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Growth, yield and radiation energy conversion of sweet potato (*Ipomoea batatas* (L.) lam.) plant under different stake angles and various mulch type in the Papua highlands

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Abstract. *The aim of this study was to obtain the right type of reflector in sweet potato plant cultivation combined with a stake technique to increase the efficient use of solar radiation energy and plant productivity. The experiment was arranged in a Split Plot Design with three replications. The main plot consisted of Cangkuang variety with 90° stake and Cangkuang variety with 60° stake. The subplots consisted of without mulch, straw mulch, white sand mulch, clear plastic mulch and silver black plastic mulch. The results show that the total dry weight continues to increase but then slows down when the crop growth rate decreases especially at the tuber development phase. The total dry weight at the silver black plastic mulch treatment with a 60° stake angle increased by 70.13% at the age of 70 to 100 days after planting and only increased by 17.50 % at the age of 100 to 130 days after planting. The conversion efficiency of radiation energy increases for all mulch uses as a reflector, especially for 60° stake angles of 32.03% at the highest tuber yields 34.15 t/ha while for 90° stake angles of 27.35% at the highest tuber yields 29.72 t/ha. The highest energy conversion efficiency value was obtained in the combination of black and silver mulch with a 60° stake angle at 2.81%.*

1. Introduction

Sweet potato (*Ipomoea batatas* (L.) Lam.) is one type of plant that has a high agronomic ability and this is indicated by the large number of leaves produced on this plant. However, the high number of leaves is not always proportional to the results of dry matter and tubers. The limiting factor, namely biotic shade due to overlapping plant leaves, plus abiotic stress due to high cloudiness in the Baliem Valley, is thought to be the cause of the low yield of sweet potato in the highlands of Papua. Based on the 2019 Papua statistical report, the average sweet potato production at the farmer level is 14.6 t/ha, while the potential for sweet potato production based on the report of the Indonesian Research Institute for legumes and tubers is 30-40 t/ha. The low production of sweet potatoes is thought to be related to the low energy conversion value of solar radiation because in agricultural cultivation practice energy conversion efficiency is closely related to plant productivity [3].

The efficiency of solar energy conversion can also be referred to as the Efficiency of Radiation Use, which is the ratio of the production of phytomas or plant dry weight per unit of energy intercepted or captured by plant leaves [10]. The maximum energy conversion efficiency (EC) that can be achieved by C_3 plants is around 4.6% and can reach 9.4% [21]. The highest energy conversion efficiency for sweet potato at 3.50% [19], while the highest EC of sweet potato ever produced was in the Papua highlands at 2.06% [16]. The low production of sweet potato in the Papua highlands is thought to be due to the low energy of solar radiation that can be captured by the plant canopy due to the nature of the mountain tropical climate which is characterized by a high level of cloudiness, then improper cultivation systems such as the use of varieties that do not pay attention to plant morphological characters that are responsive to local climatic conditions cause low conversion of solar radiation to dry matter [2]. Although the Baliem valley is a relatively fertile area, generally the sweet potato that grows there has a spreading character and dense biomass so that there is a mutual shade between the leaves and only the upper leaves get enough solar energy while the lower leaf layer gets less light for the process photosynthesis. Therefore a number of environmental modifications are needed so that plants can more efficiently use solar radiation energy for the photosynthesis process so that there is an increase in the conversion of solar radiation into dry matter and more photosynthate products are distributed to the storage organs, namely tubers.

Therefore the distribution of leaves in sweet potato plants plays an important role because it determines the level of sunlight interception [5]. In plants with high leaf angles, which are characterized by vertical leaf shapes, light can be distributed more evenly throughout the leaf sheets at each layer of the canopy, so that the plant is more efficient at utilizing light [7, 15]. Environmental engineering of sweet potatoes is expected to be able to overcome the lack of sunlight intensity and low duration of radiation in the highlands because it is based on the fact that sweet potato is a plant that likes sunlight or if there is shade it will reduce yield [8, 16].

