The dynamics of precipitation and its relation to flowering status and oil palm productivity

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Abstract. This paper exposes the relation between monthly precipitation amount dynamics with the assumably impacted flowering status of productive oil palm and its productivity in the next period. The observation was conducted in Jambi 2016-2017 and Kalimantan in 2017. Simple regression and Pearson’s correlation procedure was applied to calculate the relation between actual flower sex ratio as well as oil palm productivity. Under water scarcity conditions in the dry season, more flower infertility will be exposed in the same period of the dry season with higher response variability. Soil moisture content under the frond pile is more stabilized against evaporation so that the rate of soil demoisturizing at the upper horizon layer is slower than at the circle area and active path area. Estimated oil palm production in a period is determined by the precipitation value 36 months before harvest.

Keywords: drought stress, flower sex ratio, forecasting of productivity, water stress, frond pile

1. Introduction

Robust growth of oil palm expansion area in Indonesia over the past 20 years driven by the remarkable escalating demand for vegetable oils and biofuels. The oil palm plantation area in the mentioned period grew more than doubled. It was in an assumable manner associated with simultaneous negative natural impacts due to a massive land-use change, especially on deforestation and environmental degradation [1]. The expansion of the oil palm cultivation area has mainly relied on conversion from other crops cultivated area [2]. The time has come, that Indonesia is going to challenge scarcity for land suitable for sustainable oil palm farming shortly [3,4].

Persistent climatic variability, which results in frequent droughts and floods, is among the major impacts and reasons for better adaptive management of the production system. Water scarcity especially drives the uncertainty in plant growth stress, performance, and production, where its variability could vary from year to year. Beside them, the excessive water in certain agricultural areas brings a risk of flooding phenomena, mainly due to the reduction of infiltrated water into the soil. The lower infiltration at oil palm sites is mainly associated with degraded soil status, where its profile soil loss reached to 35 cm soil depth since the forest conversion time [5]. It means, that the lower soil layer is responsible for the lower infiltration capacity due to soil compaction and lower organic carbon content [6].

Flooding in oil palm plantation occurs in a relatively shorter period compared to scarcity. Dry season plays a significant role in the control of the flowering process and production capacity. Water consumption measured by evapotranspiration is about (543 ± 24 mm yr\textsuperscript{−1}) in smallholder farmers, and
close to doubled in corporate plantations [7]. In both cases, the annual rainfalls ranging 1800-3200 mm yr\(^{-1}\) in most areas, except some dry regions in the small Sunda Islands, are sufficient for oil palm requirements [8]. Evapotranspiration value in corporate plantations compared to smallholder farmers is associated with higher inputs energy, materials and management level, where the productivity value reaches about double [9,10,11].

Due to fibrous rooting systems in soil upper layer, the opportunity to plant water stress or scarcity is higher, where the effect on flower infertility and reduction of production are unavoidable. In a consecutive dry period more than about 2-3 months, the flower building undergoes stress, so that the building of the male flower would predominate over the female flower [8].

The problems of green water scarcity and its impact stress on flower building and productivity as well were just illustrated in the general approach. In this study, we will analyze and evaluate the performance of detailed precipitation data and make a correlation with the productive yield of oil palm. The real impact of how much precipitation minimum required for the normal growth and development of oil palm will be determined statistically.

Precipitation data collected by many private institutions, companies and state climate stations are very useful for forecasting the productivity of oil palm in the future and for required preparation regarding flooding and drought risk. Available water in recent times and its effect on productivity required long process time. The relation between analyzed monthly precipitation amount dynamics with the presumably impacted flowering status of productive oil palm and its productivity as well, are required for the forecasting of sex ratio and productivity in the next period.

The purpose of this research is to identify how far is the impact of water scarcity from a short time on a monthly precipitation basis and when the impact on flowering and production will be exposed.

