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Impact of Prolonged Dry Period on Oil Palm Yield and Mill Extraction Ratio: A Case Study

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Based on current trends in climate change, El Nino and La Nina events are likely to become more frequent, with the former having a more significant negative impact on oil palm growth and production. Since 1980, ten El Nino events or prolonged dry periods have been recorded in Indonesia, of which three and five events have been categorised as severe and moderate, respectively. The most severe of the three El Nino events occurred in 1997, followed by a more recent one in 2015. This paper is a case study which examines the impact of the 2015 El Nino event on the fresh fruit bunch (FFB) production of two generations of oil palms planted in two neighbouring estates and oil extraction ratios (OER) of a mill receiving crop from the latter two estates.

Four consecutive months of low rainfall in 2015, resulted in annual water deficits of 280 - 313 mm, which was followed by a decline in FFB production over two distinct periods i.e. 4 to 12 months and 24 to 30 months after the El Nino event, respectively. In both cases, a sharp decline in the number of harvestable bunches was the main contributing factor, likely to be due to an increase in inflorescence abortion and lowering of inflorescence sex-ratio. Average bunch weight (ABW) generally remained unaffected.

The initial impact of the drought was more severe on the younger palms, but due to a better recovery rate, the overall yield decline (23%) over a 12-month period in the following year, was significantly lower than in older palms (30%). Analysis of 14 years' yield and climatic data showed that apart from rainfall, other abiotic and biotic factors such as fruiting activity may also be contributing to the 3-year production cycles (peak crop, decline, recovery, peak crop) exhibited by both estates. As such, it was difficult to accurately apportion yield decline primarily due to water deficit from the other influencing factors.

The study also indicated a negative effect of drought on mill OER. Extended dry periods in 2015 (4 months) and 2019 (4 months) were consistently correlated with periods of declining OER, 7 to 14 months later. Like FFB, the prolonged decline could also be attributed to multiple factors.

Keywords*: El Nino, oil palm, OER, rainfall, water deficit.*

Amongst the major climatic requirements, rainfall is considered to be the most important for the growth and production of oil palm (Turner & Gillbanks, 2003). The negative consequences of inadequate rainfall or water supply on oil palm growth and yield has been documented by a number of researchers in the past. Symptomatically, the impact of moisture stress on palm growth is expressed in a number of ways which includes delayed opening of new spear leaves, frond breakage, frond desiccation and in more extreme cases, canopy and trunk fracture resulting in the death of the palms (Turner & Gillbanks, 2003; Amirul *et al*., 2016; Nuzul *et al*., 2017). On the other hand, the impact on yield is mainly due to reduction in fresh fruit bunch (FFB) numbers, brought about by floral abortion, floral sex differentiation and bunch failure (Corley & Tinker, 2003).

The duration and frequency of these

prolonged periods of drought vary with the geographical regions in which oil palm is cultivated. In West Africa where the drought occurs annually, the depressive effect on oil palm yield is quite distinct and marked over a certain period each year (Corley & Tinker, 2003). In Malaysia and Indonesia, where total annual rainfall is higher and more evenly distributed than their West African counterparts, periodic drought has also been reported to have negative impacts on oil palm growth and yield (Caliman & Southworth, 1998; Turner & Gillbanks, 2003; Amirul *et al.*, 2016; Haniff *et al.*, 2016; Nuzul *et al.*, 2017). In the latter regions, the occurrence and frequency of these prolonged periods of drought commonly referred to as "El Nino" events, have been on the increase over the last 30 years or so. Nuzul *et al.* (2017) stated that since 1980, ten El Nino events have been experienced in Indonesia, of which three, five and two events can be categorised as severe, moderate and weak, respectively. The most severe of the three El Nino events occurred in 1997 followed by a more recent one in 2015. In between these two severe cases, moderate El Nino events were also recorded in 2002 and 2006.

Like the previous El Nino events, the severity of the El Nino in 2015, varied between the provinces in Indonesia, being most severe in Lampung, Riau, Jambi, South Sumatera, East Kalimantan and less so in West Sumatra and Bengkulu (Nuzul *et al.*, 2017). This paper is a case study which examines the impact of the El Nino events of 2015 on the FFB production of two generations of oil palms planted in two estates located in one of the worse hit provinces (Jambi) in Indonesia. It also examines the impact of the latter drought on oil extraction ratios (OER) of a palm oil mill, receiving crop from the two estates.

SITE AND RAINFALL DETAILS

Estates A and B are neighbouring properties located in Tanjung Jabung Barat district, Jambi province, Indonesia. Both estates consisted of a mix of older generation 1 plantings (1993 - 2000) and generation 2 replants (2003 - 2009). Full details on planting materials, planted area, palm age, soil type are summarised in *Table 1.* Topography of both estates ranged from undulating to rolling to hilly.

Rainfall records of both estates from 2009 to 2018 (10 years) are given in *Table 2.* On average, annual rainfall exceeded 2 400 mm per year and is evenly distributed. However, a prolonged dry period (≥4 consecutive months) or El Nino event was recorded in both estates in 2015 with annual water deficits ranging from 280 mm to 313 mm.

