measured from the growth parameters and yield components.

## 2. Materials and methods

Field research in Wesakin village, Wouma district in Jayawijaya regency, Papua Indonesia, (138° 57 'E, 04° 04' S, 1550 m above sea level) during the growing season from November 2016 to April 2017. It was conducted on dry land with entisol soil type, sandy clay loam, soil pH 7.3, P-available 194 (ppm), K-available 60 (ppm) and *Cation Exchangable Cappacity* (CEC) 25.55 (me/100 g).

The materials used in this study are Cangkuang sweetpotato varieties, mulch as a reflector (straw mulch, white sand mulch, clear plastic mulch and silver black plastic mulch), wood stake with a length of 150 cm and nylon string and organic fertilizer (basic fertilizer). The tools used are: Lux meter, air temperature thermometer and soil temperature thermometer, pH tester, drying oven, shovel and sege (wooden tool to harvest sweet potato).

**Table 1**. Average of albedo (%) at two levels of stakes with five mulch type.

| Treatment | Mulch type | | | | |
|---|---|---|---|---|---|
| | Without mulch | Straw mulch | White sand mulch | Clear plastic mulch | Black silver plastic mulch |
| Stake of angle | | | (%) | | |
| 90° | 15.95 | 25.61 | 28.83 | 30.17 | 34.06 |
| 60° | 17.70 | 30.10 | 33.25 | 32.02 | 35.21 |
| Average | 16.82 | 27.84 | 31.04 | 31.10 | 34.63 |

The experiment used a split plot design with three replications so that there were 30 combinations of experimental units. The main plot consists of Cangkuang varieties with 90° stake angle ($a_1$) and Cangkuang varieties with 60° stake angle ($a_2$). The subplots consisted of without mulch ($m_1$), straw mulch ($m_2$), white sand mulch ($m_3$), clear plastic mulch ($m_4$) and black silver plastic mulch ($m_5$). Soil processing was carried out using a special shovel to cultivate the land; The plots were divided into three groups and each group was divided into two parts (main plots) and each section of the main plots is divided into individual plots of 5.25 m x 6.50 m plots. The distance between groups was 200 cm and the distance between plots was 100 cm, planting distance was 75 x 50 cm, one cutting was planted per hole in a single mound. Weeding was done on days 15, 45 and 80 after planting. Chemical fertilization and pest control were not carried out due to local government regulations prohibiting of the use of chemicals in agriculture. Observations were carried out destructively by taking two plant, not of edge plants as samples at 40, 70, 100 and 130 DAP. Sampling was done by harvesting using wooden sticks according to local residents' habits.

Observation variables were leaf are index (LAI), number of tubers per plant, marketable tuber and tuber yields (TY). The tubers number per plant was counted all tubers per plot then divided by the number of plants in the tuber; The marketable tuber was counted all economic tubers formed with the criteria of having a weight > 150 g/tuber; LAI were calculated using the [7] by formula:

$$LAI = \frac{Leaf\ area\ (LA)}{Ground\ area\ (GA)} \quad (1)$$

Note:
LA = The leaf area was measured using the punch method [8]
GA = The ground area covered by a canopy that can be assumed as the spacing

The total dry weight is calculated for each observation period by weighing the oven dry weight. Plant parts are separated into roots, stems, leaves and tubers, dried to a constant weight in an oven at 80°C. Fresh tuber yields are calculated at the time after harvesting by converting yields per plot to per hectare by the formula:

$$\frac{10.000\ m^2}{Area\ plot\ harvest}\ x\ \frac{tuber\ weight}{harvest\ plot\ x\ 0.90} \quad (2)$$

