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RACHIS NUTRIENT CONCENTRATIONS OF DIFFERENT OIL PALM GENOTYPES AS AFFECTED BY IRRIGATION AND TERRAIN

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ABSTRACT

Four clonal oil palm materials namely AVROS, Yangambi, La Me and NIFOR, and two D×P hybrid Yangambi have been planted on terraced and non-terraced contours that are subjected to irrigated and non-irrigated conditions. Under favourable growing environment, i.e., *through irrigation, and to some extent favourable terrain of undulating plain, the palms were able to retain higher rachis nutrient concentrations, and subsequently had larger petiole cross-section and exhibited higher rachis nutrient contents. There were significant differences in all rachis nutrient concentrations for all of the planting materials for both terrain and irrigation conditions except for sulphur (S) nutrient. Previous study revealed that leaf potassium (K) concentration for D×P hybrid Yangambi-DQ8 was consistently lower than AVROS-A122 by almost 15%-20% in all the growing conditions. In contrast, the rachis nutrient concentrations for both materials were comparable. In fact, D×P Yangambi-DQ8, retained higher rachis K content (by 22%) due to larger petiole cross-section (PCS) as compared to that of AVROS-A122. The poor yielding materials, appeared to contain lower nutrient concentrations particularly those of magnesium (Mg), chlorine (Cl) and calcium (Ca). The present fertiliser regime is able to sustain high yields and capable of producing more than 10.5 t ha^{-1} yr^{-1} of total economic product (TEP) without the need for additional fertiliser inputs. Therefore, the understanding of rachis nutrient behaviour on different oil palm genotypes is crucial to produce sustainable oil yield in the near future.*

Keywords: rachis nutrients, irrigation, terrain, oil palm, clones.

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INTRODUCTION

Foliar analysis results derived from the six central leaflets on both sides of frond number 17 was established as a diagnostic tool for assessing fertiliser requirements of oil palm (Goh and Hardter, 2003). It becomes one of the common methods to evaluate the palm nutritional status. Considerable references have been accumulated for the basis of using this sample (Chan *et al.*, 1982). Early works on other oil palm tissues, such as leaflets, spears, rachis, stem, inflorescences and roots have been exploited but with inconsistent results (Chapman and Gray, 1949; Broeshart, 1954; Coulter, 1958).

Rachis tissues are well-known as an organ to store substantial amount of plant nutrients but is less commonly used as a reference in oil palm (Chan and Goh, 1978). This is partly due to the tediousness of rachis sampling procedure and limited research works on the subject. In oil palm, research on some rachis nutrient concentrations were carried out during the 1980s in Malaysia on K nutrition (Teoh and Chew, 1987), and during the 1990s in Indonesia on phosphorus (P) and potassium (K) nutrition (BLRS, 2001). Overall, these rachis assessments indicated that nutrient status, particularly P and K, provides a reasonable good correlation to fresh fruit bunch (FFB) yield. In this respect, Lee *et al.* (2012) revealed that there were significant differences in all leaf nutrient concentrations for all the planting materials for both terrain and irrigation conditions during the prime yielding stages (between 9-11 years old planting); and palms managed to yield more than 10.5 t ha^{-1} yr^{-1} of total economic product (TEP) without the need of additional nutrients. Since the different planting materials gave greater responses in terms of different leaf nutrient concentrations, it is of interest to monitor the rachis nutrient concentrations and contents during the prime age of 9-11 years (2008-2011) in relation to: (i) topography of planting area, (ii) irrigation condition, and (iii) planting materials.

MATERIALS AND METHODS

Trial Site and Irrigation Method

An experiment was laid out on palms planted in 1999 at the Tun Razak Centre for Agricultural Services, Jerantut, Pahang, Malaysia (3° 52′ 55″ north, 102° 43′ 41″ east) and treatments were incepted since the beginning of palm planting. This region is moderately wet with a mean annual rainfall of about 1900 mm and with two moderately dry periods (January to March, and July to August), each lasting about two to three months. This area experienced a very wet monsoonal period from October to December (Foong and Lee, 2000). The flatbed method was deployed to irrigate the palms under undulating and terraced areas (Lee and Romzi, 2000). Irrigation was carried out to sustain the palm water demand of 5.0 to 6.0 mm per day. The water from nearby river was pumped on to the flatbed with the frequency of irrigation of about once in every five to seven days. The average amount of water delivered per irrigation session was about 2000 litres per palm. This is equivalent to the water reception of 285 litres per palm per day.

