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Physiological responses, growth and productivity of oil palm (*Elaeis guineensis* Jacq.) as affected by boron fertilization

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Abstract

Boron (B) is an essential micro nutrient that is needed by oil palms, especially to control productivity. The aim of this research was to determine the optimal dose of B for mature oil palms. The research was conducted at a smallholder oil palm plantation located in Katingan Region, Central Kalimantan Province from January to December 2022. The field experiment was a single factor arranged in a Randomized Complete Block Design (RCBD) with three blocks as replications. The factor tested was the dose of B fertilization, consisting of five doses, namely 0 g. trunk^{-1}. semester^{-1} (control); 25 g. trunk^{-1}. semester^{-1}; 50 g. trunk^{-1}. semester^{-1}; 75 g. trunk^{-1}. semester^{-1}; and 100 g. trunk^{-1}. semester^{-1}. Observations were done on several variables of micro-weather characteristics at the research site, nutrient and physiological characteristics of leaf, morphological characters and plant growth, and yield and yield components of oil palms. The data obtained were then analyzed with analysis of variance (ANOVA) α=5 %, and data showing significant differences between treatments were tested with an orthogonal polynomial. The results showed that B had positive effects on leaf B, P and K concentration and absorption, leaf chlorophyll content, number of midribs, plant height, leaf area per trunk, leaf area index, crop dry weight, pollen fertility, fruit set, pollen viability, fresh fruit bunch weight (FFB) and FFB productivity. The optimal dose of B to optimize oil palms productivity was 60.24 g. trunk^{-1}. semester^{-1} with a maximum value of FFB productivity of 6.94 tons. trunk^{-1}. semester^{-1}.

INTRODUCTION

Oil palm is a superior commodity in Indonesia because it is a profitable trading commodity. The pace of development of the palm oil industry is quite rapid due to the increasing consumption of oil palm-based vegetable oils. Oil palm produces the best quality and most versatile vegetable oil. Besides, its oil productivity is the highest compared to other vegetable oil producers (Basiron, 2007).

Oil palm commodities in Indonesia are a mainstay source of foreign exchange for the country. Indonesia's exports of oil palm products in the form of crude palm oil (CPO) and its derivative products reached more than 48.4 million tons in 2019 (Central Statistics Agency, 2020). As demand for CPO and its derivative products increases, the productivity of oil palm plantations per hectare needs to be increased. This opportunity is quite open because currently the average realized productivity of our national oil palm plantations is only 3.2 tons of CPO/ha/year, still far below the potential of 8 tons of CPO/ha/year. Indonesia has the potential to increase its annual CPO production to double the current realization without having to expand the cultivation area, namely by increasing the productivity of plantations that currently exist.

The world's need for vegetable oil is predicted to increase every year due to the increase in population. According to the Statistics Research Department

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(2022), FAO estimates that consumption of vegetable oil in Indonesia in 2022 will reach 27.75 kg per capita, and this amount will increase to 32.97 kg per capita in 2030. According to Shahbandeh (2022), 90% of palm oil production is used for food consumption and 10% for industry. The use of palm oil for food shows that oil palm productivity is very important in meeting the primary needs of society. This shows that efforts to increase the productivity of oil palm plantations are approaching the potential that should be expected to meet world food needs.

High and sustainable oil palm productivity requires intensive and optimal production management actions starting from immature plants (TBM) to mature plants (TM). These intensive and optimal production management actions include weed control, irrigation, pest and disease control, and fertilization. One of the oil palm plantation management actions that most determines the level of plantation productivity is TBM and TM fertilization. Fertilization is an activity to provide the nutrients needed by plants to meet plant needs, both providing macro and micro elements. It is important to pay attention to the management of macro and micro nutrients in oil palm plants to optimize plant growth and development, which determines high and sustainable productivity.