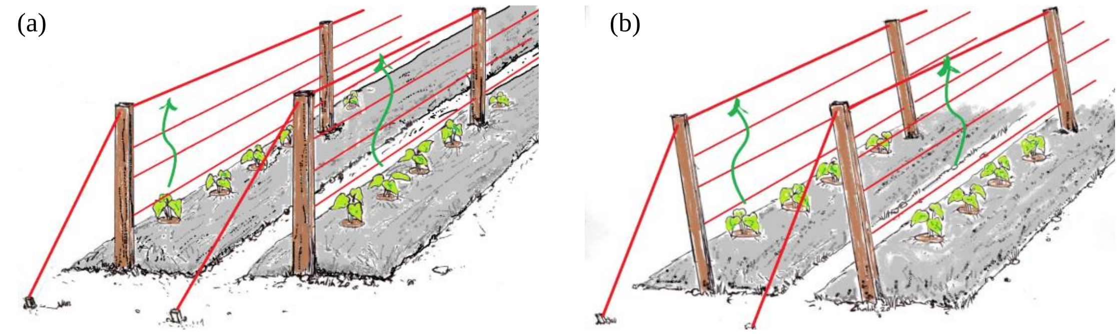


**Figure 1.** The treatments model for a 90° stake angle combination with mulch type (a) and 60° stake angle combination with mulch type (b).

Statistical analysis was performed using Analysis of Variance (ANOVA) at a 5% significant difference level. Differences between treatments were tested using the Least Significant Difference (LSD). Data were analyzed using the statistical program GenStat 18th edition by *Brawijaya University, Indonesian* and Microsoft Office Excel program 2010.

## 3. Results and Discussion

### *3.1. Leaf area index*

Based on the results of the analysis of variance, it showed that the optimum leaf area index, namely the age of 100 DAP, was significantly influenced by the interaction between the stake angle with mulch type ($p<0.05$). The average interaction between the slope level of the stakes and the kinds of mulch on the leaf area index is shown in Table 2. The treatment of stakes of 90° for the variety of mulch showed that the leaf area index was higher in the silver black plastic mulch treatment, but it was not significantly different from the leaf area index value in white sand mulch treatment. The results of this study also showed that the leaf area index value was lower in the straw mulch treatment and was significantly lower than the white sand mulch and clear plastic mulch treatment but was not significantly different from the treatment without mulch.

**Table 2**. The average optimum leaf area index in different stick angles with reflector types at plant age 100 DAP.

| | Treatment | Reflector type | | | | |
|---|---|---|---|---|---|---|
| | | Without mulch | Straw mulch | White sand mulch | Clear plastic mulch | Black silver plastic mulch |
| 100 dap | Stake angle of 90° | 3.10 ab | 2.85 a | 3.99 bc | 3.74 b | 4.45 c |
| | Stake angle of 60° | 2.03 a | 2.65 ab | 3.23 b | 3.86 bc | 4.10 c |
| | **LSD 5%** | **0.66** | | | | |

Note: Numbers accompanied by the same lowercase letters in the same row show no significant difference in LSD test 5%; dap: days after planting.

Furthermore, for the 60° stake angle treatment, a higher leaf area index was obtained in the black silver plastic mulch treatment, but it was not significantly different from the clear plastic mulch treatment. The results of this study showed that the lower leaf area index value was obtained in the treatment without mulch, significantly lower than the treatment of white sand mulch and clear plastic mulch but not significantly different from the straw mulch treatment.

The average increase in leaf area index for the 90° stake angle and the 60° stake angle was influenced by the use of mulch as a reflector compared to without using mulch, except for the straw mulch treatment. The use of silver black plastic mulch, clear plastic mulch and white sand mulch has a tendency to increase the leaf area index higher, namely 3.99 - 4.45 at a 90° stake angle and 3.23 - 4.10 at a 60° stake angle (Table 2). The high leaf area index value in the three mulch treatments was thought to be influenced by the increase in temperature around the plants due to the reflection from the three types of mulch. This result was proven by measuring the reflection of solar radiation around the plants which produced 31.06% for white sand mulch, 31.10% for clear plastic mulch and 34% for black silver plastic mulch treatment. While the increase in the results of measurement of the average reflection of solar radiation around the plants in the straw mulch treatment was only 27.84% and without mulch was 16.82% (Table 1). If there is an increase in air temperature around the sweet potato plant, it will stimulate an increase in crown growth which affects the increase in the leaf area index [9]. Likewise, the optimum leaf area index variation is determined by the amount of sunlight reaching the plant. In full sun, the optimum LAI can reach seven, at 60% full sun, the optimum is five and at 23% full sun, the optimum is only 1.5 [9].