The results of research in the Papua highlands, on Cangkuang variety of sweet potato plants with broad leaf morphology combined with a stake angle of 60° to 90° resulted in sweet potato production of 28.80 - 31.5 t/ha [15]. These results indicate that plant environmental engineering techniques have succeeded in optimizing the intensity of low sunlight so as to increase sweet potato yield. This result is much higher than the average farmer's production, however, this result has not yet reached its production potential. Therefore, a combination of technology using stakes and mulch as a reflector needs to be tried in connection with light enrichment from reflected mulch so that it is hoped that a lot of sunlight can be intercepted by plant canopies for the photosynthesis process. The purpose of this study was to obtain the efficient use of solar radiation energy on sweet potato plants in the highlands of Papua by using a combination of stakes and mulch as a reflector. Efficiency indicators can be obtained on the parameters of total dry weight, tuber yield and solar radiation energy conversion.

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 sweet potato varieties, mulch as a reflector (straw mulch, white sand, clear plastic mulch and silver black plastic mulch), wood stakes 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).

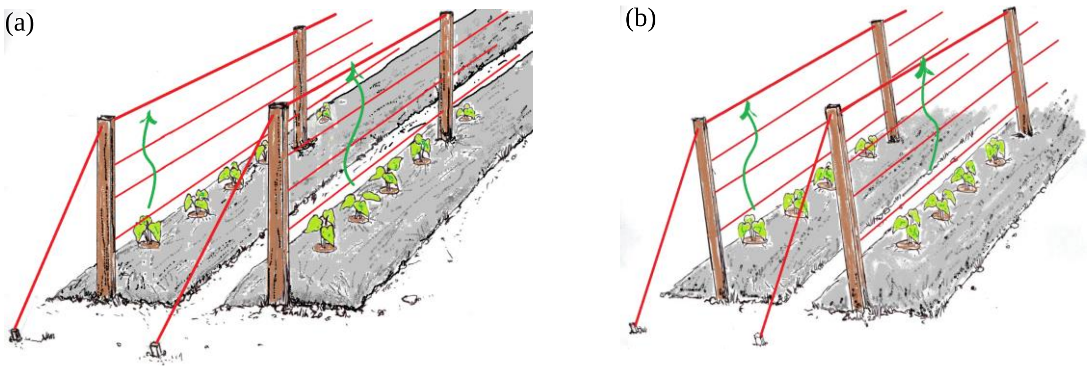

Figure 1. The treatment model for a 90° stake angle combination with mulch type (a) and 60° stake angle combination with mulch type (b).

The experiment used a split-plot design with three replications. 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 plants, not of edge plants as samples at 40, 70, 100 and 130 day after planting (DAP). Sampling was done by harvesting using wooden sticks according to local residents' habits.

Observation variables were crop growth rate (CGR), total dry weight (TDW), tuber yield (TY) and energy conversion efficiency (EC). CGR was calculated using the Evans (1972) [4] and EC were calculated using the Sugito (2012) [12] by the formula:

$$EC = \frac{\Delta W.k}{\mathrm{I.t.PAR}}\ x\ 100\% \qquad (1)$$

Note:
ΔW = Different in total dry weight (g) per m^2 in time period (t)
k = Coefficient of combustion heat (4.000 $cal.g^{-1}$)
I = Daily solar radiation intensity (cal m^2 day^{-1})
T = Specified time period (days)
PAR = Photosynthetic Active Radiation (0.45)

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:

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

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. Crop growth rate (CGR)

