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THE INFLUENCE OF VARIETY ADAPTATION AND STAKE INCLINATION ANGLE ON THE GROWTH, RESULT AND CONVERSION EFFICIENCY OF SWEET POTATO (IPOMOEA BATATAS L.) IN BALEIM VALLEY, PAPUA HIGHLAND

Soplanit Alberth*
Graduate School of Agriculture, Faculty of Agriculture, Brawijaya University & Indonesia/Papua Assessment Institute for Agricultural Technology, Indonesia

Guritno Bambang, Ariffin, Suminarti Nur Edy
Faculty of Agriculture, Brawijaya University, Indonesia

*E-mail: asoplanit@yahoo.co.id

ABSTRACT
Sweet potato (Ipomoea batatas L.) is a plant that needs full sun to grow and get optimum yield. It needs an engineering technology that is able to integrate plant and environment in order to overcome abiotic factors in Papua highland. This research aims to determine the growth, result and energy conversion efficiency contained in the sweet potato by combining variety and different stake inclination angle. This research was conducted in Balem valley of Jayawijaya district. The experimental design used was factorial group random design with three replications. The research result shows that to make plant more efficient in managing solar intensity in Papua highland, so it is advised to plant Cangkuang variety (broad leaf) and to use stake with inclination angle of 60° and 90°.

KEY WORDS
Sweet potato, variety, stake inclination, Papua highland, conversion efficiency.

Papua and West Java are two regions with the largest sweet potato harvested area in Indonesia, while for the side of production level. West Java’s sweet potato production is higher than Papua. Rauf and Lestari (2009) reported that the variety of Papua Sollosa, Papua Pattipy and Sawentar in Papua highland are harvested at 6 months old with the production of 24-25 t ha⁻¹. Furthermore, Saraswati et al. (2013) reported that Papua Pattipy, Papua Sollosa and Cangkuang planted in Balem valley at 6 months old resulted in 20.78, 14.68 and 13.28 t ha⁻¹ respectively. In west java, the varieties planted are SQ-27, Ceret, Cilembu and Prambanan with 4-5 months old, their production is 25-30 t ha⁻¹. This result indicates that the production of sweet potato in Papua is still low, let alone the production potential is 30 t ha⁻¹ on average. Agatha and Takeda’s research result (1982) in Japan can reach 40 t ha⁻¹ with solar radiation 339 cal cm² day⁻¹ and the average temperature is 24.2°C.

Most of sweet potato farmer in Papua stay in agroecosystem area of highland (Limbongan and Soplanit, 2007). Abiotic factor as higher level clouds is a limiting factor of the low harvested result of sweet potato in Papua highland. Farmer at Balem valley has a hereditary local wisdom to adapt sweet potato cultivation by growing long spiral-shaped cultivar in the middle of allotment land and crept up vertically using stake as well as short spiral-shaped cultivar is grown as egde plants (Widyastuti, 1994). All of those efforts are intended to position leaf so that able to receive low solar intensity so that the harvested result of sweet potato is higher. Soenarto (1997); Saraswati et al., 2013 report that the intensity of solar radiation in Balem valley is relatively slow and only about 1.38 KJ cm² day⁻¹ and the average of sunshine duration is 3.98 hours day⁻¹. In reality, sweet potato needs at least 10 - 11 hours of sunshine to achieve maximum photosynthesis rate (Ravi, 2003; Ravi and Saravanan, 2012).

There have been so many studies on sweet potato at Balem valley like the one conducted by Widyastuti, 1994; Soenarto, 1997 and Saraswati et al., 2013. However, almost all those studies only focus on the socio-culture aspect of the dani people in managing sweet
potato and studying agronomical aspect. While the study on the respond of plant to the abiotic factors as the result of higher level clouds is not conducted yet. For that matter, in order to make sweet potato more efficient in managing low solar radiation in Baliem valley, it is made an engineering technology by choosing variety having proper morphology as well as positioning leaf so that the angle is more vertical to receive sunshine. Therefore, it is expected the photosynthesis rate is more enhanced and the harvested result in form of carbohydrate is also storage more. According to Wargiono (1980), most of broad-leaved sweet potato is able to conduct photosynthesis effectively; the result is higher than the variety of narrow leaf or fingered leaf. Maryasa (1990) concludes that stake usage makes plant able to catch light efficiently and decrease the effect of shading each other so that the light can be distributed proportionally to all parts of leaf.