The annual water deficit was calculated based on the formula devised by IRHO (Turner & Gillbanks, 2003), as shown below:

$$WD = P + SWR - ETP$$

WD = Water deficit
P = Monthly precipitation (rainfall)
SWR = Monthly soil water reserves
ETP = Monthly evapotranspiration

Where ETP is 150 mm per month, if number of rain days is less than 10 days per month and 120 mm per month, if rain days per month are 10 days and above. The monthly soil water retention capacity of the soils of Estates A and B was estimated to be 172 mm per month and 189 mm per month respectively, based on their inherent soil texture distribution (Sidhu, 2015). IRHO proposes a fixed or standard SWR of 200 mm per month. Although the IRHO formula for calculation of water deficit is only an approximation, it is recommended for good use, as many proposed complicated

TABLE 1
DETAILS OF ESTATES A AND B, JAMBI PROVINCE, INDONESIA

Estate	*Planting materials*	*Year of planting*	*Planted area (ha)*	*Soil series*	*Distribution (%)*	*Soil texture*
A	Generation 1 Lonsum, ASD Costa Rica	1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000	2 797	Typic Dystrudepts	55	Loamy sand to sandy clay loam
				Typic Hapludults	43	Clay
				Typic Endoaquadepts	1	Sandy loam to sandy
				Typic Hapludox	1	Sandy clay loam
	Generation 2 Topaz, Marihat	2003, 2004, 2006, 2007, 2009	2 028			
Total			4 825			
B	Generation 1 Lonsum, ASD Costa Rica	1993, 1994, 1995, 1996, 1997, 1998, 1999	1 661	Typic Dystrudepts	66	Loamy sand to sandy clay loam
				Typic Hapludults	30	Clay to clay loam
				Typic Endoaquadepts	1	Clay loam to sandy
				Typic Hapludox	3	Clay loam to sandy clay
	Generation 2 Topaz, Socfin	2004, 2007, 2008	2 361			
Total			4 022			

calculations have not improved precision to any significant degree (Turner & Gillbanks, 2003).

IMPACT OF PROLONGED DRY PERIOD ON OIL PALM PRODUCTION

Estate A

Annual rainfall in Estate A averaged in excess of 2 400 mm per annum and only once in the last 10-year period dropped below 2 000 mm (*Table 2*). Distribution within individual years was generally quite even and although most years recorded between 1 to 3 dry months (< 100 mm rainfall), consecutive dry months were rare and this was reflected in the low annual water deficits (0 to 63 mm/annum), which are unlikely to have any significant negative impact on crop production (Siregar, 2020). The exception to the historical rainfall trend was recorded in year 2015, generally regarded in the oil palm industry as the most recent El Nino event (Amirul *et al.*, 2016; Nuzul *et al.*, 2017). In the latter year, annual rainfall dropped to 1 663 mm with only 96 rain days. Six months recorded rainfall less than 100 mm and there were two periods of prolonged dry weather i.e. a shorter 2-month period (January-February) followed by a longer 4-month period (July - October). Total water deficit recorded in 2015 was 313 mm of which 18 mm was recorded for the first dry period (January – February) and 295 mm for the second dry period (July – October).

Following the prolonged 4 months dry spell, a significant decline in oil palm FFB yield was recorded over two distinct periods. The first period occurred 4 to 12 months after the El Nino event and the second period, 24 to 30 months later (*Table 3*). In both cases, a decline in bunch numbers was the main contributing factor. Although a small decline in average bunch weight (ABW) was also recorded commencing one month after the dry period and up to 10 months later, the differences were not statistically significant. Turner and Gillbanks (2003) and Amirul *et al.* (2016) had also found that the main causal reason for the yield decline after El Nino events, was a significant reduction in bunch number rather than a lowering of ABW. Lee and Izwanizam (2013) also recorded similar findings, when attributing yield improvement in irrigated plots in relation to non-irrigated ones in low rainfall situations.

The significant reduction in bunch numbers is likely to be due to inflorescence abortion and alteration in the sex-ratio of the developing inflorescences. Reduction in bunch numbers from 4 to 12 months after the period of prolonged moisture stress could be attributed to abortion of floral inflorescences in various stages of their development. Female inflorescences are more prone to stress related abortion than male inflorescences and are most vulnerable, 5 to 2 months prior to anthesis or 7 to 11 months prior to harvesting (Breure & Corley, 1992; Corley & Tinker, 2003). However, due to severe moisture stress, female inflorescence abortion could have continued to occur even at a later stage of development i.e. just before, during or shortly after anthesis, accounting for the significant drop in harvestable bunches, as early as 4 to 6 months after the El Nino event. The second period of FFB decline, 24 to 30 months after the dry spell, is likely to be due to a lowering in the sex-ratio of newly developing inflorescences. Under periods of extreme stress, there is preference for the palm to produce male over female inflorescences, as the former requires lower assimilate utilisation (Breure & Corley, 1992; Corley & Tinker, 2003).

