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Effect of Soil Water Deficits on Annual Fresh Fruit Bunch Production in Central Kalimantan

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The soil water deficits have an after-effect over the time lagged fruiting activities of palms, which subsequently affects the annual fresh fruit bunch (FFB) production in the oil palm plantation. Field data from 2014 to 2018 in a reasonably well managed oil palm estate with three soils of the greater groups of Typic Dystrudept (Inceptisol), Typic Haplohumod (Spodosol) and Typic Haplohemist (Histosol) were analysed. The palms were planted in the years 2004 and 2005, and were producing FFB at its prime plateau age of yield life cycle. The amount of monthly water deficits that results in single or multiple fruiting activities responded quadratically to subsequent annual FFB production in all three soils. With two consecutive total soil water deficits in the years 2014 and 2015, the multiple time lagged fruiting activities from bunch failure to sex differentiation with change in sex ratio favouring male inflorescences resulted in reduced yield in 2016 in all three soils. Typic Haplohumod soils being sandy achieved the lowest yield in 2016. The palms planted on Typic Haplohemist showed rapid decline in crop with the slightest water deficit. The soil derived from Typic Dystrudept gave relatively high FFB production at low water deficit.

Keywords: *Water deficit, fruiting activity, fresh fruit bunch production, El nino, drought.*

The maximum potential annual fresh fruit bunch (FFB) production in a location depends on the type of inherent characters of the soil, climate, genetic potential of the planted cultivar, accuracy in planting distances and pattern and optimising the planting density of palms at the site (Kee *et al.,* 1994; Goh *et al.,* 1994; Goh *et al.,* 1997; Chew, 1997; Mathews *et al*., 2005; Mathews *et al.,* 2006). The information on climate and soils are considered as the prime factors to estimate annual potential bunch yield of a site. Of the two factors, water, especially from rainfall and its deficits in soils were the decisive factors in predicting yields of a location (Hartley, 1973; 1988). IRHO (1969) and Ochs and Daniel (1976) had worked on the relationship between annual water deficit and annual FFB yield of oil palm in Ivory Coast, Dahomey (Benin) and Cameroon and concluded that palms planted on soils of medium characteristics have third degree of yield trend curve. Dufour *et al*. (1988) too indicates the importance of water deficit to forecast yields for a period of 6 to 30 months prior to bunch harvesting in Ivory Coast and Cameroon. Caliman (1992) and Caliman and Southworth (1998) worked out the effect of water deficit and annual FFB production in Ivory Coast and Indonesia (Lampung), respectively. They drew a relationship between the water deficit and the physiological changes at the time lagged fruiting activities on annual FFB production. Broekmans (1957) and Corley (1976) had reported that the inflorescences abortion in dry months and the subsequent low yield was seen 10 months from the onset of

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drought. The water stress in the soil influences the physiology of fruiting activities by a change in the sex differentiation of the inflorescences to male; the effect could be lagged for a period of 21 to 29 months before harvesting bunches depending on the location of the country studied (Broekmans, 1957; Corley, 1976; Turner, 1977; Breure, 2003). Breure and Corley (1992) studied plant available water and sunshine hours as additional covariates that affects total weight of FFB as the result of time lagged fruiting activities in West New Britain of Papua New Guinea, North Sumatra in Indonesia and Johore in Malaysia under natural yield fluctuations in oil palm plantations. Corley and Breure (1992) investigated the fruiting activities of current yield and future yield through simulation of disbudding of inflorescences prior to anthesis in Johore, Malaysia. However, their papers on fruiting activities were aimed to forecast the yield of the oil palm plantation.

The province of Central Kalimantan in Indonesia had undergone two consecutive years of *El nino* related droughts in 2014 and 2015. Prior to that, Sumatra and Kalimantan had experienced *El nino* drought in 1997 resulting in decline of oil extraction rates in mills due to haze related low sunshine days and later the low FFB production as the result of water deficits (Caliman & Southworth, 1998). The *El nino* of 2014 and 2015 too caused peat fire haze or polluted smog. It again diminished the oil extraction rates in mills due to early abscission of fruits from the bunches on the palm tree and is expected to be due to the presence of ethylene gas in haze related peat fire (Mathews & Adrianto, 2016). The two consecutive *El nino* droughts in 2014 and 2015 affected the FFB production from late 2014 to early 2018 and low yields are believed to be the result of time lagged activities of fruiting. The palm growth was also affected by the formation of multiple spear formation with dried lower leaves in palms growing on Typic Haplohemists soils and Typic Dystrudept soils. But on Typic Haplohumod soils even the mid fronds were dried and snapped in 2014 and 2015. The objective of the present paper is to study the effect of 2014/2015 droughts and to analyse the quantum sum of monthly water deficits that leads to the time lag in single or multiple fruiting activities from bunch failure to sex differentiation of male inflorescences and relate it to the production of annual FFB in three common soils in Central Kalimantan. The quantum of monthly water deficits that lead to the time lagged fruiting activity are quantified, and compared to the annual FFB production through polynomial analysis, which may be useful to forecast future yield under similar climatic circumstances. The management of the company gave Bumitama Gunajaya Agro's Research and Development Centre to put best field practices to elevate yields in Katari Estate that covers 3 575 ha. Each operational work was monitored in that estate regularly and best practices were put in place in order to elevate crop in the estate. Data analysis is confined to three types of soils consisting of Typic Dystrudept with varying depths of upper sand layers in the soil profile, Typic Haplohumod and Typic Haplohemists with palm planted in the years 2004 and 2005 plantings. These soils are commonly found in Central Kalimantan province.

