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Relationship between yield and growth of sweet potato (*Ipomoea batatas* L.) on abiotic stress in Papua highland, Indonesia: Adaptation of varieties and sticks inclination angles

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One of the strategies to increase the use of low solar radiation in sweet potato plants (*Ipomoea batatas* Lam.) in Papua highlands is to modify the plant environment. The research was done by adapting the varieties and sticks inclination angles on the abiotic stress condition due to the high level of resistance. The field experiment used three varieties of sweet potato, combined with four sticks angles using a randomized group design with three replications. Sweet potato yield consistently correlated strongly with leaf area index, crop growth rate, net assimilation rate and total dry weight. Results of tuber yields per hectare were strongly correlated with LAI (r = 0.771**), CGR (r = 0.868**), strongly correlated with NAR (r = 587*) and were very strongly related with TDW (r = 0.904**). *Cangkuang* variety combined with 60^0 and 90^0 angles yielded tubers of 28.86 t ha^{-1} and 31.53 t ha^{-1}.

Keywords: ***Abiotic stress, Highland, Sweet potato, Sticks angles, Yield***

INTRODUCTION

Sweet potato (*Ipomoea batatas* Lam.) located in the Papua highland is locally known as *hipere*. For the *Dani* people who reside in the *Baliem* valley, this plant is not only an important food crops, but also as the animal feeds for the local community. The sweet potato plant has a fundamental role in the society described as a triangular relationship between humans, pigs and sweet potato; therefore known locally as mother's plants or “mama” (Widyastuti, 1994).

The tradition of cultivating the sweet potato by the local people has been inherited from generation to generation. Traditionally men are responsible for preparing the land for cultivation, women are responsible for the planting, cultivating, and harvesting. One of the unique planting methods by the local farmers according to Wydiastuti (1994) is to plant the sweet potato using single bunds. The plants are classified, of which the short-standing plants are planted on the edge of the plantation as the border plants, while the long-bushy and long plants are planted in the middle of the plantation. As the plants reach 40 days after planting (DAP), they are propagated by using 120-150 cm sticks with the inclination angles of sticks commonly used by the local people is 90^0. The purpose of using the sticks is that the plants may be exposed with enough sunlight, resulting in larger tubers. This method is reasonable as the average sunlight intensity in the area is only 138 Joule cm^{-2} day^{-1} and the duration of irradiation is relatively short which is for 4 hours day^{-1} (Soenarto, (1987); Saraswati *et al*. (2013)). Onwueme and Johnston (2000) reported that sweet potato is intolerant of shade, with dry yield decreasing when shade levels increase.

Studies that have been conducted in the Papua highlands are Wydiastuti (1994) on the sociocultural aspect of women farmers in cultivating sweet potato, Soenarto (1987) on the sociocultural aspect of the cultivation system of the sweet potato and Saraswati *et al*. (2013) on the agronomic diversity and nutrient content of sweet potato. The researchers conducted there have not focused on the physiological aspect of the plant and its response to abiotic stress caused by the lack of solar supply due to high levels of resistance. Therefore, Therefore to incease the amount of photosynthate translocated to the tuber, it is necessary to modify the plants environment so that the plant are more efficient in utilizing low sunlight. One of the efforts that need to be done is to adapt the varieties combined with the appropriate sticks angles so as to enable increased efficiency of solar radiation utilization by plant leaves. The wide-leaved varieties of sweet potato are photosynthetically effective, which in turn leads in to higher yields than with the narrow and fingering-leaved sweet potato varieties (Wargiono, 1980). Using different stick angles using stakes will place the angle of the leaves so that they can affect the amount of solar energy received by the plant. Lambert's Law in Rosenberg (1983) states that the amount of solar energy received by the leaf surface is strongly influenced by the angle of the light.

This study compares different sweet potato varieties growing at different sticks angles for ability to absorb solar radiation, by measuring, parameters growth, tuber yield and can see the relationship between the various growth parameters and sweet potato yield.

MATERIALS AND METHODS

Sampling

A field study was conducted in Wesakin village, Wouma district, Jayawijaya regency in Papua, Indonesia, (138^0.57' south latitude, 04^0 04' east longitude) at the altitude of 1.560 meter (asl) from April to September 2016. Soil texture: sandy loam, soil pH: 5.1, C-organic: 1.7%, N-total: 0.2%, P-available: 38.1 ppm, K-available: 56.0 ppm and CEC: 15.5 ($Cmol_c$/kg). This study employed three varieties of sweet potato, and four levels of sticks angles.

