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Early Performances of Topaz Gen-1 *Tenera* Clones in Clonal Trials and Commercial Plots in Indonesia

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Asian Agri's oil palm research station's (OPRS-Topaz) breeding programme involves the complementary development of both seedling and clonal planting materials. From 2010-2018, a total of 18 clonal trials and 890 hectares of commercial clonal plots were established in two provinces (North Sumatra, Riau) and on three major soil types (volcanic, inland, peat). This paper reports on the early performances of the clones in the latter sites.

Comparatively, elite clones only achieved 82 per cent and 85 per cent of their ortet fresh fruit bunch (FFB) and crude palm oil (CPO) yields, respectively. Analysis undertaken in five of the oldest mineral soil trials indicated either a negative or very low positive correlation between clone and ortet FFB yield, but correlations of oil to bunch (O/B) and annual height increment (Hi) were positive and highly significant, confirming the better heritability of the latter two parameters and their suitability as criteria for ortet selection.

In clonal trials, the highest yields were obtained on inland soils in Riau province, with elite clones recording average peak FFB and CPO yields of 45.1 tonnes per hectare and 11.6 tonnes per hectare, respectively. Slightly lower yields were attained on volcanic soils (36.2 tonnes FFB/ha; 9.9 tonnes CPO/ha) and on deep peat (32.6 tonnes FFB/ha; 8.5 tonnes CPO/ha) in North Sumatra. However, as the latter two sites contained some younger trials, they may have yet to achieve their maximum potential.

O/B values also differed for the same clones planted on three different soil types. On average, oil content of clones planted on peat was approximately 3 percentage points lower than their counterparts planted on either inland or volcanic soils. In all nine trials which included DxP seedling controls, the top five clones recorded higher CPO yield over their seedling controls by 7-47 per cent. However, these results should be interpreted with caution as all the DxP seedling controls belonged to the same generation as the clones. Their true yield superiority can only be ascertained when evaluated against the latest improved Topaz Series 4 DxP crosses. Nevertheless, nine clones showed good potential for commercial scale propagation, having high CPO yield (9.5 tonnes/ha), O/B (32 %) and good adaptability and consistency in performance over a wide range of sites.

Performances of untested clones (directly planted in commercial plots without evaluation in clonal trials) followed the same trend as in clonal trials. Highest yields were recorded on inland soils (39.4 tonnes FFB/ha), followed by volcanic (30.8-36.0 tonnes FFB/ha) and peat soils (27.1-29.8 tonnes FFB/ha). Likewise, as some of the latter commercial plantings were only 5-6 years of age, it is likely that their peak yields have yet to be attained.

Census conducted from 2014 to 2016 indicated a low incidence of palms with mantled fruit, averaging 3.3 per cent in clonal trials and only 0.3 per cent in commercial plantings. Such acceptable to low abnormality levels are a reflection of the good quality control practices adopted by AA's tissue culture laboratory.

Keywords *: Clones, height increment, oil to bunch, oil palm, tissue culture.*

Research on oil palm cloning was first reported in the mid-seventies and in Malaysia in the early eighties (Soh, 1986). Encouraged by the success of early clonal trials and the theoretical potential of clonal oil palm to out yield *tenera* (DxP) seedlings by as much as 30 per cent (Soh, 2018; Choo *et al*., 2018), has resulted in a proliferation of tissue culture laboratories in both Malaysia and Indonesia over the last three decades. Currently, there are 13 tissue culture laboratories in Malaysia alone and from 2006-2015, an estimated 42.6 million ramets have been produced, the main players being Applied Agricultural Resources (AAR), Felda Global Ventures (FGV), TSH Resources Bhd and IOI Corporation Bhd (Siti *et al*., 2018).

Asian Agri (AA) are relatively newcomers in the field of clonal oil palm propagation, first initiating its tissue culture programme in 2005 with the conversion of three shop lots into a temporary tissue culture laboratory before moving into a new state of the art purpose built facility in 2012 (Febriantine *et al*., 2018). AA's foray into clonal oil palm had two objectives. Firstly, to multiply elite parental palms for the production of semi-clonal or bi-clonal seed in order to further improve yields and secondly, to explore the commercial potential of planting *tenera* clones with high oil yield and specific traits of interest such as slow height increment, compact canopy, disease resistance or even drought resilience.

As AA's experiences with tissue culture protocols and propagation of elite parental palms has been covered previously by Febriantine *et al*. (2018), this paper reports on the early performances of AA's Topaz Gen-1 *tenera* oil palm clones in breeding trials and in commercial test plots in various sites in Sumatra, Indonesia.

METHODOLOGY

The generation one (Gen-1) ortets were sampled from ASD Costa Rica D x P progenies from trials established in 1996 in Topaz estate (alluvial and shallow peat soils). Sampling of ortets commenced in April 2005 and a total of 373 ortets were sampled out of which, 90 ortets were successfully cloned for evaluation in clonal trials.

In the selection of ortets, the principle of "best palms from the best D x P crosses" was used with emphasis given to the selection parameters listed in *Table 1*. Fresh fruit bunch (FFB) and crude palm oil (CPO) yields of ortets were monitored for 6 years and a minimum of three bunch analysis per ortet was carried out from the third to sixth year of harvesting, for determination of bunch components. In addition, all potential candidates for cloning were physically inspected for their phenotypic characteristics.

From 2010 to 2018, a total of 18 clonal trials were established in two provinces (North Sumatra and Riau) and on three major soil types (volcanic, inland and peat) totaling

TABLE 1
CRITERIA FOR SELECTION OF ORTETS FOR CLONAL EVALUATION

Parameter	*Criteria*
Crude palm oil (CPO) yield (tonnes/ha)	Minimum 8.0
Fresh fruit bunch (FFB) yield (kg/palm)	Minimum 250.0
Oil to bunch (O/B) (%)	Minimum 30.0
Height increment (cm/year)	Maximum 50.0

TABLE 2
DETAILS OF CLONAL TRIALS

Trial number	*Year of planting*	*Trial location*	*Soil type*	*Number of clones*
CT 01	2010	Riau	Inland (Typic Dystrudepts)	12
CT 02	2010	Riau	Inland (Typic Dystrudepts)	14
CT 03	2011	North Sumatra	Volcanic (Typic Dystrudepts)	31
CT 04	2011	North Sumatra	Peat (Typic Haplosaprists)	15
CT 05	2012	North Sumatra	Volcanic (Typic Dystrudepts)	25
CT 06	2012	North Sumatra	Peat (Typic Haplosaprists)	29
CT 07	2012	Riau	Inland (Typic Dystrudepts)	22
CT 08	2013	North Sumatra	Volcanic (Typic Dystrudepts)	45
CT 09	2013	North Sumatra	Peat (Typic Haplochemists)	49
CT 10	2013	North Sumatra	Peat (Typic Haplosaprists)	51

216 hectares. This report only covers clonal trials with a minimum of 4 years yield data (YOP: 2010-2013) and details of the ten trials are summarised in *Table 2*. Trial design was randomised complete block with three replications. Plot size per clone was 16 palms arranged in a 4 x 4 configuration. Planting density for volcanic and inland type soils was 136 and 143 palms per hectare, respectively and 160 palms per hectare for peat. The peat was second generation with sapric texture and greater than 3.0 metres in depth. In addition to clonal trials, the tissue cultured ramets were also simultaneously planted out in 30 commercial test plots in five estates totalling 890 hectares.