### *3.2. Tubers number per plant*

Based on the analysis of variance, it showed that the number of tubers per plant at harvest was determined by the interaction between the slope of the stake and the variety of mulch ($p < 0.05$). The average number of tubers per plant at harvest due to the interaction between the level of stakes and the variety of mulch is shown in Table 3.

Table 3 shows that in the 90° stake angle treatment, the number of tubers per plant produced in the straw mulch treatment was significantly more than the treatment without mulch, but was not significantly different from the treatment of white sand mulch, clear plastic mulch and black silver plastic mulch. Meanwhile, for the 60° stake angle treatment, the number of tubers per plant produced in the straw mulch was significantly more than the other four treatments. The results of this study also indicated that the black and silver plastic mulch treatment, although it produced the number of tubers per plant, was not significantly different from the white sand mulch treatment, but it was significantly higher than the treatment without mulch and clear plastic mulch.

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**Table 3**. Average number of tubers per plant due to the interaction between stakes and type of mulch at the harvest age of 150 DAP.

| | Mulch type | | | | |
|---|---|---|---|---|---|
| Treatment | Without mulch | Straw mulch | White sand mulch | Clear plastic mulch | Black silver plastic mulch |
| Stake angle of 90° | 2.20 a | 3.17 b | 2.93 ab | 2.77 ab | 2.67 ab |
| Stake angle of 60° | 2.07 a | 4.50 c | 2.30 ab | 2.07 a | 2.87 b |
| **LSD 5%** | **0.75** | | | | |

Note: Numbers accompanied by the same lowercase letters in the same row show no significant difference in LSD test 5%; dap: days after planting.

The tubers number is the initial component formed in the initiation of the yield component of the sweet potato plant. After the number of tubers is formed, it is followed by cell division and enlargement which determines the sustainability of the tuber weight. The number of tubers and tuber weight are related to the available growing space for tuber growth and development.

The interaction between stake angle and mulch type affects the number of tubers per plant in the highlands of Papua. This can be seen in the treatment of straw mulch at a stake angle of 60°, resulting in 4.50 tubers per plant, significantly more than the other four treatments (Table 3). Soil temperature at a depth of 30 cm is one of the factors that plays an important role in determining the number and weight of tubers. Low temperature conditions during the day and optimum humidity due to indirect solar radiation on the soil surface and increased physical and chemical fertility of the soil due to straw which undergoes a decomposition process and maintains soil aggregation from the kinetic energy of rainwater which is thought to be a factor in causing the number of tubers per plant. If the soil moisture is optimal, $O_2$ will be available in the soil and carbon allocation will run smoothly so that tuber formation and plant growth will increase [10]. The results of measuring the soil temperature at the age of 100 DAP and 130 DAP, which are the ages at which the tubers have been formed, show that the average soil temperature is 22.5°C and therefore low temperatures can reduce high photorespiration during the day. Soil temperature between 20-30°C is the ideal temperature for tuber formation compared to temperatures above 30°C which is more influencing on increased shoot growth than tuber growth (roots) [11].

### *3.3. Tuber yield per plot*

The analysis of variance showed that there was no interaction between the stake angle with mulch as a reflector on the yield of tubers per plot, but the stake inclination angle and the type of mulch significantly affected the yield of tubers per plot. The average tuber yield per plot due to the influence of the stake angle and the mulch type is shown in Table 4.