Research design, treatments and data collection

The trial was performed by randomized block design in three replications. Varieties consist of three kinds: *Siate*, *Papua Sollosa* and *Cangkuang*, combined with four different sticks inclination angles consisting of without stick and sticks inclination of 45^0, 60^0, and 90^0, so that there were 12 combinations of treatments. Soil processing was done by means of shovels to cultivate the soil, the plot was divided into three groups and each group was divided into 5.25 m x 6.50 m large plots. The distance between the groups was 100 cm and the distance between plots was 50 cm, spacing 75 x 50 cm, one cutting planted per hole with single ridges. Weeding was conducted on 15, 45 and 80 days after planting. Fertilization and chemical pest control were not done because of the ban on the use of chemicals for agriculture by the local government in the area. The observations were carried out destructively by taking two plants that were not peripheral as samples at 40, 70, 100 and 130 days after planting from the parameters observed in each observation, while fresh tuber harvest was done at plant age 150 days after planting. Sampling was done by harvesting using wooden stick or *sege* (local name). Global solar radiation data were obtained from Meteorological Station Class III of Wamena in Papua.

Plant measurement

Observation variables included leaf area index, crop growth rate, net assimilation rate, total dry weight and tuber yield. The leaf area was measured using the punch method (Etje & Osiru, 1988). LAI, CGR and NAR were calculated using Gardner *et al*. (1991). Leaf area index was calculated from leaf area per area of land. The crop growth rate was calculated by the total dry weight of the plant per land area and days after planting. The net assimilation rate was calculated by the total dry weight of the plant per unit of leaf area per days after planting. The parts of the plant were separated into roots, stems, leaves and tubers and dried to constant weight in the oven at 80 ^{0}C.

Table 1. Weather condition in Baliem Valley, Wamena

Observation periods	Average of air temperature (^{0}C)	Average of soil temperature (^{0}C)	Average of solar radiation (Cal.cm^{-2} day $^{-1}$)*	Average of rainfall (mm)*
2 April – 12 May	21.00	25.00	113.28	131.00
13 May – 13 June	20.00	23.00	99.31	98.00
14 June – 14 July	19.00	23.00	117.02	97.00
15 July – 15 August	19.00	23.50	107.43	67.00
16 August - 16 September	19.00	23.00	106.21	57.80
Average	19.60	23.50	108.65	90.16

Source: * = Meteorology Station Class III of Wamena, Papua.

Statistical analysis

The analyses of variance were carried out using GenStat 18 statistical software. The difference between treatments was tested using least significant differences (LSDs) test at 5% probability level. Correlations between parameters, trends in different growth parameters were analysed by linear regression, using Microsoft Office Excel program 2010.

RESULTS AND DISCUSSION

Leaf area index (LAI)

The development of leaf area index under all treatment combinations is presented in Table 2. The value of leaf index indices in combination of varieties and sticks inclination angles showed significant differences ($P<0.05$) at the age of 70 to 130 DAP and the value of leaf area index observed ranged from 0.6 – 5.5. An increase in LAI occurs due to the growth of leaves as the result of the increasing number of the leaves and reach maximum at age 100 DAP; as the leaves are aging and beginning to dry, however, the value of LAI decreases. LAI optimum at the age of 130 DAP, which was obtained with the combination of *Cangkuang* variety and sticks angles of 45^0, 60^0 and 90^0 amounted to 3.6-4.2. Wide shape of leaves from *Cangkuang* variety compared to Siate and Papua Sollosa varieties, which are likely smalled to medium, may affect the higher value of LAI. As the sticks inclination angles increases, it might affect the lower number of leaves overlaping due to the more vertical leaf orientation that allows each leaf to receive the light on each layer of the canopy. Physiologically, the width of leaf area and crown architecture are very important because it is related to the ability of plants to absorb light to the maximum level. The process of light absorption,photosynthesis, carbon absorption and assimilation through stomata, watter transpiration and volatile organic compound emissions occur through the leaf surface and depend on the position of the plant canopy. The higher value of leaf area index to a certain extent affects the amount of solar radiation received by the leaves. Brown (1992); Ravi and Saravanan (2012) estimated that on LAI value of 3-4 is required to intercept 95% of the photosynthetically active radiation in the sweet potato plants.

