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Plant Growth Performance of Top Grafted Young Cacao at Various Elevations in Indonesia

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Abstract

The purpose of this study was to evaluate the plant growth performance of top grafted young cacao cultivated in various elevations. This research was conducted from January-August 2019 in South Sulawesi and Central Sulawesi. A total of 54 plants were taken randomly from 6 locations with 3 altitudes (<300, 300-600, >600 meter above sea level as). The results showed that there was not significantly different of plant height, stem circle, crown circle, the number of primary branches, the number of flowers, the length of horizontal and vertical roots in response to different elevations. However, the height of primary stem and leaves number of cacao from <300 m asl was significantly greater than those from either 300-600 m asl or > 600 m asl. The largest crown portion of actual biomass was found in the branches, then followed by the leaves and stem. While the highest actual root biomass was found at 10-20 cm soil depth.

Keywords: altitude, biomass, crown circle, cacao root, primary stem.

Introduction

Cacao (*Theobroma cacao* L) is a tropical plant species, belonging to family Malvaceae and native to the Amazon forest (Wood and Lass, 1985). Although it is not a native plant, cacao has been widely cultivated and has become a leading plantation commodity in Indonesia (Ditjenbun, 2016). Indonesia is one of the top four cacao producing countries worldwide after Ivory Coast, Ghana and Ecuador (ICCO, 2019). Cacao is grown for its edible seed the seed is used as raw material for food, beverage, cosmetics and other derivatives industries (Lima et al., 2011).

Cacao is an annual plant that can be propagated using the generative and vegetative methods. Vegetative propagation can be done either by grafting technique (*in vivo*) or somatic embryogenesis (*in vitro*) (ICCO, 2000). The grafting technique has been widely used by cocoa farmers in Indonesia, Malaysia and the Philippines, and it has become a preferred choice for replanting cacao plants (Sodré and Gomes, 2019). This technique is relatively simple, easy to practice, true to type, able to produce a uniform plant material, and facilitate the combination of two good characteristics from different parents (Pranowo and Wardiana, 2016). The cacao derived from top grafting technique is thought to have morphological differences with generatively propagated cacao. It can be seen indirectly from the plant growth performance. Generative propagated cacao is assumed to have a higher rate in term of plant height and number of primary branches (*jorquette*) rather than vegetative ones. The height of generative propagated cacao can reach more than 1.5 m and forms 3 to 5 branches (*jorquette*) (FAO, 1984). However, there is still lack of scientific information regarding on the growth performance of vegetative propagated cacao.

In addition to propagation technique, plant growth performance can also be influenced by environmental factors, such as elevation. The elevation or altitude influence the microclimate conditions surrounding the plant. Microclimates that can affect plant growth and development are sunlight intensity (Cheng et al., 2016), rainfall (Ramos and Martínez-Casasnovas, 2014), temperature (Adams et al., 2001) and relative humidity (De Camargo, 2010). The difference in elevation of growing site can affect the plant morphology (Prastowo and Arimarsetiowati, 2019) and caffeine content of coffee beans (Artanti et al., 2016). In other plants, variation in elevation cause microclimate differences and subsequently influence the production and quality of Temanggung tobacco leaves (Nurnasari and Djumali, 2010). Tobacco produced at high elevation generally is high quality when compared to tobacco grown at low elevation. (Purlani and Rachman, 2000; Rochman and Suwarso, 2000). Differential effects of temperature were reported on cacao fruit development and bean quality of five cacao genotypes (Amelonado, AMAZ 15/15, SCA 6, SPEC 54/1 and UF 676) in Brazil, Ghana and Malaysia (Daymond and Hadley 2008). In addition, previous research by Susilo (2011) also reported the influence of elevation and agro-climate conditions on the yield stability of some superior cacao hybrids. On the other hand, a similar study specifically for cacao derived from grafting technique is still limited. Therefore, this study aims to examine the plant growth performance of top grafted young cacao plant cultivated in various land elevations.

Materials and Methods

This research was conducted from January to August 2019 in South Sulawesi and Central Sulawesi Province, Indonesia. The experimental design used was a completely randomized block design with one factor, the elevation of top grafted young cacao plantations. Land elevation and coordinates were measured using the Garmin 76CSx Global Positioning System (GPS). Land elevation was grouped into 3 levels, i.e. <300 m above sea level (asl), 300-600 m asl, and > 600 m asl. It consisted of six locations as replications for each elevation. Three plants were randomly selected as samples from every location. Present experiment used 2 to 3-year-old cacao from 4 scion varieties, S1, S2, MCC02 dan M01. The location name, coordinates of the cacao plantations at the three elevation levels are described in Table 1 and 2.

