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Cocoa Production Stability in Relation to Changing Rainfall and Temperature in East Java, Indonesia

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Abstract

Climate change as indicated by rising temperature and changing rainfall pattern has been known to affect cacao production in many production countries. However, studies on the effects of rainfall and temperature variability on the cacao production are rarely reported in Indonesia. Hence, the objective of this study is to evaluate the stability of cocoa production in relation to rainfall and temperature variability in order to develop sustainable production under climate change scenario. Research was conducted at a state owned company in Jember District, East Java, Indonesia from February to June 2015. Production and climatic data of 2010–2015 were evaluated using simple regression and correlation analysis. Results revealed that productivity fluctuated among months and among years. However, the fluctuation among months (σ^2 = 117.076) was lower than among years (σ^2 = 311.225). Rainfall and temperature showed variability among months and among years; and the fluctuation among months was lower in both rainfall and temperature. Rainfall at one to four months before harvest correlated with production (r=0.400–0.671; P= 0.000 to 0.001) and temperature at two to four months before harvest determined cocoa production (r=0.371–0.412; P=0.001–0.003). High monthly cocoa production coincided with decreasing temperature and rainfall for 4 to 5 months during pod development. The presented study implies that both short and long term strategies should be implemented under climatic variability to sustain cocoa production. It is recommended to apply production technology to stabilize micro climate temperature and to minimize the impact of high rainfall such as shade plant and canopy manipulation.

Keywords: Climate change, deficit water, high rainfall, irrigation, *Theobroma cacao*

Introduction

Cocoa bean (*Theobroma cacao* L.) and its derivatives are widely used as important materials on food and other industries because it contains theobromine (Martínez-Pinilla et al., 2015). The global trade in cocoa is worth US$10 billion per year (Wanger et al., 2014). Indonesia is the third largest global cocoa producer with a total production of 0.59 million tons (Dirjenbun, 2016). About 0.36 million ton, or 67%, was allocated for global trade in 2015 (Dirjenbun, 2016). Of the 1.7 million ha of cocoa field in Indonesia, 97% is owned by small holder farmers, while only 3% are managed by private or state-owned companies (Dirjenbun, 2016).

The cocoa tree is perennial and shade loving, mainly growing in the understorey in tropical countries (De Almeida and Valle, 2007; Oyekale et al., 2009; Teixeira et al., 2015; Schroth et al., 2016). The tree produces beans inside pods; the beans are obtained after fermentation. A mature cocoa tree starts to produce pods during the 3rd or 4th year after transplanting but may produce pods for over 25 years (De Almeida and Valle, 2007; Ntiamoah and Afrane, 2009). Thereafter, the trees are rejuvenated by planting new seedlings or by side grafting to maintain high productivity.

Recently, changing patterns in rainfall and rising global temperature due to the impact of climate change has affected the cocoa production, especially in African countries such as Côte d'Ivoire, Ghana and Nigeria (Oyekale et al., 2009; Läderach et al., 2013). As archipelagic regions, Indonesian crops are considered more vulnerable than the continental regions to climatic instability (McNamara and Prasad, 2014). USAID (2012) projects annual precipitation to increase in Indonesia, but in the southern regions the precipitation is estimated to decline up to 15% by 2100; and average annual temperature is expected to increase at a rate of 0.2 to 0.3°C per decade.

Consequently, future cocoa production is uncertain. The weather changes are concerning because cocoa plantations are an important source of income for 1.72 million farmers and contributes significant income for rural communities in many Indonesian islands including Java, Sulawesi and Sumatera (Bulandari, 2016; Dirjenbun, 2016). The cocoa also becomes an important material in local food products for home industries (Istiqomah et al., 2014). Therefore, securing cocoa supply in Indonesia is important.

There are numerous studies reporting the impact of rainfall and temperature on vegetative growth, flowering, pollination and bean production in cocoa (De Almeida and Valle, 2007; Omolaja et al., 2009; Adjaloo et al., 2012; Läderach et al., 2013; Afoakwa, 2014; Wanger et al., 2014; Teixeira et al., 2015; Towaha and Wardiana, 2015; Schroth et al., 2016). The rainfall and temperature are also utilized to predict crop production (Santosa et al., 2011; Purwanto and Santosa, 2016; Irfanda and Santosa, 2016). In cocoa, drought decreases yield (Wibawa and Baon, 2008; Carr and Lockwood, 2011) while heavy and excess rainfall promote flower drop along with high pest and disease infections (Wibawa and Baon, 2008). Floral phenology and the activity of pollinators are also sensitive to rainfall (Adjaloo et al., 2012). Moreover, the floral phenology, pod development and fruit dry weight are additionally sensitive to temperature changes (Daymond and Hadley, 2008; Adjaloo et al., 2012).

The objective of this study is to evaluate the effects of rainfall and temperature on cocoa production. The study was conducted in a well-managed cocoa plantation in order to minimize the bias of agro-inputs variability. The results of this study could benefit policy makers, agronomists and ecologists in developing better strategies for sustainable cocoa production management under the impact of climate change.

Materials and Methods

Research was conducted at a state-owned company Banjarsari Plantation managed by PTPN XII (-8.1745631 S, 113.5889067 E), Jember District, East Java, Indonesia. Field observations and interviews were conducted in February to June 2015. The study site had a relative air humidity of 65 to 95%, soil composed of Latosol and Regusol types with a pH of 6 to 7, and the area is hilly at altitude about 300 to 350 m above sea level.

The plantation has applied good agriculture practices to produce the best cacao bean known as 'Java Criollo' (means: authentic fine cocoa flavor of Java) for export. Briefly, the plantation managed 391.0 ha of cacao field, of which 227.6 ha was fine flavor cocoa (edel type cacao) and 163.4 ha of bulk cacao. In this study, only edel cacao was evaluated. The clone composed of DR1, DR 2, DR 38, and DRC 16 was arranged at a distance of 3 × 3 m or 1100 cacao tree per ha. The shade tree was Lamtoro (*Lauchaena glauca*) arranged at 3 × 6 m, or 555 trees per ha. All seedling were grafted with DR2 and DR 36 as rootstocks.