The results of this study indicated that the sweet potato yield tubers significantly increased following to the mulch type used and reached the highest in the silver black plastic mulch treatment, namely 108.98 kg/plot (Table 4). It was different when the stake angle was increased from 60° to 90°, it actually decreased the tuber yield even though the two treatments were not significantly different. The use of mulch as a reflector was able to increase tuber yield per plot by 9.01% (21.32 t/ha in straw mulch, 15.74% (23.02 t/ha) in white sand mulch, 24.75% (25.78 t/ha) in clear plastic mulch and 29.89% (27.67 t/ha) in black silver plastic mulch compared without mulch. These results indicate that the use of mulch as a reflector can increase photosynthesis active radiation (PAR), which can be intercepted by plants, thereby affecting the increase in photosynthetic yield to be stored in tuber storage organs. This result is evidenced by the high albedo produced in various types of mulch compared without mulch (Table 1). The use of mulch apart from being a reflector, also functions to suppress water loss through evaporation so that it can increase soil moisture which affects root growth and is thought to have a significant impact on tuber development [12]. The use of black silver plastic mulch affects the height of the reflection of solar radiation that can be intercepted by plants and the effect of reflection in addition to causing the soil temperature to be lower so that there is an increase in root activity in the soil to absorb nutrients, it also decreases the rate of respiration and these two factors cause an increase in sweet potato production [13].

**Table 4**. The average tuber yield (kg/plot) in the different stake angles and five reflector types at the harvest age of 150 DAP.

| Treatment | Average tuber yield (kg/plot) |
|---|---|
| ***Stick inclination angle*** | |
| Stake angle of 90° | 87.40 a |
| Stake angle of 60° | 97.22 a |
| **LSD 5%** | **12.71** |
| ***Reflector type*** | |
| Without mulch | 76.40 a |
| Straw mulch | 83.97 b |
| White sand mulch | 90.67 c |
| Clear plastic mulch | 101.53 d |
| Black silver plastic mulch | 108.98 e |
| **LSD 5%** | **4.60** |

Note: Numbers accompanied by the same letter at the same age and treatment show no significant difference in LSD test 5%. dap: days after planting.

### *3.4. Marketable tuber*

The results of the analysis of variety showed that there was an interaction between the stake angle and mulch type on the marketable tuber. The average marketable tuber due to the interaction between stakes and the use of mulch is shown in Table 5. Table 5 shows that at an inclination of 90°, the proportion economic tubers number was higher in the white sand mulch, clear plastic mulch and black silver plastic mulch compared to the without mulch treatment, however the three mulch treatments were not significantly different. The results of this study also showed that the control treatment, although it produced the marketable tuber ratio was significantly lower than the treatment of white sand mulch to silver black plastic mulch, it was not significantly different from the straw mulch treatment. Whereas for the 60° stake angle treatment, the higher number of tubers that could be marketed was obtained in the clear plastic mulch and black silver plastic mulch treatment, however, the two treatments were not significantly different. The number of marketable tuber in the straw mulch and white sand mulch treatment, although significantly lower than the clear plastic mulch and black silver plastic mulch treatment, both treatments were significantly higher than the without mulch treatment.

**Table 5**. Average ratio of marketable tuber due to the interaction between the stake angle and mulch type as reflector at the harvest age of 150 DAP.