METHODOLOGY AND RESULTS

Field and operational background

Details of the soil under greater group, palm planting years, the area (hectares) covered with stand per hectare of each planting are given in *Table 1.*

TABLE 1
THE SOILS, PALM PLANTING YEARS, PLANTED AREA COVERED AND STAND PER HECTARE OF THE STUDY SITES OF ESTATE

Parameters	*Sites*			*Total[1]/Mean[2]*
	1	*2*	*3*	
Soils (great group)	Typic Dystrudept	Typic Haplohumod	Typic Haplohemist	
Planting years	2004	2004/2005	2004/2005	
Area (hectares)	1 009	216	121	1 346[1]
Stand per hectare	135	131	130	134[2]

All the soils of the fields were surveyed according to USDA soil taxonomic classification. The total land area covered with the three soils were 1 346 ha. Only the fields with the same kind of soil mentioned in *Table 1* were selected for the study. Fields with overlapping or other soil types were not considered for data analysis, as it may not represent the true situation of the palm yield performance to the soil. The fields were reasonably well planted and managed with uniform standing palms. The palms were planted from 2004 to 2005 and harvested at their plateau yield cycle of age. The annual yield fluctuation due to water deficits is more appropriate to interpret in matured palms that had reached an age where the yield is at the peak plateau cycle. The daily harvesting records were kept for the above fields. There were regular field visits to monitor the daily operations in place for the completion of annual fertilisation, weeding and weekly harvesting with additional inputs for the water conservation programmes in soils of Typic Haplohumod and Typic Haplohemist. The range of fertiliser rates applied on per palm basis from 2014 to 2017 for different soils is given in *Table 2* below.

The fertilisers were applied within each year without much delay except in 2018. Due to exceptionally high crop for 6 months in that year, most of the operational workers were utilised for loose fruit collection. Although with

TABLE 2
RANGES OF FERTILISER (KG/PALM/YR) APPLIED FROM 2014 TO 2018

	Rates (kg/palm) by soil type		
Fertilisers applied	*Typic Dystrudept*	*Typic Haplohumod*	*Typic Haplohemist*
Egyptian rock phosphate (total P_2O_5 = 27 to 28% and citric acid soluble P_2O_5 8 to 9%)	1.75-3.00	2.25-3.00	0.75 - 1.75
Urea (N=46%)	2.50-2.75	2.25 - 3.00	1.00 - 1.50
Muriate of Potash (K_2O=60%)	3.75	4.00 - 4.50	4.25 - 4.50
Kieserite (MgO 25%)	0-1.25	0.50 – 1.75	0.00
Borate (B_2O_3 46%)	0.10-0.15	0.10-0.15	0.125-0.150
Copper sulphate (CuO 25%)	0.00	0.10	0.10-0.15
Total	8.10 - 11.15	9.20 - 12.50	6.225 - 8.05

delays, the fertilisers were fully applied towards the last quarter of 2018. During most of the years, the total fertiliser rates applied were at lower range, unless some exceptional cases arose for fertiliser adjustment to higher rates due to previous manuring history and deficiency at the leaf levels.

Soil analyses

The soils in the estate were classified as per USDA soil taxonomy up to the level of the great group. The mechanical and chemical analyses of the three groups of soil are given in *Appendix 1*. The mechanical and chemical analyses of the soil were according to the Rubber Research Institute Malaysia's manual given by Norhayati and Singh (1980). Soil profile samples from the three soils identified were classified as Typic Dystrudept, Typic Haplohumod, and Typic Haplohemist were obtained.

Soils of Typic Dystrudepts in general are deep and loam to clay in texture. The upper profile has high percent of sand and silt, while lower profile has very high content of light greyish white clay. The mean value of soil profile physical texture of Typic Dystrudept falls into borderline of clay. Typic Haplohumod is mainly sand with weak to hard spodic horizons, ranging from shallow (0-50 cm) to moderately deep (50-100 cm). The Typic Haplohemist of the study site is an organic peat with a mean depth of 1.8 m of organic matter. As much as possible, water is physically maintained in Typic Haplohemist from 40 cm to 50 cm ground level through construction of stops. However, when prolonged drought sets in, it was not possible to maintain the ground water level. As the water level subsided in nearby river, the water level in the Typic Haplohemist too ebbed completely.

Water balance in soil

Rainfall

Rainfall was measured in millimeter using rain gauge at the estate main office site as usual estate practice. It was recorded daily and monitored by research centre. The total monthly rainfall and rainy days from 2013 to 2018 are as given in *Appendix 2*. These could have been variations in the rainfall over the whole area of 1 346 ha. The 2004 and 2005 plantings were the early plantings of the estate and planted within the surroundings of main office within 3 kilometers radius. Central Kalimantan had faced two consecutive years of severe drought in 2014 from July to October and in 2015 from August to October. Haze engulfed the whole of the Central Kalimantan up to the northern region of West Kalimantan provinces. Subsequently, in 2016 the rainfall was sufficient in the estate, however, the estate had experienced minor dry months in July and August and in July of 2018 too. Generally high rainfall was encountered in 2017.