The measured variables were characteristics of crown and root growth performance of top grafted young cacao plants. Plant height was measured from the soil surface up to the highest growing point. The height of *jorquette* was measured from the soil surface up to the first branching point on the primary stem (*jorquette*). Stem circle was the mean value of the stem circle measurement at the base, middle and upper stem. The number of primary branches was the number of branches that grow on the main stem. The number of leaves, the number of flowers and the number of fruits was calculated based on the fruit and flowers that grew on each plant. measurement of biomass was done by calculating only the root and above ground shoots. Biomass measurements were carried out by destructive technique. The destructively harvested plant was separated into several fractions, i.e. leaves, stem, branches, flower, fruit and root. Biomass in this present study was expressed in

Table 1. The location of top grafted young cacao plantations

Elevation Elevation group (m asl*)	Location Code	Village	Subdistrict	District	Province
<300	a	Latuppa	Muangkajang	Palopo	South Sulawesi
	b	Lebang	West Wara	Palopo	South Sulawesi
	c	Malimbumg	Sabbang	North Luwu	South Sulawesi
	d	Kasintuwu	Mangkutana	East Luwu	South Sulawesi
	e	Tuara	Enrekang	Enrekang	South Sulawesi
	f	Sidole	Ampibabo	Parigi Moutong	Central Sulawesi
300-600	g	Latuppa	Muangkajang	Palopo	South Sulawesi
	h	Battang	West Wara	Palopo	South Sulawesi
	i	Tandung	Sabbang	North Luwu	South Sulawesi
	j	Kasintuwu	Mangkutana	East Luwu	South Sulawesi
	k	Mandatte	Angeraja	Enrekang	South Sulawesi
	l	Sawidago	North Pamona	Poso	Central Sulawesi
>600	m	Bonglo	Bassesang Tempe	Luwu	South Sulawesi
	n	West Battang	West Wara	Palopo	South Sulawesi
	o	Kandede	Limbong	North Luwu	South Sulawesi
	p	Kasintuwu	Mangkutana	East Luwu	South Sulawesi
	q	Tongko	Baroko	Enrekang	South Sulawesi
	r	Mayoa	South Pamona	Poso	Central Sulawesi

Note: *asl = above sea level

Table 2. The coordinate and altitude of the top grafted young cacao plantations

Elevation group (m asl*)	Location Code	Latitude	Longitude	Altitude (m asl)
<300	a	3°01'37.6"S	120°07'49.7"E	242
	b	2°59'06.5"S	120°09'58.7"E	123
	c	2°36'25.6"S	120°11'59.9"E	107
	d	2°23'06.4"S	120°47'42.5"E	101
	e	3°31'11.0"S	119°46'22.4"E	244
	f	0°28'42.2"S	120°02'26.9"E	15
300-600	g	3°02'09.3"S	120°06'54.3"E	366
	h	2°57'58.1"S	120°08'46.9"E	328
	i	2°37'16.6"S	120°06'13.0"E	319
	j	2°22'08.0"S	120°47'19.7"E	355
	k	3°30'42.8"S	119°46'50.2"E	545
	l	1°44'25.4"S	120°39'56.4"E	579
>600	m	3°04'37.3"S	120°05'00.3"E	862
	n	2°57'40.1"S	120°05'07.5"E	671
	o	2°34'12.7"S	120°02'14.6"E	650
	p	2°19'44.0"S	120°46'50.6"E	659
	q	3°16'36.6"S	119°47'28.8"E	1186
	r	2°13'10.7"S	120°46'14.9"E	774

Note: *asl = above sea level

grams of dry weight. Each plant fraction was dried using an oven at 75 ºC to have a constant dry weight. The crown biomass distribution was measured per 10 cm, starting from the ground surface up to a maximum plant height of 130 cm. Distribution of root biomass was measured per 10 cm, starting from the ground surface to a depth of 70 cm below the soil surface. As supporting data, the average temperature, minimum temperature, maximum temperature and annual rainfall intensity in each location were online traced through http: en.climatedata.org. Data was analyzed by using analysis of variance (ANOVA) and then a Duncan multiple range test with a confidence level of 95%, using SAS software version 9.4 (Mattjik and Sumertajaya, 2013).