Boron (B) is an essential micro nutrient for plants for normal growth. B deficiency inhibits plant growth and development in the form of inhibition of root elongation, disruption of the activity of indoleacetic acid (IAA) oxidation, inhibition of sugar translocation, disruption of carbohydrate metabolism, inhibition of nucleic acid synthesis, and failure in pollen formation (Goldbach and Wimmer, 2007). The various impacts of boron deficiency disturb metabolic processes in plants, thereby inhibiting their growth and development. This condition causes plants to be unable to optimize production, so additional boron is needed to overcome boron deficiency. According to Ahmed et al. (2009), B is really needed by plants when exposed to drought stress and oxidative stress.

B deficiency has been shown to affect leaf photosynthesis, although existing evidence is largely derived from in-vivo experiments with prolonged (10 days or more) treatment of plants with a deficient B supply (Kastori et al, 1995). The role of B in leaves may influence chloroplast membrane function by interfering with thylakoid electron transport and the energy gradient across the membrane, resulting in photoinhibition. B deficiency results in abnormal cell wall formation with altered physical properties (Ryden et al., 2003). This effect is a consequence of B's role in RG-II cell wall cross-linking and pectin assembly. Other researchers have investigated the short-term effects of B deficiency on structural changes in the cell wall. In the corn root apex, it shows that RG-II pectin is cross-linked with B, internalized in brefeldin A, which induces compartmentation (Baluska et al., 2002), and its accumulation in endocytic pathway compartments is inhibited by B deficiency, which results in increased pectin accumulation in the cell wall (Yu et al., 2002). According to Sthepanus et al. (2013), B deficiency in oil palms results in abnormal, brittle, and dark green leaf tips, which disrupts the photosynthesis process. B deficiency in mature oil palms causes abnormal leaf conditions in the form of white stripes, wrinkled conditions, fish bone shapes, and hooked leaflets. This can be caused by high nitrogen and potassium contents, even if sufficient B conditions are provided (Jacquemard et al., 2006).

Oil palm is the most productive plant in the world in producing vegetable oil but requires high amounts of B in its growth and production. Oil palm is a plant that is susceptible to B deficiency (Goh et al., 2007). This shows the importance of B fertilizer for oil palm. The application of B to oil palm plants aims to minimize B deficiency and increase productivity. In order to optimize the quality and quantity of fronds for photosynthesis, which impacts pollen fertility, application of B is required. The ideal condition of the pistils and stamens in oil palms affects fertility so that they are able to produce maximum oil palm fruit, in terms of quality and quantity. Considering the importance of sufficient B for oil palm productivity and limited information regarding this, it is urgent to carry out studies related to B management to optimize physiological activity, growth and productivity of oil palm. This research aimed to determine the effects of B and optimal B doses on physiological activity, growth and productivity of oil palm.

MATERIALS AND METHODS

Field research was carried out in the Oil Palm Plantation of Katingan, Central Kalimantan, Indonesia. Destructive observation and soil analysis activities were carried out at the Integrated Laboratory, Palangka Raya University and the Plant Production Management Laboratory, Faculty of Agriculture UGM. This research was carried out in January–December 2022. The field experiment was structured using a Randomized Complete Block Design (RCBD) environmental design with three blocks as replications. An experimental block used three oil palm stands as replications so that in total 45 trunks of 11 year-old TM oil palms, which had high uniformity, were used and selected randomly. Fertilizer B was given at the doses of 25 $g.stand^{-1}.semester^{-1}$; 50 $g.stand^{-1}.semester^{-1}$; 75 $g.stand^{-1}.semester^{-1}$; 100 $g.stand^{-1}.semester^{-1}$ and without treatment as controls. There are two stages of applying Borate fertilizer, namely the first stage, which was carried out in January 2022, and the second stage, which was carried out in July 2022. Maintenance carried out includes fertilization and weed control. Urea fertilization was given in March and September 2022 at a dose of 2.5 $g.stand^{-1}.semester^{-1}$ as basic fertilizer. Weed control was carried out using Round Up (Glyphosate), which was given in May and November 2022 at a dose of 2 liters $hectare^{-1}$. Data recording on the variables that are the focus of the study was carried out in October 2022.