Available water holding capacity

The available water holding capacity (AWHC) of soil is estimated as per tropical soil texture given by Landon (1984) and is presented in *Table 3*.

The Typic Dystrudept is at the borderline of clay and hence the AWHC is estimated to be about 130 mm per metre. The Typic Haplohumod being sand, the AWHC is estimated to be about 60 mm per metre. The water holding capacity of peat was measured to be at 413 mm per metre by Foster *et. al.* (1984). However, in Typic Haplohemist, the profile contains large undecomposed wood material e.g. tree stumps, which will not hold water like decomposed organic material. In

TABLE 3
ESTIMATED AWHC[1] VALUES FOR TROPICAL SOILS OF DIFFERENT TEXTURE AND STONE CONTENTS

Texture [2]	*Tropical AWHC (to nearest 10 mm/m) Stone and gravel content (and % reduction of stone-free tropical AWHC)*					
	Stone-free (<10%)	*Few (10%)*	*Common (25%)*	*Many (50%)*	*Abundant (70%)*	*Dominant (90%)*
Clay loam	130	120	100	70	40	10
Silty clay loam	150	140	110	80	50	20
Sandy clay	100	90	70	50	30	10
Sandy clay loam	140	130	100	70	40	10
Loamy sand	110	100	80	50	30	10
Sandy loam	130	120	100	70	40	10
Silty clay	140	130	110	70	40	10
Clay	130	120	90	60	40	10
Sand	80	70	60	40	20	10

[1]Available water holding capacity; [2] Textures quoted are the nearest USDA equivalent.
Source : Landon (1984)

such a case, there is a need to reduce the AWHC from 413 mm per metre. The collection drain cuttings showed the presence of about 20 per cent wood material in the profile. The presence of woods reduces the water holding capacity of Typic Haplohemist of the current site and estimated reduction was by 20 per cent accordingly.

Potential evapotranspiration

The potential evapotranspiration was calculated by simplified method as proposed by IRHO (1969). For the monthly rainfall of more than 10 days, the potential evapotranspiration is estimated at 4 mm per day. The value of potential evapotranspiration is 5 mm per day for the monthly rainfall of less than 10 days (IRHO, 1969; Ochs & Daniel, 1976).

Water deficit calculation

In the present paper calculation of the monthly water deficits of different soils is simplified as follows:

$$B = Res + R - Etp$$ (Surre, 1968; Ochs & Daniel, 1976)

where "B" is the theoretical balance of water at the end of the period, "Res" is the soil water reserve at the beginning of the period, "R" is the rainfall of the month and "Etp" is potential evapotranspiration during the period.

The FFB harvested in the field were collected and sent to the oil mill to quantify the weight and was documented for each harvesting of the area coverage (given in *Table 1*) daily. The yield information is used for regular monitoring in the field to understand the low yield cycles by making visual field observations and through 4 monthly bunch count censuses to understand the reasons for low and high bunch numbers on the palms. This provides the information of lack of bunches on palms and the timing of the emergence of male inflorescences intermittently.

Soil water deficit and annual FFB production

The monthly water deficits were calculated according to time lag of fruiting activities and the annual FFB production. The fruiting activities identified in oil palm are inflorescence failure (failure of anthesised inflorescence to form bunch) bunch failure (pollinated bunch rots prior to fully ripening and harvesting), inflorescence abortion and sex differentiation of change in sex ratio by the emergence male inflorescences (Breure, 2003; Corley & Tinker, 2015). The annual water deficits, the summing of water deficits that affect time lagged fruiting activities, the annual FFB production and the yield components are given in *Table 4*. The FFB production (on per hectare basis) is graphically given in *Figure 1* to illustrate the pattern of monthly cropping.

As shown in *Table 4*, the annual soil water deficit has no direct relationship with annual FFB production. The effect of water deficit is on some fruiting activity (which are: bunch failure, inflorescence failure, inflorescence abortion and sex differentiation), and which is a time lagged phenomenon that is consequently related to the annual FFB production. The effect of water deficit of a particular period on time lagged fruiting activity can stretch out over more than two-and-a-half years. There can be a single fruiting activity in a year or all the four fruiting activities due to combined effect of two successive years of water deficits. In the year 2016, there was combined additive water deficits on fruiting activities due to droughts of 2014 and 2015. A reduced level of yield has been seen in 2016 with varying degrees of FFB production depending on the soils, where Typic Haplohumod had the lowest yield of 16.51 tonnes FFB per hectare; the soil obviously known for its sandy nature. The main outcome of fruiting activity observed was the reduction in number of bunches per palm in all the three soils. This could be the consequence of inflorescence and bunch failures, female inflorescence abortion and emergence of male inflorescences with combined annual water deficit of 2014 and 2015. Lower bunch numbers were observed in both Typic Dystrudept and Typic Haplohumod as compared to Typic Haplohemist. The low bunch numbers due to fruiting activities showed some compensatory effect through an increment in average bunch weight for each year with correlation value of -0.63 for Typic Dystrudept, -0.60 for Typic Haplohumod and -0.64 for Typic Haplohemist in the 5 years of data compilation.