TABLE 2
RAINFALL HISTORY (2009-2018) OF ESTATES A AND B, JAMBI PROVINCE, INDONESIA

Estate	*Parameters*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
A	Total rainfall (mm/year)	2420	2688	3076	2751	2338	2110	1663	2794	2654	2181
	Total rain days (number/year)	125	163	148	129	120	109	96	147	134	49
	Total dry months (number/year)	3	0	1	3	3	4	6	2	1	3
	Consecutive dry months[1] (number/year)	1x2	0	0	0	0	1x2, 1x2	1x2, 1x4	0	0	1x2
	Water deficit (mm/year)	41	0	0	0	0	63	313	0	0	49
	Consecutive WD[2] months (number/year)	1	0	0	0	0	1	1x3	0	0	1
B	Total rainfall (mm/year)	2273	2623	3018	3070	2219	2834	2154	2848	2837	2272
	Total rain days (number/year)	122	154	148	140	109	139	97	150	170	150
	Total dry months[1] (number/year)	3	0	1	2	3	3	5	2	0	4
	Consecutive dry months (number/year)	1x2	0	0	0	0	1x2	1x4	0	0	1x3
	Water deficit (mm/year)	29	0	0	0	7	55	280	0	0	47
	Consecutive WD[2] months (number/year)	1	0	0	0	1	1	3	0	0	1

[1] Dry month ≤100 mm rainfall/month

[2] WD = Water deficit

TABLE 3
IMPACT OF PROLONGED DRY PERIOD IN 2015 ON OIL PALM YIELD PARAMETERS (ESTATE A)

				Relative difference[3] (%)							Relative difference[3] (%)		
Month	*Rainfall (mm)*	*WD[1] (mm)*		*FFB yield/ha*	*NOB[4]*	*ABW[5]*	*Month*	*Rainfall (mm)*	*WD[1] (mm)*	*MAMS[2]*	*FFB yeld/ha*	*NOB[4]*	*ABW[5]*
2015							2017						
January	83	0	+8	-21	-26	+7	January	88	0	-16	+157	+142	+15
February	27	18	+7	+9	0	+9	February	301	0	-17	+93	+75	+18
March	262	0	+6	+8	+1	+7	March	348	0	-18	+90	+70	+18
April	272	0	+5	+6	0	+6	April	154	0	-19	+84	+67	+17
May	296	0	+4	+20	+17	+3	May	145	0	-20	+81	+66	+15
June	163	0	+3	+56	+49	+6	June	191	0	-21	+43	+30	+11
July	17	0	+2	+30	+25	+5	July	125	0	-22	+60	+49	+11
August	49	62 }	+1	+13	+8	+5	August	189	0	-23	+20	+10	+9
September	11	139 } 295	0	+11	+10	+1	September	260	0	-24	-25	-32	+7
October	56	94 }	-1	+11	+14	-3	October	258	0	-25	-34	-38	+4
November	176	0	-2	+10	+13	-3	November	247	0	-26	-19	-22	+4
December	251	0	-3	+20	+25	-5	December	348	0	-27	-30	-32	+3
2016							2018						
January	221	0	-4	-43	-42	-1	January	48	0	-28	-32	-35	+3
February	271	0	-5	-35	-28	-7	February	114	0	-29	-28	-31	+4
March	208	0	-6	-49	-40	-9	March	393	0	-30	-17	-19	+3
April	299	0	-7	-53	-45	-8	April	219	0	-31	0	-2	+2
May	139	0	-8	-59	-55	-4	May	198	0	-32	+30	+27	+2
June	385	0	-9	-58	-57	-2	June	41	0	-33	+50	+50	0
July	33	0	-10	-55	-54	-1	July	46	41	-34	+67	+67	0
August	327	0	-11	-49	-49	0	August	142	8	-35	+41	+46	-3
September	273	0	-12	-11	-14	+3	September	128	0	-36	+58	+68	-10
October	125	0	-13	+20	+6	+13	October	147	0	-37	+32	+38	-6
November	437	0	-14	+24	+8	+15	November	404	0	-38	+10	+18	-7
December	78	0	-15	+27	+8	+17	December	301	0	-39	+4	+12	-7

[1] Water deficit
[2] Months after period of moisture stress (> 200 mm)
[3] Differential between same period of the previous year e.g January 2015 (2015 x 2014), January 2016 (2016 x 2015), January 2017 (2017 x 2016), January 2018 (2018 x 2017)
[4] Number of bunches
[5] Average bunch weight

Estate B

Being neighbouring properties, the rainfall trend and distribution in Estate B was historically similar to Estate A, although its average rainfall (2,615 mm) was slightly higher. Like its sister estate, it also experienced a prolonged 4-month dry period extending from July to October 2015, with an estimated yearly water deficit of 280 mm.