Crop growth rate (CGR)

The effect of combination of varieties and inclination angle on the crop growth rates (CGR) is shown in Table 3. Crop growth rate shows changes in dry weight over periods of time. The calculation results of CGR at the age 40 to 70 DAP ranged from 1.40 to 3.22 g m^{-2} day^{-1}. The response of each combination treatment within 70-100 DAP period was 1.38-3.46 g m^{-2} day^{-1}. Similarly, the growth rate within 100-130 DAP has mixed results with the value of 1.02-3.06 g m^{-2} day^{-1}.

The effect of combination of varieties and inclination angle during the initial phase, the formation of tubers until harvest showed significant difference ($P<0.05$). In the mid-growth phase, CGR increased with increase in the sticks angles of all varieties and reached the highest in the three varieties and the angles of 90^0. In the final phase of the combination of Siate and Papua Sollosa varieties on the angle of 90^0 tends to decrease the growth rate because, in this treatment, the leaves tend to experience senescence. According to Ravi and Saravanan (2012), the growth rate is strongly influenced by the environmental conditions of the plants, that the growth rate value of the sweet potato will be higher if the intensity of solar radiation can be utilized optimally by the plants for photosynthesis.

Table 2. Effect of combination of varieties and the stick angle on the leaf area index at four periods of observation (means of three replications)

Combination of varieties and stick angles	Average of LAI at days after planting (DAP)			
	40	70	100	130
P1 (Siate without stick)	1.1	3.4 bc	3.0 bc	2.1 bc
P2 (Siate + stick angle of 45^0)	1.2	3.6 bc	2.7 abc	2.0 b
P3 (Siate + stick angle of 60^0)	1.0	2.3 a	2.4 ab	3.0 def
P4 (Siate + stick angle of 90^0)	1.0	3.0 ab	1.6 a	0.6 a
P5 (P.Sollosa without stick)	0.9	2.2 a	3.7 cd	2.9 cdef
P6 (P.Sollosa + stick angle of 45^0)	0.9	2.8 ab	4.6 de	2.0 b
P7 (P.Sollosa + stick angle of 60^0)	1.1	3.2 abc	3.3 bc	2.5 bcde
P8 (P.Sollosa + stick angle of 90^0)	1.0	2.7 ab	2.9 bc	2.2 bcd
P9 (Cangkuang without stick)	0.9	3.0 ab	4.6 de	3.1 ef
P10 (Cangkuang + stick angle of 45^0)	1.1	4.1 c	4.8 de	3.6 fg
P11 (Cangkuang + stick angle of 60^0)	0.9	4.0 c	5.5 e	4.1 g
P12 (Cangkuang + stick angle of 90^0)	1.0	3.6 bc	5.1 e	4.2 g
LSD 5 %	ns	1.0	1.1	0.8

Notes: numbers with different fonts in the same column show significant difference in LSD test (P<0.05); DAP = days after planting; ns=Not significant.

Table 3. Crop growth rates in the combination of varieties and sticks angles in the three periods of observation (means of three replications)

Combination varieties and sticks angles	Crop growth rates (g m^{-2} day^{-1}) at days after planting (DAP)		
	40 – 70	70 - 100	100 -130
P1 (Siate without stick)	1.76 a	1.38 a	1.02 a
P2 (Siate + stick angle of 45^0)	1.48 a	2.09 a	1.27 ab
P3 (Siate + stick angle of 60^0)	1.40 a	1.99 a	2.78 de
P4 (Siate + stick angle of 90^0)	3.32 b	2.94 b	1.20 ab
P5 (P.Sollosa without stick)	1.96 a	1.45 a	1.17 ab
P6 (P.Sollosa + stick angle of 45^0)	1.55 a	1.62 a	2.14 cd
P7 (P.Sollosa + stick angle of 60^0)	1.57 a	1.96 a	2.65 de
P8 (P.Sollosa + stick angle of 90^0)	2.99 b	3.46 b	1.08 ab
P9 (Cangkuang without stick)	1.53 a	1.47 a	1.55 abc
P10 (Cangkuang + stick angle of 45^0)	1.71 a	1.59 a	1.71 bc
P11 (Cangkuang + stick angle of 60^0)	1.66 a	2.06 a	2.76 de
P12 (Cangkuang + stick angle of 90^0)	3.20 b	3.27 b	3.06 e
LSD 5%	0.7	0.7	0.6

Notes: Numbers with different fonts in the same column show significant difference in LSD test (P<0.05); DAP = days after planting.