The average crop growth rate due to the interaction between the stick angle treatment and the kinds of reflectors is shown in Table 1, while the plant growth rate due to the influence of the stick angle treatment and the kinds of reflectors is presented in Table 2. The results of the analysis of variance show the interaction and the real effect on the stick angle treatment with a variety of mulch on plant growth rate. The crop growth rate variable (CGR) is useful for knowing the speed of plant growth at a certain period during growth. The rate of plant growth is strongly influenced by changes in environmental factors. The value of the plant growth rate increased in the observation period 40-70 DAP to 70-100 DAP, then slows down and tends to decrease when it reaches the 100-130 DAP period (Table 1 and Table 2), while biomass production and tuber growth based on indicators of dry matter weight continue increases with the age of the plant. Although the increase in total dry weight continues to increase but has slowed due to the declining plant growth rate. This can be seen in the stake angle treatment of 60° with the use of silver black plastic mulch for the observation age of 70-100 DAP, Total dry weight (TW) shows an increase from 90.5 g to 301.50 g plant^{-1} or an increase of 70.1%, but at age Observation of 100-130 DAP, TW showed an increase from 301.50 g plant^{-1} to 365.40 g plant^{-1} or experienced an increase of only 17.5% (Table 1).

The decrease in plant growth rate in the observation period 100-130 DAP was due to the declining leaf area index due to the unbalanced leaf fall with new growing leaves. Sweet potato plants will experience a slowing growth rate after the age of 16 weeks due to the high number of leaves that experience senescence due to the death of several main branches and lateral branches [17, 18].

The results showed that the use of silver black plastic mulch reflector during the observation period of 40-70 DAP resulted in a plant growth rate of 2.79 g m^{-1} day^{-1} compared to without using a mulch of 1.72 g m^{-2} day^{-1}. Likewise, in the observation period of 100-130 DAP, the plant growth rate was 3.64 g m^{-2} day^{-1} for black silver plastic mulch and 3.30 g m^{-2} day^{-1} for clear plastic mulch, while without using mulch of 1.91 g m^{-2} days^{-1}. These results indicate that the plant growth rate in the 70-100 DAP observation period is more influenced by the interaction between mulch and stake angle, as seen in the value of plant growth in the silver black plastic mulch treatment with a stake angle of 60° of 6.78 g m^{-2} days^{-1} compared without using mulch of 2.08 g m^{-2} day^{-1}. The increase in plant growth rate in the silver black plastic mulch treatment with a stake angle of 60° indicates that the radiation that falls to the surface can be reflected back to the plant so that the right angle of inclination of the leaves allows the intensity of solar radiation captured through the stomata to increase. Furthermore, the results of this study also show that the plant growth rate increases with the development of plant age and reaches the highest at the age of 70-100 DAP and decreases until it reaches the harvest phase.

Table 1. The average crop growth rate (g m^{-2} day^{-1}) in different stick angles with various reflector types at plant age 70-100 DAP.

Treatment	Reflector type				
	Without mulch	Straw mulch	White sand mulch	Clear plastic mulch	Black silver plastic mulch
Stake angle of 90°	2.93 a	4.44 b	4.53 b	4.52 b	4.62 b
Stake angle of 60°	2.08 a	4.57 b	4.93 b	5.39 b	6.78 c
LSD 5%	**0.96**				

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

Table 2. The average crop growth rate (CGR) in the different stake angles and five reflector types for the two observation periods.

Treatment	Average crop growt rate (CGR) (g m^2 day^{-1}) in the observation period (40-70 and 100-130 DAP)	
	40 – 70	100-130
Stick inclination angle		
Stake angle of 90°	1.90	2.27
Stake angle of 60°	2.32	2.95
LSD 5%	**ns**	**ns**
Reflector type		
Without mulch	1.72 a	1.91 ab
Straw mulch	1.76 a	1.39 a
White sand mulch	1.93 a	2.79 bc
Clear plastic mulch	2.33 b	3.30 c
Black silver plastic mulch	2.79 c	3.64 c
LSD 5%	**0.25**	**0.97**

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

3.2. *Total dry weight (TDW)*

The results of the analysis of variance showed that there was an interaction between the stick angle and the kinds of reflectors on the total dry weight of the plant, except at the age of 70 DAP. The mean total dry weight of plants (TDW) due to the interaction between the stick and the kinds of reflectors is shown in Table 3, while the total dry weight of plants due to the influence of the stick and the kinds of reflectors is shown in Table 4.

Table 3. The average total dry weight (g $plant^{-1}$) in different stake angles with various reflector types at plant age 40-100-130 DAP.