The impact of the El Nino event on crop yield followed a similar pattern as that observed in Estate A. An initial decline in FFB yield occurred 4 to 12 months after the period of moisture stress, followed by a second distinct period of FFB decline, 24 to 27 months later. As in the earlier case, the decline in FFB yield in both periods was due to a significant drop in bunch numbers rather than due to a reduction in ABW. In fact, ABW continued to increase steadily, although the quantum of increment in the first period was smaller than the second period (*Table 4*). In view of a similar lag time between the period of moisture stress and response in both Estates A and B, floral abortion and lowering of inflorescence sex-ratio can be attributed again, as the main factors responsible for the significant decline in bunch numbers over the two distinct periods, mentioned above.

It was also noted in both estates, a significant increase or recovery in yield occurred after each distinct period of yield decline. This recovery commenced 13 months after the drought and lasted up to 23 months, as a result of an increase in both bunch number and bunch weight, clearly demonstrating the ability of the oil palms to reduce but not completely compensate for the earlier short fall in crop.

Palm age

Nuzul *et al.* (2017) and Siregar (2020) reported that the impact of an El Nino event is more severe on older palms as compared to younger palms. Data summarised in *Table 5* compares the impact of the 2015 El Nino on the production of generation 1 plantings (15-22 years old) and generation 2 replants (6-12 years old) and tends to support their view point.

In both Estates (A + B), the initial impact of the prolonged drought was more severe in the younger palms. In the first 6 months of the year following the El Nino event, younger palms exhibited a drastic yield decline ranging from 52 to 56 per cent (average : 54 per cent) as compared to 41 to 46 per cent (average:44 per cent) in the older palms. However, in the subsequent 6 months, yield recovery was quicker and stronger in the younger palms as compared to the older palms. As such, the yield of younger palms in the second half of the year, was 6 per cent higher than the same period in the previous year, whilst the yield of the older palms remained 19 per cent lower. Over a 12-month period, younger palms recorded a 23 per cent decline in yield compared to 30 per cent in the older palms (*Table 5*).

The difference in impact of the drought on younger and older palms is likely to be due to differences in their carbohydrate reserves. During a period of extreme moisture stress, the palm's first response will be to conserve moisture by reducing transpiration loss. It will do this *via* partial or full stomatal closure, resulting in the slowing or temporary cessation of photosynthesis and production of carbohydrates (Corley & Tinker, 2003). As younger palms have smaller carbohydrate reserves compared to older palms, their depletion will be more rapid, with the initial negative impact of the drought being more severe on the former. However, when the stress is removed, due to their more rapid frond production and vegetative growth rates, recovery in younger palms will be quicker than older palms and will partially compensate

TABLE 4
IMPACT OF PROLONGED DRY PERIOD IN 2015 ON OIL PALM YIELD PARAMETERS (ESTATE B)

Month	Rainfall (mm)	WD[1] (mm)		*elative difference[3](%)* FFB yield/ha	NOB[4]	ABW[5]
2015						
January	142	0	+8	-6	-19	+13
February	84	0	+7	+3	-11	+14
March	450	0	+6	+10	-2	+13
April	466	0	+5	+17	+9	+7
May	259	0	+4	+36	+30	+5
June	166	0	+3	+55	+47	+8
July	53	0	+2	+45	+36	+8
August	40	18	+1	+9	+3	+6
September	13	137 } 280	0	+8	+3	+4
October	25	125	-1	+17	+15	+2
November	212	0	-2	+3	0	+3
December	244	0	-3	+27	+25	+2
2016						
January	127	0	-4	-52	-65	+13
February	77	0	-5	-39	-48	+10
March	226	0	-6	-52	-60	+8
April	181	0	-7	-21	-59	+9
May	316	0	-8	-56	-63	+7
June	178	0	-9	-39	-47	+8
July	82	0	-10	-39	-48	+9
August	181	0	-11	-38	-42	+5
September	279	0	-12	-2	-12	+10
October	345	0	-13	+26	+6	+18
November	687	0	-14	+27	+8	+18
December	169	0	-15	+34	+13	+19

Month	Rainfall (mm)	WD[1] (mm)	MAMS[2]	*Relative difference[3](%)* FFB yeld/ha	NOB[4]	ABW[5]
2017						
January	128	0	-16	+152	+138	+13
February	343	0	-17	+70	+52	+17
March	282	0	-18	+75	+55	+20
April	199	0	-19	+46	+28	+18
May	214	0	-20	+56	+35	+20
June	154	0	-21	+11	-6	+18
July	118	0	-22	+21	+4	+16
August	220	0	-23	+19	+2	+17
September	271	0	-24	-26	-39	+13
October	186	0	-25	-38	-48	+11
November	347	0	-26	-15	-26	+11
December	375	0	-27	-22	-31	+10
2018						
January	96	0	-28	+4	-5	+9
February	106	0	-29	+5	+1	+5
March	410	0	-30	+17	+14	+3
April	289	0	-31	+31	+29	+1
May	233	0	-32	+47	+47	+1
June	37	0	-33	+59	+64	-5
July	84	0	-34	+66	+71	-5
August	94	47	-35	+26	+32	-6
September	151	0	-36	+30	+41	-11
October	174	0	-37	+30	+38	-8
November	363	0	-38	-1	+8	-9
December	235	0	-39	-6	+1	-7