2. Methodology

2.1. Study site

The observations were conducted at a smallholder oil palm plantation in Jambi 2016-2017 for analyzing flowering performance and in PT SKJ Oil Palm Plantation Berau, East Kalimantan in 2017 for analyzing oil palm production dynamics.

Soil for the research location in Jambi is reddish yellow podzolic as terrestrial soil type classified as acidic soil ultisol with a covering area of 8 ha. Coordinate of site location is 103°16'18" E and 1°51'25" S at 55 m above sea level. The location is undulating soil surface with slope gradient variation from 3-32%. The oil palm plantation was 8-year old and underwent land-use conversion from previously rubber. In rainy season herbicides mostly Round-up was applied at the field at the rate of 2-4 L active ingredient per ha. There was no additional application of lime, fertilizer, nor insecticides during the immature and mature period.

The population consisted of 143 trees per ha with planting space 9m x 9m x 9m.

The Plantation in Berau managed about 5003 ha oil palm area in mineral soil with a central location at 118°03'12" E and 02°17’18” N. The company managed 7 area division. The plants were 7-year old and at a productive age from 48 months before. The application of fertilizer and herbicide was intensive. In the time of observation, 2 kg N, 1 kg P\(_2\)O\(_5\) and 2 kg K\(_2\)O per tree were applied. The population consisted of 143 trees per ha with planting space 9m x 9m x 9m.

2.2. Data collection

For the collection building of the flowering parameter, male and female flowers were observed. During the dry season in 2016, soil moisture was analyzed in the soil depth of 10-20-30-40 cm. Soil moisture status was identified at circle area, active path area, and frond pile area. Male and female flowers were observed at 4 level undulating soil surface levels, i.e.: plain, slight, medium and heavy gradient slopes. Each slope level was 4 times replicated. Four trees were observed for samples at any unit slope and replication. There were 64 palm trees were observed. The precipitation data were obtained from Meteorology, Climatology and Geophysics National Agency - Sultan Thaha Airport in Jambi, situated about 32 km from the study site.

FFB (Fresh Fruit Bunch) was selected as a production parameter. Secondary data of FFB were obtained from the company. The available FFB data were collected as monthly data from the field since
5 years ago. The company installed previously ombrometer for collecting precipitation data. During the field observation, primary monthly data of precipitation was collected.

2.3. Data analyses

Simple regression analyses and Pearson’s correlation procedure was applied to calculate the relation between actual flower sex ratio and soil moisture content in the dry season in Jambi. The soil moisture data were collected during the dry season in May, June, July and August 2016. Furtherly, it was followed by regression and correlation analyses. Soil moisture data at the various soil depth were combined with the area distribution of oil palm site, i.e. circle area, active path area, and frond pile area. Besides, an average of soil moisture records at different positions i.e. plain area, slight slope area, medium slope area, and heavy slope area, were correlated with the flowering performance parameter, i.e. the ratio of the female and male building during the dry season.

Collected data of oil palm production in Berau were consolidated to monthly FFB production data and furtherly to be correlated with monthly precipitation data. The analyses of the monthly precipitation data were particularly related to the oil palm productivity in the previous time of 12-36 months before. The regression and correlation analyses were applied at every single month data of productivity and single month data of precipitation. The relation with significance on determination coefficient and regression slope analyses were considered as the selected formula for the forecasting of the next productivity base on the existing monthly precipitation value.

3. Results and discussion

Dry season contributed very low soil moisture, where soil water concentration under frond pile was about 2-4% higher than at circle area and active path of oil palm plantation area (Fig. 1a). The installment of the frond pile area reduced water scarcity risk. After the precipitation, soil moisture reduced about 0.2% per day until 12 days after the rainfall in 0-40 cm soil depth. However, in 0-10 soil depth, the demoisturizing level is clearly to be confirmed compared to at the soil depth 30-40 cm (Fig 1b, 1c). It is also obviously to be noted, that loss of water content at the upper soil layer at the frond pile area is much less than at the active path area.
Figure 1. Soil moisture reduction pattern in 3-13 days after precipitation event in the dry season at the soil layer depth of 0-40 cm (A), 10 cm (B) and 40 cm (C).