Treatment		Reflector type				
		Without mulch	Straw mulch	White sand mulch	Clear plastic mulch	Black silver plastic mulch
40 DAP	Stake angle of 90°	9.09 c	7.27 b	9.78 c	6.15 a	5.38 a
	Stake angle of 60°	6.34 a	7.39 b	5.93 a	8.89 c	6.83 ab
	LSD 5%	**0.95**				
100 DAP	Stake angle of 90°	143.15 a	181.40 b	197.85 b	211.90 b	220.80 b
	Stake angle of 60°	129.20 a	207.60 b	218.00 bc	240.70 c	301.50 d
	LSD 5%	**32.71**				
130 DAP	Stake angle of 90°	192.35 a	208.04 a	261.80 b	303.00 c	325.61 c
	Stake angle of 60°	194.60 a	260.54 b	321.70 c	347.83 d	365.40 d
	LSD 5%	**23.31**				

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

The total plant dry weight (TDW) is the result of the accumulation of carbohydrates in plant tissue as a product of the photosynthesis process. The value of the total dry weight of the plant describes the amount of plant production to store photosynthetic products. The results of this study indicate that there is an interaction between the slope of the stake and various kinds of mulch as a reflector, especially at the age of 40, 100, and 130 DAP. At the beginning of growth, there was no significant difference at TDW between treatment without mulching and using mulch at various stakes. However, at the age of 100 to 130 DAP, it was seen that the treatment of black silver plastic mulch and clear plastic mulch at a 60° angle was able to increase the TDW by 365.40 g plant^{-1} and 347.83 g plant^{-1} compared to treatment without mulch on the stakes angle of 60° which only yielded 194.60 g plant^{-1}.

Table 4. The average total dry weight (g plant^{-1}) in the different stake angles and five reflector types at plant age 70 DAP.

Treatment	Average total dry weight (g plant^{-1}) at plant age 70 DAP
Stick inclination angle	
Stake angle of 90°	64.65 a
Stake angle of 60°	76.74 b
LSD 5%	**4.00**
Reflector type	
Without mulch	60.78 a
Staw mulch	59.19 a
White sand mulch	65.81 a
Clear plastic mulch	77.63 b
Black silver plastic mulch	90.05 c
LSD 5%	**3.16**

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

Whereas the results of TDW at 70 DAP showed that black silver plastic mulch was able to increase of TDW by 90.05 g plant^{-1} compared to 60.78 g plant^{-1} in the treatment without mulch or silver black plastic mulch treatment was able to increase of TDW by 32.5% compared without using mulch. The results of this study illustrate that in conditions of low solar radiation intensity in the Baliem valley in the highlands of Papua, the use of silver black plastic mulch reflectors and clear plastic mulch at a stake angle of 60° can increase the intensity of solar radiation that can be intercepted by plant leaf surfaces compared to without using mulch. The use of a kind of reflector was able to increase the total dry weight at a 90° stake angle nor a 60° stake angle.

3.3. Tuber yield (TY)

The analysis of variance showed that there was an interaction between the slope of the stake and the kinds of reflectors on the yield of tubers at harvest. The average tubers yield due to the interaction between the stakes and the kinds of reflectors are presented in Table 5.

The results showed that the average stick angle treatment with mulch application can improve the tuber yield per ha compared without using mulch. Treatment of 60° stake angle and silver black plastic mulch was able to increase tuber yield from 22.75 t/ ha to 34.15 t/ha or an increase of 33.4%. Whereas in the 90° stake angle treatment and clear plastic mulch and black silver plastic mulch were able to increase the tuber yield from 21.73 t/ha to 28.43 and 29.72 t/ha (Table 5). The results of both two mulch treatments were not significantly different, but when compared, the use of clear plastic mulch was more efficient than black silver plastic mulch. This is evidenced by the results of the farm analysis which showed the R/C ratio for clear plastic mulch was 2.7 while the use of black and silver plastic mulch resulted in an R/C ratio of only 2.2 (data not shown). This difference is due to the price of black silver plastic mulch which is relatively more expensive than clear plastic mulch. The tuber yield produced in the treatment of black silver plastic mulch with a 60° stake angle showed that the silver color which reflected the higher rays, plus the 60° angle position caused the intensity of solar radiation intercepted by plants not only from the top of the leaves but also from the lower leaves then accumulate, causing the rate of photosynthesis to increase high.