This research aims to test the respond of variety and morphology of narrow leaf, medium leaf and broad leaf as well as different stake inclination angle that can increase plant ability to take advantage of solar radiation efficiently. As an assessment of how big the availability of plant efficiency to manage solar radiation intensity in Papua highland can be measured from the harvested result, dry matter production and energy conversion efficiency during the growth period of sweet potato.

**MATERIALS AND METHOD OF RESEARCH**

A field study was conducted at Wesakin village, Wouma subdistrict, Jayawijaya district, Papua, Indonesia, (138°57’ East longitude, 04°04’ south longitude, 1560 m above sea level) during the planting season in April until September 2016. On dry land with soil type of entisol, soil texture is sandy loam and the pH is 5.2. This research uses three varieties of sweet potato: Siate (local), Papua Sollosa (improved variety) and Cangkuang (improved variety).

An experiment to use factorial group random design is conducted in three replications. Variety of factor A is made up of three types: Siate (V1) represents narrow leaf, Papua Sollosa (V2) represents medium leaf and Cangkuang (V3) represents broad leaf. Four different stake inclination angles as factor B are made up of using no stake (A0), stake angle 45° (A1), stake angle 60° (A2), and stake angle 90° (A3). Soil was managed using a special scoope; the land was divided into three groups and each of then was divided again into 5.25 x 6.50 m plot. The distance between the groups is 100 cm and the distance between the plot is 50 cm, while the planting distance is 75 x 50 cm, every one cutting is planted in a whole of single mound. Hand weeding was conducted at the 15, 45, and 80 day after planting (DAP). Fertilizer application and pest control chemically are not conducted since there is chemical prohibition of usage for agriculture by the local government. Observation was conducted destructively by taking sample of two plants that were not the edge plant at 40, 70, 100, and 130 days or the observed parameter at every observation. Sample taking was conducted by harvesting sweet potato using stake or local people call it sege. Interception of solar radiation was measured above and under canopy at 11 a.m when the wheather is bright using LX 1330 B meter lux. A set of measurement was conducted 3 times above the cannyop and 3 times on the surface soil. The data of global solar radiation was gained from Wamena meteorology station class 3.

| Observation Period  | Average air temperature (°C) | Average soil temperature (°C) | Average solar radiation (Cal.cm⁻².hr⁻¹)* | Average rainfall (mm)* |
|---------------------|-----------------------------|-------------------------------|----------------------------------------|------------------------|
| 2 April - 12 May    | 21.00                       | 25.00                         | 113.28                                 | 131                    |
| 13 May - 13 June    | 20.00                       | 23.00                         | 99.31                                  | 98                     |
| 14 June - 14 July   | 19.00                       | 23.00                         | 117.02                                 | 97                     |
| 15 July - 15 August | 19.00                       | 23.50                         | 107.43                                 | 67                     |
| Average             | 19.75                       | 23.63                         | 109.26                                 | 98.25                  |

*Source: * = Wamena meteorology station class III
Observation variables include total leaf, plant dry weight, harvested result and energy conversion efficiency. Total leaf was counted of all leaf been opened perfectly on a two plant sample. Total sweet potato was counted entirely at every plot and divided by total plant during harvesting season. While the energy conversion efficiency uses a method developed by Yoshida (1981). Part of plant was separated into root, stem, leaf and tuber, and then dried in an oven until reach the weight constant with temperature of 80º. Plant dry weight was counted by adding all parts of plant that has been dried in an oven. Photosynthesis efficiency was measured based on the total dry weight (g.m²) divided by solar radiation accumulative (cal²days⁻¹) after harvesting.

Statistics analysis was conducted using Analisis Varians (ANOVA) at 5% significance level. The difference between treatment was tested using Duncan Multiple Range Test (DMRT) 5%. Analysis data was conducted buing Genstat 17 statistic program and Microsoft Office Excel program 2010.