Field upkeep and maintenance in all trials and commercial test plots were as per AA standard operating procedures (SOP) which utilises the zero-burning land preparation technique and the concept of best management practices (BMP) for oil palm cultivation (Sidhu *et al.*, 2019). In all sites, harvesting was carried out at seven to ten intervals and FFB was harvested at a ripeness standard of one loose fruit per bunch in clonal trials and five loose fruit per bunch for the commercial test plots.

RESULTS

Clone *vs* ortet performance

Comparative performances of the top five yielding clones *versus* their respective ortets in five trials established on mineral soils is summarised in *Table 3*. On average, the clones only achieved 82 per cent and 85 per cent of their ortet FFB and CPO yields, respectively. The shortfall in FFB and CPO yield was primarily due to a reduction in bunch number in the clones, as bunch weight was higher (compensation for decline in bunch number) and oil to bunch (O/B) equal to their ortets (Dedywiryanto, 2019). Tan *et al.* (2003) also observed low correlation between ortet and clone FFB yield, further supporting previous assertions of the low heritability of FFB yield and its poor efficiency for ortet selection (Soh, 1986; 1998).

Correlation analysis between ortet and respective clone for FFB yield, O/B and annual height increment (Hi) in the same five trials established on mineral soils is given in *Table 4*. As FFB heritability is known to be low, average r values for FFB were negative

TABLE 3
COMPARATIVE YIELD* BETWEEN CLONE AND RESPECTIVE ORTET

Trial number	*Year of planting*	*Location*	*Soil type*	*Yield of clone expressed as a percentage (%) of respective ortet yield*									
				FFB yield					*CPO yield*				
				Yr 3	*Yr 4*	*Yr 5*	*Yr 6*	*Average*	*Yr 3*	*Yr 4*	*Yr 5*	*Yr 6*	*Average*
CT 01	2010	Riau	Inland	85	63	79	100	81	85	64	80	101	82
CT 02	2010	Riau	Inland	81	70	70	116	83	80	67	68	115	81
CT 03	2011	North Sumatra	Volcanic	70	93	67	71	75	77	104	74	79	83
CT 05	2012	North Sumatra	Volcanic	86	73	75	-	78	92	77	80	-	83
CT 07	2012	Riau	Inland	88	92	87	-	89	89	95	90	-	92
Average of five trials				82	79	75	95	82	85	81	78	97	85

Notes:
*Yield of top 5 yielding clones in each trial
FFB - fresh fruit bunch; CPO - crude palm oil

(r = - 0.100) whilst r values for O/B (r = 0.788) and Hi (r = 0.612) showed good positive correlation in all five trials, confirming the higher heritability of O/B and Hi recorded by other breeders (Tan *et al*., 2003; Soh *et al*., 1986).

Performance in clonal trials

Performance of the top five Topaz Gen-1 clones in each of the ten trials is summarised in *Table 5***.**

The highest yields were obtained in trials established on inland soils in Riau province. Peak FFB yields ranged from 40.6-47.2 tonnes per hectare (average: 45.1 tonnes/ha) and CPO yields from 11.1-12.4 tonnes per hectare (average: 11.6 tonnes/ha). These elite clones were able to achieve FFB yields more than 35 tonnes per hectare by the third year in harvesting and their peak yields more than 40 tonnes per hectare by the sixth year in harvesting. Slightly lower yields probably due to a lower planting density, were attained on volcanic soils in North Sumatra province. In the latter location, peak FFB yields ranged from 34.7-41.1 tonnes per hectare (average: 36.2 tonnes/ha) and CPO yields from 9.3-11.3 tonnes per hectare (average: 9.9 tonnes/ha). As expected, being a more difficult and marginal growth medium, the lowest yields were recorded in the trials on deep peat. Peak FFB yields ranged from 30.3-36.0 tonnes per hectare (average: 32.6 tonnes/ha) and CPO yields from 7.8-9.4 tonnes per hectare (average: 8.5 tonnes/ha). Peak yields are reflective of the genetic potential of the planting materials, as they are the maximum yield attainable under a given set of site and climatic conditions (Sidhu *et al*., 2019).

Oil to bunch values of the same 25 clones planted in three soil types (volcanic, inland, peat) are summarised in *Table 6*. In trials established in North Sumatra province, similar aged clones planted in volcanic soils had significantly higher O/B (3.3 percentage points) than their counterparts in peat. Likewise, the same clones planted in inland soils also had significantly higher O/B (3.0 percentage points) than those planted in peat. As neither of these four trials on different soil types were established in the same estate, there is always