The silver color of the mulch is thought to reflect sunlight (*albedo*) so that it reduces evaporation of groundwater and the black color will inhibit weed growth and maintain soil moisture. Thus, the use of mulch, especially black silver plastic mulch, in addition to functioning as a reflector but also prevents the leaching of nutrients by the kinetic energy of rainwater and the evaporation of nutrients caused by direct sunlight can also be prevented. Therefore, the use of silver black plastic mulch can improve the interception ability of solar radiation by plants, because higher solar radiation reflection causes lower soil temperatures. This can be used to increase root activity to absorb nutrients in the soil and reduce the rate of respiration, thereby increasing the yield of sweet potato [20]. Furthermore, the increase in the intensity of sunlight that can be intercepted by the leaves is directly proportional to the rate of photosynthesis. Most of the photosynthetic active radiation (*PAR*) that can be intercepted by plants will increase the rate of photosynthesis so that it will affect the increase in plant growth rate and the process of tuber formation [9].

Table 5. Average tuber yield (t/ha) at different stake angles with reflector types at age of harvest 150 DAP.

	Reflector type				
Treatment	Without mulch	Straw mulch	White sand mulch	Clear plastic mulch	Black silver plastic mulch
Stake angle of 90°	21.73 a	23.36 b	24.62 b	28.43 c	29.72 c
Stake angle of 60°	22.75 a	25.85 b	28.52 c	31.07 d	34.15 e
LSD 5%	**1.29**				

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

High sweet potato production is also supported by good soil fertility, as evidenced by the high to very high K-available and P-available elements and high Cation Exchangeable Capacity (CEC) and neutral soil pH values. If the availability of water and nutrients is sufficient, the use of efficient solar radiation by the canopy will be determined by the interception of sunlight by the canopy and the distribution pattern of sunlight in the canopy [13].

3.4. Energy conversion efficiency (EC)

The results of the analysis of variance showed that there was no interaction between the stake angle and the application of mulch as a reflector against the interception of solar radiation. However, there is an interaction between the stake angle and the type of reflector on energy conversion efficiency (EC). The average EC value due to the interaction between the stake angle and the reflector type is shown in Table 6.

Table 6. The average energy conversion efficiency (%) in different stake angle with various reflector types at the plant age 130 DAP.

Treatment	Reflector type				
	Without mulch	Straw mulch	White sand mulch	Clear plastic mulch	Black silver plastic mulch
Stake angle of 90°	1.78 a	1.92 b	2.02 b	2.34 c	2.45 c
Stake angle of 60°	1.91 a	2.12 b	2.35 c	2.55 d	2.81 e
LSD 5%	**0.11**				

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

Sweet potato is planted in high altitude climatic conditions with an average intensity of solar radiation of 109.8 cal cm^{-2} $days^{-1}$. The use of Cangkuang variety at a stake angle of 60° and when given mulch as a reflector can increase the EC value from 1.91% to 2.12% in straw mulch, 2.35% in white sand mulch, 2.55% in clear plastic mulch and reached the highest value of 2.81% in black silver plastic mulch.

Meanwhile, when the stakes were increased to 90° and mulched as a reflector, it turned out that the EC value was increased from 1.78% to 1.92% for straw mulch, 2.02% for white sand mulch, 2.34% for clear plastic mulch and 2.45% on silver black plastic mulch. However, between the straw and white sand mulch and clear plastic mulch and black silver plastic mulch, the EC values were not significantly different. The results showed that EC increased for each type of reflector, especially at a stake angle of 60° during plant growth by 2.12% to 2.81% compared to without using a reflector which was only 1.91%, or an increase of 32.03%. Whereas at a stake angle of 90°, EC increased from 1.92% to 2.45% compared to 1.78% without using mulch or an increase of 27.35% (Table 6).