[1] Water deficit
[2] Months after period of moisture stress (> 200 mm)
[3] Differential between same period of the previous year e.g. January 2015 (2015 x 2014), January 2016 (2016 x 2015), January 2017 (2017 x 2016), January 2018 (2018 x 2017)
[4] Number of bunches
[5] Average bunch weight

TABLE 5

IMPACT OF PROLONGED DRY PERIOD IN 2015 ON FFB YIELD OF GENERATION ONE AND GENERATION TWO OIL PALM PLANTINGS

						FFB Yield/ha (tonnes)							
						2015			2016			2017	2018
Oil palm estate	*WD[1] 2015 (mm/year)*	*Planting generation*	*Year of planting*	*Palm age (years)*	*Planted area (ha)*	*SM1**	*SM2*	*Total*	*SM1*	*SM2*	*Total*	*Total*	*Total*
A	313	1	1993-2000	15-22	2 797	10.63	13.13	23.76	5.75 (-46)**	10.88 (-17)	16.64 (-30)	19.94 (-16)	21.66 (-9)
		2	2003-2009	6-12	2 028	13.43	15.58	29.00	5.89 (-56)	15.35 (-1)	21.24 (-27)	24.62 (-15)	30.31 (+5)
		Average	1993-2009	6-22	4 825	11.80	14.16	25.96	5.81 (-51)	12.76 (-10)	18.57 (-29)	21.91 (-16)	25.30 (-3)
B	280	1	1993-1999	16-22	1 661	11.31	15.11	26.41	6.66 (-41)	12.02 (-21)	18.69 (-29)	22.28 (-16)	26.12 (-1)
		2	2004-2008	7-11	2 361	15.88	14.84	30.72	7.60 (-52)	16.79 (+13)	24.39 (-21)	25.36 (-17)	32.65 (+6)
		Average	1993-2008	7-22	4 022	13.99	14.95	28.94	7.21 (-49)	14.82 (-1)	22.03 (-24)	24.09 (-17)	29.95 (+4)
A+B	298	1	1993-2000	15-22	4 458	10.88	13.86	24.74	6.09 (-44)	11.30 (-19)	17.39 (-30)	20.81 (-16)	23.32 (-6)
		2	2003-2009	6-12	4 389	14.75	15.18	29.93	6.81 (-54)	16.12 (+6)	22.93 (-23)	25.02 (-16)	31.57 (+5)
		Average	1993-2009	6-22	8 847	12.80	14.51	27.31	6.45 (-50)	13.69 (-6)	20.14 (-26)	22.90 (-16)	27.41 (+0.4)

[1] Water deficit

* Semester 1 (January-June), Semester 2 (July-December)

** Figures in parentheses is the relative FFB yield expressed as a percentage of the FFB yield in 2015 for the large initial loss in yield, although not fully.

Water deficit x yield relationship

The negative relationship between water deficit and oil palm yield has been documented by a number of researchers in the past. Early work in West Africa suggested that 100 mm of water deficit reduced FFB yield between 10 - 20 per cent (Hartley, 1988; Ochs & Daniel, 1976). Based on statistical models developed on single year droughts in Lampung province, Indonesia, Caliman and Southworth (1998) projected that 100 mm of water deficit recorded in year N, will result in a FFB yield decline of 8 to 10 per cent in year N + 1, 3 to 4 per cent in year N + 2 and a slight negative impact in year N + 3, which is significant if the water deficit in year N was severe (> 400 mm/year). Siregar (2020) based on data compiled by the Indonesian Oil Palm Research institute (IOPRI) suggested that the negative impact on FFB production is only likely, if annual water deficit is equal or exceeds 200 mm per annum and the following impact scale was proposed:

Stage	*Water deficit (mm/year)*	*Yield decline in N + 1 year (per cent)*
1	200-300	0-15
2	300-400	5-20
3	400-500	10-25
4	> 500	15-100

Regression analysis of data derived from 27 estates in the Asian Agri group during the 2015 El Nino event showed that although the relationship was linear, correlations between water deficit and yield decline, expressed either as a percentage (R^2 = 0.4225) or in FFB tonnage per hectare (R^2 = 0.3985) was moderate to low. Corley and Tinker (2003) suggest that the relationship between water deficit and yield is unlikely to be simple, in view of the fact that there are multiple inter-related climatic and site factors such as the level of sunshine received (haze effect), soil texture, topography, planting materials etc., which may either heighten or mitigate the palm's response to different levels of moisture stress. In addition, the water deficit data is at best, an estimate, whose precision and accuracy is sometimes questionable.