TABLE 4
CORRELATION ANALYSIS ORTETS X CLONES

Clone	*Ortet*			*CT01*			*CT02*			*CT03*		
	FFB[1]	*O/B*	*Hi*	*FFB*[1]	*O/B*	*Hi*	*FFB*	*O/B*	*Hi*	*FFB*	*O/B*	*Hi*
D05	37.7	30.3	36.0	-	-	-	-	-	-	31.9	32.6	47.2
D11	50.8	24.0	44.2	37.9	24.9	37.2	-	-	-	18.4	25.3	44.1
D13	34.6	16.6	42.9	30.2	22.5	42.8	-	-	-	-	-	-
D15	33.8	27.8	33.6	38.2	26.0	34.7	37.4	24.5	32.0	33.9	30.4	49.1
D17	39.8	30.0	36.2	33.9	27.3	32.5	34.5	26.4	34.1	30.1	28.6	42.9
D21	42.1	22.6	34.9	30.9	25.5	35.6	31.2	27.1	31.9	-	-	-
D23	40.6	30.1	58.7	34.0	29.8	43.5	31.4	27.2	37.2	36.4	31.6	53.8
D25	50.0	28.3	44.7	-	-	-	-	-	-	35.1	32.0	47.5
D26	47.2	26.0	41.3	38.3	31.4	34.4	36.5	29.0	33.3	35.8	32.0	49.8
D27	44.5	26.2	46.0	-	-	-	35.5	26.0	31.4	33.8	30.6	54.6
D28	46.8	29.4	42.4	38.3	29.2	36.4	35.2	29.0	34.4	31.6	30.2	53.9
D29	45.6	21.0	54.2	33.0	25.1	45.3	-	-	-	-	-	-
D32	47.9	31.1	48.5	-	-	-	-	-	-	-	-	-
D33	42.2	26.8	38.2	-	-	-	-	-	-	30.3	32.2	56.3
D36	41.4	32.1	43.5	-	-	-	-	-	-	33.0	32.7	44.8
D37	34.8	32.5	44.7	-	-	-	-	-	-	28.8	33.5	43.3
D39	40.0	31.1	44.2	-	-	-	29.2	29.8	30.9	29.1	34.3	59.9
D41	36.5	32.0	44.9	-	-	-	-	-	-	-	-	-
D42	41.2	31.0	39.8	-	-	-	-	-	-	31.2	34.6	47.9
D43	47.9	29.7	36.2	37.4	26.6	34.5	39.7	29.0	38.4	33.6	32.7	52.4
D44	39.2	38.3	40.7	-	-	-	34.2	35.0	35.7	31.9	35.0	48.5
D45	39.9	29.2	46.7	-	-	-	-	-	-	32.7	32.7	51.8
D47	50.3	30.7	40.5	-	-	-	-	-	-	31.6	30.1	53.2
D49	48.7	31.3	53.8	-	-	-	36.5	31.0	34.5	37.4	32.8	59.1
D52	49.0	30.7	42.2	40.1	26.9	41.0	35.8	24.6	34.5	30.9	31.2	55.6
D53	53.8	26.9	47.1	-	-	-	-	-	-	31.1	31.7	50.8
D54	44.6	29.5	39.1	36.5	29.4	35.5	38.1	29.6	35.4	34.6	33.6	47.3
D55	45.6	27.3	45.5	-	-	-	-	-	-	27.9	31.4	50.3
D57	49.2	32.2	40.0	-	-	-	-	-	-	28.3	34.4	50.4
D60	49.7	28.4	40.4	-	-	-	-	-	-	33.0	31.5	50.4
D61	48.2	31.1	53.3	-	-	-	-	-	-	-	-	-
D63	37.3	33.5	52.4	-	-	-	-	-	-	31.8	32.2	50.5
D64	48.3	28.3	59.8	-	-	-	41.0	28.4	47.6	33.1	31.4	53.9
D65	41.5	33.0	50.4	-	-	-	-	-	-	34.2	32.0	54.8
D67	41.7	31.4	37.3	-	-	-	-	-	-	-	-	-
D68	43.4	28.7	55.6	-	-	-	-	-	-	28.0	34.4	58.8
D69	41.3	30.1	52.9	-	-	-	-	-	-	23.3	30.3	46.1
D70	49.5	34.5	57.5	-	-	-	-	-	-	-	-	-
D71	54.7	30.7	59.6	-	-	-	-	-	-	-	-	-
D72	44.7	31.9	52.7	-	-	-	-	-	-	31.3	30.8	54.7
D77	42.6	31.1	49.3	-	-	-	-	-	-	-	-	-
D81	46.2	31.3	58.2	-	-	-	-	-	-	-	-	-
D83	44.5	30.9	43.5	-	-	-	-	-	-	-	-	-
D85	46.6	29.5	56.0	-	-	-	-	-	-	-	-	-
D90	50.3	27.8	41.8	-	-	-	-	-	-	-	-	-
					CT01			*CT02*			*CT03*	
Correlation				*FFB*	*O/B*	*Hi*	*FFB*	*O/B*	*Hi*	*FFB*	*O/B*	*Hi*
ortet vs clone				0.535	0.688	0.824	0.457	0.643	0.569	-0.040	0.543	0.390

[1] Average of 4 years yield (third - sixth year of harvesting)

Contd.

TABLE 4
CORRELATION ANALYSIS ORTETS X CLONES (CONTD.)

Clone	*CT05*			*CT07*			*Mean CT*		
	FFB	*O/B*	*Hi*	*FFB*	*O/B*	*Hi*	*FFB*	*O/B*	*Hi*
D05	27.2	30.4	42.1	-	-	-	29.5	31.5	44.7
D11	-	-	-	-	-	-	28.1	25.1	40.7
D13	-	-	-	-	-	-	30.2	22.5	42.8
D15	-	-	-	-	-	-	36.5	27.0	38.6
D17	24.3	28.4	37.3	-	-	-	30.7	27.7	36.7
D21	-	-	-	-	-	-	31.0	26.3	33.8
D23	-	-	-	-	-	-	34.0	29.6	44.8
D25	-	-	-	-	-	-	35.1	32.0	47.5
D26	26.8	30.3	44.5	29.0	31.0	40.6	33.3	30.7	40.5
D27	-	-	-	-	-	-	34.6	28.3	43.0
D28	-	-	-	-	-	-	35.0	29.4	41.6
D29	-	-	-	-	-	-	33.0	25.1	45.3
D32	25.5	31.1	51.4	27.1	28.7	39.6	26.3	29.9	45.5
D33	26.4	31.6	54.4	-	-	-	28.3	31.9	55.3
D36	27.6	34.6	48.3	-	-	-	30.3	33.6	46.6
D37	-	-	-	-	-	-	28.8	33.5	43.3
D39	-	-	-	-	-	-	29.1	32.0	45.4
D41	25.0	32.3	52.0	29.4	31.4	47.4	27.2	31.9	49.7
D42	-	-	-	-	-	-	31.2	34.6	47.9
D43	26.6	31.3	49.1	28.9	31.1	47.0	33.2	30.2	44.3
D44	24.8	35.3	42.3	28.8	35.0	42.0	29.9	35.1	42.1
D45	-	-	-	-	-	-	32.7	32.7	51.8
D47	-	-	-	-	-	-	31.6	30.1	53.2
D49	27.9	31.3	51.6	31.8	33.7	51.8	33.4	32.2	49.3
D52	27.6	27.0	48.6	-	-	-	33.6	27.4	44.9
D53	23.3	30.7	45.8	-	-	-	27.2	31.2	48.3
D54	27.5	32.4	43.6	29.3	29.7	38.8	33.2	30.9	40.1
D55	30.8	31.6	49.7	32.1	31.5	46.0	30.3	31.5	48.7
D57	-	-	-	-	-	-	28.3	34.4	50.4
D60	26.9	30.1	43.0	29.8	27.0	38.1	29.9	29.5	43.8
D61	21.2	32.6	58.0	24.1	33.0	51.4	22.6	32.8	54.7
D63	-	-	-	-	-	-	31.8	32.2	50.5
D64	26.8	30.7	47.4	31.4	29.1	45.5	33.1	29.9	48.6
D65	30.9	32.0	54.6	-	-	-	32.6	32.0	54.7
D67	24.5	32.3	41.4	25.7	30.6	38.3	25.1	31.4	39.8
D68	22.2	30.5	57.0	24.1	30.0	48.0	24.8	31.6	54.6
D69	21.8	30.9	41.6	13.6	28.1	38.8	19.5	29.7	42.2
D70	22.5	32.9	65.5	22.7	33.2	60.3	22.6	33.0	62.9
D71	27.7	31.9	60.0	27.6	32.2	55.4	27.6	32.1	57.7
D72	-	-	-	24.9	35.2	51.6	28.1	33.0	53.2
D77	-	-	-	30.8	31.0	49.7	30.8	31.0	49.7
D81	23.8	32.6	67.6	24.1	32.8	59.3	23.9	32.7	63.5
D83	27.4	32.4	54.2	27.5	28.3	40.6	27.5	30.4	47.4
D85	-	-	-	29.4	28.2	45.6	29.4	28.2	45.6
D90	-	-	-	29.2	27.3	43.1	29.2	27.3	43.1
		CT05			*CT07*			*Mean CT*	
Correlation	*FFB*	*O/B*	*Hi*	*FFB*	*O/B*	*Hi*	*FFB*	*O/B*	*Hi*
ortet *vs* clone	0.006	0.559	0.678	0.172	0.597	0.679	-0.100	0.788	0.612