Based on *Figure 1*, there was a reduction in monthly yield at time lagged for 6 to 14 months (January 2015 to August 2015), 19 to 25 months (January 2016 to August 2016) and 29 to 34 months (November 2016 to April 2017) from the onset of water deficit from August to October 2014. The decline of yield for the 6-14 months from the onset of 2014 drought could be due to the possibility of inflorescence or bunch failures and female inflorescence abortions. On the Typic Haplohumod soil (being sand in nature), the bunch failure was observed by the presence of rotting bunches as the result of water deficit in that soil. The rotting bunches was the result of bunch failure that attracts *Tirathaba* pest and the high infestation could exclusively be seen on Typic Haplohumod soils (Mathews *et al.*, 2018). There could have been natural abortion of young inflorescences prior to anthesis and this could be the reason for prolonged cycle of low yield in the second quarter of the year 2015. Field visual observations prior to decline in yield in May 2015 to August 2015 showed a low number of about three developing bunches on fronds 21 to 30.

TABLE 4
ANNUAL SOIL WATER DEFICIT (INCLUDING TIME LAG ON IMPACT, TYPE OF IMPACT, YIELD COMPONENTS AND YIELD) TO EXPECTED FRUITING ACTIVITY THAT AFFECTS ANNUAL FFB PRODUCTION AND ITS COMPONENTS

			A) On a Typic Dystrudept soil		
Year	2014	2015	2016	2017	2018
Annual water deficit (mm)	240	217	0	0	0
Months of water deficits	Aug-Oct	Aug-Oct	-	-	-
Quantum of summed water deficit (mm) to fruiting activities that affects annual yield	164	391	457	217	65
FFB (t/ha)	27.25	23.93	19.56	24.68	33.16
Bunch no. per palm	16.671	13.463	9.469	9.661	14.025
Average bunch weight (kg)	12.10	13.17	15.30	18.92	17.51
Total FFB (kg per palm)	201.72	177.31	144.88	182.79	245.58
Type of fruiting activities expected on annual yield	BF (2014)	IF (2014) +IA(2014) +BF (2015)	IF (2015) +IA (2015) +MI (2014)	MI (2015)	MI (2015 and 2016)
			B) On a Typic Haplohumod soil		
Year	2014	2015	2016	2017	2018
Annual water deficit in mm	310	287	59	0	70
Months of water deficits	Jul-Oct	Aug-Oct	Aug	-	Jul
Quantum of summed water deficit (mm) to fruiting activities that affects annual yield	239	532	656	346	184
FFB (t/ha)	24.05	21.55	16.51	20.42	29.12
Bunch no per palm	17.459	13.955	9.622	9.685	13.593
Average bunch weight (kg)	10.51	11.79	13.10	16.09	16.35
Total FFB (kg per palm)	183.49	165.53	126.05	155.83	222.25
Type of fruiting activities expected on annual yield	BF (2014)	IF (2014) +BF (2014 +2015) +IA(2014)	IF(2015) +BF (2015 & 2016) +IA (2015) +MI(2014)	IF (2016) +IA (2016) +MI (2015)	MI(2015 & 2016) +BF (2018)
			C) On a Typic Haplohemist soil		
Year	2014	2015	2016	2017	2018
Annual water deficit in mm	40	17	0	0	0
Months of water deficits	Oct	Oct	-	-	-
Quantum of summed water deficit (mm) to fruiting activities that affects annual yield	0	40	57	17	17
FFB (t/ha)	26.03	23.06	18.19	24.34	28.40
Bunch no. per palm	19.778	16.457	11.540	12.683	15.433
Average bunch weight (kg)	10.12	10.78	12.12	14.76	14.16
Total FFB (kg per palm)	200.15	177.41	139.86	187.20	218.53
Type of fruiting activities expected on annual yield	BF (2014)	IF (2014) +BF(2015) +IA (2014)	IF (2015) +IA(2015) +MI(2014)	MI (2015)	MI (2015 and 2016)

**Notes:* BF= Bunch failure, IF= Inflorescence failure, IA= Inflorescence abortion, MI= Sex differentiation to male inflorescences