Urea (46% N), TSP (36% P_2O_5), KCL (60% K_2O), Kieserit (MgO), and ZA (24% SO_4^{2-}; 21% N) were applied three times a year, i.e., at January to February, April to May, and October to November. Annual rate of urea was 120 g, TSP was 200 g, KCL was 200 g, kieserite was 100 g, and ZA 80 g per plant. Additional foliar fertilizers in the form of urea solution at 5 to 10 $g.L^{-1}$ were applied if trees exhibited nutrient deficiency symptoms; the foliar fertilizer was applied twice a month during April to June and September to October and micro nutrient solution containing 2 $g.L^{-1}$ of each $MgSO_4$, $MnSO_4$, $CuSO_4$, and $FeSO_4$ was applied 5 times a year. Micro nutrient solution containing $ZnSO_4$ was applied separately twice a month for three consecutive months starting from young pod, in order to increase bean size.

Data on culture technique, bean production and rainfall of 2010 to 2015 were obtained from the company reports. Additional data related to technical on water management, tree condition and tree responses related to climate variability were collected through interviews with field workers and managers. In present study, beans composed of dried edel bean after fermentation, irrespective of its AA, A, B, C and S qualities. The beans were collectted from mature trees aged 7 to 19 years old grown on a total area 227.6 ha. Dried beans with water content 6 to 7% were obtained after drying in the sun or oven. Rainfall was measured using the Ombrometer method. Additional temperature data was obtained from the local weather station at Banjarsari subdistrict, Jember District managed by the Agency on Meteorology and Geophysics (BMKG), located about 20 km from the plantation.

Correlation between rainfall and temperature and bean production was calculated by assuming linear model, where Y: monthly bean production (kg), $\beta_k X_{ki}$: independent variables of total monthly rainfall (mm) and average monthly temperature (ºC). Data analysis was done using Minitab 15, [$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \varepsilon$; where Y: cacao bean production; β_0: Constant at all predictor setted at zero; β_1 and β_2: Constant of X_1 and X_2, variables, respectively and ε: error. The data of Y_T (bean production at present month-*T*0) was correlated with rainfall and temperature at *T*-0, *T*-1 (1 month before harvest-MBH), *T*-2 (2 MBH), *T*-3 (3 MBH), *T*-4 (4 MBH), and *T*-5 (5 MBH). The five months before harvest was based on Alvim (1988) and Towaha and Wardiana (2015).

A multiple regression model used the least squared approached by assuming no multicollinearity, heteroscedastisity, and autocorrelation (Mirer, 1995; Juanda, 2009). Multicollinearity was estimated from variance inflation factor value (VIF) of less than 10. Acceptable heterocedastisity was estimated from absence of distribution pattern between errors to Y (Mirer, 1995). Autocorrelation was estimated from Durbin Watson (DW) value where 2 means no autocorrelation existed; if DW < 2 or DW > 2, the Cochrane-Orcutt method was applied.

Soil water was considered as a deficit when water balance (WB) was negative; its calculation followed Santosa et al. (2011). Briefly, $WB_m = (WS_m+P_m)-ET_m$, where WB_m: present month water balance, WS_m: present soil water stock, P_m: present precipitation (mm), ET_m: present evapotranspiration, and *m-1*: data previous month. The equation worked with assumption: $WS_m = 0$ if WB_{m-1} is zero or not determined; WSm = 200 if $WB_{m-1} > 200$; $WS_m = WB_{m-1}$ when WB_{m-1} value 1 to 200 mm. ET_m = 150 mm or 120 mm when number of monthly rainy day (RD) < 10 days or RD $\geq$ 10 days, respectively. The amount of water deficit (WD_m, mm) = $[WB_m] + ET_m$; where $[WB_m]$ is an absolute value.

Results and Discussion

Production Stability

Total annual production ranged from 69.7 to 105.6 tonnes and efficiency ranged from 306 to 464 kg.ha^{-1} per year (Figure 1). Productivity of the plantation was highest in 2012 and the lowest in 2013. When compared to the total national productivity the tree productivity on this study site was considered as low (Dirjenbun, 2016). The low crop productivity was presumably related to cocoa genotypes, population density and fertility level of the soil. The cocoa productivity in latosol soil type is much lower than other soil types, such as Regosol (Hazriyal et al., 2015). In this study site, the plants that died due to common disease or physiological disorders were replaced using the following procedure: two dead plants were replaced with one seedling. If the tree death was due to root disease or infertile soil the trees were not replaced. The white root disease was an apparent problem in the site. As a result, actual tree population decreased from 1100 trees at the initial planting into 700 to 900 trees per ha.

Monthly productivity ranged from 3 to 56 kg.ha^{-1} (Figure 1C). On a monthly basis, the productvity could be divided into three levels, i.e., low season (up to 10 kg.ha^{-1} per month), medium (10–30 kg.ha^{-1} per month), and high season harvesting (> 30 kg.ha^{-1} per month) coresponding to January to April, May to August, and September to December, respectively. The January to April contributed 6 to 19%, May to