Note: FFB - fresh fruit bunch; O/B - oil to bunch; Hi - height increment

TABLE 5
COMPARATIVE YIELDS OF TOPAZ GEN-1 CLONES* IN THREE SOIL TYPES

Trial number	*Year of planting*	*Soil type*	*Trial location*	*Yield parameter (tonnes/ha)*	*Year of production*								*Average*	
					Yr 1	*Yr 2*	*Yr 3*	*Yr 4*	*Yr 5*	*Yr 6*	*Yr 7*	*Average*	*O/B*	*OER*
CT 01	2010	Inland	Riau	FFB	15.4	27.2	36.4	29.5	38.9	42.9	44.2	33.5	29.3	25.1
				CPO	3.9	6.8	9.1	7.4	9.7	10.7	11.1	8.4		
CT 02	2011	Inland	Riau	FFB	14.0	27.8	37.0	33.4	34.1	47.2	39.2	33.2	30.6	26.2
				CPO	3.7	7.3	9.7	8.7	8.9	12.4	10.2	8.7		
CT 07	2012	Inland	Riau	FFB	17.7	29.1	36.1	39.4	40.6	-	-	32.6	32.8	28.0
				CPO	5.0	8.2	10.1	11.1	11.4	-	-	9.1		
Average	2010-2012	Inland	Riau	FFB	15.7	28.0	36.5	34.1	37.9	45.1	41.7	33.1	30.9	26.4
				CPO	4.2	7.4	9.6	9.1	10.0	11.6	10.7	8.7		
CT 03	2011	Volcanic	North Sumatra	FFB	21.3	33.3	31.6	41.1	34.3	33.5	-	32.5	32.2	27.5
				CPO	5.9	9.2	8.7	11.3	9.4	9.2	-	8.9		
CT 05	2012	Volcanic	North Sumatra	FFB	17.5	28.6	36.7	32.8	36.4	-	-	30.4	32.7	28.0
				CPO	4.9	8.0	10.3	9.2	10.2	-	-	8.5		
CT 08	2013	Volcanic	North Sumatra	FFB	18.2	29.4	33.8	34.7	-	-	-	29.0	31.2	26.7
				CPO	4.8	7.8	9.0	9.3	-	-	-	7.8		
Average	2011-2013	Volcanic	North Sumatra	FFB	19.0	30.4	34.0	36.2	35.4	33.5	-	30.6	32.0	27.4
				CPO	5.2	8.3	9.3	9.9	9.8	9.2	-	8.4		
CT 04	2011	Peat	North Sumatra	FFB	12.2	26.8	35.7	36.0	34.7	31.6	-	29.5	30.7	26.2
				CPO	3.2	7.0	9.4	9.4	9.1	8.3	-	7.7		
CT 06	2012	Peat	North Sumatra	FFB	10.0	25.0	28.0	31.0	30.4	-	-	25.0	30.4	26.0
				CPO	2.6	6.6	7.3	8.1	7.9	-	-	6.5		
CT 09	2013	Peat	North Sumatra	FFB	13.7	25.6	30.0	31.1	-	-	-	25.1	30.3	25.9
				CPO	3.6	6.6	7.8	8.1	-	-	-	6.5		
CT 10	2013	Peat	North Sumatra	FFB	14.9	25.5	30.3	28.5	-	-	-	24.8	30.0	25.7
				CPO	3.8	6.5	7.8	7.3	-	-	-	6.4		
Average	2011-2013	Peat	North Sumatra	FFB	12.7	25.7	31.0	31.7	32.6	31.6	-	26.1	30.4	26.0
				CPO	3.3	6.7	8.1	8.2	8.5	8.3	-	6.8		

*Yield of top 5 clones in each trial
Note: O/B - oil to bunch; OER - oil extraction rate; FFB - fresh fruit bunch; CPO - crude palm oil

TABLE 6
COMPARATIVE OIL TO BUNCH OF CLONES ESTABLISHED ON MINERAL AND PEAT SOILS

Clone	*Year of planting : 2011*			*Year of planting : 2012*		
	CT 03 North Sumatra Volcanic soil O/B (%)	*CT 04 North Sumatra Peat soil O/B (%)*	*Difference (%)*	*CT 07 Riau Inland soil O/B (%)*	*CT 06 North Sumatra Peat soil O/B (%)*	*Difference (%)*
D 15	30.3	25.6	+4.7	-	-	-
D 17	28.9	24.5	+4.4	-	-	-
D 26	32.1	29.4	+2.7	31.4	27.9	+ 3.5
D 27	30.4	26.2	+4.2	-	-	-
D 28	30.1	26.6	+3.5	-	-	-
D 32	-	-	-	28.1	29.3	+1.2
D 41	-	-	-	32.1	28.0	+4.1
D 43	32.1	30.4	+1.7	31.3	26.9	+4.4
D 44	34.9	32.5	+2.4	35.5	31.9	+3.6
D 49	31.0	27.8	+3.2	33.2	29.1	+4.1
D 52	31.3	26.6	+4.7	-	-	-
D 54	-	-	-	30.9	28.4	+2.5
D 55	-	-	-	31.8	27.4	+4.4
D 60	31.0	27.6	+3.4	28.6	25.5	+3.1
D 61	-	-	-	32.7	29.9	+2.8
D 64	34.0	29.4	+4.6	29.9	26.6	+3.3
D 67	-	-	-	32.3	27.2	+5.1
D 68	30.5	29.6	+0.9	30.7	26.7	+4.0
D 69	32.4	30.8	+1.6	29.0	28.3	+0.7
D 70	-	-	-	32.5	30.1	+2.4
D 71	-	-	-	32.8	32.9	+0.1
D 72	-	-	-	34.3	29.1	+5.2
D 77	-	-	-	31.4	27.3	+4.1
D 81	-	-	-	33.7	31.0	+2.7
D 83	-	-	-	29.9	29.4	+0.5
Average	31.5	28.2	+3.3	31.6	28.6	+3.0

Note: O/B - oil to bunch

the outside possibility that the observed differences in O/B could be due to a location effect rather than just influence of soil type. However, these results are consistent with those recorded by Ang *et al.* (2010). In their extensive first generation progeny trial evaluating the same 394 DxP crosses on two soil types (alluvial, peat) in the same estate, they noted that on average, the O/B in peat was 1.8 percentage points lower than that of mineral soil. Bunch component analysis indicated that FFB from peat had significantly higher moisture, stalk, shell to fruit and mesocarp fibre content but lower fertile fruit to bunch, oil to dry and oil to wet mesocarp content (Ang *et al*., 2010). This is also in line with private palm oil millers in North Sumatra, who offer a lower price for FFB harvested from peat soils, in view of the expected lower oil extraction rate (Goh, pers. comm., 2010).