The increasing trend of CGR shows similar pattern to the leaf area index. Therefore, CGR is determined by how much solar radiation can be intercepted by plant leaves to achieve the optimum photosynthetic level. Paulus (2010) reported that CGR of sweet potato will increase following the parabolic curve, meaning that CGR will increase in the vegetative growth phase and begin to decline into the generative phase. Agatha (1982) concluded that the value of the crop growth rate of sweet potato is higher to the mid-growth phase and then tends to decrease irregularly before the age of harvest. Furthermore Brown (1992) concluded that LAI value of 3-4 is obtained at plant age between 56 and 112 DAP. This LAI value is the maximum CGR value resulting in dry content of 106-133 g m^{-2}.

Net assimilation rate (NAR)

Biomass production and the growth of tubers are dependent on the growth rate of the plant which are expressed in the form of dry matter depending on photosynthetic performance or net assimilation rate. The response of net assimilation rate to the combination of varieties and stick angle at the beginning of growth to the stage of harvesting indicates a significant figure. The net assimilation rate of sweet potato planted in the Papua highland at the age of 40-70 DAP by 3.6 - 6.9 mg m^{-2} $days^{-1}$, then significantly ($P<0.05$) increased at 70-100 DAP, varied depending on the combination of varieties and sticks angles amounted to to 5.8 - 88.2 mg m^{-2} $days^{-1}$. The values of NAR at 100-130 DAP were observed to decrease and vary from 1.5 - 31.7 mg m^{-2} day^{-1}. The results showed that the net assimilation rate (NAR) increased at the beginning of growing phase, and the highest rate was in the mid-growth phase of 70-100 DAP, and the rate decreased until the harvesting phase. Gardner (1985) concluded that the value of NAR of the sweet potato is not possible to decrease along with the increasing plant age because the increasing age of the plants means the results of the photosynthesis are utilized for the formation of tubers.

The highest net assimilation rate was obtained on the combination of Cangkuang variety and 60^0 angles in the age of 70-100 DAP of 88.2 mg m^{-2} $days^{-1}$ (Table 4). This result is higher than the research carried out by Widaryanto and Saitama (2017) in Malang, Indonesia at 303 meter asl., showing that the net assimilation rate (NAR) varies between lowland and highland. Low temperatures in the highland causes photosynthates used for respiration are smaller than the lowlands. Hozyo *et al*. (1986) concluded that the maximum NAR is affected by the elevation, and the result was between 40-50 g m^{-2} $weeks^{-1}$ in the lowlands and 50-70 g m^{-2} $weeks^{-1}$ in the highland.

Total dry weight (TDW)

Treatments on the combination of varieties and sticks angles to the total dry weight showed significant difference ($P<0.05$) in the initial phase of tuber formation at the age of 70 DAP until before the harvest phase. The total dry weight of the plants at the age of 70 DAP was 19.6-105.1 g $plant^{-2}$, then increased at the age of 100 DAP ranging between 52.5 g $plant^{-2}$ - 229.5 g $plant^{-2}$. The total dry weight of sweet potato plants reached the highest value in the final phase namely at the age of 130 DAP, which was largely influenced by the increase of dry weight of the tubers, and it varied in various treatments on the combinations amounted to 79.9-326.9 g $plant^{-2}$. The treatment on the combination of *Cangkuang* variety and all sticks angles at the age of 70 DAP showed a significant increase in total dry weight of plant compared to other treatments. Furthermore, at the age of 100-130 DAP, the total dry weight obtained on the combinations of Cangkuang variety at 90^0 sticks angles was respectively 229.5 g $plant^{-2}$ and 326.9 g $plant^{-2}$ (Table 5). The increase in total dry weight generated on the Cangkuang variety and sticks angles of 90^0 indicated that the wide morphological character of the leaves combined with a more upright leaf orientation allows more solar radiation that can be intercepted by plants resulting in much of the assimilates stored through the photosynthesis. Plenet *et al*., (2000) said that the number of intercepted radiation depends on LAI and canopy orientation of the plants. The photosynthetically active radiation absorbed by the canopy depends on the LAI and the arrangement of plant leaves.

