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Effects of Organic Materials and Rainfall Intensity on the Productivity of Oil Palm Grown under Sandy Soil Condition

Sri Gunawan[#, +], Maria Theresia Sri Budiastuti[*], Joko Sutrisno[*], Herry Wirianata[+]

[#]*Doctoral Program of Agricultural Science, Graduate School, Sebelas Maret University Surakarta, Indonesia*
E-mail: sriegun@instiperjogja.ac.id

[*] *Study Program of Agricultural Science, Graduate School, Sebelas Maret University Surakarta, Indonesia*
E-mail: budiastutiw@gmail.com, jokosutrisno@staff.uns.ac.id

[+]*Department of Agrotechnology, Faculty of Agriculture, Stiper Agricultural Institute Yogyakarta, Indonesia*
E-mail: her.wirianata@gmail.com

***Abstract*— Oil palm plantations in Indonesia are cultivated on various types of land, ranging from very suitable to unsuitable types. This cultivation method is increasingly vulnerable to drought caused by climate change. Climate change due to global warming negatively affects the management of oil palm plantations in the long term. The upper-temperature limit for efficient photosynthesis in oil palm leaves is >38 °C. The increase in temperature (2°C above the optimum) and rainfall by 10% is projected to cause a yield decline of up to 30%. The water shortage is also a major limiting factor for palm oil production. Such vulnerability is predicted to worsen, and thus its negative effects should be explored. The purpose of this study is to reveal the role of organic matter applied as empty bunches (EFB) and the management of Nephrolepis bisserata vegetation in reducing the adverse effects of rainfall on palm oil production on sandy soils. The survey method and observations were carried out for over 3 years on plants aged 14–16 years on blocks. Empty fruit bunches (EFB) of 40 tons/ha/year was applied to each block, and Nephrolepis biserrata was used as ground cover which planted in path. The parameters observed included the number and average weight of fresh fruit bunches (FFB). The relationship between fluctuations in the conditions of monthly rainfall intensity on oil palm production was determined through regression analysis. Rainfall strongly influenced the number of FFB, whereas the average weight of FFB remained relatively constant. The application of EFB and management of Nephrolepis biserrata vegetation facilitates the reduction of drought impacts and increase in oil palm production (15%) as shown in bunch weight and bunch number. EFB and Nephrolepis biserrata vegetation can increase soil organic matter content and improve soil water holding capacity.**

***Keywords*— EFB; rainfall; sandy land; productivity; organic matter; oil palm fruit bunches.**

I. INTRODUCTION

Oil palm, currently the world main vegetable oil crop, is characterised by large productivity and a long life span (⩾ 25 years) [1]. Indonesia is the largest palm oil producer in the world, with a plantation area of approximately 16 million hectares [2]. This commodity has a strategic role in terms of economic, social, environmental and political aspects. Palm oil production generally remains lower than its production potential. This yield gap is caused by soil, climate and technical culture [3]. The expected effects of climate change on worldwide palm oil production are reviewed by Corley and Tinker [4]. Climate change due to global warming negatively affects the management of oil palm plantations in the long term. The upper-temperature limit for efficient photosynthesis in oil palm leaves is >38 °C, provided that the vapour pressure deficit is small [5]. Increase in temperature (2°C above the optimum) and rainfall by 10% is projected to cause a yield decline of up to 30% [6], and water shortage is a major limiting factor for palm oil production [7]. The production is determined by the number and weight of fruit bunches. Water deficit delays the opening of the spear, decreases the sex ratio and the fall of the flower and causes failure of the bunches [8].

Water availability is an interaction between climate (rainfall) and soil characteristics. Oil palm transpires approximately 6 mm water per day under non-limiting conditions and sufficient rainfall throughout the year [1]. The average actual transpiration rates in oil palm plantations are 4.0–6.5 mm per day in the rainy season and 1.0–2.5 mm per day on dry days [9]. Sandy soil has marginal agricultural uses because of its rough texture [10], low organic C soil [11], poor aggregate stability and low water retention capacity [12].