All of these soil moisture phenomena are to be associated with the space distribution area, where active path area occupied 82% of total plantation area, frond pile area 13% and circle area 5% respectively. Concerning moisturizing capacity in the soil upper layer, this layer position is very important for maintaining water availability, whereas oil-palm coarse root and fine roots distribution are relevant to the water absorption for the plant. Both of these categorized roots were found mainly at the position of 10-30 cm soil depth [12]. Infiltrated water in the dry season for the moisturizing of
plantation soil is worst and much lower due to almost half of the precipitation water is captured by the oil palm canopy as crown interception [13].

Higher soil moisture levels drove the female/male ratio of oil palm to more fertility to about 7.3% more at every 1% of soil moisture increase in the dry season (Fig.2). However, this occurrence was not supported by sufficient significance, whereas its variability was very high and its determination coefficient was very low. Hence, the forecasting of flowering performance using the equation formula related to soil moisture content at the various gradient slope levels in the dry season, in this case, is not reliable enough.

![Figure 2](image)

**Figure 2.** The relation between soil moisture content and flowering performance

After analyzing the monthly productivity along three years and correlated with the monthly precipitation value in the previous time, there was found, that the most significant result occurred at 36 months time difference between precipitation time and the next productivity value. Adequate or insufficient or even excessive monthly precipitation in a month supported the oil palm productivity in the next 36 months growing time. The linear equation result is presented in Figure 3.

![Figure 3](image)

**Fig. 3.** Simple regression between monthly precipitation and FFB production in 36 months thereafter
Estimated FFB production in the next 36 months, supposed to be without rainfall in this month, will amount to 774 ± 45 (Std error) kg/ha, with average monthly precipitation from 2014-2017 in the amount of 173 ± 11 mm (Std error) will be 924 kg/ha and with maximum rainfall in the same period of time in a recorded value of 519 mm in May 2015 would be 1224 kg/ha in May 2018. The simple regression and correlation analyses corresponding to the estimation of the FFB production in a time difference of 12-36 months after the precipitation is presented in Table 1.

**Table 1. Regression analyses of monthly precipitation Jan.-July 2017 and previous oil palm production.**

| Month | Correlation | R   | R²   | n | Se    | Regression equation               |
|-------|-------------|-----|------|---|-------|-----------------------------------|
| 12    | +           | 0.61| 0.37 ns | 6 | 59.99 | y = +0.4368x+844.26ns            |
| 13    | -           | 0.48| 0.23 ns | 6 | 66.60 | y = -0.3333x+947.91ns           |
| 14    | +           | 0.30| 0.09 ns | 6 | 72.28 | y = +0.1869x+876.5ns            |
| 15    | -           | 0.17| 0.03 ns | 6 | 74.64 | y = -0.1339x+928.19ns           |
| 16    | -           | 0.34| 0.12 ns | 6 | 71.20 | y = -0.2433x+941.27ns           |
| 17    | -           | 0.55| 0.30 ns | 6 | 63.25 | y = -0.3450x+953.58ns           |
| 18    | -           | 0.13| 0.02 ns | 6 | 75.16 | y = -0.0837x+912.70ns           |
| 19    | +           | 0.45| 0.20 ns | 6 | 67.59 | y = +0.2957x+876.26ns           |
| 20    | +           | 0.80| 0.44 ns | 6 | 43.58 | y = +0.6871x+849.39ns           |
| 21    | +           | 0.23| 0.05 ns | 6 | 73.68 | y = +0.2428x+887.45ns           |
| 22    | +           | 0.42| 0.18 ns | 6 | 68.78 | y = +0.1996x+879.83ns           |
| 23    | +           | 0.31| 0.10 ns | 6 | 71.98 | y = +0.1027x+882.45ns           |
| 24    | -           | 0.38| 0.15 ns | 6 | 70.04 | y = -0.1427x+939.69ns           |
| 25    | -           | 0.57| 0.33 ns | 6 | 62.15 | y = -0.2539x+977.24ns           |
| 26    | -           | 0.37| 0.13 ns | 6 | 70.49 | y = -0.1767x+958.32ns           |
| 27    | +           | 0.07| 0.00 ns | 6 | 75.60 | y = +0.0321x+894.38ns           |
| 28    | -           | 0.20| 0.04 ns | 6 | 74.25 | y = -0.0805x+924.51ns           |
| 29    | -           | 0.05| 0.00 ns | 6 | 75.67 | y = -0.0334x+910.19ns           |
| 30    | +           | 0.51| 0.26 ns | 6 | 65.20 | y = +0.3607x+845.51ns           |
| 31    | +           | 0.75| 0.56 ns | 6 | 49.98 | y = +0.6411x+808.41ns           |
| 32    | -           | 0.24| 0.06 ns | 6 | 73.60 | y = -0.3085x+942.91ns           |
| 33    | -           | 0.53| 0.28 ns | 6 | 64.31 | y = -0.6950x+989.50ns           |
| 34    | -           | 0.79| 0.62 ns | 6 | 46.70 | y = -0.1336x+1046.3ns           |
| 35    | +           | 0.50| 0.25 ns | 6 | 65.82 | y = +0.7391x+806.07ns           |
| 36    | +           | 0.81| 0.65 ns | 6 | 44.67 | y = +0.8665x+773.98**           |