These results may explain that the proper genetic characteristics of plants combined with environmental factors can both influence each other to produce the optimum dry weight of the sweet potato plants. Sanoussi *et al*., (2016) suggested that partition dry weight of sweet potato are namely the highest leaves and stems growth during the vegetative phase, while during the generative phase, dry weight partition will be the highest level on the tubers. At the harvesting phase, the partition of sweet potato tubers can reach even 90% of the total dry weight of plant.

Tuber yield

The results showed that various treatments on the combination of varieties and the sticks angles were significantly different ($P<0.05$) on the results of the sweet potato (Figure 1a). The tuber yield per hectare varied ranging from 10.28-31.53 t ha^{-1} and the highest yields obtained from the combination of *Cangkuang* variety with the 90^0 and 60^0 angles, namely 31.53 t ha^{-1} and 28.86 t ha^{-1} respectively. This result is higher than Saraswati e*t al*. (2013) in the *baliem* valley of Cangkuang varieties without environmental modification just reach 13.28 t ha^{-1}. The combination of varieties of sweet potato, especially *Cangkuang* varieties wich have wide morphology leaves with higher angles allows the position of the leaves in a more vertical position against the angle of sunlight, and even in low conditions the intensity of solar radiation, this still allows most of the leaves capture the light optimally for the photosynthesis.

Table 4. Net assimilation rate in the combination of varieties and sticks angles in the three periods of observation (means of three replications)

Combination of varieties and stick angles	Net assimilation rate (mg m^{-2} day^{-1}) at days after planting (DAP)		
	40 – 70	70 – 100	100 -130
P1 (Siate without stick)	3.6 a	5,8 a	4.3
P2 (Siate + stick angle of 45^0)	4.2 ab	8,8 ab	3.8
P3 (Siate + stick angle of 60^0)	3.7 ab	19,5 d	3.4
P4 (Siate + stick angle of 90^0)	6.5 cd	31,8 e	1.5
P5 (P.Sollosa without stick)	3.7 ab	6,5 a	8.9
P6 (P.Sollosa + stick angle of 45^0)	3.6 a	20,5 d	4.4
P7 (P.Sollosa + stick angle of 60^0)	3.7 ab	12,5 c	3.8
P8 (P.Sollosa + stick angle of 90^0)	6.9 d	61,3 g	3.1
P9 (Cangkuang without stick)	4.9 ab	18,9 d	9.0
P10 (Cangkuang + stick angle of 45^0)	4.6 ab	11,3 bc	31.7
P11 (Cangkuang + stick angle of 60^0)	3.6 a	88.2 h	22.7
P12 (Cangkuang + stick angle of 90^0)	5.2 bc	47,2 f	16.1
LSD 5 %	1.5	3.4	ns

Notes: numbers with different fonts in the same column shows significant difference in LSD test (P<0.05); DAP = days after planting.

Table 5. The average dry weight of the plants on various combinations of varieties and stick angle at the four ages of observations (means of three replications)

Combination varieties and tilted angles	Total dry weight (g $plants^{-1}$) at days after planting (DAP)			
	40	**70**	**100**	**130**
P1 (Siate without stick)	6.5	19.6 a	52.5 a	79.9 a
P2 (Siate + stick angle of 45^0)	7.6	78.9 c	108.3 cd	137.2 b
P3 (Siate + stick angle of 60^0)	5.9	79.2 c	118.7 cde	174.7 cd
P4 (Siate + stick angle of 90^0)	5.6	55.3 b	91.3 b	102.9 a
P5 (P.Sollosa without stick)	5.6	47.6 b	105.7 c	147.8 bc
P6 (P.Sollosa + stick angle of 45^0)	5.4	56.2 b	121.4 de	221.1 e
P7 (P.Sollosa + stick angle of 60^0)	6.0	60.1 b	129.7 e	227.3 ef
P8 (P.Sollosa + stick angle of 90^0)	6.0	47.1 b	89.3 b	151.7 bc
P9 (Cangkuang without stick)	5.0	48.9 b	117.1 cde	202.5 de
P10 (Cangkuang + stick angle of 45^0)	5.9	94.5 d	177.6 f	261.1 fg
P11 (Cangkuang + stick angle of 60^0)	5.4	101.9 d	184.4 f	283.5 g
P12 (Cangkuang + stick angle of 90^0)	4.9	105.1 d	229.5 g	326.9 h
LSD 5 %	ns	6.4	13.6	33.8

Notes: numbers with different fonts in the same column shows significant difference in LSD test (P<0.05); DAP = days after planting.