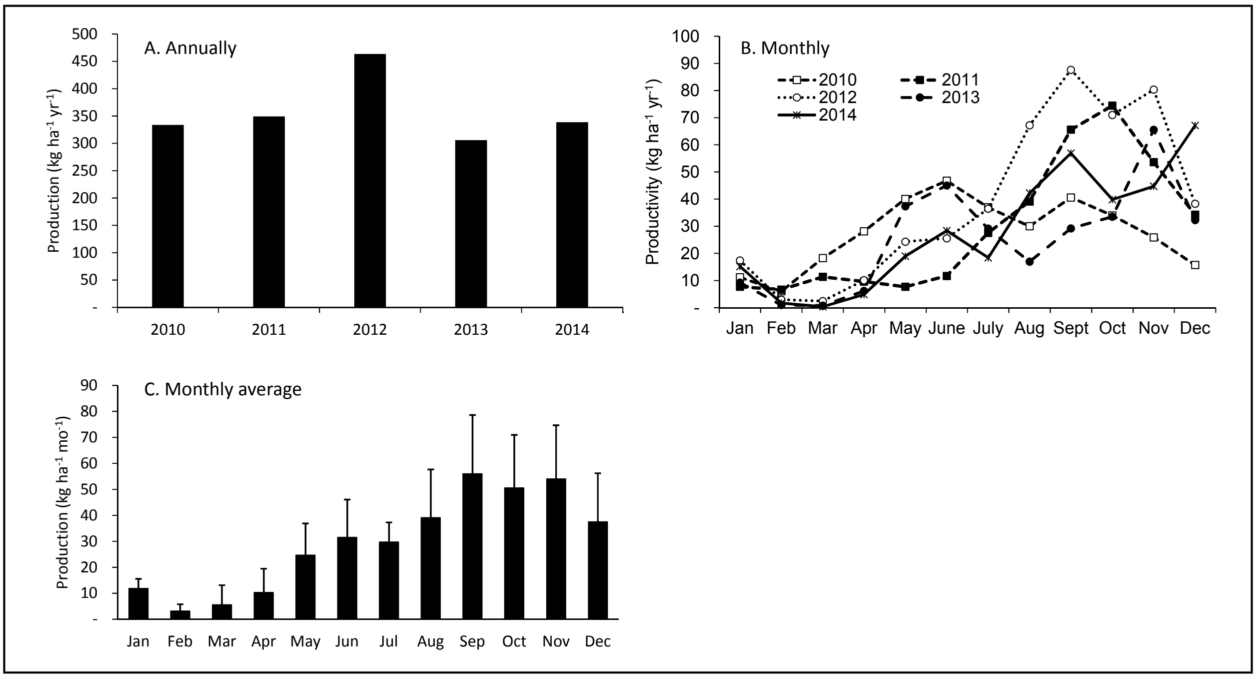

Figure 1. Annual (A) and monthly (B and C) cacao productivity in Banjarsari estate, East Java, Indonesia from 2010 to 2014. Values are mean±SD.

August contributed 22 to 34% and September to December contributed 23 to 47% of total annual production.

There was significant variation (σ^2) in productivity among years and among months ($p<0.001$; Tables 1 and 2). Annual variation (average $\sigma^2=467.669$) was significantly higher than that of the monthly variation (average $\sigma^2=175.927$). This indicates the annual climate variation greatly affected productivity. According NOAA (2017), Indonesian climate was under influence of La Nina in 2010, El Nino in 2011, and normal weather in 2012-2014. It is likely that under La Nina effects, productivity variation among months within particular year was lower as compare to the other effects (Figure 1B).

Table 2 shows that January and February had the lowest productivity variation whereas high variation was apparent in August to December. In this case, high productivity variation in the last five months was mainly due to low productivity in 2010 in situation of La Nina (Figure 1B). La Nina in Indonesia is not usually followed a substantial number of dry months (Suwandi et al., 2014). It is probable that a humid micro climate during La Nina was the main constrain on the production of cocoa in this study. However, further studies are needed on how the microclimate profile affects cocoa production in Indonesia.

Rainfall Distribution and Variability

Rainfall exhibited variation among month within years and among months across years (Tables 1 and 2, Figure 2). The rainfall variation value was lower among months across years than among months within year, i.e., $\sigma^2=19{,}121.920$ and $\sigma^2=56{,}176.444$, respectively. It seemed that December and January had the highest rainfall variability, while July to October had the lowest across years with exception of September (Table 2).

Table 1. Variant (σ^2) of annual cacao productivity (P), rainfall (R) and temperature (T) in Banjarsari estate, Jember district, East Java

Year	σ^2 P	σ^2 R	σ^2 T
2010	149.189	15,255.917	0.187
2011	544.515	28,072.743	0.874
2012	852.831	74,174.521	0.667
2013	348.755	72,397.188	0.572
2014	443.053	90,981.854	0.493
Average	467.669	56,176.444	0.559
σ^2 total	492.664	55,899.407	0.675

Table 2. Variant (σ^2) of monthly cacao productivity (P), rainfall (R) and temperature (T) in Banjarsari estate, Jember district, East Java

Month	σ^2 P	σ^2 R	σ^2 T
Jan	11.533	30,589.556	0.074
Feb	5.452	9,419.333	0.050
Mar	47.314	18,028.139	0.154
Apr	69.695	10,388.472	0.239
May	124.229	18,143.222	0.134
June	170.564	16,481.840	0.690
July	46.104	3,877.760	0.599
Aug	274.486	6,523.440	0.375
Sep	410.038	17,851.360	0.260
Oct	333.803	6,620.960	0.219
Nov	340.331	17,624.800	0.104
Dec	277.574	73,914.160	0.120
Average	175.927	19,121.920	0.252
σ^2 total	492.664	55,899.407	0.675

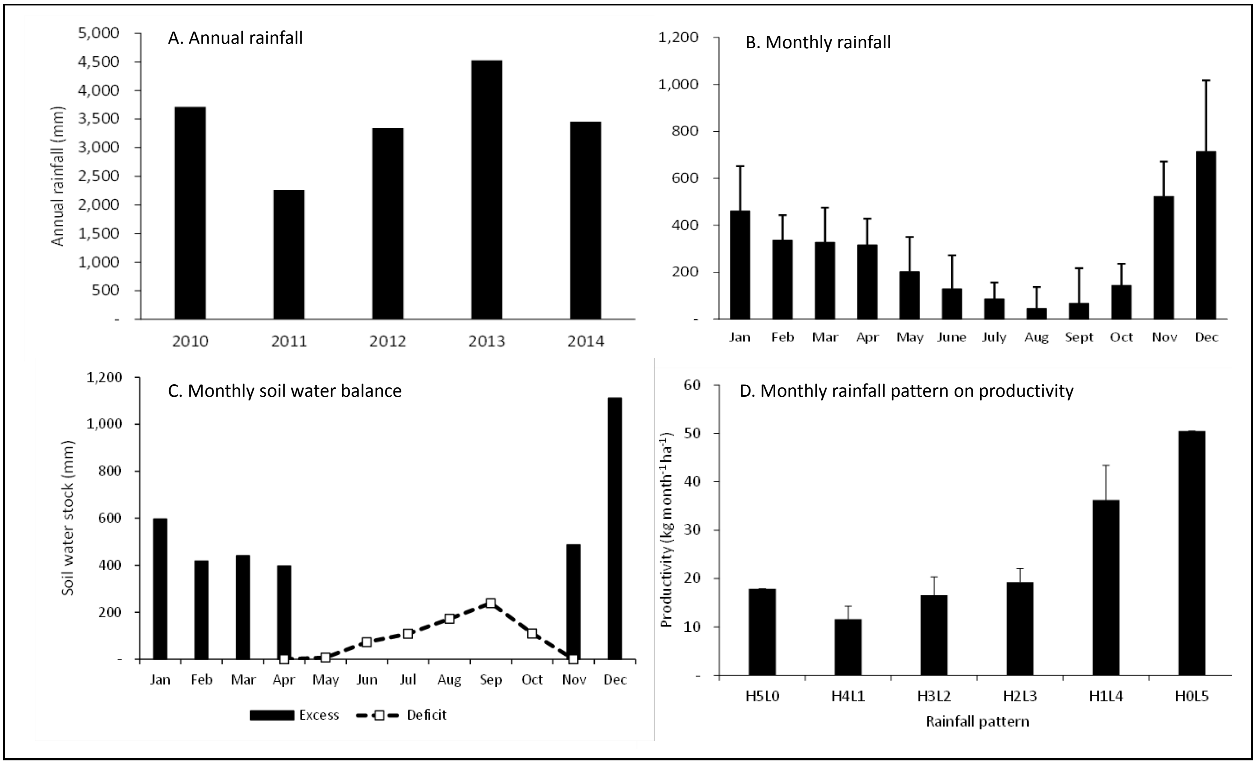

Figure 2. Annual (A) and monthly rainfall (B), water balance (C) and monthly cocoa productivity (D) in Banjarsari cacao plantation, Jember, East Java from 2010 to 2014. A: total annual rainfall, B: average monthly rainfall, C: average monthly water deficit and excess water, D: rainfall pattern during pod development; H5L0: high rainfall for five months, H4L1: high rainfall for four months and low rainfall for one month. H0L5: low rainfall for five months; H: rainfall >200 mm. Values are mean±SE.