The variables observed in this study consisted of microclimate characteristics consisting of air temperature, air humidity and rainfall, soil characteristics, nutrient content and physiological characteristics in leaves, plant morphological characteristics, growth characteristics and plant growth analysis, and yield components.

The data obtained were then analyzed for variance (ANOVA) at an α level of 5%. Significant differences between treatments were then tested using the orthogonal polynomial test at the α level of 5%. The orthogonal polynomial test was carried out to determine the optimal dose of B in order to optimize physiological activity, growth and productivity of oil palm plants. The various variables obtained were then connected to the FFB productivity variable, which was analyzed using multiple regression using the stepwise method to obtain information for the general discussion. The applications used in data analysis are the R Studio, SPSS, and Microsoft Excel.

Leaf area measurement was carried out to determine the physiological capacity of plants through the appearance of leaves, especially related to photosynthetic ability (Corley and Tinker, 2016), using the following formula:

A = b (nlw) + c ....(1)

Remarks:

A = leaf area (cm^2)

n = number of leaf leaflets

l = average length (cm)

w = average middle width (cm)

b & c= constants

The leaf area index (L) depends on the area per leaf, the number of leaves per oil palm stand and the number of trees per hectare. The ILD value gives an idea of the amount of leaf area that covers each unit of land area. The ILD value can be calculated by the following formula:

L = (A.NL.NT)/LA ....(2)

Remarks:

L = leaf area index

A = leaf area (m^2)

NL = number of fronds

NT = number of trees

LA = land area

RESULTS AND DISCUSSION

Figure 1 shows a regression relationship between leaf area per stand of oil palm plants measured in October, November and December 2022 and boron fertilization. Boron fertilization has a quadratic regression relationship with leaf area per stand of oil palm plants measured in October, November and December 2022. Based on the quadratic graph, the optimal boron fertilization dose to optimize leaf area size per stand of oil palm plants in October, November and December measurements was 53.99, 53.61 and 52.63 grams per principal per semester, respectively. At the optimal dose of boron fertilizer, the maximum leaf area per stand of oil palm plants for measurements in October, November and December 2022 was 79,568.42, 80,999.18, and 83,802.09 cm^2, respectively.

Figure 2 shows the regression relationship between leaf area index per stand of oil palm measured in October, November and December 2022 and boron fertilization. Boron fertilization has a quadratic regression relationship with leaf area index per stand of oil palm measured in October, November and December 2022. Based on the quadratic graph, the optimal boron fertilization dose to optimize the size of the leaf area index per stand of oil palm plants in October, November and December 2022 measurements was 57.72, 53.71, and 58.60 grams per principal per semester, respectively. At the optimal dose of boron fertilizer, the maximum leaf area index per stand of oil palm plants for measurements in October, November and December 2022 was 5.22, 5.45, and 5.79, respectively. The value of leaf area index affects