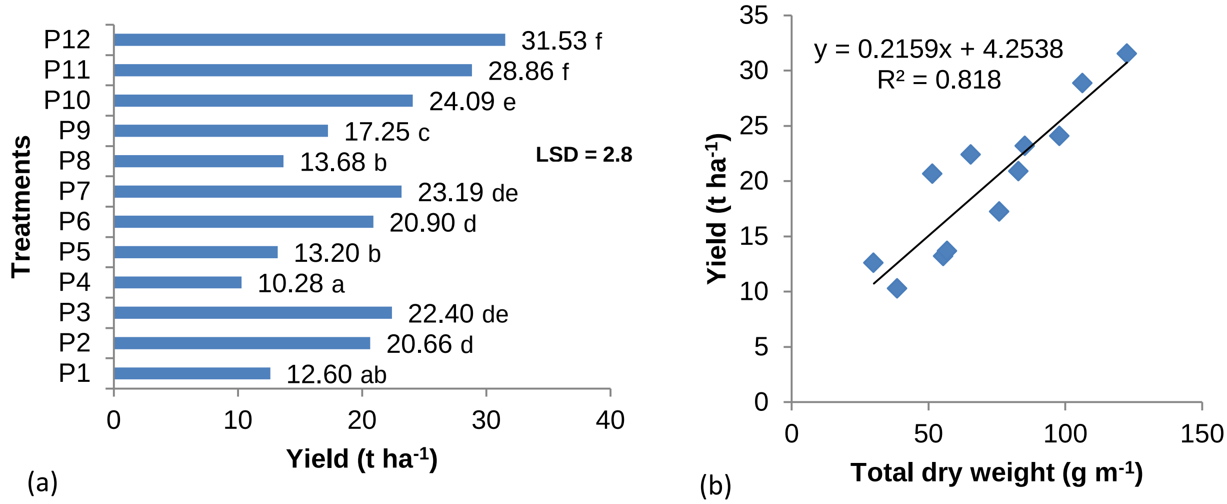

Figure 1. The effect of combination of varieties and sticks angles on tuber yield ha^{-1} (a) and the relationship between total dry weight and tuber yield ha^{-1}, with linear equation y = 0.2159x + 4.2538, R^2 = 0.818 (b).

Based on the calculation of the angles of the position of the sun hourly against the sticks angles indicates that the perpendicular position of the sunlight for the 90^0 stick angle falls at 12 p.m., the perpendicular position of the sunlight for the 60^0 stick angle falls at 10 a.m. and the perpendicular position of the sunlight for the 45^0 angle falls at 9 a.m. (data not shown). The average sunlight in Jayawijaya as the highland in Papua begins at 10 a.m. before that hour, the sunlight is still covered with clouds and fog. The data may explain that the sweet potato plant gets full irradiation angle at 10 a.m to 12 p.m, and it occurs at sticks angles of 90^0 and 60^0. Ravi (2003) reported that the maximum photosynthesis shown on the sweet potato leaves ranging from 10 a.m. to 12 p.m, and the rate decrease significantly in the afternoon, marked by the closure of the stomata on the leaves. The increase of total dry weight is closely related to the results of the photosynthate stored in the tubers; therefore, the value of total dry weight greatly affects the tuber yields with the linear equation $y = 0.2159x + 4.2538$, $R^2 = 0.818$ (Figure 1 b). This equation shows that 81% of total dry weight affects tuber yields per hectare while the other 21% is influenced by other factors. The results of this study can explain that in the conditions of low solar intensity of radiation in Papua highland, Cangkuang variety with morphological characters of wider leaves combined with the 60^0 - 90^0 sticks angles will improve the efficiency of photosynthesis, it can be seen on the highest total dry weight and tuber yield.

Correlation between CGR, LAI and NAR

The correlation between crop growth rate and leaf area index and net assimilation rate is shown in Table 6. The parameters of CGR have a strong correlation with LAI during the vegetative phase with the correlation coefficient (r = 0.609*), but not for NAR (r = 0.519^{ns}). Furthermore, CGR is not correlated with LAI during the generative phase with the correlation coefficient (r = 0.460^{ns}), but strongly correlated with NAR (r = 0.735**).