Due to the complex inter-relationships, it is often difficult to separate the effects of water deficit on FFB yield from the other contributing factors. The yield pattern of the oil palms planted in Estates A and B over a 14-year period (2006 – 2019) is summarised in *Table 6*. Both estates depict a cyclical trend in FFB production, with peak crops occurring every 3 years (3-year cycle) i.e. in 2006, 2009, 2012, 2015 and 2018. Each peak cropping year (N) is than followed by a subsequent decline in yield (N + 1), recovery phase (N + 2) and then peak crop again (N + 3) and the cycle is repeated consistently. Such a 3-year cycle has also been recorded in most Asian Agri estates sited in various other provinces in Indonesia. Over the 14-year period, El Nino events occurred in only two of the five peak cropping years i.e. 2006 (WD : 283 – 317 mm/year), 2015 (WD : 280 -313 mm/year). In the remaining 12 years, total rainfall was very satisfactory (> 2,000 mm/ year) and its distribution fairly even, without consecutive dry months or water deficit generally less than 100 mm per annum. Nevertheless, despite the lack of moisture stress in the two preceding years, FFB yield still declined in the year following the peak crops of 2009, 2012 and 2018. As temperature and sunshine activity is unlikely to vary significantly during years of normal weather conditions, other factors apart from climate may be contributing to these 3-year cyclical peaks and

TABLE 6
RAINFALL AND PRODUCTION DETAILS OF ESTATES A AND B

Estate A						Estate B					
Year	*Rainfall (mm)*	*WD[1] (mm/year)*	*Consecutive months with WD*	*FFB Yield (tonnes/ha)*	*Comments*	*Year*	*Rainfall (mm)*	*WD[1] (mm/year)*	*Consecutive months with WD*	*FFB Yield (tonnes/ha)*	*Comments*
2006	1 794	317	4	21.21	Peak crop	2006	1 760	283	4	22.23	Peak crop
2007	2 604	0	0	18.28	Decline	2007	2 529	0	0	19.03	Decline
2008	3 232	0	0	21.73	Recovery	2008	3 136	0	0	22.35	Recovery
2009	2 420	41	0	22.62	Peak crop	2009	2 273	29	0	25.32	Peak crop
2010	2 688	0	0	20.26	Decline	2010	2 623	0	0	18.42	Decline
2011	3 076	0	0	21.32	Recovery	2011	3 018	0	0	20.69	Recovery
2012	2 751	0	0	24.64	Peak crop	2012	3 070	0	0	24.80	Peak crop
2013	2 338	0	0	22.33	Decline	2013	1 938	92	0	21.90	Decline
2014	2 110	63	0	22.82	Recovery	2014	2 834	94	0	24.57	Recovery
2015	1 663	313	3	25.96	Peak crop	2015	2 154	280	3	28.94	Peak crop
2016	2 794	0	0	18.57	Decline	2016	2 848	0	0	22.03	Decline
2017	2 654	0	0	21.91	Recovery	2017	2 837	0	0	24.09	Recovery
2018	2 181	49	0	25.30	Peak crop	2018	2 272	47	0	29.95	Peak crop
2019	2 072	266	3	21.36	Decline	2019	1 849	27	0	25.82	Decline

[1] Water deficit

declines. Breure and Corley (1992) and Corley and Tinker (2003) have suggested that although seasonal fluctuations in yield are undoubtedly largely caused by changes in climatic factors, the effects of fruiting activity on future yield components may perpetuate a yield cycle even in a relatively unchanging climate. Fruiting activity which they defined as the "bunch load" or the amount of developing inflorescences and FFB the palm is carrying at any one time, has a significant effect on inflorescence abortion, bunch failure, bunch weight and inflorescence sex-ratio. Before and during a period of high yield (peak crop), the large number of developing inflorescences and FFB creates a high demand for assimilates, which induces a higher inflorescence abortion rate and lowers the sex-ratio in the following crop (Broekmans, 1957). As such, heavy fruiting activity could lead to negative feedback oscillations and endogenous yield cycles (Corley & Tinker, 2003). Breure and Corley (1992) further suggest that these effects of fruiting activity may be mediated through changes in plant hormone levels. In view of the above, it is often difficult to apportion the quantum of yield decline due primarily to water deficit from other contributing factors such as yield cycles, haze etc. In these two case study Estates, the average yield decline following peak years which experienced drought (2006, 2015) was 21 per cent (range : 14 - 29 per cent), whilst the yield decline following peak crops without drought (2009, 2012, 2018) was 12 per cent (range : 9 - 16 per cent). As such, the yield decline attributed to only water deficit is likely to be smaller than recorded.