Results and Discussion

Microclimate of Study Site

Based on Koppen climate classification, all locations were categorized as AF type or tropical rainforest climate region with an average of rainfall intensity of at least 60 mm monthly. Thus, the range of annual rainfall intensity in all observed locations were higher than 1200 or in range of 1644-3113 mm. The group of <300 m asl showed the highest temperature compared to others, i.e. 26.28°C, 22.71°C and 30.53°C for mean temperature, minimum temperature and maximum temperature, respectively. The average of mean temperature, minimum temperature and maximum temperature from 6 locations in 300-600 m asl were 25.73°C, 21.04°C, 29.73°C, respectively. In the highest location group (>600 m asl), the average of mean temperature, minimum temperature and maximum temperature from six locations were 22.22°C, 17.97°C, 26.03°C, respectively (Table 3).

Plant Growth Performances

Our study demonstrated that plant height, stem circle and crown circle of top grafted young cacao were not significantly affected by land elevation (Table 4). There was an improvement in terms of plant height, horizontal and vertical root lengths by about 8.7%, 9.4% and 18%, respectively, on the cacao at <300 m asl compared to those in > 600 m asl. The stem circle of top grafted young cacao plants was relatively similar in range 19-20 cm. Those insignificant variation in plant growth performance could be attributed to the good adaptation ability of cacao. Cacao plants could be cultivated in areas with an altitude of 0-800 m asl, and it could even grow to a maximum altitude of 1.200 m asl (Somarriba and Sampson, 2018).

Primary stem was the main stem that became the main structure of the plant and had a role to supports

Table 3. The microclimate of the top grafted young cacao plantations

Elevation group (m asl*)	Location Code	Climate type	T mean (°C)	T max (°C)	T min (°C)	Annual rainfall intensity (mm)
<300	a	AF	25.7	22.93	29.85	2773
	b	AF	26.6	22.51	30.6	2289
	c	AF	26.8	22.81	30.75	2989
	d	AF	26.6	22.67	30.69	2446
	e	AF	26.4	22.38	30.41	2459
	f	AF	25.6	22.93	30.85	1644
300-600	g	AF	25.7	21.76	29.75	2773
	h	AF	26.6	20.53	30.45	2289
	i	AF	25.9	21.93	29.85	2962
	j	AF	26.6	20.12	30.32	2446
	k	AF	25.5	22.53	30.63	2410
	l	AF	24.1	19.39	27.4	2286
>600	m	AF	22.2	18.23	26.38	3113
	n	AF	24.5	19.03	27.04	1821
	o	AF	19.8	15.75	23.83	2690
	p	AF	22.7	18.68	26.69	2229
	q	AF	21.2	17.2	25.31	2873
	r	AF	22.9	18.9	26.9	2181

Note: AF= climate type based on Koppen; T mean= mean temperature; T max= minimum temperature; T min= minimum temperature
*asl=above sea level

the crown. The first branching that formed in primary stem was called as *jorquette*. Our results did not show any significant differences in term of the number of primary branches. The *jorquette* was formed by 2-3 branches. The number of primary branches could also be varied by the genus, for example the genus of *Criollo* and *Forastero* had as many as 4-5 primary branches. The pruning applied to form only 3 branches. The height of the *jorquette* was significantly affected by land elevations. Cacao plants that grow at an altitude of <300 m asl had a lower *jorquette* height rather than those from 300-600 m asl or > 600 m asl (Table 4). Although it had a shorter *jorquette*, plants at elevations <300 m asl had a higher number of leaves and it was significantly different than other locations. The result of previous studies by Kofidis et al., (2007) showed that the increased of elevation could cause the change in leaf growth performances such as leaf number, leaf biomass, leaf thickness, leaf area and stomatal density.

Our study showed that the number of flowers and fruit was not significantly different in response to various land elevations (Table 4). It was likely that the age of observed cacao plants were still relatively young, around 2-3 years, so they had not yet demonstrate their optimal ability to produce flowers and fruits. In general, cacao fruit production was relatively stable when plants were 4-5 years old (Adabe and Emilienne, 2014).

In general, the biomass of cacao plants was partitioned into four parts, i.e 38.76% in branches, 21.94% in stem, 20.08% in roots, and 19.22% in leaves. These results were in line with previous studies by Cotta et al., (2008) who showed the largest canopy biomass was found in the branches and followed by stem and leaves. The mean value of stem, branches and roots biomass was not significantly affected by the land elevation (Table 5). While the mean value of leaf biomass was significantly different between land elevation levels, where plants from <300 m asl had greater leaf biomass compared to those from 300-600 m asl and > 600 m asl (Table 5). Compared to plants from 300-600 and > 600 m asl, leaf biomass from <300 m asl increased by 37.7% and 38.2%, respectively. The higher leaves biomass value from plants at <300 m asl was likely related to more number of leaves, and *vice versa* to plants from 300-600 m asl and > 600 m asl.