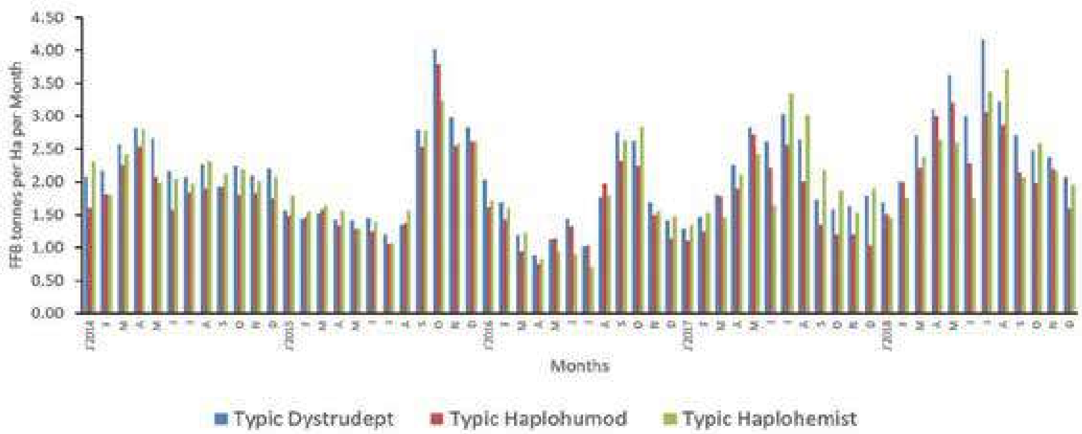


Figure 1 *Monthly FFB production from 2014 to 2018*

As shown in *Figure* 1, and from the inception of water deficits from August 2015 to October 2015, there was a reduction of monthly yield well ahead at 6 to 12 months (January 2016 to June 2016), followed by reduced yield at 16 to 21 months (November 2016 to March 2017) and 26 to 31 months (September 2017 to February 2018). However, the diminution of yield at 19-26 months due to 2014 water deficit was overlapped with reduction of yield of 6-12 months of water deficit in 2015. There was emergence of male inflorescences at that time. Whether the emergence of the male inflorescences was the result of preferential survival of young male inflorescence during the 2015 drought or due to the sex differentiation as the result of 2014 drought is difficult to ascertain. Corley (1976) reported female inflorescences are more prone to abortion than males when palms are stressed by excessive frond pruning or subjected to soil moisture stress. There could be quadruple impacts of yield sensitivity due to inflorescence and bunch failures, inflorescence abortion and male inflorescences emergence in 2016. The effect of contiguous water deficits during 2 years i.e. 2014 and 2015 on yield was observed in 2016, where the yield was less than 1 tonne FFB per hectare in certain months. Similarly, diminution of yield at 29-34 months after the onset of water deficit in 2014 was overlapped with 16-21 months of 2015 water deficits. Here the male inflorescences emerged from April 2016 to July 2016, and later the low yield was observed from November 2016 to February 2017. Another cycle of male inflorescences emerged from March 2017 to July 2017 and also showed low FFB production from September 2017 to February 2018; and this is expected to be the effect of 2015 water deficit. The low yield in the last quarter of 2018 could be due to the two successive months of zero water deficits with low rainfalls in Typic Dystrudept and Typic Haplohemist in July and August 2016. If the two successive monthly zero water deficits months with the two low rainfall months have any impact on the sex ratio change in 2018 is yet to be fully evaluated. The assumption is that all the three soils showed the same pattern of monthly yield profile, but there were differences in magnitude of yield variation. Hence, there could have been some effects of the low rainfall months of July 2016 and August 2016 later on the yield. However, few male inflorescences emerged on palms on Typic Dystrudept and Typic Haplohemist soil in mid-June 2018 and July 2018, while moderate level of male inflorescences emerged on palms on Typic Haplohumod soil in May 2018 and June 2018 (22 to 23 months later after dry months), which gave the moderately low yield in October 2018 to November 2018. Palms on Typic Haplohumod could partially be affected by light bunch failure due to water deficit in July 2018 and eventually affected the yield in December 2018. Whether the 6 months peak yield from March 2018 to August 2018 and the delay in fertiliser application in 2018 due to high yields has any role to play is yet to be evaluated. There was a reduction in bunch weight in the second half of 2018.

The anticipated impact on actual annual FFB yield based on fruiting activity of varying water deficits observed for the palms on the three different types of soils are given in *Figure 2* (*a,b & c*).

The quadratic trend of annual cropping in all the three soil groups against the sum of monthly water deficits derived according to fruiting activities is indicated in *Figure 2*. The pattern or trend behaviour was a similar parabolic curve for palms on Typic Dystrudept and Typic Haplohumod. For palms on Typic Haplohemist the trend was an inverted parabolic, where with little water deficit the yield was maintained and declined rapidly as the sum of time lagged water deficit quantity increases. On Typic Dystrudept soil group the first 300 mm deficit at every 100 mm interval the crop reduction was about more than 10 per cent; while from 400 mm at 100 mm interval the crop reduction was less than 10 per cent. On Typic Haplohumod soils, the first 400 mm deficit at every 100 mm interval, the crop reduction was about more than 10 per cent. On Typic Haplohemist soils the yield dwindled with slight water deficit to fruiting activity (*Figure 2c*). The water deficit at every 10 mm interval up to 20 mm showed the FFB reduction of about less than 2 per cent. Above the 60 mm deficit level the reduction in crop production will be higher than 10 per cent and the margin of reduction widens drastically thereafter. It appears that with zero monthly water deficit the Typic Haplohemist palms shows a similar yield pattern to mineral soils perhaps due to very low bulk density, which is a regular requirement of physical water maintenance in the drains and field.