Note: ** significant at p<0.01, ns=not significant at p<0.05

The estimated FFB production in 2020 after precipitation data collecting in the field from January - June 2017 in the 7 Division area of the oil palm plantation area is presented in Table 2. Each division managed averagely about 715 ha. Minimum rainfall occurred in June 2017 in Division 7 amounting to 64 mm, and maximum rainfall in Division 1 in January 2017 in the amount of 289 mm. Hence, the estimated FFB production will amount to 812 kg/ha in June 2020 in Division 7 and 1024 kg/ha in January 2020 in Division 1. Weather-based production forecasting with 68% coefficient of determination was reported for time interval of 1-24 month before harvest, where the main effect on reduction on bunch number generated in 20-24 months on sex determination problem before harvest by available water holding capacity status (AWHCS) and 10-11 months before harvest on inflorescence abortion by the AWHCS as well [14].
Table 2. Estimated FFB Production of Division 1-7 of the oil palm plantation in January-June 2020

| Month | Precipitation 2017 (mm) | FFB Production 2020 (kg/ha/month) |
|-------|------------------------|-----------------------------------|
|       | Division 1 | Division 2 | Division 3 | Division 4 | Division 5 | Division 6 | Division 7 | Division 1 | Division 2 | Division 3 | Division 4 | Division 5 | Division 6 | Division 7 |
| 1     | 289        | 237        | 200        | 185        | 169        | 156        | 171        | 1024       | 979        | 946        | 933        | 919        | 908        | 921        |
| 2     | 261        | 238        | 242        | 261        | 236        | 216        | 209        | 1000       | 980        | 983        | 1000       | 978        | 961        | 955        |
| 3     | 247        | 207        | 199        | 274        | 176        | 228        | 256        | 988        | 952        | 946        | 1011       | 926        | 971        | 995        |
| 4     | 149        | 154        | 169        | 219        | 195        | 217        | 189        | 903        | 906        | 920        | 963        | 942        | 962        | 937        |
| 5     | 139        | 130        | 127        | 95         | 100        | 145        | 88         | 894        | 886        | 884        | 856        | 860        | 899        | 849        |
| 6     | 122        | 92         | 86         | 127        | 184        | 64         | 45         | 879        | 853        | 848        | 884        | 933        | 829        | 812        |

4. Conclusion
Under water scarcity conditions in the dry season, more flower infertility will be exposed in the same period of the dry season with higher response variability. Soil moisture content under the frond pile is more stabilized against evaporation so that the rate of soil demoisturizing at the upper horizon layer is slower than at the circle area and active path area. Estimated oil palm production in a period is determined by the precipitation value 36 months before harvest.