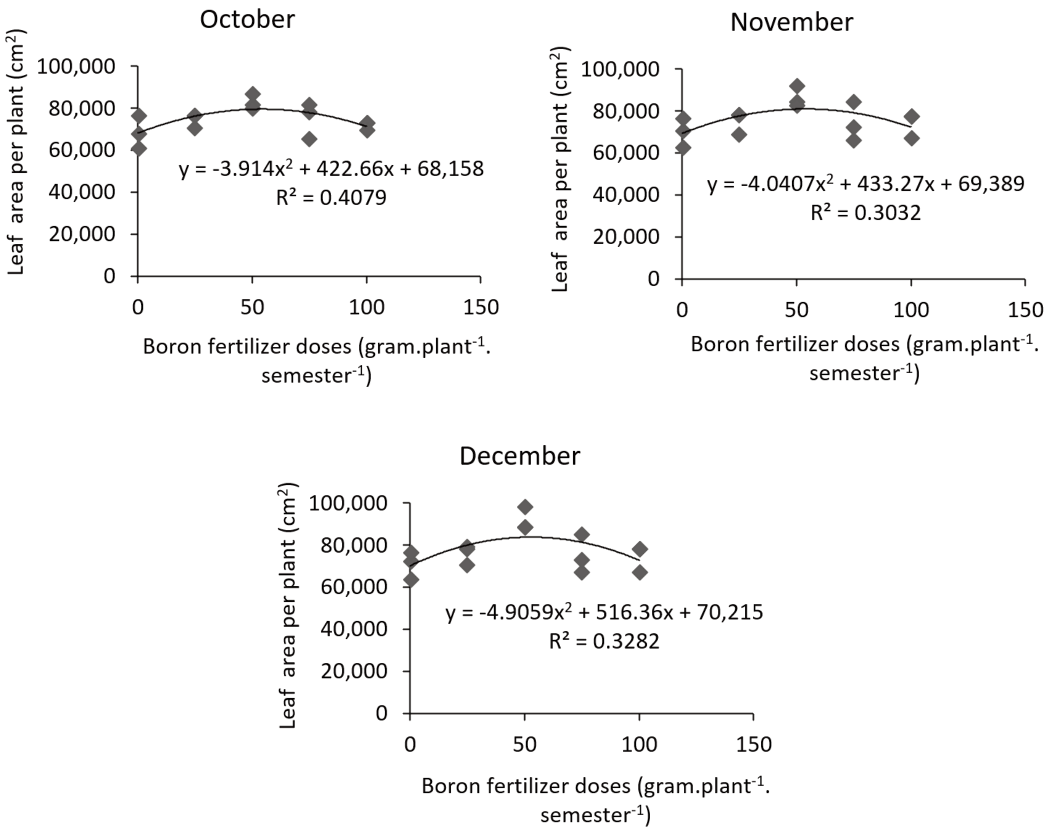

Figure 1. Regression relationship between leaf area per stand of oil palm plants and boron fertilization measured in October, November and December