The performance of Topaz Gen-1 clones against standard DxP seedling controls in each trial is given in *Table 7*. In all nine trials (CT.01 had no DxP seedling control), the top five clones recorded significantly higher CPO yields than their DxP seedling controls by 7-47 per cent. However, these results should be interpreted with caution as all the DxP seedling controls belonged to the same generation as the clones. As the latter were the best individual palms from this generation of seedlings, they are expected to perform better than their progenies (Soh, 2012). Nevertheless, there were some positive points. In five of the trials (CT.02, CT.03, CT.06, CT.08, CT.09), the standard link cross Da 209.15 x E316.14 was used as the DxP seedling control and based on its performance in progeny trials, the latter has a CPO yield potential of 10.9 tonnes per hectare. The fact that the top five clones out yielded the standard link cross by 8-32 per cent, reflects their high yield potential. As clonal development will always be one generation behind seedling development (Soh, 2012), all new clonal trials in AA will include elite DxP crosses from the latest Topaz Series 4, in addition to standard link crosses and clones. As these elite crosses have a CPO yield potential of 12.0 tonnes per hectare (Ang *et al*., 2018), their inclusion will help to ascertain the true potential of the clones being evaluated.

Out of the 90 clones evaluated in the ten clonal trials, nine clones show good potential for commercial scale propagation (*Table 8*). They recorded peak FFB yield of 31-51 tonnes per hectare and CPO yield of 9-15 tonnes per hectare with O/B ranging from 30.1-35.1 per cent. They also had satisfactory genetic diversity, being derived from three *dura* (Dami, Chemara, Harrisons & Crosfield) and four *pisifera* families (Ghana, Nigeria, Ekona, Dami). The nine clones also displayed good adaptability and consistency in performance when evaluated over a wide range of sites (North Sumatra, Riau) and soil types (volcanic, inland, peat) (*Table 9*). In addition, a number of clones displayed low height increment of less than 45 cm per annum, a highly desirable specific trait that could facilitate harvesting and prolong the economic life span of the palms.

Performance in commercial plots

Performance of untested clones directly planted in commercial plots without first evaluation in clonal trials is summarised in *Table 10*.

TABLE 7
PERFORMANCE OF GEN-1 CLONES *VS* DXP PROGENIES IN CLONAL TRIALS

Planting materials	*CPO yield/ha (tonnes)*									
	*CT 01 2010 Inland 7 years**	*CT 02 2010 Inland 7 years*	*CT 03 2011 Volcanic 6 years*	*CT 04 2011 Peat 6 years*	*CT 05 2012 Volcanic 5 years*	*CT 06 2012 Peat 5 years*	*CT 07 2012 Inland 5 years*	*CT 08 2013 Volcanic 4 years*	*CT 9 2013 Peat 4 years*	*CT 10 2013 Peat 4 years*
Topaz clones (Top 5)	8.4	8.7	8.9	7.7	8.5	6.5	9.1	7.8	6.5	6.4
Topaz DxP seedlings	-	6.6	7.4	5.5	5.8	6.0	7.5	6.3	4.9	6.0
% Increase	-	32	20	40	47	8	21	24	33	7

Note:
* number of years in recording
CPO - crude palm oil

TABLE 8
GEN-1 TOPAZ CLONES
POTENTIAL CANDIDATES FOR COMMERCIAL PLANTING

Clone number	*Clone code*	*FFB yield (tonnes/ha)*		*CPO yield (tonnes/ha)*		*O/B (%)*	*OER (%)*	*K/B (%)*	*Hi (cm/yr)*
		Average[1]	*Peak range*	*Average*	*Peak range*				
1	D26	35.6	35-46	9.4	9-12	30.7	26.3	4.0	39
2	D36	33.6	33-39	9.7	10-11	33.7	28.8	2.9	45
3	D43	35.2	35-51	9.0	9-13	30.1	25.7	2.8	42
4	D44	33.5	36-48	9.9	11-15	35.1	30.0	3.4	42
5	D49	35.9	36-42	9.9	10-11	32.2	27.5	4.3	47
6	D54	35.6	37-48	9.4	10-12	30.9	26.4	3.3	39
7	D55	35.8	31-44	9.5	8-12	31.3	26.8	3.4	50
8	D65	35.9	39-41	9.8	10-11	30.8	26.3	3.9	55
9	D71	33.8	34-41	9.3	9-11	32.1	27.5	2.3	N/A[2]
Clone average		35.0	31-51	9.5	9-15	31.9	27.3	3.4	41

Note:
[1] Average of 4 years yield (third - sixth year of harvesting)
[2] Not available as clone is currently only 7 years old. Hi measurements are conducted at 8 years after planting
FFB - fresh fruit bunch; CPO - crude palm oil; O/B - oil to bunch; OER - oil extraction rate; K/B - kernel to bunch; Hi - height increment

TABLE 9
GEN-1 CLONE CPO YIELD RANKING CONSISTENCY

Clone code	*CT 01 Riau Inland soil*	*CT 02 Riau Inland soil*	*CT 03 North Sumatra Volcanic soil*	*CT 04 North Sumatra Peat soil*	*CT 05 North Sumatra Volcanic soil*	*CT 06 North Sumatra Peat soil*	*CT 07 Riau Inland soil*	*CT 08 North Sumatra Volcanic soil*
D26	1	7	4	2	13	6	7	-
D36	-	-	10	-	3	-	-	-
D43	6	1	2	4	10	20	8	-
D44	-	3	6	1	7	2	3	-
D49	-	4	1	3	8	3	1	-
D54	4	4	5	5	4	9	11	-
D55	-	-	27	-	2	12	2	6
D65	-	-	9	-	1	4	-	8
D71	-	-	-	-	6	1	9	-

On inland soils in Riau (KGD), average FFB yields over the 219 hectares exceeded 30 tonnes per hectare by the third year in harvesting and 39 tonnes per hectare by the sixth year in harvesting. Based on the commercial mill oil extraction rate (OER) of 24.9 per cent, the untested clones achieved a CPO yield of 9.8 tonnes per hectare. As the