To increase the productivity of dryland sandy soil, soil conditioners, such as organic compost, should be applied [13]. The application of organic matter as soil ameliorant can improve aggregation and porosity (macro and micropore balance) and increase productivity. The use of oil palm EFB as an environmentally friendly solution can increase oil palm production on sandy land [14]. A yield response usually arises with EFB mulch compared to using normal estate fertilisers alone [15]. Soil benefits from EFB include increased pH, exchangeable cations and available phosphorus. The increase in organic carbon and nitrogen are small and irregular. Continued organic material addition is typically necessary to increase soil carbon and nitrogen significantly, and a single addition has little effect. Roots multiply in locations where EFB has been applied [16]. The effect of EFB addition is generally assessed directly through production and as a substitute for fertiliser, but its effect as a soil conditioner has not been extensively studied for marginal soils, including sandy soils.

Under fast-growing vegetation such as *Nephrolepis biserrata*, the physical properties of sandy soils can be improved through the secretion of organic matter from its root system. This plant is tolerant of shade, has high potential as ground cover, can protect the soil from surface erosion and increase water infiltration [17]. *Nephrolepis bisserata* planted on the edge of a terrace can improve groundwater balance [18]. This paper presents the results of research into the performance of oil palm production on sandy soil in relation to rainfall fluctuations and the benefits of EFB and Nephrolepis biserrata in reducing the adverse effects of climate condition that contributed to oil palm production. The purpose of this study is to reveal the role of organic matter applied as empty bunches and the management of *Nephrolepis bisserata* vegetation in reducing the adverse effects of rainfall on palm oil production on sandy soils.

II. Materials and Methods

The research was carried out in an oil palm plantation in Kendawangan, Ketapang, West Kalimantan with a 2004 planting year. There were 3 plantation divisions with an area of 2,552.42 hectares spread in 78 blocks. Each area of 30 hectares blocks with sandy soil. The depth of the sand layer is around 1.5 meters above soil surface. N, P, K and Mg fertilizers are given twice a year in accordance with recommendations based on soil and tissue analysis.

EFB has been applied routinely, as much as 500 kg per tree (given twice a year). EFB are placed in a dead layer one layer thick (to prevent it from being a breeding place for rhinoceros beetles). In addition, *N bisserata* was planted in a block with low to moderate vegetation covering density.

Planting of *Nephrolepis bisserata* uses clump division which is taken from natural vegetation, using a spacing of 40 x 60 cm in a dead space (path) on a sandy garden block. The effect of EFB and Nephrolepis bisserata on soil properties was observed in blocks of moderate density (10-15 individuals per m2). Distribution of soil samples in accordance with estate recommendations for soil and tissue nutrient analysis. Soil is taken at depths of 10 and 20 cm to determine moisture content, nitrogen and phosphate, organic matter, and pH.

Monthly rainfall data is collected for four years (2013-2016), while monthly production data includes production tonnage, average fruit bunch weight, and number of fruit bunches collected for three years (2014-2016).

The effect of the application of EFB on oil palm production is determined by comparing the actual production of garden blocks routinely applied to this source of organic material and the presence of Nephrolepis bisserata vegetation and the potential production of sand fields which are not applied to these organic materials in the same tree age range. In addition, to reveal the relationship of rainfall with the weight and number of fruit bunches and total production, regression and correlation analyzes are used. This analysis is based on the phytomer production cycle of oil palm by performing a serial analysis of the duration of the monthly gap between rainfall events and the components of oil palm production. The difference in oil palm production between the plantation division is determined based on the t test. The close relationship between the two variables is determined based on the significance of the regression coefficient and correlation, using the Equation (1):

$$Y = c + \beta \log X \qquad (1)$$

III. Results and Discussion

Rainfall fluctuated annually and monthly, thereby producing an effect on groundwater availability. Rainfall is relatively high with fluctuated distribution throughout the year (Table 1). In 2015, two dry months could have reduced palm oil production on sandy land. The existence of a dry month has great potential to cause water stress on sandy soils because of the low water holding capacity triggered by high percolation.