DISCUSSION

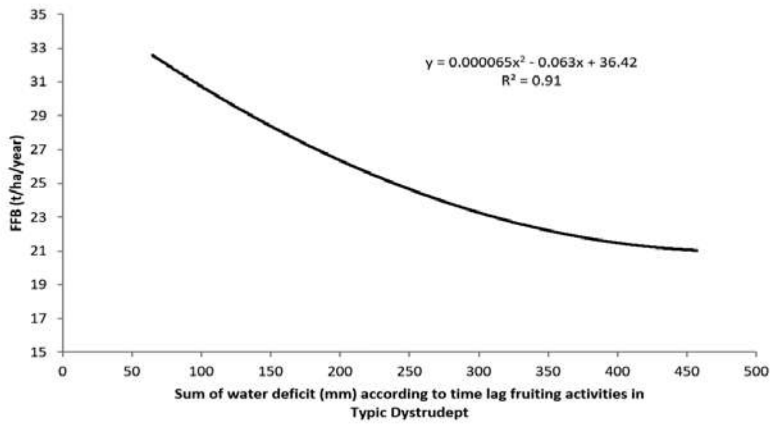
The balance of water adequacy in a plant is the phenomenon of soil moisture absorbed by roots and loss of water through soil and leaf evapotranspiration. The water loss by evapotranspiration is the demand component and the soil moisture absorbed by roots is the supplying component for crop growth and production. The disruption in demand and supply of water components in plant results in the diminution of photosynthetic activity and subsequently affects the growth and yield (Ochs & Daniel, 1976). The progressive closure of stomata during water deficit months or drying of soil is the reason for the disruption of the supply and demand components which results in reduction of the photosynthetic activity of palms (Dufrene *et al*., 1990). The relationship of soil water deficits and annual FFB production was reported in the equatorial belt of West African countries (Surre, 1968; Ochs & Daniel, 1976; Frere, 1986; Dufour *et al*., 1988; Caliman, 1992). Annual water deficits of 150 mm to 550 mm showed third degree of yield trend curves in the Ivory Coast, Dahomey and Cameroon (Ochs & Daniel, 1976). These West African countries have two distinct water deficit periods every year from November to February and from July to September (Ochs & Daniel, 1976; Caliman, 1992). However, in South East Asian countries where oil palms are planted, the annual rainfall is high and the drought cycle is once in 3 to 5 years through occurrence of minor or major *El nino* (Caliman, 1992; Caliman & Southworth, 1998). Moreover, the potential yields of palms in South East Asian regions are much higher than in the West African regions. In Central Kalimantan, (where this study was done) in general there was adequate to high annual rainfall where the annual average for 6 years was indicated to be close to a total of 3 000 mm per year with 165 rain days. In 2014 and 2015, there were two successive droughts with water deficits encountered in the study site.

The ultimate outcome of water deficit on palms is the time lagged physiological changes especially in "fruiting activity"; the term was first coined by Broekmans (1957). The term referred to the number of bunches between anthesis and ripeness at any given time, which may be affected due to time lag of inflorescence abortion and change in sex ratio by sex differentiation, thus producing male inflorescence cycle. It is essential to understand the overall time lagged fruiting activity concept that eventually affects the yield cycles of palms. Corley (1976) and Breure (2003) illustrated that the fruiting activities from inflorescence initiation to bunch ripening took about 36 months; although there are some variations from palm to palm. Frere (1986), Dufour *et al.* (1988), Caliman (1992) and Caliman and Southworth (1998) called these results of fruiting activities as yield sensitivities due to water deficits. Broekmans (1957) found regular peaks of male flower production 20 months after dry season in Nigeria. He also studied the inflorescence abortion 3 to 4 months before anthesis or about 9 to 10 months before bunch harvest. Corley (1976) observed a time lag in change of sex differentiation and anthesis by 17 to 20 months from high density and thinning trials. He also observed that severe pruning or defoliation of palm canopy about 10 months before bunch harvest causes preferential abortion of female inflorescences than the male inflorescences. Turner (1977) observed drought to affect male inflorescence emergence in 16 to 21 months to anthesis; and hence 21 to 26 months before harvesting bunches there will be a decline in yield. Breure and Corley (1992) observed that the average time lag between sex differentiation and anthesis of male inflorescence was about 16 months in Papua New Guinea and 18 months in Sumatra. This translates to an average 22 months in Papua New Guinea and 24 months in Sumatra before harvesting bunches.

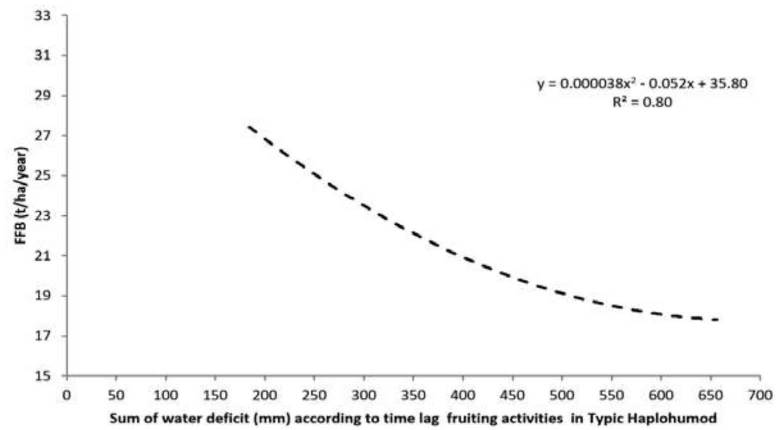
Oil palm yield sensitivity period has been evaluated by Frere (1986), Dufour *et al.* (1988), Caliman and Southworth (1998). Frere (1986) indicated that effect of the monthly water deficit in Dahou on FFB production can be classified into three periods. The first period was 30-33 months before harvesting bunches that could correspond to sex differentiation to male cycle. The second period was 19-24 months, which Caliman and Southworth (1998) later indicated that it may correspond to fast growth of leaves supporting the inflorescences. The third period was 7 to 13 months before harvesting of bunches that corresponds to the abortion period. Caliman and Southworth (1998) observed in Lampung, Indonesia monthly low yield sensitivities in three periods i.e. between 4 and 10 months, between 18 and 22 months and between 30 and 33 months before harvesting. However there was no mention of the type of fruiting activities in such time lagged yield diminution. The present data analysis too indicated three periods in 2014 and 2015. In 2014, the time lagged fruiting activity periods were 29 to 34 months, 19 to 25 months and 6 to 12 months before bunch harvesting. In 2015, the time lagged fruiting activities were 27 to 31 months, 16 to 21 months and 6 to 12 months before bunch harvesting. With two successive years of drought in 2014 and 2015, there were overlapping of time lagged multiple fruiting activities from bunch failure to male flower emergence in 2016, the lowest yield was observed in that year.