TABLE 10
PERFORMANCE OF UNTESTED TOPAZ GEN-1 CLONES IN COMMERCIAL PLOTS

Estate	*Year of planting*	*Number of blocks*	*Ha*	*SPH*	*Soil type*	*Region*	*FFB yield/hectare (tonnes)*						
							Yr.1	*Yr.2*	*Yr.3*	*Yr.4*	*Yr.5*	*Yr.6*	*Yr.7*
KGD	2010	3	71	137	Inland	Riau	12.3	23.0	33.5	27.5	33.5	40.2	37.4
	2011	2	60	142	Inland	Riau	15.4	24.6	32.8	34.1	39.7	38.5	-
	2012	3	88	140	Inland	Riau	14.2	27.2	25.3	32.9	37.1	-	-
Total	2010-2012	8	219	140	Inland	Riau	13.9	25.1	30.0	31.5	36.7	39.4	37.4
KBA	2011	7	169	138	Volcanic	North Sumatra	11.1	22.9	24.7	30.1	27.5	30.8	-
KTD	2013	2	29	155	Volcanic	North Sumatra	15.8	27.3	30.1	36.0	-	-	-
	2014	1	30	147	Volcanic	North Sumatra	19.7	24.0	36.2	-	-	-	-
Total	2013-2014	3	59	156	Volcanic	North Sumatra	17.8	25.6	33.2	36.0	-	-	-
KNS	2011	2	81	138	Peat	North Sumatra	7.3	22.0	24.9	28.0	29.2	28.4	-
	2012	3	118	142	Peat	North Sumatra	9.3	18.8	19.5	23.9	25.3	-	-
	2013	1	36	161	Peat	North Sumatra	11.7	19.0	27.4	29.4	-	-	-
Total	2011-2013	6	235	144	Peat	North Sumatra	9.0	19.9	22.6	26.2	26.9	28.4	-
KNU	2013	1	37	162	Peat	North Sumatra	10.0	21.3	27.8	27.1	-	-	-
	2014	1	37	153	Peat	North Sumatra	11.3	23.1	29.1	-	-	-	-
Total	2013-2014	2	74	158	Peat	North Sumatra	10.7	22.2	28.5	27.1	-	-	-
KTS	2013	2	70	160	Peat	North Sumatra	12.0	20.8	26.4	29.8	-	-	-
	2014	2	64	161	Peat	North Sumatra	14.1	23.7	27.0	-	-	-	-
Total	2013-2014	4	134	161	Peat	North Sumatra	13.0	22.2	26.7	29.8	-	-	-

Note: SPH - Stand per hectare; FFB - fresh fruit bunch mill OER was based on a combination of Gen-1 (22-24 years old) and Gen-2 (7-9 years old) seedling material, the actual CPO yield of the clones is likely to be higher, if only FFB of the clones had been processed independently, as the latter had been primarily selected for their high oil content (minimum of 30 per cent O/B).

As observed in the clonal trials, FFB yields were slightly lower on volcanic soils (228 ha) in North Sumatra, but as the palms were planted at a lower density and were still young, could in the long run, be on par or even higher than those in Riau. The newer plots established in KTD could also achieve 30 tonnes FFB per hectare by the third year in harvesting and 36 tonnes FFB per hectare a year later and may have yet to reach their peak yield.

Commercial plots established on deep peat (443 ha) yielded lower than either inland or volcanic soils, nevertheless, yields close to 30 tonnes FFB per hectare were achieved by the fourth to fifth year in harvesting. As commercial plantings in KNU and KTS were also still young (YOP: 2013-2014), it is also likely that their maximum yields have yet to be attained (*Table 10*).

Clonal abnormality

A census was carried out in 2014, 2015 and 2016 to determine the level of abnormality in the clonal trials and commercial plots (*Tables 11 & 12*). Out of the 14 657 palms inspected in the clonal trials, 3.3 per cent showed some level of mantling (range: 0.4-8.2 per cent). Approximately, 27 per cent of the clones evaluated had mantled FFB, although light in severity. Clonal abnormality was much lower in the commercial plots with only 182 (0.3 per cent) out of the total of 67 583 palms displaying mantled FFB. Most of this was also light in severity and in many cases, disappeared over time. Reversibility in mantling has also been noted by other researchers (Tan *et al*., 2003). The low level of mantling in both clonal trials and commercial plantings were similar to those reported by Choo *et al.* (2018) and Siti *et al.* (2018) and a reflection of the quality control protocol adopted by AA's tissue culture laboratory.

DISCUSSION AND CONCLUSION

Despite the presence of 13 tissue culture laboratories in Malaysia and probably half a

TABLE 11
ABNORMAL (MANTLING) PALM CENSUS* OF CLONAL TRIALS

Trial number	*Year of planting*	*Location*	*Soil type*	*Number of clones*	*Total number of palms*	*Number of abnormal clones*	*Number of abnormal palms*	*Abnormality (%)*
CT 01	2010	Riau	Inland	12	574	1	47	8.2
CT 02	2010	Riau	Inland	14	878	2	4	0.5
CT 03	2011	North Sumatra	Volcanic	31	1 449	3	6	0.4
CT 05	2012	North Sumatra	Volcanic	25	1 830	2	98	5.4
CT 07	2012	Riau	Inland	22	1 760	7	84	4.8
CT 08	2013	North Sumatra	Volcanic	45	2 200	14	56	2.5
CT 09	2013	North Sumatra	Peat	49	2 110	15	48	2.3
CT 010	2013	North Sumatra	Peat	51	3 856	22	139	3.6
Total				249	14 657	66	482	3.3

*Abnormal palm census conducted in 2015 and 2016

TABLE 12
ABNORMAL (MANTLING) PALM CENSUS* IN SEMI COMMERCIAL PLOTS

Estate	*Year of planting*	*Location*	*Soil type*	*Total number of palms*	*Number of abnormal palms*	*Abnormality (%)*
KGD	2010	Riau	Inland	10 115	120	1.2
KGD	2011	Riau	Inland	5 794	8	0.1
KGD	2012	Riau	Inland	9 288	0	0
KBA	2011	North Sumatra	Volcanic	23 034	20	0.1
KNS	2011	North Sumatra	Peat	5 561	17	0.3
KNS	2012	North Sumatra	Peat	13 791	17	0.1
Total				67 583	182	0.3

*Abnormal palm census conducted in 2014 and 2015

dozen more in Indonesia, commercial clones have yet to make a significant impact in terms of production and field planting on the industry for the past 15 years or so, constituting less than 10 per cent of all oil palm planting materials produced annually (Soh, 2012; 2018). The lack of full upscaling in the propagation of oil palm clones can be attributed to a number of constraints (Soh, 2018). Choo *et al.* (2018) cited the unpredictability and high levels of abnormality (often manifested as mantled fruit), as a major issue undermining confidence in the mass propagation of oil palm clones. Although initial levels of abnormality were high, with improved protocols, culture management and more stringent quality control of the tissue culture process, current levels of mantling have been kept below 3 per cent (Choo *et al.*, 2018; Siti *et al.*, 2018). This is likely to be further improved upon with the breakthrough in the identification of the cause of the mantling phenomenon and the development of relevant molecular markers (Ong-Abdullah *et al.*, 2015).

Another major constraint is the long "gestation" period required for the selection, evaluation and development of the clones. If the latter includes the establishment of progeny trials (source of origin of the ortets), then the entire road map could take as long as 21-24 years (*Figure 1*). By then, newer and superior DxP progenies would have come off the production line, as the development of clones is always one generation behind the development of seeds (Soh, 2012). However, with the recent development of Genome Select (GS) technology which enables early yield prediction and integrating it with tissue culture through use of zygotic embryos, could do away with progeny testing and save 7-8 years in the selection cycle (Suzaini *et al.*, 2018). The satisfactory performance of "untested " clones in commercial plots in AA estates may lend further credence questioning the need for clonal evaluation in trials, if selection of the best ortets (from the best families) is stringent and based on highly heritable traits such as oil to bunch, height increment etc. Although clones are prone to strong G x E interaction effects due to their homogeneous nature, the planting of a "basket" of clones with a wide genetic heritage, could help to mitigate the latter. Because of their genetic diversity, the basket of clones would be behaving similar to a heterogeneous seedling population, with the higher yielding clones compensating for the lower yielding ones, still resulting in high average yield.