The annual rainfall in 2011 was the lowest (Figure 2A), while 2013 and 2014 had normal rainfall (NOAA, 2017). Total annual rainfall was 35.3% higher in 2013 and 3.2% higher in 2014 than the rainfall in 2012. The excess rainfall may explain the lower production in both 2013 (34%) and 2014 (27%) compared to 464 kg.ha^{-1} in 2012 (Figure 1A). The monthly rainfall showed unimodal distribution (Figure 2B). On average, a wet month had minimum rainfall of 108 to 117 mm and maximum of 483 to 1031 mm. Peak rainy season occured in December or January in each year. Average numbers of monthly rainy days were 13.3 days, with maximum 22 to 27 days within a month.

Rainfall in the dry months of July to September was less than 100 mm. Deficit soil moisture predominantly occured for three to five months around May to October (Figure 2C). Based on interviews to managers, the plantation had applied activities to maintain soil moisture during dry months thoroughly to reduce evaporation, conserve soil humidity and irrigation such as applying mulch inside silt pit. Soil evaporation was minimized by controlling weeds and mild soil plowing at the end of rainy season to cut soil capilary channels. A set of *rorak* (silt pit) of 2 m × 0.6 m × 0.4 m for about 25% of total land was constructed in order to collect runoff water and control soil erosion along the edge of terracing. The *rorak* also functioned as dumping site for litters, pod skin, and pulled weeds. In severe dry season (August to October), about 45000 L.ha^{-1} water was supplied into an irrigation channel twice a month for the area closest to the water spring. Otherwise, individual tree watering was applied 40 L per day at similar watering frequency using a pump. However, the amount of water might be insufficient particularly during El Nino in 2012. As a result, some trees suffered from drought and intensive leaf fall. Cacao roots are sensitive to drought (Moser et al., 2010). According to Valle et al. (1987), a non-shaded cacao tree transpires 45 L per day on a cloudy and 90 L per day on sunny days, while it is 26 and 40 L per day for a shaded cacao tree on cloudy and sunny days, respectively.

Correlation of Rainfall with Cocoa Production

There was a significant correlation between monthly cacao production and rainfall (Table 3). Rainfall for four months before harvest significantly affected the production ($p < 0.01$), while current monthly rainfall (HM) and five months before harvest (5 MBH) had no significant correlation. This finding matches previous studies (Alvim, 1988; Towaha and Wardiana, 2015).

In this study, all significant correlation was negative, indicating that high rainfall was followed by low production. High constant values of 2 and 3 MBH, i.e., r^2=-0.671 and r^2=-0.647, implied that the rainfall of those months played important role in the total production.

Figure 3A shows that increasing monthly rainfall, irrespective of the month before harvest, was followed by lower yield. However, based on correlation value (r^2=0.1559–0.4501), the correlation was relatively weak. Further analysis by using the monthly average, was revealed that monthly rainfall at a range of 125 to 200 mm was the best rainfall range for high yield (data not shown). Rainfall less than 125 mm tended to achieve higher production compared to rainfall higher than 200 mm. The higher yield could be due to proper management on soil moisture during pod growth and development, especially the utilization of irrigation channels, during a mild dry period.

A simulation on rainfall distribution, considering that pod growth and development requires 5 months, demonstrated that the rainfall pattern determined production. Figure 2D shows that under continuous exposure of high rainfall for 2 to 5 months (H5L0, H4L1, H3L2, H2L3) the trees had lower productivity. On the other hand, 4 to 5 months with rainfall 200 mm or less (H1L4, H0L5) correlated with high productivity. It has been known that adequate soil moisture during about 5 months of pod growth and development secures cocoa production (Tjasadihardja, 1987; Alvim, 1988; De Almeida and Valle, 2007; Adjaloo *et al*., 2012; Ortiz, 2016). According to Tjasadihardja (1987), 3 months after anthesis is the most critical time for the physiological disorder causing cherelle wilt. Moreover, Adjaloo *et al.* (2012) stated the rainfall determines the floral phenology and it accounts for 75 to 78% of the variation in the floral production. The effect of rainfall variability during pod growth and development that determined cocoa production needs further verification. Zuidema et al. (2005) speculated that annual rainfall during the dry season explained 70% of the variations in annual seed yields in the tropical cacao producing areas.

High rainfall promotes high flower flushing irrespective of the cocoa clones (Prawoto, 2014); it also promotes floral bud production (Adjaloo et al., 2012). In this study, most trees underwent high flowering flush in January to March and October to December, although low flush still occured in some trees in the other months. Moreover, during the rainy season many flower buds were formed. However, it is still unclear why production was low in January to March when high monthly rainfall and positive soil water balance was obtained (Figure 2B-C). It is possible that the low production during the high rainfall is related to high incidents of flower drop pod rot by *Phytophtora palmivora* and vascular streak dieback caused by *Oncobasidium theobromae* Talbot and Keane as reported by Wibawa and Baon (2008) and Purwati (2011).

Although mild dry months benefit production in the present study site, extended dry spells could severely reduce yield as in 2012 when El Nino caused inadequate rainfall to support the water reservoir. According Towaha and Wardiana (2015), drought for six months before harvest decreases cacao production by 4.92–42.54%. Drought also promotes high incident of cherelle wilt according to Prawoto (2014). In the study site, the water table ranged from 2.5 to 3.0 m below soil surface based on water level inside the existing wells. Medina and Laliberte (2017) noted that fine cocoa roots concentrated at 0.2 to 0.4 m below soil surface, means that most cocoa roots in the Banjarsari plantation were unable to utilize the soil water table. Therefore, biomulch application as well as planting deeper rooting tree species as shade plant could benefit to maintain microclimate during long dry spell as has been rrecorded by Vanhove et al. (2016) in in agroforestry cocoa production.