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References:
[1] Acosta P M and Curt M C 2019 Understanding the expansion of oil palm cultivation: A case-study in Papua Journal of Cleaner Production 219 199-216
[2] Manoli G, Meijide A, Huth N, Knohl A, Kosugi Y, Burlando P, Ghazoul J, Fatichi S 2018 Ecohydrological changes after tropical forest conversion to oil palm Environ. Res. Lett. 13 064035
[3] Culman M, de Farias C M, Bayona and Cruz J D C 2019 Using agrometeorological data to assist irrigation management in oil palm crops: A decision support method and results from crop model simulation Agricultural Water Management 213 1047-62
[4] Varkkey H, Tyson A and Choiruzzade S A 2018 Palm oil intensification and expansion in Indonesia and Malaysia: Environmental and socio-political factors influencing policy Forest Policy and Economics 92 148–59
[5] Merten J, Röll A, Guillaume T, Meijide A, Tarigan S, Agusta H, Dislich C, Dittrich C, Faust H, Gunawan D, Hein J, Hendrayanto, Knohl A, Kuzyakov K, Wiegand K, Hölscher D 2016 Water scarcity and oil palm expansion: social views and environmental processes Ecology and Society 21 1-21
[6] Guillaume T, Holtkamp A M, Damris M, Brümmer B and Kuzyakov Y 2019 Soil degradation in oil palm and rubber plantations under land resource scarcity Agriculture, Ecosystems and Environment 232 110–8
[7] Röll A, Niu F, Meijide A, Ahongshangbam J, Ebhrech M, Guillaume T, Gunawan D, Hardanto A, Hendrayanto, Hertel D, Kotowska M M, Kreef H, Kuzyakov Y, Leuschner C, Nomura M, Polle A, Rembold K, Sahner J, Seidel D, Zemp C D, Knohl A, Hölscher D 2019 Transpiration on the rebound in lowland Sumatra Agricultural and Forest Meteorology 274 160–71
[8] Comte I, Colin F, Whalen J K, Gruenberger O and Caliman J P 2012 Agricultural Practices in Oil Palm Plantations and Their Impact on Hydrological Changes, Nutrient Fluxes and Water Quality in Indonesia: A Review Advances in Agronomy 116 71-124
[9] Euler M, Hoffmann M P, Fathoni and Schwarze S 2016 Exploring yield gaps in smallholder oil palm production systems in eastern Sumatra, Indonesia Agricultural Systems 146 111–9
[10] Hoffmann M P, Donough C R, Cook S E, Fisher M J, Lim C H, Lim Y L, Cock J, Kamb SP, Mohanaraj S N, Indrasuara K, Tittinutchanon P and Oberthür T 2017 Yield gap analysis in oil palm: Framework development and application in commercial operations in Southeast Asia Agricultural Systems 151 12–9
[11] Afriyanti D, Kroeze C and Saad A 2016 Indonesia palm oil production without deforestation and peat conversion by 2050 Science of the Total Environment 557–558 562–70
[12] Pransiska Y, Triadiati T, Tjitrosoedirjo S, Hertel D, Kotowska MM 2016 Forest conversion impacts on the fine and coarse root system, and soil organic matter in tropical lowlands of Sumatera (Indonesia) Forest Ecology and Management 379 288–98
[13] Agusta H, Hendrayanto, Sudaryanto MT, Dewi AM, Hoelscher D. 2019. Infiltrated Water and Runoff at Four Gradient Slopes at Smallholder Oil Palm Plantation in Dry Season in Jambi, Indonesia J. Jpn. Inst. Energy 98 101-5
[14] Yong K K and Wong M K 2012 Statistical Modeling of Weather-based Yield Forecasting for Young Mature Oil Palm APCBEE Procedia 4 58 – 65