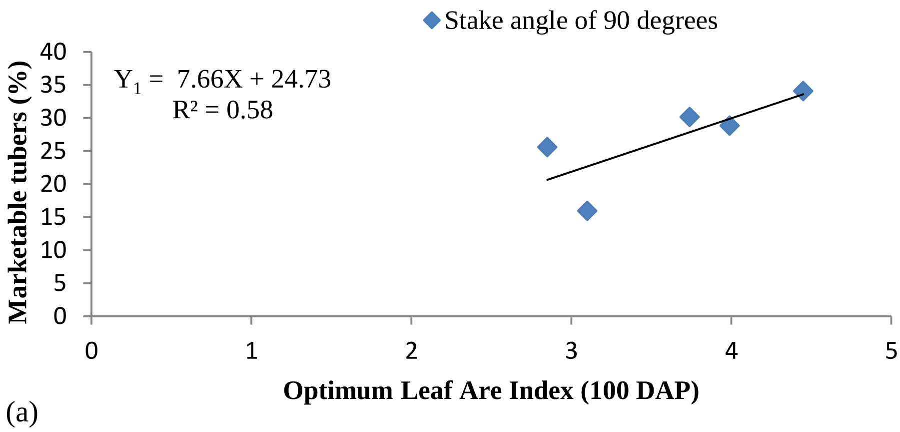
| | Mulch Type | | | | |
|---|---|---|---|---|---|
| | Without mulch | Straw mulch | White sand mulch | Clear plastic mulch | Black silver plastic mulch |
| Treatment | | | (%) | | |
| Stake angle of 90° | 41.97 a | 51.90 ab | 56.47 b | 53.00 b | 59.23 b |
| Stake angle of 60° | 32.47 a | 44.67 b | 46.03 b | 65.83 c | 57.63 c |
| **LSD 5%** | **10.09** | | | | |

Note: Numbers accompanied by the same lowercase letters in the same row show no significant difference in LSD test 5%; dap: days after planting.

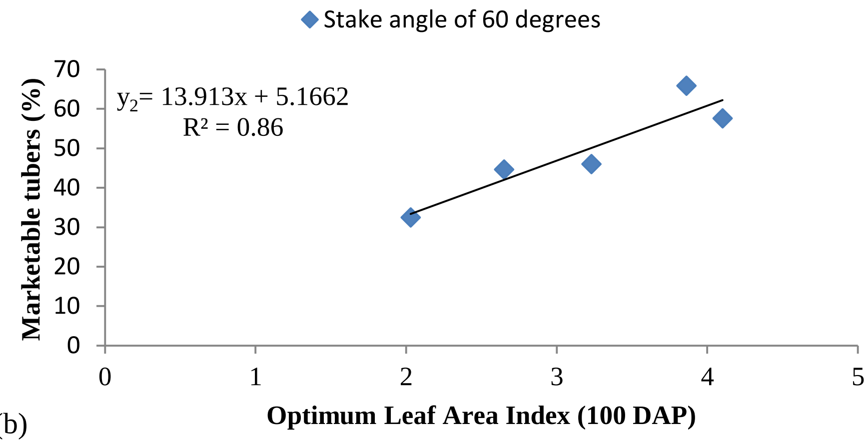
The results of this study indicate that the use of mulch as a reflector is able to increase the proportion of tubers that can be marketed compared to without using mulch both at an inclination of 90° and a stake of 60°. This means that the use of mulch as a reflector is able to produce a larger percentage of large tubers than without using mulch. The treatment of clear plastic mulch and silver black plastic mulch at a stake angle of 60° and treatment of white sand mulch, clear plastic mulch and black silver plastic mulch at a 60° stake angle were able to increase the proportion of tubers that could be marketed higher. This result is related to the ability of each mulch to reflect sunlight and then intercepted by the plant canopy. Thus it can be explained that clear plastic mulch and black silver plastic mulch at a stake angle of 60° and white sand mulch, clear plastic mulch and black silver plastic mulch at a 90° stake angle were more efficient in utilizing the intensity of solar radiation through the reflection process compared to other treatments. The indicator is that the treatment can increase the capacity of plants to store photosynthetic products in tubers. This can be proven by the average ability of the three types of mulch to reflect sunlight from 31.04 to 34.63% compared to without mulch and straw mulch which was only 16.82 to 27.84% (Table 1). The high capacity of tubers to store photosynthate could be measured by the number of large tubers per plant for each type of agroecology [14]. The use of mulch on sweet potato plants caused an increase in the marketable tuber ratio by 38.24% and tuber yield by 38.23% compared without mulch [15] and then plastic mulch can increase water use efficiency by 25% to 30%, increase leaf area, photosynthesis, root dry matter and produce for fruit yields by 36% and root yield 20-30% [15,16].