Temperature Variability and Its Effects on Cocoa Yield

Temperature variability was low within particular months across years, while the variability increased

Table 3. Correlation test the effect of monthly rainfall and temperature on cacao bean production in Banjarsari cacao estate, Jember district, East Java

Variable	P Value					
	HM	1 MBH	2 MBH	3 MBH	4 MBH	5 MBH
Rainfall	0.842	0.000**	0.000**	0.000**	0.001**	0.908
Temperature	0.629	0.052	0.002**	0.001**	0.003**	0.455
	Correlation Value					
Rainfall	-0.025	-0.431	-0.671	-0.647	-0.400	0.015
Temperature	-0.061	-0.244	-0.390	-0.412	-0.371	-0.099

Note: HM=harvesting month; MBH=month(s) before harvest; **values are significantly different according to at α 1%.

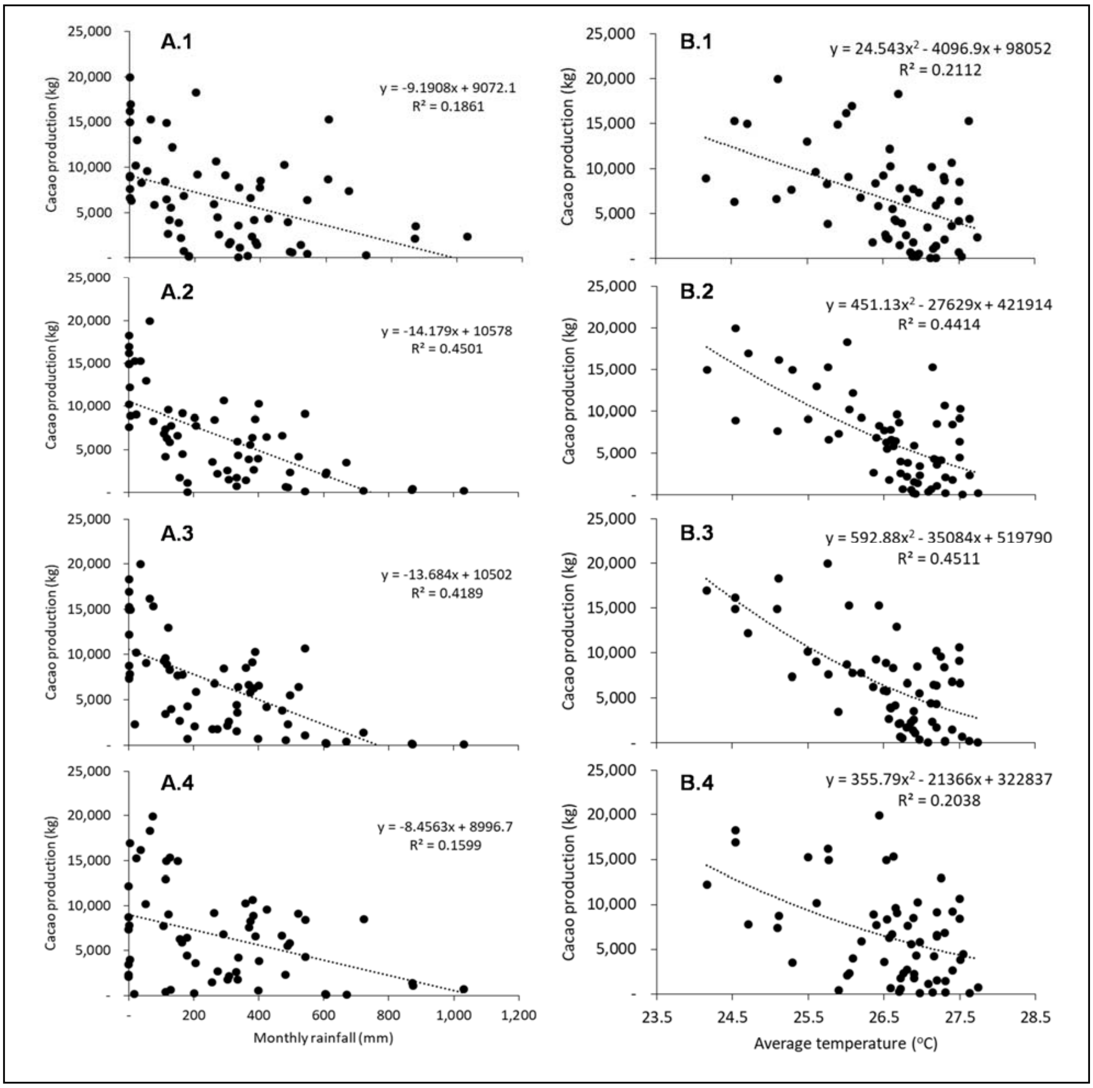

Figure 3. Rainfall (A) and temperature (B) in relation to monthly production of Banjarsari cacao estate, Jember, Indonesia; A1 or B1 are one month before harvest (MBH), A2 or B2 are 2 MBH, A3 or B3 are 3 MBH and A4 or B4 are 4 MBH.

among months within particular years (Tables 1 and 2, Figure 4). Average monthy temperature was 26.6 ºC (24.2 to 27.7 ºC), and the low average was in June to September and sometimes extended to October (Figure 4B). Interestingly, absolute maximum temperature tended to decrease by 1.05 ºC on average during 2010 to 2014, although in some months around June to August the maximum temperature decreased up to 5 ºC (Figure 4A). Similar trends were noted on the absolute minimum temperature, it tended to decrease 0.68 ºC on average. Some nights during June to August, the night temperature was below 18 ºC, which is below the minimum temperature for cocoa growing according to Afoakwa (2014).

There was significant correlation between monthly cacao production and temperature (Table 3). In January 2013, the average temperature was recorded at 20.89 ºC. However, it was considered uncommon thus it was excluded from further analysis. In this study, the effect of temperature was negative to production, indicating that decreasing temperature favoured on high yield. This finding is in line with Daymond and Hadley (2008). On the other hand, Adjaloo et al. (2012) found that temperature has a positive effect on floral bud production and the opening of flowers. It is probable that the effect of temperature depends on growing stages of flowers and pods. The number of flower bud abortions and pod setting is strongly affected by clone (Prawoto, 2014; Sari and Susilo, 2015); it is also possible that different clones have different sensitivity to temperature.