Perhaps the biggest drawback to clonal propagation is the very low efficiency of the tissue culture process itself. Despite introduction of stringent quality control measures and improvement in tissue culture technology (Wong *et al*., 1997), callogenesis and embryogenesis rates remain very low at 14-19 per cent and 3-7 per cent, respectively (Ong -Abdullah *et al*., 2018). The impact of this inefficiency is high production costs and high ortet requirements. Production cost for clones is approximately eight to ten times higher than that of seed and approximately 100 ortets are required to produce 500 000 ramets (Choo *et al*., 2018; Soh, 2018).

In view of the above, it may not be economical to produce clones especially if their CPO yield is only marginally superior to DxP seedlings. Although a yield advantage of 10-15 per cent is often quoted from the results of well-run clonal trials, this was normally achieved against the prevailing generation of seedlings.

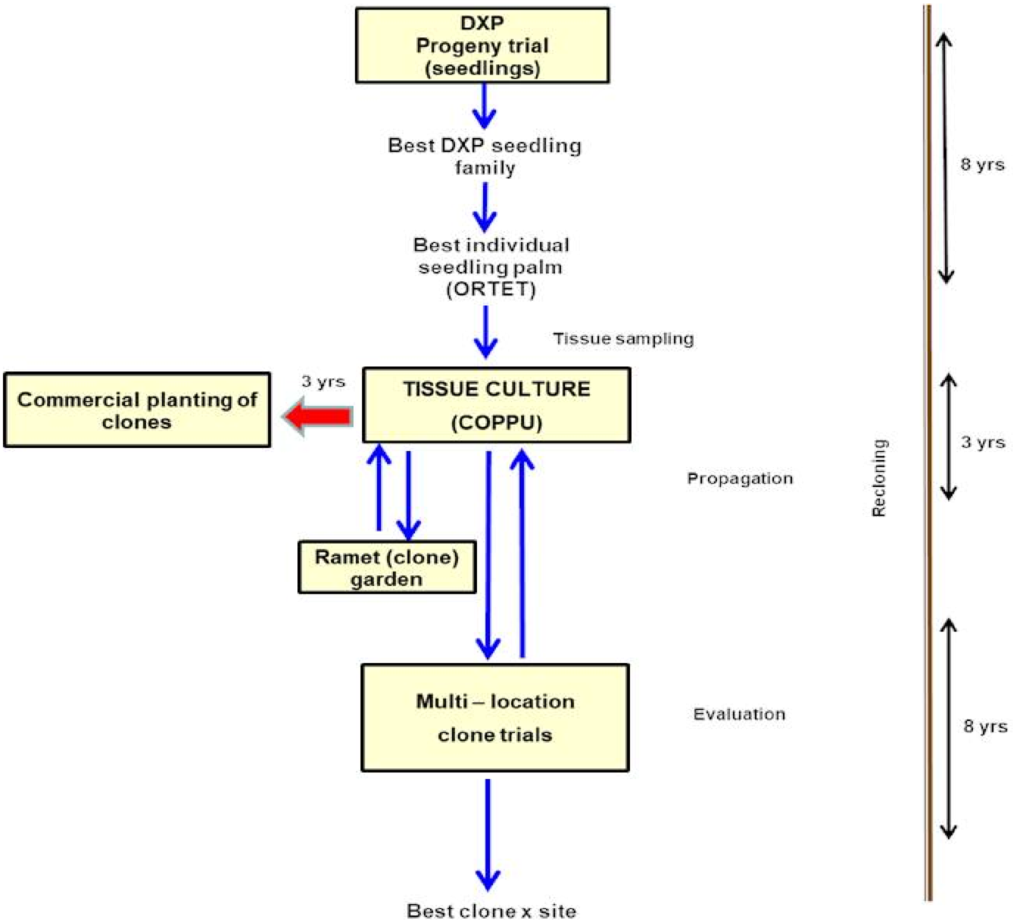

Figure 1   Current pathway for cloning commercial clones

Yield differences between clones and a new generation of elite DxP seedlings could even be less, as Gen-1 clones will always lag behind new improved Gen-2 DxP planting materials (Soh, 2018). The nine shortlisted Topaz Gen-1 clones have an average CPO yield potential of 9.5 tonnes per hectare (peak yield range: 9 - 15 tonnes CPO/ha) which is on par with Topaz Series 2 DxP, but lower than that reported for Topaz Series 3 and Series 4 DxP seedlings (Ang *et al*., 2018). Based on the latter scenario, commercial propagation of clones is only justified if candidate clones have both high CPO yield as well as specific traits of interest that will value add and compensate for their higher production costs. In view of this, AA's R&D (research and development) unit has recently embarked on phase two of their clonal development programme (CDP) with equal emphasis given to oil yield and specific traits of interest particularly low height increment and tolerance to *Ganoderma* root-rot disease. Unlike the Gen-1 clones whose ortets came from Gen-1 DxP crosses imported from ASD Costa Rica (1996 progeny trials), the Gen-2 ortets are being selected from improved DxP crosses in 20 Gen-2 progeny trials established from 2002-2010. Consequently, an improvement in DxP has led to an improvement in the yield potential of the ortets, with many of the new trials producing ortets capable of yielding more than 12 tonnes CPO per hectare (*Table 13*). Compared to Gen-1 ortets, the criteria used for selection of Gen-2

TABLE 13
CANDIDATE ORTET PALMS FOR GEN-2 CLONAL EVALUATION

Trial	*Estate*	*OP*	*CPO (tonnes/ha)*						
			10.0-10.9	*11.0-11.9*	*12.0-12.9*	*13.0-13.9*	*14.0-14.9*	*> 15.0*	*Total*
PT01	KPM	2002	5	-	-	-	-	-	5
PT02	KSG	2003	169	33	2	2	-	-	206
PT03	KPM	2003	8	1	1	-	-	-	10
PT07	KBA	2004	7	1	1	-	-	-	9
PT08	KTR	2006	24	13	3	-	-	-	40
PT09	KPM	2006	28	12	3	-	-	-	43
PT10	KBL	2006	64	8	2	-	1	-	75
PT13	KNS	2006	4	2	-	-	-	-	6
PT14	KPM	2007	27	7	-	-	-	-	34
PT15	KPM	2007	14	3	-	-	-	-	17
PT16	KBL	2007	34	16	5	1	-	-	56
PT17	KBL	2007	35	14	-	-	-	-	49
PT18	KBD	2007	25	5	1	-	-	-	31
PT19	KBL	2008	104	84	30	12	1	-	231
PT20	KBL	2008	27	27	12	6	2	1	75
PT21	KBD	2008	54	49	27	11	2	-	143
PT22	KBD	2008	150	143	76	23	7	-	399
PT26	KPM	2008	134	78	15	4	-	-	231
PT27	KPM	2008	22	8	2	-	-	-	32
PT29	KSN	2010	28	6	-	-	-	-	34
Total			963	510	180	59	13	1	1 726

Note: OP - ortet palm; FFB - fresh fruit bunch ortets has also been raised to ensure that only ortets with a minimum yield potential of 12 tonnes CPO per hectare, 33 per cent O/B and a maximum annual height increment of 45 cm are propagated for evaluation in clonal trials and commercial plots (*Table 14*). To-date, a total of 69 candidate ortets with an average yield potential of 13.5 tonnes CPO per hectare, 36 per cent O/B and a maximum height increment of 39 cm per annum, are being cultured for evaluation (*Table 15*). They will also be concurrently screened for *Ganoderma* tolerance in nursery trials, as reported by Dedek *et al*. (2018).