Table 4. Plant growth performance of top grafted young cacao plant at various elevations

Plant growth performance	Elevation group (m asl)			CV (%)
	<300	300-600	>600	
Plant height (cm)	181.54±4.39	178.48±10.35	165.57±10.98	11.21
Stem circle (cm)	20.00±0.23	20.30±0.73	19.50±0.50	5.92
Crown circle (cm)	504.03±42.94	487.78±51.88	456.59±36.94	17.66
Jorquette height (cm)	19.81±0.74b	29.90±3.72a	27.80±2.14a	20.38
Primary stem number	2.40±0.11	2.60±0.10	2.60±0.13	10.79
Leaf number	157.38±22.51a	98.05±9.24b	98.77±10.96b	35.48
Flower number	2.83±2.83	1.50±1.50	2.25±1.79	165.57
Fruit number	1.00±1.00	0.00±0.00	0.50±0.50	424.26
Horizontal root length (cm)	134.26±33.00	117.63±14.90	109.96±14.60	19.28
Vertical root length (cm)	50.96±10.20	52.35±10.90	54.37±9.00	15.22

Note: Mean values followed by standard of error and different alphabet within the same row was significantly different based on Duncan multiple range test at 5%. CV= coefficient of variance (%).

Table 5. Plant biomass of top grafted young cacao at various land elevations

Biomass dry weight (g)	Elevation group (m asl)			CV (%)
	<300	300-600	>600	
	------	g per plant	------	
Stem	469.51±21.67	431.62±49.94	406.60±27.71	17.02
Branches	807.50±102.09	750.78±111.24	751.99±106.04	31.72
Leaves	511.35±73.13a	318.58±30.04b	315.87±37.08b	35.48
Root	429.35±21.05	410.17±38.69	357.35±23.11	20.77

Note: Mean values followed by standard of error and different alphabet within the same row was significantly different based on Duncan multiple range test at 5%. CV=coefficient of variance (%).

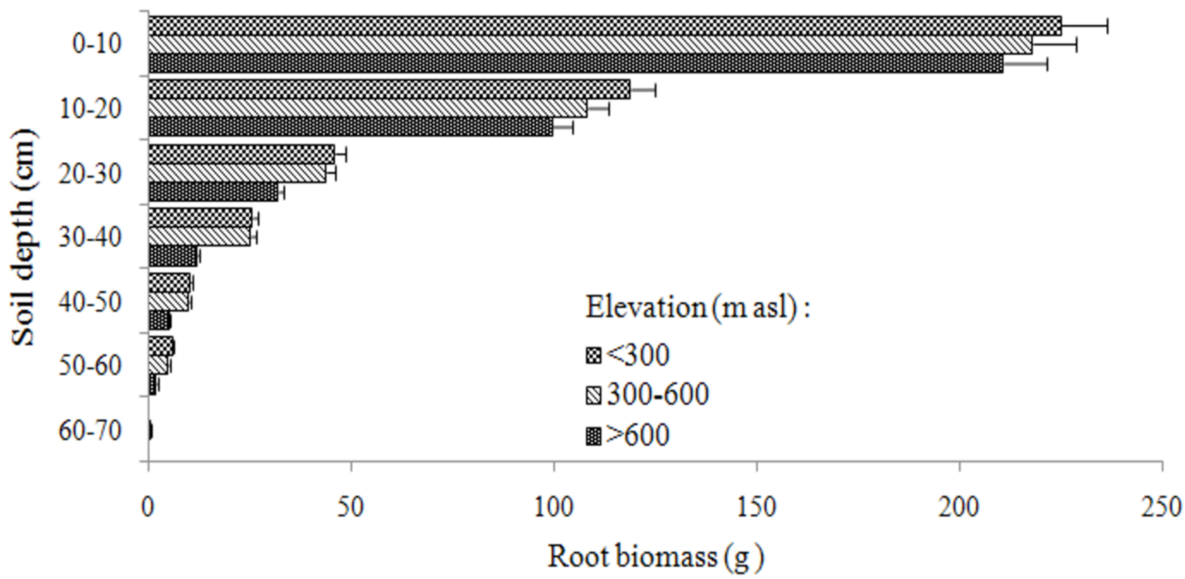

Figure 1. Root biomass distribution of top grafted young cacao at various elevations