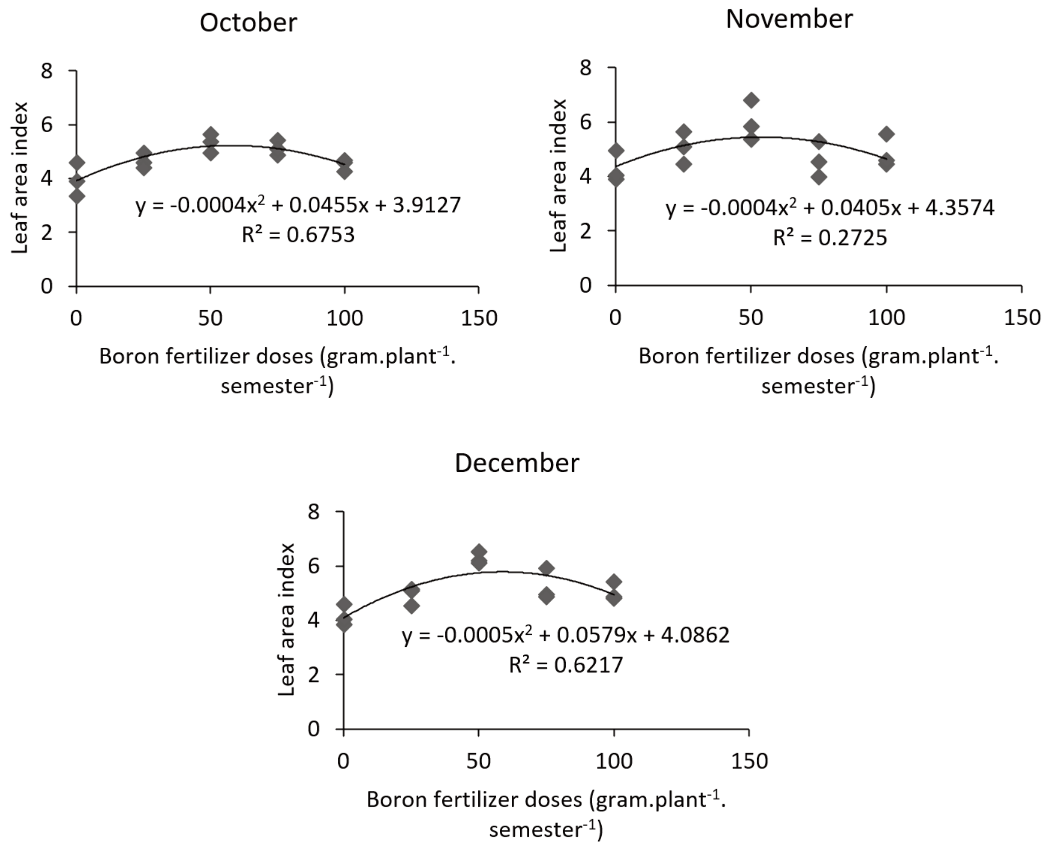

Figure 2. Regression relationship between leaf area index of oil palm plants and boron fertilization in measurements in October, November and December

the rate of photosynthesis of oil palm plants. The higher the leaf area index, the higher the rate of photosynthesis. Boron deficiency results in low rates of photosynthesis. The leaf area index of oil palm leaves that experience White Stripe is reduced, thus decreasing the rate of photosynthesis (Sutarta and Syarovy, 2019).

Figure 3 shows the regression relationship between the weight per FFB of oil palm plants and boron fertilization. Boron fertilization has a quadratic regression relationship with weight per FFB of oil palm plants. Based on the quadratic graph, the optimal dose of boron fertilization to optimize the size of the weight per FFB of oil palm plants was 67.07 grams per principal per semester. At the optimal dose of boron fertilization, oil palm plants are able to produce FFB with an average weight of 17.5 kg. Fresh fruit bunches are affected by the presence of fruit sets in oil palm. The large number of fruit sets increases the percentage of pollen viability and fertility, thus affecting fruit quality. Boron is able to increase fruit set and yield (Hapuarachchi et al., 2022). Therefore, giving boron at the optimal dose can increase the size of FFB produced by oil palm plants.

Figure 4 shows the regression relationship between FFB productivity of oil palm plants and boron fertilization. Boron fertilization has a quadratic regression relationship with FFB productivity of oil palm plants. Based on the quadratic graph, the optimal dose of boron fertilizer to optimize FFB productivity of oil palm plants was 67.95 grams per principal per semester. At the optimal dose of boron fertilizer, oil palm plants were able to produce a maximum FFB weighing 6,940.28 $kg.semester^{-1}.ha^{-1}$.

Based on further tests of multiple regression analysis, the following information was obtained:

Y = - 627 + 396.009 (X20) + 2.409 (X13) + 2.30 (X9) (R2 = 1.00)

Remarks :

Y = FFB productivity of oil palm commodities per hectare per year

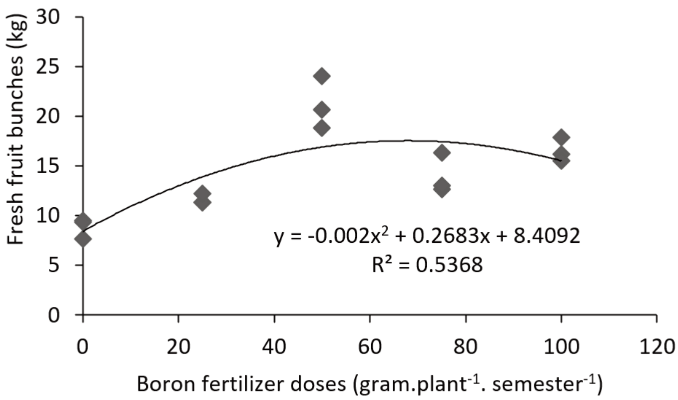

Figure 3. Regression relationship between weight per fresh fruit bunch and boron fertilization