RESULTS OF STUDY

Leaf number. Sweet potato plant was conducted after the end of el nino long dry season in 2015 at midle montana area, Papua. The average time of 8.25 hours sunshine is 66 - 69%, solar radiation intensity of 150 DAP is 20,661.90 cal cm² day⁻¹ (unpublishe data). The development of total sweet potato leaf planted after the end of long dry season indicates the first real difference of growth until 130 DAP. Total leaf increases at all treatment conditions following plant development and reaches the highest number at V1A0 treatment condition at 100 DAP, it tends to decrease at 130 DAP until approaching harvesting season. The lowest leaf umber is gained at a combination of V1A3 treatment. the high number of leaf during the V1A0 treatment combination is influenced by Siate characteristic having longer sucker than other varieties and aproaching ground so that getting nutrient to maintain the leaf longer. In opposite way, V1A3 treatment experiences a decrease since the appearence of new surculus is not balances with the number of dried leaf. The relationship between variety treatment combination and stakle inclination angle to the leaf number parameter are demonstrated in (Figure 1).

![Figure 1](image-url)

Figure 1 – The relationship between variety combination and stakle inclination angle with leaf number of sweet potato of local Siate variety (a), Papua Sollosa (b) and Cangkuang (c). Polynomial model for Siate, Papua Sollosa and Cangkuang variety is V1y = -0.0553x² + 10.127x - 288.43, R² = 0.9793; V2y = -0.0393x² + 8.0302x -241.55, R² = 0.998 dan V3y = -0.0267x² + 6.0344x - 185.4, R² = 0.9918 respectively.

Plant dry weight. The influence of variety treatment combination and stakle inclination angle on the total dry weight indicates significant difference at all phases of growth excluding vegetative phase at 40 DAP. The highest dry weight is gained from V3A3 treatment combination at 130 DAP (326.9 g plant⁻¹) (Figure 2). Cangkuang leaf morphology that is relatively broad with vertical inclination angle truly influences the ability of leaf to catch solar
radiation. The higher the solar radiation catch, the higher the photosynthesis rate so that the assimilate resulted in form of dry matter is high. This result can explain that the intensity of solar radiation is a more dominant factor in increasing biomass production to actuate metabolism activity and plant genetical characteristic. Gifford et al. (1984); Adeboye et al. (2016) states that in a field condition, plant development depends on the canopy capacity to intercept radiation incident and change it into new biomass. Total radiation incident intercepted depends on the index of leaf area and canopy orientation. Leaf area index is influenced by leaf number and leaf area covering canopy. Furthermore, Plenet et al. (2000) concludes that Photosynthetically Active Radiation (PAR) absorbed by canopy depends on the LAI and plants leaf structure.

![Graph showing dry weight vs day after planting](image)

**Figure 2** – The relationship between variety combination and stakle inclination angle to the total dry weight of sweet potato. Polynomial model for Siate variety (a), Papua Sollosa (b) and Cangkuang (c) respectfully is $y = -0.0104x^2 + 286.14x - 92.246$, $R^2 = 0.9989$; $y = -0.0059x^2 + 0.5938x - 26.281$, $R^2 = 0.9984$ dan $y = 0.0008x^2 + 37.661x + 147.08$, $R^2 = 0.9978$

**Tuber yield.** Variance analysis result of the number of tuber and marketable tuber proportion during harvest of 150 DAP is presented in (Table 2). Variety treatment combination and stakle inclination angle is not significantly different to the number of tuber. Type of sweet potato variety has a significant influence ($p<0.05$) on the tuber number per plant. On average, the highest tuber number gained from Cangkuang variety is 3.68 and the lowest is gained by Papua Sollosa and local variety by 3.08 and 2.72 tubers respectively. Stakle inclination angle has a significant influence ($p<0.05$) on the tuber number per plant. It is obvious that the variety with broader leaf and stakle uses is able to increase tuber number per plant. The highest tuber number is gained from stakle inclination angle 45° and 60° by 3.70 and 3.28 respectively, but not significantly different with stakle angle 90° (3.11) (Table 2).