TABLE I
Rainfall Fluctuations for Three Years

Year	Rainfall (mm/year)	Rain Distribution (day/year)	Dry Month
2014	3,971	203	1
2015	2,792	147	2
2016	3,731	177	0

In 2016, land fires decreased the length and intensity of irradiation sunlight received by oil palm plantations at approximately 4-5 hours per day. Both conditions exert a major influence on the decline in production that occurs simultaneously or several months later, depending on the stage of the vegetative and generative growth as presented in Table 2.

Table 2 reveals that oil palm is in a stable production stage and can thrive under suboptimum climatic conditions. Variations in oil palm yields are largely caused by the changes in the amount of fresh fruit bunches harvested [19]. A different response occurs between weight and amount of FFB. FFB weight in three years of observation is lower than its potential production. The total of FFB resulted from EFB application was higher 15% than that of non EFB application/ sandy soil potential. It indicated the economic value of using EFB as soil organic source.

TABLE II
PRODUCTION OF OIL PALM ON SANDI LAND

Year	Age	Potential Production			Actual Production (EFB Application)			Difference (%)		
		Bunch Weight (BW) (kg)	Bunch Number (BN)	Yield (ton/ha/ year)	Bunch Weight (BW) (kg)	Bunch Number (BN)	Yield (ton/ha/ year)	Bunch Weight (BW) (kg)	Bunch Number (BN)	Yield (ton/ha/ year)
2014	10	16.000	12.500	26.000	13.190	14.716	25.999	-21.31	15.06	0.01
2015	11	17.400	11.500	26.000	14.017	14.150	26.104	-24.14	18.73	0.40
2016	12	18.500	10.800	26.000	15.778	9.615	19.879	-17.18	-12.32	-30.79

The biggest decline occurred in 2015. FFB weight is determined by fruitset and individual fruit growth in bunches such that conditions that occur during the anthesis range until before harvest (5-6 months) affect the bunch weight. The influence of sub-optimum climatic conditions on the two production components works under different mechanisms. During the dry season, the activity of Elaeidobius kamerunicus is low and influences pollen condition by decreasing pollen viability. Lack of water in the dry season reduces photosynthesis so the carbon assimilates that are translocated into bunches are unable to support fruit growth (fruitset).

Conversely, the number of FFB increased from 2014-2015. This latest result revealed that sex determination was influenced by the groundwater status several months earlier. The annual rainfall over three years exceeds ideal conditions (1,750-2,500 mm per year), is above 2,500 mm with uneven distribution and does not cause stress that can stimulate male flower production, so it does not change the sex ratio. The 2016 FFB production decreased because of the dry month of 2015 that affected the 2016 sex ratio. Haze reduces the carbon assimilation that is transplanted to support fruit growth so that the 2016 yield is only 70% of the potential for sandy soil production. Low groundwater content and sucrose supply to generative organs (flowers) cause the accumulation of reactive oxygen species which, in turn, triggers flower abortion. The effect of stress on the undifferentiated inflorescence meristem on oil palms found in the -20 leaf is the determination of the sex, while the effect on inflorescence after differentiation is the death of their tissue [20, 21].

Rainfall had a major influence on the weight of the bunch, the number of fruit bunches and the oil palm yields, with values of R2 and coefficient of variation at 0.97 and 2.72; 0.96 and 7.99; and 0.95 and 7.78, respectively. The influence of rainfall fluctuations on the three components of these results are presented in Figures 1, 2 and 3. The effect of rainfall intensity shows a different pattern between the weight of the bunch and the number of oil palm fruit bunches. This difference is caused by differences in sensitivity of vegetative and generative growth of oil palm to rainfall. Fruit bunch growth is sensitive to water conditions for four months after the anthesis, and the number of bunches is determined by the status of the water at sex determination. Moreover, oil palm yield is largely dependent on the number of bunches.