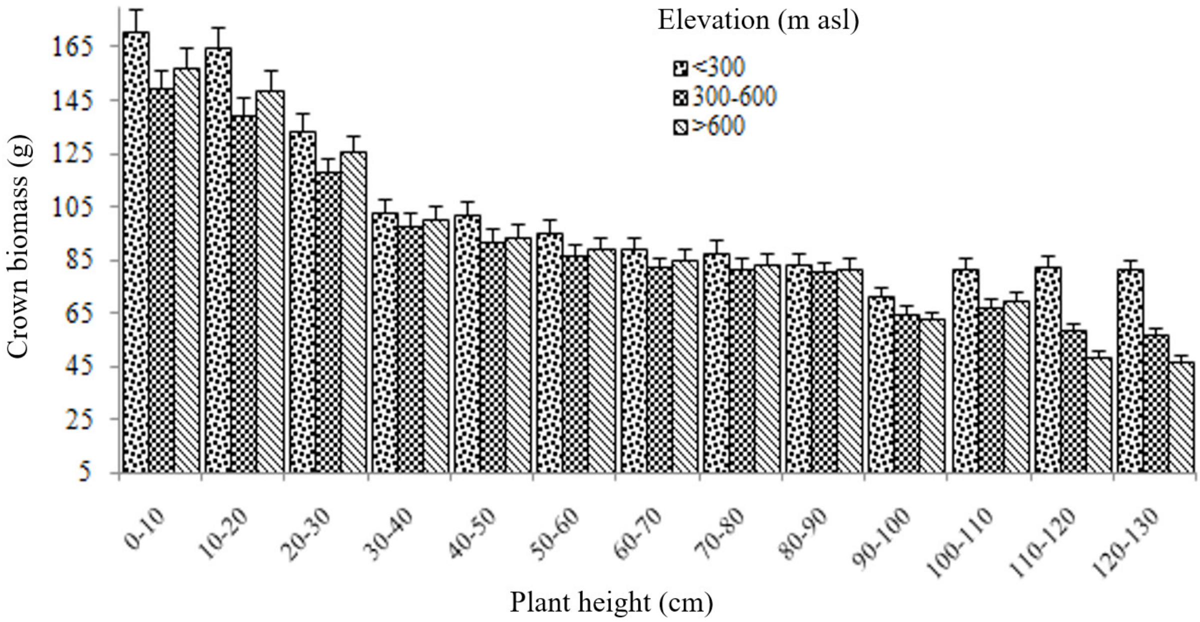

Figure 2. Crown biomass distribution of top grafted young cacao at various elevations

In root section, 54.30% from total root biomass was distributed at the 0-10 cm soil depth, then at soil depth of 10-20 cm (27.12%), and the rest was spread over up to 80 cm soil depth. At a soil depth of 0-10 cm and 10-20 cm, the root biomass of cacao plants from <300 m asl was slightly higher than those from 300-600 m, and even > 600 m asl (Figure 1). For crown section, the biomass was concentrated at a height of 0-10 cm, 10-20 cm and 20-30 cm above the soil surface with a proportion for about 12.84%, 12.19% and 10.16%, respectively. While 65% was evenly spread over the entire crown up to the maximum crown height of 130 cm above soil surface. The crown biomass distribution was relatively uniform in response to different elevations, except at plant heights of 0-10 cm, 10-20 cm, 110-120, and 120-130 cm which showed the greater results from > 300 m asl rather than others (Figure 2).

Biomass is an important indicator of the plant growth and development, and it also could be used to calculate the carbon storage of plants. According to Lodhiyal and Lodhiyal (2003), plant biomass is defined as a measurable variable of the total content of organic matter or dry matter that are stored in the entire plant body at a certain place and time. Plants are autotrophic organisms with an ability to photosynthesis absorb CO_2 from the air and then bind carbon in their bodies as dry matter or biomass (Purwanto et al., 2012). Our study has clearly quantified the growth performance of cacao grown at various elevations. This information would be useful for cacao growers, so they could expect highly similar growth performances of top grafted seedlings at various elevation.

Conclusion

Plant height, stem circle, crown circle, number of primary branches, number of flowers, number of fruits, vertical and horizontal root lengths of the top grafted cacao seedlings were not significantly affected by the land elevation. *Jorquette* height, number of leaves and actual biomass of cacao leaves from elevations <300 m asl were significantly higher than those from 300-600 m asl and >600 m asl. The distribution of root biomass was concentrated at soil depth of 0-20 cm. In similar, the distribution of crown biomass was also mostly distributed at a plant height of 0-20 cm above the soil surface.

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