**Table 2** – The average influence of variety combination and stakle inclination angle on the tuber number/plant and marketable tuber (%)

| Treatment          | Average number of tuber and marketable tuber |       |      |
|--------------------|-----------------------------------------------|-------|------|
|                    | Number of tuber/plant                         | Marketable tuber (%) |      |
| Variety            | -                                             | -     | -    |
| V1 (Siate)         | 2.73 a                                        | 42.78 a |      |
| V2 (Papua Sollosa) | 3.08 a                                        | 39.50 a |      |
| V3 (Cangkuang)     | 3.68 b                                        | 52.25 b |      |
| Stakle angle       | -                                             | -     | -    |
| A0 (without using stakle) | 2.57 a                                      | 36.52 a |      |
| A1 (Stakle angle 45°)     | 3.70 b                                        | 50.09 b |      |
| A2 (Stakle angle 60°)     | 3.28 b                                        | 51.08 b |      |
| A3 (Stakle angle 90°)     | 3.11 ab                                       | 41.68 ab |      |

*Note: The number followed by different letter in the same column indicates significant difference at Duncan test ($p=0.05$).*
Sweet potato variety has a significant influence (p<0.05) on the marketable tuber proportion, it is obvious that the highest total marketable tuber is Cangkuang variety by 52.25% higher than Papua Sollosa and local Siate variety by 42.78% and 39.50% respectively. The influence of stakle angle is significantly different (p<0.05) to the total marketable tuber, the highest total marketable tuber is at the stakle angle 60° and 45° by 51.08% and 50.09% but not significantly difference with stakle angle 90° (41.68%). This result can explain that the use of variety with broad leaf and stakle use is able to increase marketable tuber proportion. The relationship between tuber number and marketable tuber proportion is demonstrated in (Figure 3a).

Variance analysis yield to the sweet potato yield of 150 DAP is presented in Figure 3b. Combination of variety treatment and stakle inclination angle to the parameter result of sweet potato indicates significance different (p<0.05) and ranges between 12.60 - 31.53 t ha⁻¹. The highest result of tuber is gained from the combination of V3A3 and V3A2 by 31.53 t ha⁻¹ and 28.86 t ha⁻¹ respectively. The increase treatment of stakle inclination angle of those three varieties can increase sweet potato result, excluding V1A3 and V2A3 treatment, tends to decrease result. The lowest result of sweet potato is gained from the combination of V1A0, V1A3 and V2A0, V2A3 treatment.

The number of tuber, marketable tuber proportion, tuber yield is a parameter that can represent the result (Table 2 and Figure 3b). Low sunshine condition in Baliem valley, Papua highland enables Cangkuang variety to have more efficient leaf morphology in getting solar radiation, as indicates by the higher tuber number of sweet potato and marketable tuber proportion compared to other varieties. An efficiency of catching solar radiation is also influenced by stakle inclination angle treatment since the leaf position is more vertical to the solar system direction. This also influences tuber number per plant and marketable tuber proportion is higher than the treatment without using stakle. This matter is inline with Maryasa (1990) opinion that stakle use makes plant able to catch sunlight more efficiently. Moreover, Oswald and Midmore (1995) states that sweet potato shaded will curate an initiation of tuber structuring, number of tuber and size tuber.

\[ y = 9.8782x + 13.588 \]
\[ R^2 = 0.5397 \]

Figure 3 – The relationship between number of tuber per plant and marketable tuber proportion. The linear model is \( y = 9.8782x + 13.588 \), \( R^2 = 0.5397 \), r= 0.7346

It appears that the combination of sweet potato varieties especially broad-leaved varieties with increasingly higher stakle inclination angle makes the location of the leaves more vertical, in low conditions, sunshine enables most leaf sheets to capture light for photosynthesis. While the combination treatment of varieties without using stakle causes only the upper leaf sheet that receives light while the leaves on the bottom layer lacks light because it shades and affects the low net photosynthesis results. The low yield of sweet potato on the combination of V1A3 and V3A3 treatments is due to the fact that some leaves of the photosynthesis agent dried up.
**Figure 4** – The relationship between the interception efficiency (Ei) and the energy conversion efficiency (EC) of sweet potatoes in the combination of variety treatment and the stable inclination angle, the line in the figure is an estimation of linear model $y = 1.2171x - 79.481$, $R^2 = 0.3650$, correlation coefficient value, $r = 0.6041$