Planting Materials and Planting Density

A total of six oil palm planting materials of various origins, namely (i) AVROS-A122 clone, (ii) La Me-L110 clone, (iii) Yangambi-Y103 clone, (iv) NIFOR-N114 clone, and two D×P hybrids, (v) Yangambi-DQ8 (ML161 which represents the present standard FELDA commercial planting material) and (vi) Yangambi-SC3, were chosen in this study. The palms were planted on two terrains *i.e.* undulating (2^0-5^0 slope) and terraced area (6^0-12^0 slope). For the undulating area, palms were planted at 136 palms ha^{-1} and terraced area at 128 palms ha^{-1}.

Rachis Sampling and Tissue Analyses

Frond number 17 from the treatment palms was used to determine palm nutrient status. Rachis sample was chosen from the same location on the frond where leaflet samples were collected. A 15 cm length sample was cut into small slices approximately 1 cm thick to facilitate drying. All the rachis samples from one plot were bulked in one bag. They were then dried at 80°C for four days. The samples were then ground to pass through 1 mm sieve and kept in labelled plastic bags. The dried samples were analysed in the laboratory for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), chlorine (Cl) and boron (B) following the methodologies set out in the Malaysian SIRIM (1980) Standards.

An equation was developed based on actual measurements of the petiole cross-section (PCS) and its actual rachis dry weight, *W* (g), which is;

$W = [(P \times 0.0324) + 0.0248]$, $R^2 = 0.742$
where *P* is the PCS.

For the estimation of respective rachis nutrient content per frond (g), mean value over four years of *P* was used and the estimated rachis dry matter was derived from the above equation.

Fertiliser Regime

The same regime of fertiliser application was applied to all of the experimental palms. All experimental palms received a similar fertiliser regime as tabulated in *Table 1* which is in accordance with FELDA estates standard practices.

Bunch Component Analysis

For each type of planting material included in this study, at least 60 bunches were harvested over

TABLE 1. TYPES AND QUANTITY OF NUTRIENTS APPLIED

Year	Nutrient applied (kg palm^{-1} yr^{-1})							
	N	P	K	Mg	Ca	*B	S	Cl
2008	0.893	0.297	1.728	0.204	0.658	0.000	1.295	1.631
2009	1.027	0.371	1.623	0.244	0.822	0.011	1.504	1.532
2010	0.995	0.371	1.574	0.244	0.822	0.011	1.468	1.485
2011	0.945	0.371	2.241	0.244	0.822	0.000	1.410	2.115
Mean	0.965	0.353	1.792	0.234	0.781	0.006	1.419	1.691

Note: *Boron applied if foliar nutrient level below critical level.

the four-year period. These bunches were weighed and taken to the laboratory for bunch analysis and the oil and kernel contents of the fruits were determined as described by Blaak *et al.* (1963).

Data Analysis

The experiment was laid out as a 2 × 2 × 6 factorial trial comprising two irrigation types, two terrain and six planting materials in a randomised complete block design (RCBD) with two replications. Due to limited ramets in some clones, unequal plot sizes were used. For data recordings, the inner core of replicate 1 with 16 palms (4 × 4) of the 6 × 6 palm plots and replicate 2 with 4 palms (2 × 2) of the 4 × 4 palm plots were used. Due to the nature of two replications for each treatment, the analysis used was to pool or average out and confine to effects of planting materials (n=8). For separation of means, Tukey's HSD (honestly significantly different) test was carried out. All the statistical analyses were performed using the SAS package version 9.0 for Windows (2002).