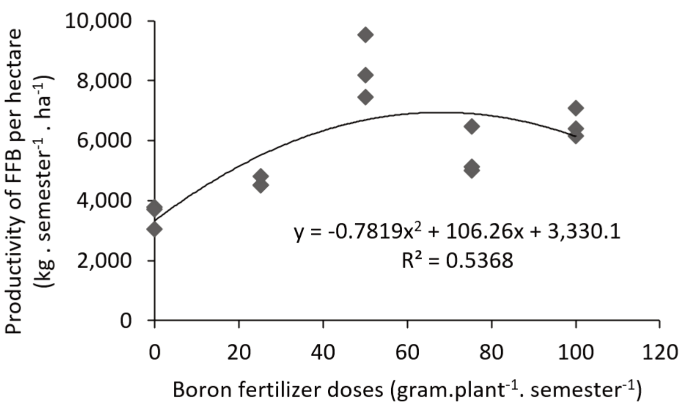

Figure 4. Regression relationship between FFB productivity produced by oil palm plants and boron fertilization

X20 = average weight per FFB
X13 = leaf Area Index
X9 = leaf Area

The results of the equation show the relationship between the productivity of oil palm FFB per hectare per year and the variables of average weight per FFB, leaf area index per stand and leaf area per stand. Based on the results of multiple regression analysis, it is found that the FFB productivity of oil palm commodities per hectare per year was significantly influenced by the average weight per FFB, leaf area index and leaf area. The increase in FFB productivity of oil palm commodities per hectare per year was due to an increase in the average weight per FFB, LAI and LA size per oil palm.

The high FFB productivity of oil palm commodities per hectare per year is determined by the size per FFB. The larger size per FFB contributes significantly to the increase in FFB productivity of oil palm commodities per hectare per year. Meanwhile, the size per FFB is determined in real terms by the LAI of oil palm stands. Based on the results of multiple regression analysis, it is known that higher LAI of oil palm stands causes the FFB size to be larger. The larger FFB size causes the average weight per FFB to also become heavier. The LAI value of oil palm stands according to the results of aggregated regression analysis is positively determined by the LA of oil palm stands. Oil palm stands with wider leaf size have higher LAI values.

Oil palm stands with wider leaf sizes certainly have higher LAI values. The high LAI value of oil palm stands causes an increase in the level of light so that the harvesting of solar radiation per stand is optimized. The maximum rate of harvesting solar radiation is directly related to the photosynthetic capacity of oil palm stands. As a result, oil palm stands also have a high photosynthetic capacity. The high photosynthetic capacity of oil palm stands causes these stands to be able to produce assimilate (biomass) with heavier weight sizes. Heavier assimilate production per stand of oil palm is indeed positively related to FFB production per stand. Oil palm stands with more assimilate production are able to produce more FFB and weigh more per FFB. This condition causes FFB yields per oil palm stand to be heavier. Heavier FFB yields per stand are directly positively related to higher FFB productivity per hectare per hectare per year.

