Land management strategy for cocoa cultivation at home gardens

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Abstract. The climate change significantly gives impact on microclimate home garden by enhancing the temperature from 25 to 29 °C. The canopy stratification influences microclimate condition (light intensity, air temperature, soil humidity) which are less supportive for cocoa growth. Limitation of light intensity resulted in lower chlorophyll on photosynthesis, so that a management strategy to increase the chlorophyll with balanced fertilization especially on nitrogen enrichment is required. Research purposes were to study the effects of surrounding cocoa microclimate on canopy growth, fruit and seed qualities (physical and chemical), and also to analyze the role of nitrogen to replace the light intensity limitation of cocoa. A survey method was conducted to collect the data at Punung village, Pacitan Regency, East Java, Indonesia. Based on shade condition, three sub-villages were selected as sampling sites, namely Klepu 1, Jatisari and Klepu 2 which represented low, dense and very dense canopy closure, respectively. Four cocoa trees of 4-5 years age were selected at every sub-village as samples and treated with nitrogen fertilizer. Microclimate components were analyzed with descriptive quantitative and followed with correlation analysis. Analysis of variant and F test were used to determine nitrogen requirement to support the chemical quality of seeds. The results found the light interception (4.5-11.14%) caused the growth of canopy was less than optimal due to cocoa needs 15% of light interception for better growth. Physical qualities (uniformity of fruit size, the weight of seed per fruit and number of seeds per 100 g) were affected by temperature (29-30°C) and also the chemical quality. Closed relationship and positive correlation (r=0.62) showed that temperature significantly influences seeds development. Nitrogen deficiency due to light limitation could be replaced with 850 g of urea per tree per year, and thus recommended as a land management strategy for cocoa cultivation at home gardens.

1. Introduction
Cocoa is one of the main plantation commodities in Indonesia and this plant becomes a significant contributor to the country's foreign exchange [1]. Currently, Indonesia is in the third ranking of cocoa producer in the world (550,000 Tons) [2]. The high cocoa production is mostly produced by large state-owned and private plantations with adequate infrastructure and facilities, while smallholder cocoa plantation has not been able to provide optimal production. However, smallholder plantations
cannot be underestimated because they also strongly contribute to national production. Capital and cultivation technology are the main limitations in the cocoa cultivation of smallholder plantations, especially the availability of land resources that are less than optimal [3].

Climate change has a significant impact on weather and ecology. In many places, precipitation and temperature play a substantial role in cocoa production. Due to climate change, extreme temperature unfavorably influenced cocoa yield. Moreover, temperature raise and precipitation decrease will decline cocoa output in the future [4].

One of the cocoa plantations area in East Java Province that contribute largely to national production is Pacitan regency. Pacitan regency produces 28,575 tons in government plantations, and 6,000 ha in private plantation area [5]. On the other hand, smallholder plantations are less optimum because cocoa cultivation is mostly done in the home garden. With many other plants in the home garden, the light conditions become under optimum or shaded. In addition, farmers do not pay attention to the nutrients availability with fertilization, hence resulting in lower cocoa yields. So, this requires knowledge of the role of microclimate and technological innovation to overcome the limitations of light.

Microclimate conditions affect the growth and development of crops such as cocoa. These need to be considered to anticipate climatic factors that are less supportive to the plant metabolism. Low light intensity on cocoa is due to the shade of some trees such as teak, mahogany, jackfruit, mango, and others. Therefore, the arrangement of planting spacing of cocoa and pruning of the tree canopy is necessary. Similarly, the temperature and humidity of the air, both affect the process of photosynthesis and the development of plant pests and diseases. Identification of microclimate is the initial information for cultivation activity.

Low light intensity disrupts the formation of chlorophyll b (antenna pigment) and results in a reduction of the reaction center activity (chlorophyll a). Naturally, the plant will adapt to low light conditions by increasing chlorophyll b when the nitrogen element is sufficient. Existing facts, soil analysis shows low fertility with moderate levels of N content (0.27%). Therefore, nitrogen fertilizer application is necessary to increase the chlorophyll. Therefore, the limitation of light intensity can be overcome and the function of chlorophyll become optimum [6].

2. Research method

The research was conducted by survey method to obtain qualitative descriptive data and field experiment. The experiment was conducted from March to August 2017. Field experiment used a randomized block design on a purposive sampling of home gardens based on the shade condition (which represented low, dense and very dense canopy closure). The study sites consisted of three villages (Klepu 1, Jatisari, Klepu 2), in Punung District, Pacitan Regency, East Java Province (08°07’10”S -111°01’83” E, with elevation 1,268 m above sea level). Cocoa used as the samples (4 trees and was repeated 3 times) consisted of 4-5 years old.