RESULTS AND DISCUSSION

Influence of Irrigation and Terrain

Irrigation had no significant influence on all the rachis nutrient concentrations except for K and B concentrations where irrigated palms showed almost 4% and 23% respective increment as compared to that of non-irrigated palms (*Table 2*). Irrigated palms have significant increment of rachis P, K, S and B contents by 9%, 9%, 23% and 30%, respectively as compared to non-irrigated palms (*Table 3*).

Palms planted at undulating area have significant increase ($p>0.01$) on rachis N, P and B concentrations by 9%, 22% and 5%, respectively as compared to those planted on terraced area (*Table 2*). Palms grown on undulating terrain also showed an increase in rachis contents of P (by 18%), but have substantial reduction on Ca (by 11%) and Cl (by 6%) as compared to palms planted on terraced area (*Table 3*).

Irrigation had improved oil to bunch ratio by almost 5% as compared to non-irrigated conditions which concomitantly gave an overall gains of oil yield and TEP (*Table 4*). Thus, under the present favourable growing environment, by implementation of irrigation, had improved the palm growth through expression of larger PCS (by 5%), and subsequently giving a higher nutrient contents. Overall, under optimum fertiliser inputs and appropriate good agriculture practices (GAP) (Foong and Ilangovan, 1999), palms are capable to produce over 30 t of FFB ha^{-1} yr^{-1} with more than 10.5 t TEP ha^{-1} yr^{-1}.

Influence of Planting Materials on Rachis Nutrient Concentrations, Rachis Contents, Yields and its Expected Nutrient Requirement

All the planting materials evaluated in this study showed significant differences on all the rachis nutrient concentrations except for S (*Table 2*). The clonal material NIFOR-N114 consistently showed significantly ($p\leq0.01$) lower rachis nutrient concentrations, especially on N, K, Mg, and Cl, as compared to other planting materials. The Yangambi-SC3 also showed lower value of rachis nutrient concentrations. In contrast, clonal materials AVROS-A122, Yangambi-Y103 and hybrid Yangambi-DQ8 appeared to have significantly ($p\leq0.01$) higher rachis nutrient concentrations especially N, K, Ca, Mg and Cl. Planting materials had significant responses in vegetative growth, especially on PCS and estimated dry frond weight. Overall, the high yielding clonal materials, such as Yangambi-Y103 and AVROS-A122 had smaller PCS (reduced by almost 28%) and subsequently resulting in lighter rachis weight. All of the materials studied demonstrated marked differences in all of the rachis nutrient contents except for Ca.

It appeared that high yielding clonal materials, such as AVROS-A122, Yangambi-Y103, La Me-110, and hybrid Yangambi-DQ8, have high rachis

TABLE 2. EFFECT OF PLANTING MATERIALS ON RACHIS NUTRIENT CONCENTRATION IN FROND (values are averaged over terrain and irrigation conditions) FOR THE PERIOD OF 2008-2011