Impact on FFB oil content

Apart from its impact on FFB yield, the distribution of rainfall also influences the seasonal variation in the oil content in FFB and hence, the OER in palm oil mills (Ho, 1993). Countries which experience marked rainfall patterns with sharply defined protracted wet and dry months, also record extreme OER values. This is observed in Southern Thailand and other oil palm growing countries in West Africa. In these seasonally dry climates, water deficit is known to shorten the period of bunch maturation leading to reduced oil to bunch (O/B) content *via* a reduction of oil in the mesocarp (Ochs & Daniel, 1976; Ho, 1993). In Dahomey, severe water deficit depressed oil to wet mesocarp (O/WM) with a time lag of 2 months. Likewise in Cameroon, correlation analysis showed that protracted periods of low rainfall lowered O/B, with secondary and primary effects recorded 3 and 9 months later, respectively. In Malaysia, Ho (1993) also found strong correlations between low rainfall and mill OER, with primary depressive effects being recorded 9 to 13 months later and lesser secondary effects, 2 months later. Examining bunch analysis component data from oil palm breeding trials established on both coastal and inland-type soils, he concluded that the primary depressive effects on O/B were mainly due to a reduction in fruit to bunch (F/B) and secondary effects due to a lowering of O/WM.

Bunch component analysis provides a more accurate estimation of changes in oil content in FFB compared to mill OER, as the latter are influenced by numerous other management factors such as ripeness standard and fruit quality, mill processing efficiency and oil losses etc. Nevertheless, extreme changes in OER can be indicative of climatic impact, as shown by previous researchers.

In the current case study, the mill OER shows a specific annual trend. The monthly OER over a 13-year period (2008-2020) is summarised in *Figure 1.* Seasonal variation in monthly OER is noted, with higher OER recorded from December to March, followed by a decline in April to July and then partial recovery and improvement from August onwards. It is not fully understood what factors are responsible for this annual trend in OER, but since rainfall was a dominating influence in other oil palm growing regions, a correlation analysis was carried out for all 13 years to evaluate the impact (if any) of each individual year's rainfall on the OER over three subsequent time periods i.e. 0-12 months, 13-24 months and 25-36 months. The results indicated very low positive or negative correlations for 11 out of the 13 years being assessed. Moderate positive correlations (r = 0.518, 0.706) were only obtained in 2 years i.e. 2015 and 2019 and in the 13-24 months period only. Statistically, regression analysis showed a positive correlation between both the El Nino events of 2015 (r = 0.635) and 2019 (r = 0.753) and a decline in OER 11 to 14 months later. Under normal circumstances, the annual seasonal dip in OER stretches from 4 to 6 months, but in years following both these El Nino events, the depression in OER was prolonged for 7 to 8 months, occurring approximately 7 to 14 months, after the period of water deficit. The decline in OER at its extreme, can range from 1.9 to 2.6 percentage points.

However, further examination of the 13 years' rainfall data also showed that almost each year had a number of months where the rainfall exceeded 300 mm (wet month). Over the 156 months period, a total of 30 months (19 per cent) had rainfall ranging from 301 mm to 610 mm, out of which 19 months statistically depressed the OER in the same month (as compared with the preceding month) and also depressed the OER, 5 to 6 months later. Heavy and frequent rainfall can depress OER within the same month by increasing the moisture

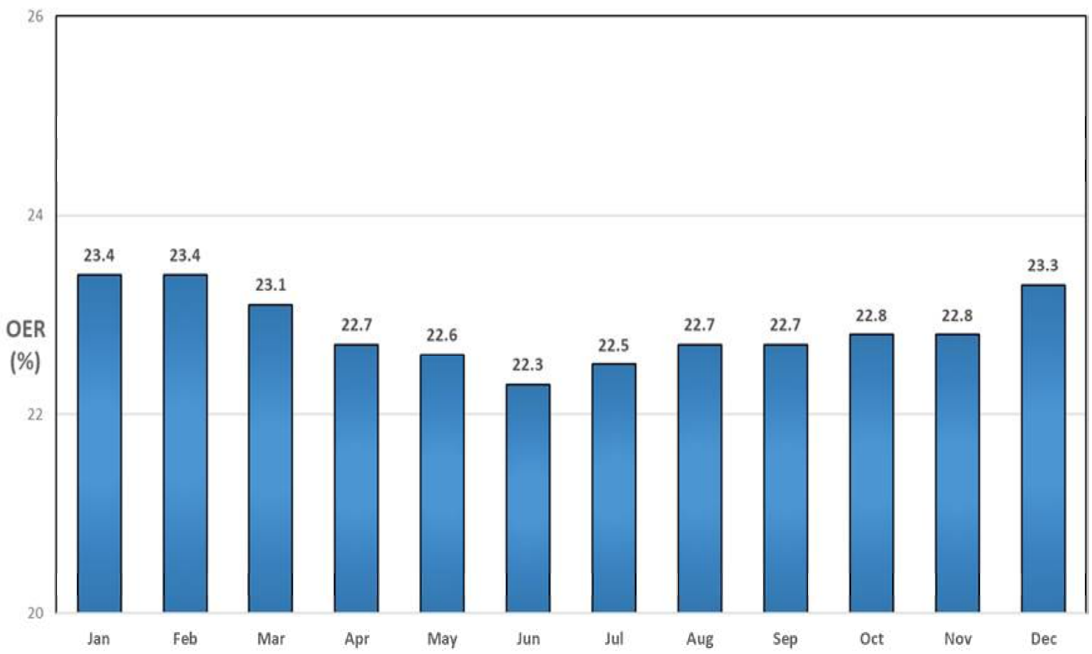

Figure 1 Average monthly OER trend (2008-2020)

content of FFB being sent to the mill and interfere with the collection of loose fruits (high oil content). The depressive impact on OER 5 to 6 months later is normally due to its negative impact on flower pollination (Donough *et al*, 1996; Sugih *et al*, 1996; Hoong & Donough, 1988 ; Rao & Law, 1998).