The low clay content of sandy soil causes its problematic management. This soil has a water retention ability, thereby rendering it highly vulnerable to the effects of water stress and nutrient deficiency. The application of EFB as organic mulch and Nephrolepis bisserata vegetation can reduce the surface temperature that is increased on sandy soil and minimise the impact of climate change [22].

Figure 1 shows that FFB weight fluctuations are closely related to rainfall variability with a consistent pattern even though there are variations in bunch weight between blocks. Estate blocks that have dense Nephrolepis bisserata vegetation and periodic EFB applications can maintain groundwater conditions so that FFB growth is better. The lower vegetation in the block creates an appropriate microclimate condition (humidity around 60-75%) to support the activity of E. kamerunicus in pollination so that fruitset has increased and obtained heavier FB. FFB growth depends on the supply of photosynthates and the relationship between sinks which has the potential for competition between organs, including among fruit bunches after pollination.

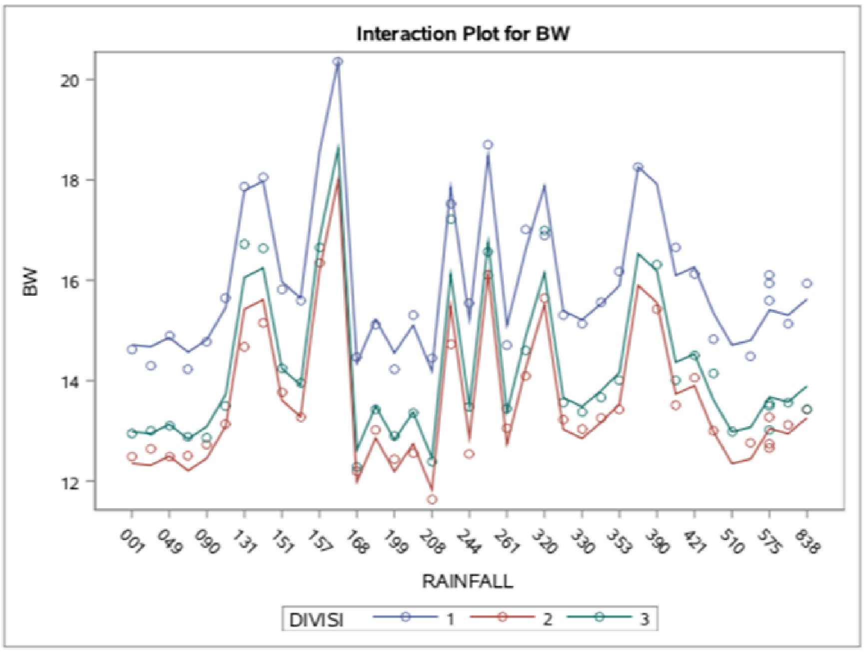

Fig. 1 Effect of Rainfall on the Weight of Oil Palm Fruit Bunches

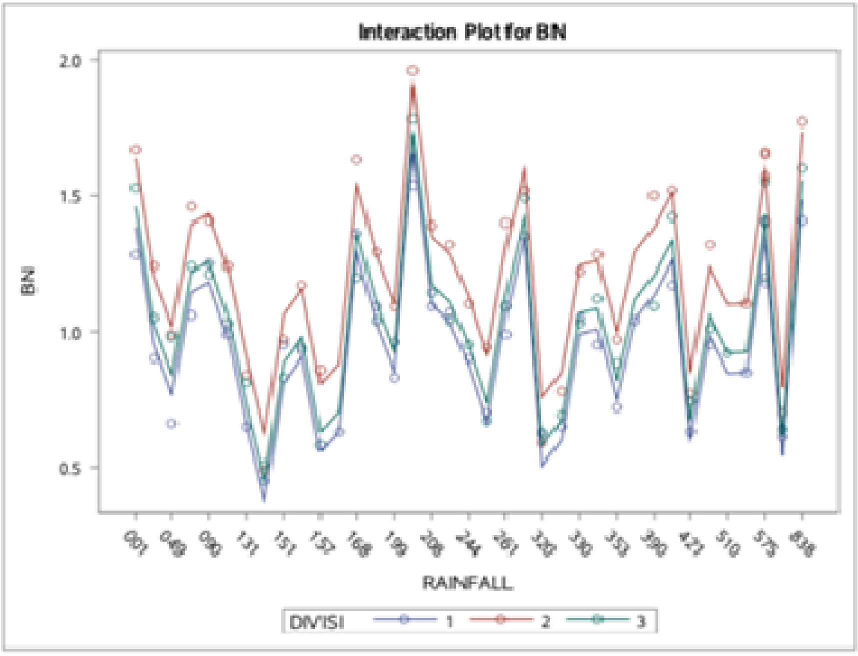

Fig. 2 Effect of Rainfall on the Number of Oil Palm Fruit Bunches