The average weight per FFB is significantly affected by the dose of boron fertilizer application (Figure 4). The optimal dose of boron fertilizer to optimize the average weight per FFB was 67.07 g per semester per stand. The heavier average weight per FFB has an effect on increasing the productivity of palm oil FFB per hectare per year. Boron is a microelement that affects plant productivity (Hapuarachchi et al., 2022). Boron application increases the percentage of fruit sets, thus affecting the high percentage of FFB (Mahendra and Hasnelly, 2019). Boron application can increase fruit weight, fruit volume, and fruit harvest. This is in line with the research of Bhatt et al. (2012), which reported that the addition of 0.5% borax to mango plants gave a significant difference in weight (167.29 g) and volume (154.52 ml) of mango plants given application of 1% $Ca(NO_3)_2$, 1.2 % $CaCl_2$, and without fertilizer application. The weight and volume of mangoes affect the maximum yield of 28.52 kg per tree. Boron affects the increase in carbohydrates and RNA metabolism so that it affects the condition of the fruit. Giving boron can stimulate metabolism in plants, thereby increasing yield. The combination of boron and zinc applied to guava plants provides maximum weight and diameter of the fruit (Trivedi et al., 2012). Increased fruit weight affects the increase in plant productivity.

Another variable that greatly affects FFB productivity directly in oil palm plants is leaf area. Leaves are one of the plant organs used in the process of processing assimilate to produce a product. Normal plant leaf conditions greatly affect leaf area. In oil palm plants, abnormal leaf conditions (wrinkled, twisted), or referred to as spear leaves, have a negative impact on oil palm productivity. This is because oil palm plants are not able to carry out photosynthesis optimally, thus reducing yields. One of the abnormal leaves in oil palm is caused by boron deficiency (Srisook et al., 2022). Boron deficiency conditions greatly affect the capacity of photosynthesis and product transport in photosynthesis (Goldbach and Wimmer, 2007). Decreased stomatal conduction and CO_2 assimilation, as well as increased intercellular CO_2 concentrations can be found in boron-deficient plants. Decreased CO_2 assimilation leads to accumulation of starch and hexose, resulting in oxidative damage (Han et al., 2008). Giving boron to oil palm plants is highly recommended to overcome boron deficiency so as to minimize abnormal leaf conditions. Based on this study (Figure 1), a dose of 53.41 g per semester per stand was able to optimize leaf area in oil palm plants. Maximum leaf area conditions in oil palm plants have a positive influence on increasing oil palm productivity.

FFB productivity is not only influenced by FFB weight and leaf area but also by LAI. In a land area, LAI affects microclimate conditions, such as air humidity and temperature, so it has an influence on plant productivity. The size of LAI per oil palm stand has a positive influence on photosynthesis speed, carbon uptake and assimilation rate, sunlight capture and transpiration (Patil et al., 2018).

In oil palm plantations, LAI in oil palm plants within 5–10 years has an LAI value of 0–4, and in the following year, the LAI value is stagnant because fruit harvesting requires a decrease in midrib. The Leaf Area Index has a correlation with Fresh Fruit Bunches assuming there are 138 stands in one hectare with 40 fronds per stand so that it can produce a Leaf Area Index value of 5. (Hardon et al., 1969). Environmental factors affect LAI values in oil palm plants, in addition to genetic factors. In oil palm plants planted in Kandista (water deficit), genotypes 63 and 83 had the same LAI values between, while in oil palm plants planted in Batu Mulia area, genotype 63 had lower LAI values than genotype 83 (Legros et al., 2009). These results show that oil palm plants adjust environmental conditions to survive to optimize production. The abnormal condition of oil palm leaves (White Stripe) can also reduce the leaf area index, thereby decreasing photosynthesis rate (Sutarta and Syarovy, 2019) and reducing FFB weight, thus affecting FFB productivity. Boron fertilization in oil palm plantations is essential in optimizing the value of LAI.

CONCLUSIONS

Boron nutrient applied to oil palm commodities has a positive influence on levels and uptake of boron, phosphorus and potassium, leaf chlorophyll content, number of fronds, stand height, leaf area per trunk, leaf area index per trunk, stand dry weight, pollen fertility, fruit set, pollen viability, FFB weight and FFB productivity. The optimal dose of boron fertilizer to optimize FFB productivity for palm oil commodities is 60.24 gram.plant^{-1}.semester^{-1}.

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