Although the correlation between rainfall in the El Nino years (2015, 2019) and its negative impact on OER was statistically significant, a number of wet months were also recorded in the years following the droughts (2016 and 2020). In the former case, wet months occurred in June (385 mm), August (327 mm) and November (437 mm) 2016 and their perceived negative effects overlapped with the period of prolonged depression of OER from April to November 2016. Likewise in 2020, wet months were recorded in April (303 mm) and November (333 mm) and their perceived negative impact overlapped with the depression of OER from April to November 2020. It should also be noted, that out of these 5 “wet months”, only 2 months had a high frequency of rain days (17 & 21 days), whilst the remaining 3 months recorded a normal frequency of rainfall of 10 - 12 days per month. In addition, there are no records on whether this was “day or night” rain and whether it affected pollinating activity. Likewise, as no pre and post wet month fruit set and bunch component analysis data was available, it remains to be confirmed whether these periodic wet months had negatively contributed to the prolonged decline of the OER or whether their perceived effects were incidental (*Table 7*).

Even though the relationship and lag phase between water deficit and decline in OER in the current case study closely mirrors earlier findings by Ho (1993), other inter-related factors such as effective sunshine hours (impact of haze), periodic wet periods, fruiting activity (bunch load), crop quality and management can influence the OER and as such, cannot be discounted. Like FFB yield, it is difficult to apportion the negative effects of drought on OER from other influencing factors. More detailed and in-depth investigations will be required in future to ascertain this.

CONCLUSION

The findings from this case study correlates with and supports earlier work done by other researchers. The four consecutive months of dry weather in 2015 resulting in annual water deficits of 280-313 mm, had a significant negative impact on FFB production over the next 30 months. The decline in FFB production ranging from 24 to 29 per cent, was attributed to a reduction in number of harvestable bunches. The impact was more severe on older palms and although both age groups were affected, subsequent recovery was better in the younger palms. The study also showed that apart from rainfall, other abiotic and biotic factors such as fruiting activity may also be contributing to the 3-year production cycles exhibited in both estates. As such, it was difficult to accurately apportion yield decline primarily due to water deficit from the other influencing factors.

There was also good indication of the negative effect of drought on mill OER. Extended dry periods in 2015 (4 months) and 2019 (4 months) were correlated with periods of progressive to sharp decline in OER, 7 to 14 months later and the decline in OER could be in excess of 1.9 percentage points. Like FFB, the prolonged decline in OER could also be attributed to multiple factors. More detailed studies will be required to ascertain this.

With the current trend in climate change, it

TABLE 7
IMPACT OF PROLONGED DRY PERIODS ON MILL OIL EXTRACTION RATIO

Month	*Rainfall (mm)*	*WD[1](mm)*	*MAMS[2]*	*OER[3](%)*	*Month*	*Rainfall (mm)*	*WD[1](mm)*	*MAMS[2]*	*OER[3](%)*
2015					2019				
July	17	0	+2	22.6	July	79	0	+2	22.1
August	49	62	+1	22.9	August	18	99	+1	22.7
September	11	139	0	22.6	September	33	117	0	23.0
October	56	94	-1	22.0	October	99	51	-1	22.1
November	176	0	-2	22.5	November	237	0	-2	22.5
December	251	0	-3	23.0	December	280	0	-3	22.9
2016					2020				
January	221	0	-4	22.7	January	106	0	-4	23.5
February	271	0	-5	23.7	February	97	0	-5	23.7
March	208	0	-6	23.4	March	99	0	-6	23.6
April	299	0	-7	23.1	April	303	0	-7	22.7
May	139	0	-8	22.9	May	172	0	-8	22.1
June	385	0	-9	22.6	June	94	0	-9	21.5
July	33	0	-10	22.4	July	82	0	-10	21.1
August	327	0	-11	21.8	August	56	0	-11	21.2
September	273	0	-12	21.5	September	104	2	-12	21.0
October	125	0	-13	22.2	October	253	0	-13	21.6
November	437	0	-14	22.2	November	333	0	-14	21.6
December	78	0	-15	23.1	December	78	0	-15	22.5

[1] Water deficit
[2] Months after period of moisture stress
[3] Oil extraction ratio

is highly likely that these El Nino events could become more frequent and severe in the near future. As such, practical and effective agronomic practices coupled with irrigation and the planting of more drought resilient oil palm varieties, may be required to mitigate the negative effects of extreme dry weather.

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