Fluctuations in the amount of FFB are closely related to variations in rainfall, but the variation between plantation blocks is relatively small (Figure 2). The amount of FFB is influenced by sex determination, interest abortion, pollen availability, and bunch failure. Flowering phenology is sensitive to environmental influences. This stage is sensitive to the effects of water stress that occurred a few months earlier. The existence of competition between different bunches of growth stages causes variations in the amount of FFB. Variations in oil palm production are closely related to variations in the amount of FFB harvested than the weight of FFB.

Figure 3 shows fluctuations in oil palm production influenced by variations in rainfall, but the difference in production between plantation blocks is very small. Management of organic material sources can reduce the negative effect on palm oil production on sandy soils. Some development processes that determine the palm oil FFB production cycle are variations in frond production, sex determination, bunch growth rate before and after frond emittion, flower abortion, pollination efficiency and other factors that influence the development and ripening of FFB [23].

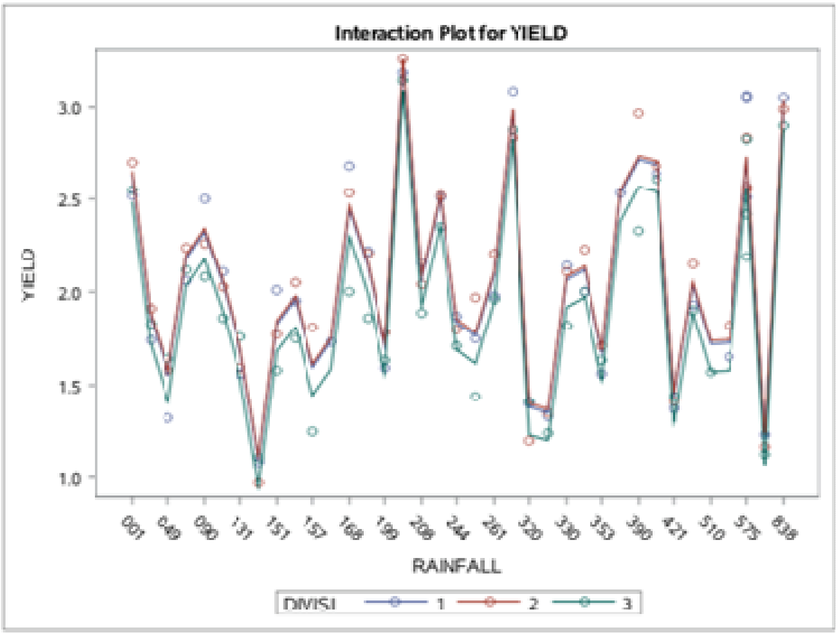

Fig. 3 Effect of Rainfall on Oil Palm Yields

TABLE III
VARIOUS COMPONENTS OF PALM OIL PRODUCTION IN SANDY SOIL

Yield component	Unit	Division 1	Division 2	Division 3
Bunch weight	Kg/bunch	15.87 c	13.45 a	14.08 b
Bunch number	Bunch/palm/month	0.98 a	1.23 c	1.06 b
Yield	Ton/hectar/month	2.09 b	2.11 b	1.94 a