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TABLE 14
COMPARATIVE SELECTION CRITERIA FOR GEN-1 AND GEN-2 ORTETS

Parameter	*Gen-1 ortets*	*Gen-2 ortets*
CPO yield (tonnes/ha)	min. 8.0	min. 12.0
FFB yield (kg/palm)	min. 250	min. 300
Oil to bunch (%)	min. 30	min. 33
Height increment (cm/year)	max. 50	max. 45
Crown disease score (Scale 0-3)	max.1.0	max.1.0

Note: Gen-1 ortets : selected from ASD Costa Rica PT 1996
Gen-2 ortets : selected from Topaz PT 2003-2008
CPO- crude palm oil; FFB - fresh fruit bunch

TABLE 15
YIELD POTENTIAL OF GEN-2 ORTETS WITH SPECIFIC TRAITS OF LOW-MODERATE HEIGHT INCREMENT

Ortet group	*Ortet selection criteria*				*Average specification of selected ortets*							
	FFB (kg/palm)	*CPO (tonnes/ha)*	*O/B (%)*	*Hi (cm/yr)*	*Total ortets*	*FFB (kg/palm)*	*FFB (tonnes/ha)*	*CPO (tonnes/ha)*	*O/B (%)*	*OER (%)*	*K/B (%)*	*Hi (cm/yr)*
A1	≥ 300	≥ 13	≥ 35	≤ 40	14	313	43	14	37.7	32.2	4.1	34
A2	≥ 300	≥ 13	≥ 35	≤ 45	22	322	44	14	37.6	32.1	4.1	43
B1	≥ 300	≥ 12	34-34.9	≤ 40	9	326	44	13	34.4	29.4	4.2	34
B2	≥ 300	≥ 12	34-34.9	≤ 45	7	327	45	13	34.6	29.4	4.8	43
C1	≥ 300	≥ 12	33-33.9	≤ 40	8	339	46	13	33.5	28.6	4.6	37
C2	≥ 300	≥ 12	33-33.9	≤ 45	9	333	45	13	33.6	28.7	4.7	43
Total/weighted average					69	325	44	13.5	35.9	30.6	4.3	39

Note:
FFB- fresh fruit bunch, CPO - crude palm oil, O/B- oil to bunch, Hi - height increment, OER - oil extraction rate, K/B - kernel to bunch

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REFERENCES

ANG, B.B., SIDHU, M. and SRI PURWANTI. 2010. Comparative oil content of DxP progenies planted on various soil types. Asian Agri internal report. 12pp.

ANG, B.B., HARKINGTO, RIZKI, A., SIDHU, M., SAMOSIR, Y. and SHARMA, M. 2018. Performance of Topaz DxP Series 4 on various soil types and sites in Sumatera, Indonesia. International Palm Oil Congress 2018. IOPRI. Medan. Indonesia 2018. 13pp. Preprint.

CHOO, C.N., WONG, C.K. and MELODY, M.P. 2018. Experience and challenges in commercial production of elite oil palm clones in Applied Agricultural Resources Sdn Bhd. In: *Proceedings of International Seminar on Status of Oil Palm Tissue Culture Technology.* 2018. Medan, Indonesia. 31-41.

DEDEK, H., HARKINGTO, SIDHU, M., SAMOSIR, Y., PANJAITAN, T., HADI, H. and SHARMA, M. 2018. Screening and development of Topaz *Ganoderma* tolerant materials. International Palm Oil Congress 2018. IOPRI. Medan, Indonesia 2018. 9pp. Preprint.

DEDYWIRYANTO, Y. 2019. Clonal performance in AA clonal trials. *Asian Agri internal report.* 14pp.

FEBRIANTINE, I., ANG, B.B., IZHARUL, I., SIDHU, M., SAMOSIR, Y. and SHARMA, M. 2018. Status of oil palm cloning program at Asian Agri. In: *Proceedings of International Seminar on Status of Oil Palm Tissue Culture Technology.* 2018. Medan, Indonesia. 41-54.

GOH, B.S. 2010. Personal communication.Kuala Lumpur.

ONG-ABDULLAH, M., ORDWAY, J.M., JIANG, N. 2015. Loss of Karma transposon methylation underlies the mantled somaclonal variant of oil palm. *Nature* 525: 533-537.

ONG-ABDULLAH, M., TARMIZI, A.H. and ZAMZURI, I. 2018. A holistic perspective of current progress in oil palm tissue culture. In: *Proceedings of the International Seminar on Status of Oil Palm Tissue Culture Technology.* 2018. Medan. Indonesia. 15-16.

SITI, H.R., RAFIDAH, M.K and RAJA, B.N.R.H. 2018. Is there a future in tissue culture for the oil palm industry? In: *Proceedings International Seminar on Status of Tissue Culture Technology.* 2018. Medan. Indonesia. 59-71.

SIDHU, M., ANG, B.B., ZULKASTA, S., ERA, W., AZIZ, A. and SHARMA, M. 2019. Yield performance of commercial Topaz DxP Series 2 oil palm plantings on various sites in Indonesia. *The Planter* **95** (1119) : 395-407.

SOH, A.C. 1986. Expected yield increase with selected oil palm clones from current DxP seedling materials and its implications on clonal propagation, breeding and ortet selection. *Oleagineux* 41 : 51-56.

SOH, A.C. 1998. Review of ortet selection in oil palm. *The Planter* **74** (865): 217-226.

SOH, A.C. 2012. The future of oil palm clones in Malaysia. *Journal of Oil Palm & the Environment* 2012, 3: 93-97.

SOH, A.C. 2018. Quo Vadis (Wither) oil palm tissue culture clonal propagation?. In: *Proceedings of International Seminar on Status of Tissue Culture Technology 2018*. Medan. Indonesia. 7-14.

SUZAINI, Y., JAAFAR, N.A. and HASNOOR, L.M.H. 2018. A new perspective to the oil palm cloning program in Sime Darby Plantation. In: *Proceedings International Seminar on Status of Tissue Culture Technology*. 2018. Medan. Indonesia. 75-79.

TAN, C.C., WONG, G., SOH, A.C., HOR, T.Y., CHONG, S.P. and GOPAL K. 2003. Experiences and lessons from oil palm clonal evaluation trials and commercial test plantings. Preprint. 27pp.

WONG, G., TAN, C.C. and SOH, A.C. 1997. Large scale propagation of oil palm clones – experiences to date. *Acta Horticulture* 447 : 649-658.