This experiment utilized GPS (Garmin Oregon 550t), Digital Luxmeter (401025 Extech), Thermo Hygrometer Digital (Isolab), and soil tester, for measuring elevation, latitude, light intensity, temperature, air humidity, soil pH and soil moisture, respectively. Rainfall employed secondary data obtained from the observation station of Pacitan regency (2017).

The experimental factor was nitrogen fertilization consisting of 3 levels of urea (850, 870, 920 g trees⁻¹ year⁻¹ and control). Meanwhile, as a block was the condition of shade in the three villages. Urea was applied gradually at harvest (middle of March), initiation of flowering (middle of June) and fruit formation (the end of August). In addition to urea, each tree was also fertilized with P (SP36), and K (KCl) at a dose of 1,390 and 1,000 g trees⁻¹ year⁻¹, respectively.

Prior to fertilization, soil analysis (composite soil sample) was carried out on several parameters including N total (Kjeldahl method), available P (Olsen method), cation exchange capacity (CEC, extraction method with NH₄OH), organic C and Organic Material (Walkley & Black method) and pH (Electrode glass method). In addition, leaf tissue analysis was also performed on the N, P and K contents using the same method with soil analysis. Analysis of plant tissue (several youngest leaves
from the terminal branch) was carried out in Soil Chemistry and Soil Fertility Laboratory Faculty of Agriculture UNS. While the analysis of seed content (protein, fat, and polyphenols) was done in the laboratory of Food Science Faculty of Agriculture UNS.

The data were analyzed by F test (ANOVA/analysis of variance) of 5% level and followed by Duncan's Multiple Range Test (DMRT 5%) if the differences were significant. Relationships among variables were analyzed using Pearson correlation and continued by regression.

3. Results and Discussion

3.1. Microclimate and soil conditions
Almost all cocoa trees in Punung (Klepu 1, Jatisari and Klepu 2) are planted in the home garden, with sengon (Albizia falcataria), banana (Moses paradisiacal), coconut (Cocos nucifera), and cassava (Manihot utilissima) in surroundings. Sengon and coconut habitus reach 10-15 m tall, hence their canopy interception and light transmission determined the available light for cocoa below. Sunlight is intercepted in large quantities by the surrounding tree canopy, so the light transmitted and received by cocoa tree only ranged from 4.5-11.14%. Klepu 2 site received the lowest light transmission, while Jatisari and Klepu 1 received higher. Light transmitted is strongly influenced by the surrounding plants [7]. Cocoa growth (canopy development) requires about 15% of light to meet the needs for photosynthetic which ranges from 6 to 30% [8]. A decrease in light intensity results in a decrease in temperature and an increase in relative humidity (RH) of air. The temperature around cocoa was 29-30°C with relative humidity ranged 65 -70%. Actually, the optimum temperature for cocoa is 30-32°C [2] and relative humidity 80-90% [9]. In Africa, optimum production is achieved at a temperature of about 29°C with rainfall of 900-1000 mm year⁻¹ [10].

| Soil Parameters | Jatisari | Klepu I | Klepu II | Category |
|-----------------|---------|---------|----------|----------|
| N (%)           | 0.27    | 0.29    | 0.28     | Moderate |
| Available P (ppm) | 11.12  | 10.19   | 9.95     | Moderate |
| Exch. K (me%)   | 0.26    | 0.25    | 0.23     | Low      |
| CEC (me%)       | 24.80   | 20.80   | 21.60    | Moderate |
| C organic (%)   | 2.88    | 2.64    | 2.55     | Moderate |
| OM (%)          | 4.97    | 4.55    | 4.40     | High     |
| pH              | 6.68    | 6.57    | 5.73     | Neutral  |

In general, the soil in the study sites has moderate levels of N, P, CEC, and organic C with low K (Table 1). This means that N, P, and K fertilizers are needed to achieve optimum yield. Tropical soils generally containing high moisture with low pH as a contributor to increase CEC [11]. Soil acidity (pH) of 6.33 is included in the appropriate range for cocoa growth (pH 6-7.5)[2]. This means that the availability of nutrients for crops is high because it is supported by organic material content (OM> 3%), which is derived from the accumulation of plant litter in the home gardens. The cocoa plant grows well on soil with organic material more than 3.5%, with moderate to the high level of N, P, K, Ca, Mg contents [9].