Unlike in a common hypothesis where higher rainfall correlates with lower temperature (Estiningtyas et al., 2007), this study demonstrated that monthly

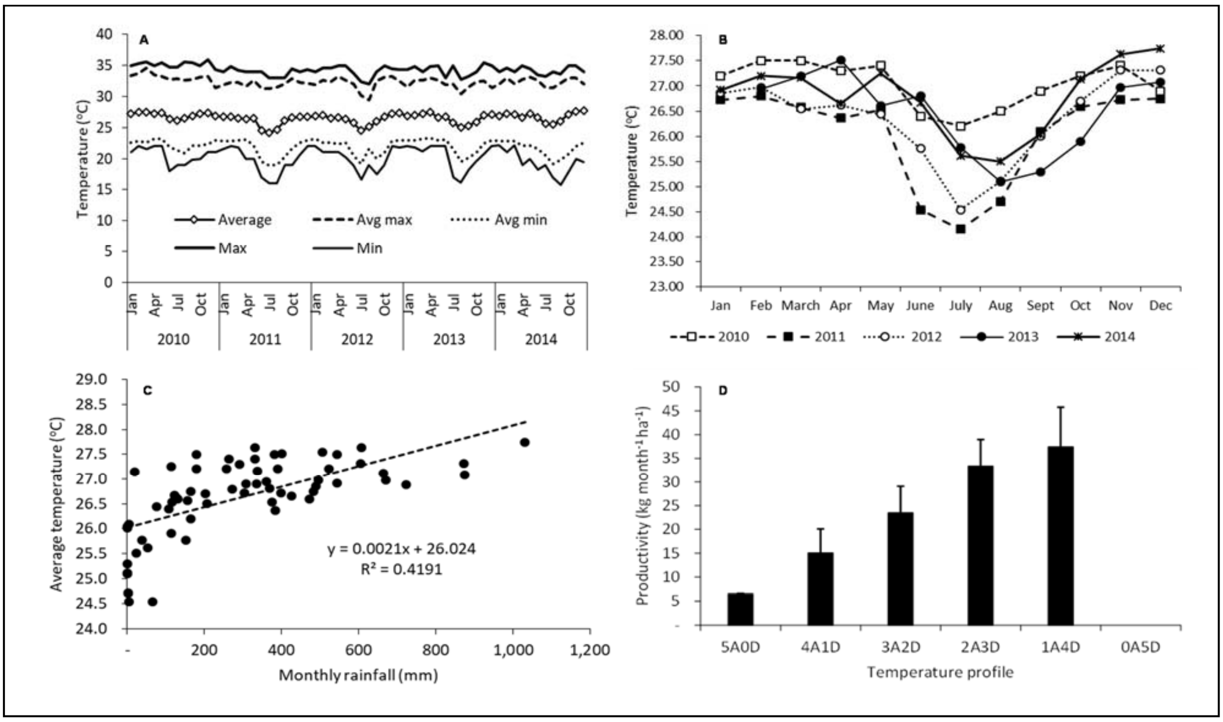

Figure 4.Annual profile of temperature (A), average monthly temperature (B), relationship between rainfall intensity and temperature (C) and the effect of five months temperature before harvest on productivity (D) of 2010 to 2015 in Banjarsari cacao estate, East Java. 5A0D: temperature ascending for five month, 4A1D: temperature ascending for four months and descending for one month; 0A5D: temperature decrease for 5 months. No data for 0A5D. Values are mean±SE.

temperature tended to increase during high rainfall (Figure 4C). This fact might explain why disease infection in the study site was recorded high during rainy season. According to Purwati (2011), high rainfall and high relative air humidity stimulates higher pathogenicity of vascular streak disease (VSD) infection caused by *O. theobromae*. In the present study, raising temperature during pod growth and development negatively affected the productivity (Figure 4D). It seemed that decreasing temperature for a consecutive 4 months (1A4D) produced the highest productivity as compared to other conditions. However, increasing temperature for 5 months (5AD0) during pod growth and development caused the lowest productivity. Figure 3B shows that the relationship between temperature on cacao growth was non linear. Although this finding needs further verification using individual pod, the study suggested that maintaining low temperature might benefit cacao production.

Future Challenges in Tropical Cocoa Production

The present study revealed that cocoa production in Jember was strongly influenced by rainfall and temperature. Unlike general problems faced in cocoa production by increasing temperature and shortage of rainfall, the fluctuation on temperature and rainfall became prominent in this study. Therefore, generic tools to improve production stability could include enhanced number of shade tree that produce more pollen as pollinator rewards, creating micro climate stability, and providing shade trees (Wanger et al., 2014; Schroth et al., 2016; Medina and Laliberte, 2017).

Secondly, in most Indonesian cases, cost structure in cocoa production was close to the break even point. Any increase in cost of production by 5% should be followed by increasing farm gate price of cocoa bean by 5%, otherwise the production will decline by 5% (Kawati, 2013). Most plantations have achieved technical efficiency with a value of 83.3% of production potential. Therefore, the chance to improve production was less than 20% (Arfitasari, 2015). Hence, technological approaches that increase labor force causes the production to become less competitive (Sarini, 2017). Moreover, intervention on production such as investment of new type shade tree, irrigation facilities, could increase the cost of production leading to higher cocoa bean price. For instance, planting denser shade trees might benefit during dry season, but detrimental effect during rainy season due to increasing labor force for shade tree prunning.

Three approaches for cocoa stability were proposed.

First, the approach followed by Vanhove et al. (2016), e.g., integrated approaches using agroforestry system especially shade trees is a more viable result because it is linked with the creation of an environment that improves cocoa crop physiology and reduces pressure of pests and diseases. Introduction of clone with high pod setting (Prawoto, 2014) and high success pollination rate such as Sca 6 (Sari and Susilo, 2015) could be considered; in addition to adopt Wanger et al. (2014) suggestion, i.e., using shade trees that make plantations more resilient to drought and provide habitat for pollinators.

Second, because heavy rainfall is usually followed by strong winds, managing cocoa canopy architecture to reduce direct impact of rain drop on flower buds and humidity to reduce disease incidents are important. Securing the flower buds from strong wind impact should be considered in the future to sustain production during high rainy season. Excess heavy rainfall might directly cause flower bud drop, partial lodging on fine roots of cocoa, and might disturb pollinators' activities. Bertolde et al. (2012) stated that continous flooding on cacao tree cause plant dead.

Third, an integrated approach on culture technique should be implemented in Indonesia through stabilize production during rainy and dry seasons as well by maintaining optimum cocoa canopy architecture. Observation in a small holder plantation close to study site by Wijayanti (2010) revealed that plant productivity vary greatly among seasons with maximum production 500 kg.ha^{-1} per year. Regular prunning and proper fertilizers application are recommended.