The EC value obtained in this study was higher than the EC value in tubers reported in India of 1.6 to 1.9% [10], from the estimated theoretical maximum EC potential of 5.3% [19]. The low solar radiation intensity factor in the Baliem valley during the course of the study when compared to the high weight of dry matter produced, is the cause of the high EC value obtained.

3.5. The relationship between crop growth rate and tuber yield

The crop growth rate was very closely related to the results of tuber per ha, especially the treatment of stake angle 60° with reflector type. The results of the regression analysis showed that the higher the plant growth rate (x), the higher the yield of ha^{-1} (y) tubers. This is shown in the positive linear equation in (Figure 2), below: $Y_1 = 3.25x + 11.89$, $R_1 = 0.50$ for the 90° angle (a) and $Y_2 = 2.47x + 16.74$, $R_2 = 0.91$ for the stake angle of 60° (b). This equation model can explain about 50 percent of the relationship between plant growth rate and tuber yield ha^{-1} at 90° angle treatment and about 91 percent can explain the relationship between crop growth rate and tuber yield ha^{-1} at 60° angle treatment with various types of the reflector. The results of this study indicate that the tuber yield of 34.15 t ha^{-1} was achieved at the highest crop growth rate of 6.78 g m^{-2} days^{-1} at the harvest age of 150 DAP (Table 1 and Table 5). Based on the results of the study, to obtain tuber yields above 40 t ha^{-1}, required a crop growth rate of at least 11.5 g m^{-2} day^{-1} and plants were harvested at the age of more than 100 days [6].

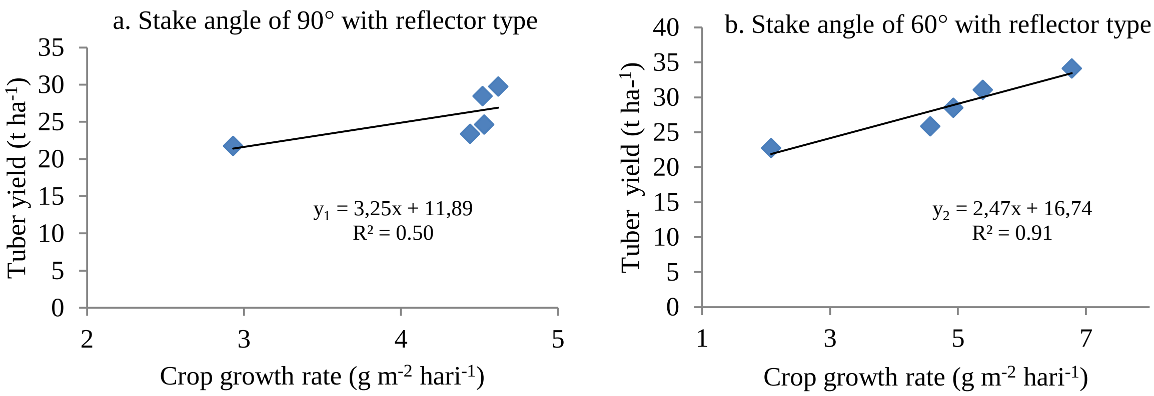

Figure 2. The relationship between crop growth rate and tuber yield at stake angle of 90° with various reflector type (a) and a stake of 60° with various reflector type (b).

4. Conclusions

The crop growth rate (CGR), tuber yield (TY) and energy conversion efficiency (EC) were improved in all use mulch types as a reflector compared to without mulch on both stakes inclination angle. Planting of the Cangkuang variety using stakes of 90° and using clear plastic mulch reflectors more efficiently utilizes solar radiation energy when viewed from the TY of 28.3 t ha^{-1} and R/C ratio of 2.7 with an EC value of 2.43 % and then planting Cangkuang variety of sweet potato using stake of 60° and the use of silver black plastic mulch reflector is more efficient in utilizing solar radiation energy when viewed from the tuber production 34.15 t ha^{-1} with (EC) value of 2.81%.

Declarations

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

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