The result of correlation analysis between CGR and LAI showed a positive correlation, it can be explained that the increase of leaf area index during the vegetative phase will be followed by the increase of plant growth rate, while during the generative phase, the value of LAI does not affect the increase of crop growth rate. Hozyo *et al*. (1986) concluded that the growth rate progresses rapidly until the age of 16 weeks, then decreases due to the declining of leaf area index ; this condition happens due to dead leaves which are unbalanced with new leaves that grow. A positive correlation was shown in CGR with NAR, indicating that the increase of NAR during the vegetative phase was not followed by an increase in CGR. During the generative phase, however, NAR was greatly influenced by the increase of CGR.

Table 6. The correlation coefficient between crop growth rate (CGR) with leaf area index (LAI) and net assimilation rate (NAR) in the vegetative growth phase and the formation of tubers (generative) phase.

Parameters	Vegetative phase		Generative phase	
	LAI	NAR	LAI	NAR
CGR	0.609*	0.519 ns	0.460 ns	0.735**

Notes: NS = Not significant, * = significant at 5 %, ** = significant at 1 %

Table 7. The correlation coefficient between tuber yield per hectare and conversion efficiency with parameters of growth, yield and interception of solar radiation.

Parameters of yields and conversion efficiency	Parameters of growth, yield, interception of radiation						
	LAI	CGR	NAR	TDW	DWT	HI	
Yield (t ha^{-1})	0.771**	0.868**	0.587*	0.904***	0.885**	0.851**	

Notes: NS = Not significant, * = significant at 5 %, ** = significant at 1 % and *** = significant at 0.1%, LAI = leaf area index, CGR= crop growth rate, NAR = net assimilation rate, TDW = total dry weight, DWT = dry weight of tuber, HI= harvest index.

Wargiono and Manshuri (2012) concluded that the pattern of CGR and NAR in one cyclical plant life cycle showed the same trend at two peaks, each at the age of 7-10 weeks for CGR and 19-21 weeks for NAR. Furthermore, Hozyo et al., (1986) concluded that CGR, NAR and each variety would be different when planted in different climates either in the highland and lowlands. These differences indicate the presence of internal and external factors that influence tuber growth.

Correlation between tuber yields and growth parameters

The results of correlation analysis between tuber yield and growth parameters of sweet potato are shown in Table 7. The result of tuber yield ha^{-1} was correlated with LAI, CGR, NAR and canopy dry weight parameters showed strong to very strong correlations with correlation value ranging from 0.587 - 0.904. The results of correlation analysis in this study indicate that in combination of varieties and sticks angles of LAI to the growth parameters, CGR, NAR and canopy dry weight greatly affect the results of sweet potato. That increase to the four parameters will be followed by the increase of tuber yields per hectare. Modification of environmental factors of sweet potato plants by using the sticks inclination angles combined with the morphological characters of different varieties can increase the growth and yield of sweet potato, with strong and very strong correlations.

One strategy to increase the efficiency of solar radiation energy used in Papua highland is to apply the sticks inclination angles to the sweet potato varieties with wider leaves to allow a balance between vegetative and generative growth; therefore more assimilates of photosynthesis are translocated to the tubers. Thus the use of appropriate varieties with bigger potential for tuber development and agronomic environment management technology that can overcome abiotic stress is an option to increase the production of sweet potato in the Papua highlands.

CONCLUSION

The combination of *Cangkuang* variety and 60^0 and 90^0 sticks angles, yields fresh tubers 28.86 t ha^{-1} and 31.53 t ha^{-1} respectively. There is a correlation between parameters of plant growth and the yields of sweet potato in the treatment of varieties combined with the sticks inclination angles. The growth rate of sweet potato plants is strongly correlated with LAI and NAR. Tuber yield is strongly correlated with net assimilation rate, leaf area index, crop growth rate and total dry weight.

CONFLICT OF INTEREST

The authors declared that present study was performed in absence of any conflict of interest".

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AUTHOR CONTRIBUTIONS

The article is part of the PhD thesis and all the authors have contributed: AS, Prof.BG, Prof.A and Dr.NES designed the experiments and reviewed the manuscript. AS did the research, Prof. A supervised the field and then Prof.BG, Dr.NES and AS worked on data analysis and manusscript writing. All authors read and approve the final version.

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