The performance of the oil palm production components between estate divisions shows the difference resulted from the application of organic material and the management of *Nephrolepis bisserata* vegetation in all estate blocks in each division (Table 3). EFB applications are more even and routine in division 1, the fertilizer applied can be absorbed more effectively, resulted to weighter FFB than division 2 and 3. On the other hand, division 2 produces a greater amount of FFB. The amount of FFB reveals the sensitivity of oil palm to the influence of suboptimum conditions during the sex determination phase which occurs 10-16 months before the bunch is harvested as state by the many researchers [23].

EFB application and Nephrolepis bisserata vegation in sandy soils can improve soil properties as presented in Table 4. High organic C content can improve sandy soil aggregation, thereby improving soil capacity to retain water which can indirectly improve the process of mineral nutrient absorption and reduce their loss due to leaching.

Regression analysis revealed that rainfall has a close relationship with the weight and amount of FFB and yields (Table 5). Oil palm growth and development is largely based on the variability of climatic conditions. Its relation was determined by regression and correlation analysis according the phytomere production. The serial analysis based on monthly time lag showed that the close relation was observed ten months ahead of climatic condition to FFB production Water deficit is the most important climatic factor affecting oil palm yield. When evapotranspiration exceeds rainfall (or rainfall plus irrigation), the soil water content decreases and may reach a point at which the palm cannot extract water from the soil quickly enough for transpiration to continue at the potential rate [4].

TABLE IV
SANDY SOIL CONTENT APPLIED EMPTY FRUIT BUNCH AND COVERED BY *NEPHROLEPIS BISSERATA*

	Content
The content is moist as deep 10 cm (%)	0.52-1.99
The content is moist as deep 20 cm (%)	0.47-1.91
C organik (%)	4.06-11.83
Nitrogen (%)	0.04-0.17
Total phosphate (%)	0.0011-0.003
Phosphate is available (ppm)	1.22-25.91
pH	4.77-5.17

The relationship between rainfall and oil palm production components in sandy land is caused by the role of organic matter in improving the physical properties of the sandy land. Application of EFB and the presence of N. bisserata vegetation has a direct or indirect role in increasing the organic matter content and aggregation of sandy soil. Vegetation helps the even proliferation of palm oil vertically and horizontally [24]. The rapid growth of N. bisserata causes a succession of undergrowth species, which can gradually suppress the growth of weeds that are detrimental [25]

TABLE V
RELATIONSHIP BETWEEN RAINFALL AND COMPONENTS OF OIL PALM PRODUCTION IN SANDY SOIL

Component of production	Regression equation	Prob.5%
Fresh fruit bunch weight	Y = 13.326 + 0.18105 log X	Significant
Fresh fruit bunch number	Y = 1.038 + 0.00021 log X	Significant
Yield	Y = 1.8949 + 0.00047 log X	Significant

Empty fruit bunch management and vegetation resulted a variety of benefits. This source of organic material is part of the scheme for anticipating the adverse effects of climate change and the substitution of inorganic fertilisers. The results of this study provide preliminary information on the prospect of *N. bisserata* as part of the sandy soil management.

IV. CONCLUSION

Oil palm production was determined by the amount and weight of the FFB affected by rainfall. Rainfall strongly influences the amount of FFB in sandy soil plantation. The FFB amount is affected by the determination of sex as influenced by rainfall a few months earlier, especially in the presence of a dry month. Conversely, the weight of FFB is affected by the rainfall during the growth and development of the bunches. The weight and number of FFB show different response patterns to rainfall fluctuations. The application of EFB and the management of *Nephrolepis bisserata* vegetation can reduce the negative impacts caused by drought and increase palm oil production (15%). Such application can increase soil organic matter content and improved soil water holding capacity.

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