**Interception efficiency (Ei) and Energy conversion efficiency (EC).** Varieties treatment was significantly different ($p<0.05$) on the interception radiation efficiency (Ei). Variance result analysis of efficiency parameter of solar radiation shows that Cangkuang variety produces the highest Ei compared to Papua Sollosa and local Siate varieties, which is 87.62%, 83.68% and 83.26% respectively (Figure 4b). When viewed from the aspect of efficiency interception, it shows that Cangkuang variety having broad-leaved morphology more efficient in catching incoming PAR radiation compared to Papua Sollosa and Siate whose leaf is medium and narrow. The combination of variety treatment and the angle of inclination was not significantly different from the interception efficiency parameter.

The sweet potato grown in Papua highland with solar intensity for 150 days of 20,661.90 cal cm$^{-2}$ day$^{-1}$ produces energy conversion efficiency (EC) of 1.78 - 7.50%. The highest EC values were obtained in a combination of V3A3 treatment by 7.50%, while the lowest EC was obtained in a combination of V1A0 treatment by 1.78% (Figure 4a). The amount of EC is influenced by the high production of dry matter to PAR which falls on the canopy. The result of energy conversion efficiency is high because conversion efficiency for root crop, according to Rana and Rana (2014) is 1.6 - 1.9 %. The relationship between interception efficiency and energy conversion efficiency is shown in (Figure 4b).

Based on the estimation of sun position from hour angle to the stable inclination angle, it indicates that the perpendicular position of the sunlight for staked angle 90º falls at 12 a.m, the perpendicular position of the sunlight for staked angle 60º falls at 10 a.m and the perpendicular position of sunlight for staked angle 45º falls at 9 a.m (data not shown). The average sun exposure in Baliem valley starts at 10 a.m, before that the sunlight is still covered with clouds and fog. This data explain that the sweet potato gets full sun angle at 10 a.m to 12 a.m, and it occurs at the 90º and 60º staked angles. Fujise and Tsuno (1962) states that the rate of photosynthesis of sweet potato shows a cycle with a specific pattern during normal sunshine periods, that is high radiance in the morning until afternoon and then getting low again. Moreover, it is said that in the subtropical zone, net photosynthetic rate is about 12 mg CO$_2$ dm$^{-2}$ hour$^{-1}$ between at 9 a.m - 1 p.m, then decrease until hingga 2 mg CO$_2$ dm$^{-2}$ hour$^{-1}$ at 5 p.m.

Thus, it can be concluded that the interception and the use of solar radiation is influenced by genetic factors and plant environment and both of them interact with each other. In addition to the leaf morphological characteristic that affects plant physiological response, inclination angle position of leaf toward the arrival of sunlight becomes the determinant factor of the number of energy conversion efficiency of sweet potato. Goudriaan (2016) states that the distribution of leaf angle plays an important role in determining the interception of light. In the absence of water and nutrient shortages, the efficiency of solar radiation is determined by light interception, especially PAR by canopy and patterns of light.
distribution in plant canopy (Monteith, 1977; Sitaniaapessy, 1985; Russell et al., 1989; Tesfaye et al. 2006).

CONCLUSION

Dry matter production increase is influenced by leaf number increase influencing the broad of leaf area. Leaf morphology and the inclination angle interact each other in increasing plant dry matter, tuber yield and energy conversion efficiency of sweet potato. Morphological form of leaf characterized by broad leaf truly influences the high efficiency of radiation interception causing number of tuber and marketable tuber proportion enhancement. Separately, stake inclination angle influences the high number of tuber per plant and marketable tuber proportion. Due to the low condition of solar radiation intensity in Papua highland, variety with broader leaf together with more vertical stake inclination angle interact each other to influence the high value of energy conversion efficient of solar system. The combination of Cangkuang variety treatment and stake angle 90° results in highest EC by (7.50%) compared to the combination of Siate variety treatment without using stake (1.78%).

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