Nevertheless, as the majority of cocoa production in Indonesia is managed by small holder farmers, these three approaches need further evaluation on the effectiveness to reduce vulnerability to climate change particularly for small holder farmers.

Conclusion

There was significant correlation between rainfall and temperature with cacao bean production. Variability in annual productivity was more significant than monthly productivity. Monthly bean production could be predicted from monthly variability in rainfall and temperature. High monthly rainfall and temperature at 2, 3 and 4 months before harvest had detrimental effects on the monthly cocoa bean production. Based on the correlation value, it is likely that the effect of rainfall at 2 and 3 MBH was more pronounced than the effect of temperature, e.g., $r = -0.671$ and -0.647 and $r = -0.390$ and -0.412, respectively. Monthly rainfall 125 to 200 mm seems to promote high cacao production, but rainfall of > 200 mm had negative impacts on production. However, in the present study, production estimation based on rainfall and temperature model resolved unsatisfy results because of the weak correlation value of $r < 0.500$. It means that other variables such as crop management and edaphic factors should be considered as key components in the production estimation. It implies that to enhance sustainable cacao production under excess rainfall or increasing temperature, integrated approaches should be implemented.

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References

[Dirjenbun] Direktorat Jenderal Perkebunan. (2016). Tree Crop Estate Statistics of Indonesia 2015-2017: Cocoa. Directorate General of Estate Crops, Ministry of Agriculture Republic of Indonesia. http://ditjenbun.pertanian.go.id. [January 25, 2018].

[NOAA] National Oceanic and Atmospheric Administration. (2017). Analysis monitoring enso-stuff enso-years. http://origin.cpc.ncep.noaa.gov/products/ analysis_monitoring/ensostuff/ONI_v5.php [January 25, 2018].

[USAID] United States Agency for International Development. (2012). Indonesia climate vulnerability profile. https://www.climatelinks.org/sites/default/files/asset /document/indonesia_climate_vulnerability_profile_jan2013.pdf. [January 25, 2018].

Adjaloo, M.K., Oduro, W., and Banful, B.K. (2012). Floral phenology of upper amazon cocoa trees: Implications for reproduction and productivity of cocoa. *ISRN Agronomy* **2012**, ID 461674. DOI: 10.5402/2012/461674.

Afoakwa, E.O. (2014). "Cocoa Production and Processing Technology". CRC Press. Boca Raton London New York. 374p.

Alvim, P.T. (1988). Relações entre fatores climáticos e produção do cacaueiro *In* "Proceeding of 10th

International Cocoa Research Conference" pp.159–167. Santo Domingo, Dominican Republic.

Arfitasari, R.D. (2015). "Analysis of Technical Efficiency Factors Using of Bulk Cocoa Commodity Production at PTPN XII Kebun Banjarsari Jember". [Undergraduate thesis]. Department of Agribusiness, Faculty of Agriculture, University of Jember. http://repository.unej.ac.id

Bertolde, F.Z., Almeida, A.A.F., Pirovani, C.P., Gomes, F.P., Ahnert, D., Baligar, V.C., and Valle, R.R. (2012). Physiological and biochemical responses of *Theobroma cacao* L. genotypes to flooding. *Photosynthetica* **50**, 447–457. DOI: 10.1007/s11099-012-0052-4

Bulandari, S. (2016). Effect of cocoa production on economic growth in Kolaka Utara District. [Undergraduate thesis]. Department of Economics, Faculty of Economy and Moslem Bussiness, Alaudin Islamic State University, Makassar, Indonesia. Http://repositori.uin-alauddin.ac.id

Carr, M.K.V., and Lockwood, G. (2011). The water relation and irrigation requirements of cacao (*Theobroma cacao* L.): a review. *Experimental Agriculture* **47**, 653–676.

Daymond, A.J. and Hadley, P. (2008). Differential effects of temperature on fruit development and bean quality of contrasting genotypes of cacao (*Theobroma cacao*). *Annals of Applied Biology* **153**, 175–185. DOI: 10.1111/j.1744-7348.2008.00246.x

De Almeida, A-A.F., and Valle, R.R. (2007). Ecophysiology of the cacao tree. *Brazilian Journal of Plant Physiology* **19**, 426–448. DOI:10.1590/S1677-042020070004000 11.

Estiningtyas, W., Ramadhani, F., and Aldrian, E. (2007). Correlation analysis of rainfall and Indonesia sea surface temperature, and its implications on rainfall prediction: Cilacap case study. *Jurnal Agromet Indonesia* **21**, 46–60.

Hazriyal, Y., Anhar, A., and Karim, A. (2015). Evaluation of land characteristics and cocoa production in Peudawa and Peunaron subdistricts, East Aceh district. *Jurnal Manajemen Sumberdaya Lahan* **4**, 579–590.

Irfanda, M., and Santosa, E. (2016). Production estimation of oil palm (*Elaeis guineensis* Jacq.) in Sei Air Hitam estate base on agroecological factors. *Buletin Agrohorti* **4**, 282–287. DOI: 10.29244/agrob.4.3.282-287

Istiqomah, S., Hanani, N., and Dwiastuti, R. (2014). The economics behavior of Indonesian cocoa. *Habitat* **25**, 135–142.

Juanda, B. (2009). "Econometics Modelling and Estimation". IPB Press, Bogor. 240 p. (In Indonesian).

Kawati, E.R. (2013). "Financial Feasibility and Prospect of Bulk Cocoa Farming at PTPN XII (Persero) Banjarsari Plantation, Jember Regency". [Undergraduate thesis]. Department of Social-Economics of Agriculture, Faculty of Agriculture, University of Jember, Indonesia. http://repository.unej.ac.id. [January 25, 2018].

Läderach, P., Martinez, A., Schroth, G., and Castro, N. (2013). Predicting the future climatic suitability for cocoa farming of the world´s leading producer countries, Ghana and Côte d'Ivoire. *Climate Change* **119**, 841–854. DOI: 10.1007/s10584-013-0774-8

Martínez-Pinilla, E., Oñatibia-Astibia, A., and Franco, R. (2015). The relevance of theobromine for the beneficial effects of cocoa consumption. *Frontiers in Pharmacology* **6**, 30. DOI: 10.3389/fphar.2015.00030.

McNamara, K.E., and Prasad, S.S. (2014). Coping with extreme weather: communities in Fiji and Vanuatu share their experiences and knowledge. *Climatic Change* **123**, 121–132.