### *3.5. The relationship between leaf area index and marketable tubers*

Sweet potato plants were C3 plants that have more stomata on the lower leaf surface than on the upper leaf surface, so that the leaves more efficiently use the light obtained from reflected mulch as an energy source for photosynthesis. The results of the correlation analysis showed that the increase in the maximum leaf area index due to the influence of the interaction of stakes and mulch as reflectors had a significant effect on the increase in the marketable tuber number with correlation coefficient value (r = 0.76*). Furthermore, based on the results of regression analysis, it shows that the increase in the leaf area index greatly affects the increase in the number of tubers that can be marketed with the following equation model: $Y_1$ = 24.73X + 7.66, $R^2$ = 0.58 for a 90° stake angle (Figure 2a) and $Y_2$ = 5.17 X + 13.91, $R^2$ = 0.86 for stake angle of 60° (2b).




(a)




(b)

**Figure 2**. The relationship between leaf area index with marketable tubers at combination of mulch with stake angle of 90° (a) and a stake of 60° (b).

This equation model can explain about 58 percent of the relationship between the leaf area index and the marketable tuber at the 90° stake angle treatment and about 86 percent can explain the relationship between the leaf area index and the marketable tuber number in the 60° stake angle treatment with various types of mulch. Figure 2 proves that the increase in leaf area expressed through the leaf area index causes more solar radiation that can be intercepted by plants, which is then converted through photosynthesis into biomass in the form of dry matter stored in tubers. Thus it can be explained that an increase in one unit of leaf area index causes an increase in the marketable tubers by 7.66% at a stake angle of 90° and an increase in one unit in the leaf area index causes an increase in the marketable tubers by 13.91% at a 60° stake angle. The leaf area index value reflects the level of surface potential that is used for the photosynthesis process. The higher the leaf area index of a plant, the higher the potential for producing photosynthate. The use of organic and inorganic mulch as a reflector for soybean plants under the shade of oil palm can increase the leaf area index value, causing increased interception of solar radiation and the ability of plants to convert solar energy into biomass through energy conversion efficiency (RUE) [5].

The sweet potato plant (*Ipomoea batatas* L.) had a higher stomatal density in the lower epidermis than other root crops such as taro (*Colocasia esculenta)* and other small tuber crops, therefore sweet potato was not resistant to shade [17]. Thus it can be explained that the use of mulch as a reflector combined with a stake angle can increase the value of the leaf area index which causes plants to absorb solar radiation efficiently so that the photosynthetic rate increases which in turn increases the plant photosynthate yield and is distributed to the tubers. Therefore, the treatment of using mulch as a reflector resulted in a higher proportion of large tubers than without using mulch on all stakes (Table 4). The low intensity of solar radiation results in reduced chlorophyll content of leaves and further reduces the rate of photosynthesis which has an impact on the results of photosynthate in the storage organs [9]. This can be seen in the number of tubers that can be marketed, which is relatively low in the treatment that does not use mulch, not only at an stake inclination angle of 90° but also stake angle of 60°.

## 4. Conclusion

Contribution of various types of mulch as a reflector to photosynthesis active radiation which can be intercepted by plant canopy is 27.84% for straw mulch, 31.04% for white sand mulch, 31.10% for clear plastic mulch and 34.63% for black silver plastic mulch compared without mulch of 16.82%. The use of straw mulch and clear plastic mulch and silver black plastic mulch at a stake angle 60° is more efficient in utilizing solar radiation energy than without mulch, when viewed from the number of

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tubers per plant as much as 4.50 and the marketable tuber of 57.63 - 65.83%. The use of straw mulch, white sand mulch, clear plastic mulch and black silver plastic mulch is more efficient in utilizing solar radiation than without mulch when seen from tubers yield per plot which increased from 9.01% to 29.89%.

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## Declarations

Contribution: In this article, Alberth Soplanit acts as the main contributor and Merlin K Rumbarar acts as a member contributor.