As stated by Caliman (1992), the statistical models developed on water deficits and yield forecast varied from location to location. The models developed and applied were according to the growing situation of that particular location. Dufour *et al.* (1988) developed a simple model for yield forecast in Ivory Coast using water deficit cumulated for 3 years prior to harvesting with a formula of production FFB tonnes per hectare = -0.0071 water deficit + 22.12 with a correlation value of 0.94. In their study they noted that annual water deficit from 0 mm to 500 mm reduces by 10 per cent at every 100 mm deficit interval from the potential production with no water deficit. Caliman and Southworth (1998) indicated the occurrence of periodic moderate to high water deficits in 3 to 5 years interval in Lampung, Indonesia. They have not observed overlapping droughts in two successive years in that region. They suggested that as for the case in Lampung, it would be good to obtain a model for the individual annual deficits over a period of 2 or 3 years, instead of cumulating it like in West Africa. That made them to suggest when year "n" is considered as water deficit year, then in n + 1 year, there will be about 8 to 10 per cent yield reduction from potential yield with no water deficit. In n+2 year about 3 to 4 per cent yield reduction is expected and year n+3 would show slight reduction of yield; but significant reduction is expected, if the drought of the "n" year is very severe e.g more than 400 to 500 mm. In the present study, the approach of the model analysis is different from the earlier authors. The monthly water deficits were summed according to time lagged fruiting activities and plotted against annual yield. The model appeared to be a quadratic trend for all three soil group of Typic Dystrudept, Typic Haplohumod and Typic Haplohemist. The three soil groups considered for the studies responded quadratically with similar behaviour trend of parabolic curve in Typic Dystrudept and Haplohumod as compared to inverted parabolic curve in Typic Haplohemist (*Figures 2 a, b & c*). In the present analysis on Typic Dystrudept, the first 0 - 300 mm deficit at every 100 mm interval the crop reduction was about 12 - 15 per cent from the potential FFB on that soil. On Typic Haplohumod, the first 400 mm deficit at every 100 mm interval the crop reduction was about 11-14 per cent of potential crop. On Typic Haplohemist the yield reduced with slight summed water deficit to fruiting activity (*Figure 2c*). The water deficit of every 10 mm interval up to 30 mm showed the FFB reduction of about less than 2-6 per cent of potential crop. At more than 40 mm level of water deficit, the reduction of crop production will be higher than -10 per cent and the margin of reduction widens drastically thereafter.

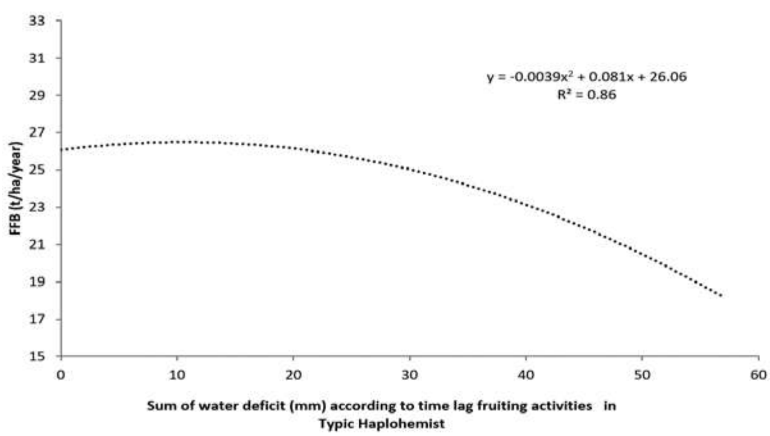
The soil group Typic Dystrudept has sand layer of several centimeters depth on the upper profile and heavy clay of white Kaolinite in the lower profile. It is believed that the soil beneath the profile has higher moisture holding capacity than the soil on the upper layer due to nature of the soils' physical texture. In Typic



a) Palms on Typic Dystrudept soil



b)Palms on Typic Haplohumod soil



c) Palms on Typic Haplohemist soil and its response to annual FFB production

Figure 2 Time lag impact of soil water deficits experienced over a period of time on FFB yield