3.2. Nitrogen, fertilizer and plant tissue
Cocoa did not effectively absorbed the nitrogen in the first and second months after urea application of 820, 850, and 920 g tree⁻¹ doses (Table 2). The first and second months after urea application, N content in the leaves ranged from 2.04-2.05%.
The quality of cocoa beans in this study ranged from 68 to 100 g, the quality of cocoa beans is divided into categories: AA to C. Correlation analysis shows that the temperature positively correlated with physical and chemical quality of seed (r> 0.5). The temperature also positively correlated with the length, width of the seed, and the weight of the seed per fruit. The temperature below the optimum causes the fall of flowers and young fruit [16], so if in that condition the fruit is formed, the development becomes imperfect.

3.3. Microclimate and seed characteristics
Cocoa beans are in the flesh so that the number and weight of the seeds depending on the size and weight of the fruit. The quality of cocoa beans is physically based on the number of seeds per 100 g, while chemically based on fat, protein, and polyphenol contents. Based on the number of seeds per 100 g, the quality of cocoa beans is divided into categories: AA (total seeds <85), A (total seeds: 86-100), B (total seeds: 101-110), C (total seeds: 111-120), and S (total seeds> 120) [14][15]. The number of cocoa beans in this study ranged from 68-119 per 100 g, indicates that cocoa production in the study sites categorized as AA to C. Correlation analysis shows that the temperature positively correlated with physical and chemical quality of seed (r> 60%). The temperature also positively correlated with the length, width of the seed, and the weight of the seed per fruit. The temperature below the optimum causes the fall of flowers and young fruit [16], so if in that condition the fruit is formed, the development becomes imperfect.

3.4. Nitrogen and seed characteristics
Beside light, chlorophyll formation is also determined by the availability of soil N. Plants will increase chlorophyll b levels if the light is below optimum, because of the function of chlorophyll b as an...
Increasing chlorophyll requires higher N availability to increase photosynthesis, in which some of the yields will be mobilized to seed. The number of seeds from the application of N fertilizer at a dose of 0, 820, 850, and 920 g trees\(^{-1}\) was 82, 85, 68 and 119 seeds per 100 g, respectively (Table 5). This shows that the application of N fertilizer up to a dose of 850 g tree\(^{-1}\) increased seed size.

Table 5. Effects of urea dosage on cocoa beans physical quality

| Urea dosage (g tree\(^{-1}\)) | Length (cm) | Width (cm) | Seed weight per pod (g) | 100 Seed weight (g) | Number of seed per pod | Number of seed per 100 g |
|-------------------------------|-------------|------------|-------------------------|---------------------|------------------------|-------------------------|
| 0                             | 1.95        | 1.1        | 33.1                    | 122.6               | 27                     | 82                      |
| 820                           | 2.06        | 1.1        | 40.2                    | 118.3               | 34                     | 85                      |
| 870                           | 2.31        | 1.3        | 51.1                    | 146.0               | 35                     | 68                      |
| 920                           | 2.03        | 1.0        | 36.9                    | 83.8                | 44                     | 119                     |

The dose of urea greatly affected the protein and fat content of seeds (R\(^2\): 0.86 and 0.98) whereas the polyphenol content was not significantly affected (R\(^2\): 0.49) (Figure 1). Polyphenols are secondary metabolites produced in the respiratory process either through glycolysis or pentose phosphate pathways. When the polyphenols are low, the respiration of the seeds is still at an early stage. In addition to physical quality, protein content (20.57\%), fats (47.34\%), and polyphenols (6\%) in accordance with SNI (Indonesian National Standard) for cocoa seed quality were achieved at urea dose of 850 g tree\(^{-1}\). Cocoa beans contained protein and fats of 15 and 50-51\%, respectively, as the raw material of chocolate products (Indonesian Coffee and Cocoa Research Institute, ICCRI). However, the cocoa bean polyphenol in this study was 6\%, which is lower than general (12-18\%) [15].

Figure 1. Effects of N doses on protein, fat and polyphenol content

4. Conclusion

- The quality of cocoa beans was high to medium because of the number of beans was between 68-119 per 100 g. In addition, microclimate did not become a constraint of growth.
- The light received by the cocoa plants was only 4.5-11.14\%, but the application of urea fertilizer 850 g tree\(^{-1}\) year\(^{-1}\) improved the quality of cocoa in the home garden.
- Protein (20.57\%), fat (47.34\%) and polyphenols (6\%) contents were in accordance with SNI (Indonesian National Standard).
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