Medina, V., and Laliberte, B. (2017). A review of research on the effects of drought and temperature stress and increased CO_2 on *Theobroma cacao* L., and the role of genetic diversity to address climate change. Costa Rica: Bioversity International. https://www.bioversityinternational.org/fileadmin/user_upload/Review_laliberte_2017_new.pdf.

Mirer, T.W. (1995). "Economic Statistics and Econometrics". Prentice Hall. 449p.

Moser, G., Leuschner, C., Hertel, D., Hölscher, D., Köhler, M., Leitner, D., Michalzik, B., Prihastanti, E., Tjitrosemito, S., and Schwendenmann, L. (2010). Response of cocoa trees (*Theobroma cacao*) to a 13-month desiccation period in Sulawesi, Indonesia. *Agroforestry Systems* **79**, 171–187. DOI: 10.1007/s10457-010-9303-1.

Ntiamoah, A., and Afrane, G. (2009). Life Cycle Assessment of Chocolate Produced in Ghana. pp 35-41. *In* Appropriate Technologies for Environmental Protection in the Developing World (E.K. Yanful, ed.). Springer, Dordrecht. DOI: 10.1007/978-1-4020-9139-1_5.

Omolaja, S.S., Aikpokpodion, P., Adedeji, S., and Vwioko, D.E. (2009). Rainfall and temperature effects on flowering and pollen productions in cocoa. *African Crop Science Journal* **17**, 41–48.

Ortiz, F. (2016). *Theobroma cacao* L Monograph. Colegio Bolivar 2016-17. http://www.colegiobolivar.edu.co/garden/wp-content/uploads/2017/06/FOrtiz-Theobroma-cacao-2017.pdf.

Oyekale, A.S., Bolaji, M.B., and Olawa, O.W. (2009). The effects of climate change on cocoa production and vulnerability assesment in Nigeria. *Agriculture Journal* **4**, 77–85.

Prawoto, A.A. (2014). Pattern of flushing, cherelle wilt, and accuracy of yield forecasting of some cocoa clones. *Pelita Perkebunan* **30**, 100–114.

Purwanto, I.J., and Santosa, E. (2016). Relationship between fruit quality and precipitation on free fatty acids content of palm oil. *Buletin Agrohorti* **4**, 250–255. DOI: 10.29244/agrob.4.3.250-255

Purwati, E. (2011). “Relationship of Inoculum Density and Disease Intensity of VSD on Cocoa Planting at Two Locations of Plantation Area of PTPN XII”. [Undergraduate thesis]. Department of Agronomy, Faculty of Agriculture, the University of Jember. http://repository.unej.ac.id.

Santosa, E., Sulistio, H., and Dharmawan, I. (2011). Estimation of oil palm production in Kalimantan using agronomical and agroecological data. *Jurnal Agronomi Indonesia* **39**, 193–199.

Sari, I.A., and Susilo, A.W. (2015). Phenology of flowering and pod maturity on some cocoa clones (*Theobroma cacao* L). *Pelita Perkebunan (Coffee and Cocoa Research Journal)* **3**, 73–80.

Sarini. (2017). Efficiency on cocoa agroinputs uses at Dolago village Parigi Selatan subdistrict, Parigi Moutong District. *e-Jurnal Mitra Sains* **5**, 37–47.

Schroth, G., Läderach, P., Martinez-Valle, A.I., Bunn, C., and Jassogne, L. (2016). Vulnerability to climate change of cocoa in West Africa: Patterns, opportunities and limits to adaptation. *Science of the Total Environment* **556**, 231–241. DOI: 10.1016/j.scitotenv.2016.03.024.

Suwandi, Zaim, Y., and Tjasyono, H.K.B. (2014). The effect of a hundred years period (1991-2000) enso and dipole mode activities on rainfall patterns in Maluku and Papua regions. *Jurnal Meteorologi dan Geofisika* **15**, 71–76.

Teixeira, P.J.P.L., Thomazella, D.P.T., and Pereira, G.A.G. (2015). Time for chocolate: Current understanding and new perspectives on cacao witches’ broom disease research. *PLoS Pathogens* **11**, e1005130. DOI: 10.1371/journal.ppat.1005130.

Tjasadihardja, A. (1987). “Relationship between flushing, pod development, and indole acetic acid in seed and cherelle wilt in cocoa (*Theobroma cacao* L.)”. [PhD Dissertation]. Faculty of Graduate School. Bogor Agricultural University, Bogor, Indonesia. http://repository.ipb.ac.id.

Towaha, J., and Wardiana, E. (2015). Evaluation of the tolerance levels of 35 cacao genotypes to dry periods. *Jurnal Tanaman Industri dan Penyegar* **2**, 133–142. DOI: 10.21082/jtidp.v2n3.2015.p133-142.

Valle, R.R., Silva, W.S., and Miranda, R.A.C. (1987). Stomatal resistance and transpiration rates of shaded and unshaded cacao trees. *Revista Theobroma* **17**, 175–187.

Vanhove, W., Vanhoudt, N., and Van Damme, P. (2016). Effect of shade tree planting and soil management on rehabilitation success of a 22-year-old degraded cocoa (*Theobroma cacao* L.) plantation. *Agriculture, Ecosystems & Environment* **219**, 14–25. DOI: 10.1016/j.agee.2015.12.005.

Wanger, T.C., Tscharntke, T., Schroth, G., and Klein, A-M. (2014). Pollination curbs climate risk to cocoa. *Nature* **511**, 155. DOI: 10.1038/511155b.

Wibawa, A., and Baon, J.B. (2008). Land suitability *In* “Cocoa” (T. Wahyudi, R. T. Pangabean and Pujiyanto, eds). pp. 63–67. Penebar Swadaya. Jakarta. (In Indonesian).

Wijayanti, V.R. (2010). “Cocoa farming and economic level of farmer in Banjarasri village, Kalibawang subdistrict, Kulon Progo district". [Undergraduate thesis]. Study Program of Geographic Education, Faculy of Social Science and Economic, State University of Yogyakarta. https://core.ac.uk/download/pdf/11059024.pdf

Witjaksono, J., and Asmin. (2016). Cocoa farming system in Indonesia and its sustainability under climate change. *Agriculture, Forestry and Fisheries* **5**, 170–180. DOI: 10.11648/j.aff.20160505.15.

Zuidema, P.A., Leffelaar, P.A., Gerritsma, W., Mommer, L., Anten, N.P.R. (2005). A physiological production model for cocoa (*Theobroma cacao*): Model presentation, validation and application. *Agricultural System* **84**, 195-225.