Dystrudept not much additional inputs except standard operational inputs such as regular manuring, weeding with soft weed maintenance, progressive pruning and placement of pruned fronds on inter-rows were carried out. The Typic Haplohumod soil is generally sand in nature throughout more than 1 m profile depth and in such soils, the retention of water is poor (Landon, 1984; Foster *et al.,* 1984). The Typic Haplohumod soil is subjected to quicker water stress than Typic Dystrudept. Hence additional inputs for soil water conservation programme with empty fruit bunch as mulch were annually carried out. Drains were cut from road to inner field level and water was maintained above the spodic layer through overflow of partitioned infield drains. Continuous physical maintenance of high water levels in drains softened the palm trunk which succumbed to stem rot, which was observed mainly in 2017 and early 2018 in Spodosols (Mathews *et al.,* 2018). Fertiliser dosage per palm was higher in the Spodosol with high frequency of application in low dosages. Soft weed *Nepherolepis biserrata* was grown in the field. The litter from soft weeds provide mulching effect to the soil. Typic Haplohemist in general has high water holding ability, but due to low bulk density the standing palms are leaned. The leaning nature has poor orientation of the palm canopy resulting in lower maximum potential yield. Drains are constructed and water is physically retained in the drain with proper overflow stop structures at 40-50 cm from peat ground level in Typic Haplohemist. These structures were constructed only in 2015 and could have some influence on the higher yield in 2018. However, during drought the level of water in the drain receded along with the nearby river below 1 m within a month.

CONCLUSIONS

Water deficit causes the time lagged physiological change of fruiting activities and subsequently affects the yield of oil palm in three soils that are commonly seen in Central Kalimantan. In the two successive years of 2014 and 2015 water deficits in Central Kalimantan caused overlapped multiple fruiting activities and caused depressive yield in 2016. The monthly water deficits summed according to fruiting activity and yield showed quadratic response to annual yield in all three soils. The effect of severe drought experienced in 2014 and 2015 can be extended for a period of about 3 years with intervals of 6 to 12-14 months, 16-19 to 21-26 months and 26-29 to 33-34 months before harvesting bunches or from the onset of water deficit months. The effect of severe water deficit extends up to close to 3 years under Central Kalimantan conditions.

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APPENDIX 1

SOIL PHYSICAL AND CHEMICAL ANALYSES OF THE ESTATE

Soil great group	*Typic Dystrudept*			*Typic Haplohumods*					*Typic Haplohemist*	
Soil depth (in cm)	0-34	34-65	65-100	0-5	5-27	27-55	55-90	90-100	0-60	60-100
Clay (%)	26	21	73	4	3	8	2	3	-	-
Silt (%)	42	47	13	4	2	3	5	0	-	-
Fine sand (%)	20	21	11	5	1	4	8	3	-	-
Coarse sand (%)	12	11	3	87	95	85	85	94	-	-
pH	4.90	4.88	4.80	4.98	5.81	5.20	5.41	5.44	3.86	3.16
Texture type	Loam	Loam	Clay	Sand	Sand	Sand	Sand	Sand	Peat	Peat
Organic carbon (%)	0.89	0.69	0.61	1.26	0.69	0.63	1.74	0.78	43.81	38.85
Nitrogen (%)	0.21	0.14	0.14	0.21	0.14	0.13	0.19	0.14	1.20	0.72
Total phosphorus (ppm)	121	82	76	135	130	125	120	107	338	211
Available phosphorous (ppm) Bray 2	13	9	7	14	7	6	5	5	30	18
Cationic exchange capacity (meq/100 g soil)	16	17	30	17	8	10	13	11	37	23
Exchangeable Ca (meq/100 g soil)	1.74	1.94	1.99	0.47	0.40	0.41	0.44	0.42	2.73	2.60
Exchangeable K (meq/100 g soil)	0.21	0.19	0.19	0.21	0.17	0.18	0.17	0.17	0.19	0.12
Exchangeable Mg (meq/100 g soil)	0.33	0.41	0.49	0.38	0.32	0.30	0.33	0.34	0.85	0.71

APPENDIX 2

MONTHLY RAINFALL (MM) AND RAIN DAYS (GPS CO-ORDINATION UTM49 N= 9.779.521 E=00.728.947)

Month	*2013*		*2014*		*2015*		*2016*		*2017*		*2018*		*Mean*	
	Rainfall	*Rain days*	*Rainfall*	*Rain days*	*Rainfall*	*Rain days*	*Rainfall*	*Rain days*	*Rainfall*	*Rain days*	*Rainfall*	*Rain days*	*Rainfall*	*Rain days*
January	148	13	202	13	138	10	376	18	277	18	181	21	220	16
February	269	10	169	12	398	16	421	20	284	15	236	16	296	15
March	440	17	389	20	222	11	261	16	358	19	263	16	322	17
April	400	23	230	9	201	9	473	23	234	17	396	18	322	17
May	366	16	449	16	166	8	313	16	229	15	256	18	297	15
June	107	8	150	14	189	8	155	11	151	11	152	9	151	10
July	339	16	89	8	152	5	97	12	332	13	22	6	172	10
August	234	12	62	7	21	4	58	6	325	19	172	6	145	9
September	119	12	11	2	1	1	219	14	185	15	198	9	122	9
October	201	9	76	7	87	8	476	20	411	19	479	15	288	13
November	213	14	363	11	327	21	466	19	174	14	502	24	341	17
December	313	20	254	14	467	16	181	21	313	20	314	19	307	18
Total	3 149	170	2 444	133	2 369	117	3 496	196	3 273	195	3 171	177	2 984	165