	n	N			P			K			Ca			Mg			Cl			S			B		
		Percentage																							
		All values are averaged over 6 planting materials and 2 terrain conditions																							
Irrigation					$x10^{-2}$									$x10^{-2}$						$x10^{-2}$			$x10^{-3}$	$x10^{-4}$	
Irrigated (IR)	24	0.32	± 0.01	a	0.090	± 0.35	a	1.58	± 0.04	a	0.32	± 0.01	a	0.07	± 0.45	a	1.76	± 0.04	a	0.06	± 0.40	a	0.86	± 0.15	a
Non-irrigated (NIR)	24	0.33	± 0.01	a	0.087	± 0.24	a	1.51	± 0.05	b	0.32	± 0.01	a	0.08	± 0.53	a	1.76	± 0.07	a	0.06	± 0.20	a	0.70	± 0.15	b
IR/NIR (%)		99			103			104			99			96			100			117			123		
Terrain		All values are averaged over 6 planting materials and 2 terrain conditions																							
Undulating (U)	24	0.34	± 0.01	a	0.097	± 0.30	a	1.55	± 0.04	a	0.31	± 0.01	b	0.07	± 0.45	a	1.73	± 0.05	a	0.06	± 0.41	a	0.80	± 0.27	a
Terraced (T)	24	0.31	± 0.01	b	0.080	± 0.17	b	1.53	± 0.05	a	0.33	± 0.01	a	0.07	± 0.50	a	1.79	± 0.06	a	0.06	± 0.22	a	0.76	± 0.17	b
U/T (%)		109			122			101			92			100			97			99			105		
Planting Material		All values are averaged over 2 terrains and 2 irrigation conditions																							
FELDA Clone																									
Yangambi-Y103	8	0.31	± 0.02	ab	0.087	± 0.30	bc	1.65	± 0.05	a	0.37	± 0.02	a	0.11	± 0.27	a	2.03	± 0.02	a	0.06	± 0.37	a	0.79	± 0.42	ab
NIFOR-N114	8	0.29	± 0.02	b	0.082	± 0.42	c	1.18	± 0.07	b	0.30	± 0.02	bc	0.06	± 0.26	c	1.45	± 0.06	b	0.07	± 1.14	a	0.76	± 0.40	ab
La Me-L110	8	0.33	± 0.02	ab	0.101	± 0.78	a	1.55	± 0.03	a	0.27	± 0.01	c	0.05	± 0.31	c	1.64	± 0.07	b	0.05	± 0.36	a	0.73	± 0.44	b
AVROS-A122	8	0.34	± 0.02	ab	0.082	± 0.24	c	1.68	± 0.02	a	0.38	± 0.01	a	0.10	± 0.50	a	2.04	± 0.08	a	0.06	± 0.39	a	0.79	± 0.24	ab
FELDA DxP																									
Yangambi-DQ8	8	0.33	± 0.02	ab	0.084	± 0.40	c	1.61	± 0.03	a	0.34	± 0.02	ab	0.08	± 0.43	b	1.85	± 0.06	a	0.06	± 0.36	a	0.77	± 0.39	ab
Yangambi-SC3	8	0.35	± 0.01	a	0.097	± 0.47	ab	1.59	± 0.05	a	0.25	± 0.01	c	0.06	± 0.26	c	1.55	± 0.04	b	0.06	± 0.24	a	0.85	± 0.44	a
		ANOVA results																							
	df																								
Irrigation (IR)	1	n.s.			n.s.			*			n.s.			n.s.			n.s.			n.s.			**		
Terrain (TR)	1	*			**			n.s.			*			n.s.			n.s.			n.s.			*		
Planting material (PM)	5	*			**			**			**			**			**			n.s.			*		
Interaction (IR x TR)	1	**			n.s.			n.s.			n.s.			*			n.s.			n.s.			*		
Interaction (IR x PM)	5	n.s.			n.s.			n.s.			n.s.			n.s.			*			n.s.			n.s.		
Interaction (PM x TR)	5	n.s.			n.s.			n.s.			n.s.			n.s.			n.s.			n.s.			n.s.		
C.V (%)		11.08			9.82			8.30			12.94			13.10			7.79			26.07			8.06		

Note: n - number of replicate. * P<0.05, ** P<0.01, n.s P>0.05 (not significant). Degree of freedom are: irrigation 1, planting material 5, terrain 1, irrigation x planting material interaction 5, irrigation x terrain interaction 1, planting material x terrain interaction 5. ±S.E. n.s. - not significant.

TABLE 3. EFFECT OF PLANTING MATERIALS ON RACHIS NUTRIENT CONTENT IN FROND (values are averaged over terrain and irrigation conditions) FOR THE PERIOD OF 2008-2011

	n	PCS			Dry wt			N			P			K			Ca			Mg			Cl			S			B		
		cm^2			kg			g $frond^{-1}$																							
		All values are averaged over 6 planting materials and 2 terrain conditions																													
Irrigation																												$X10^{-2}$	$X10^{-3}$	
Irrigated (IR)	24	40.71	± 1.51	a	1.34	± 0.05	a	4.35	± 0.21	a	1.22	± 0.07	a	20.95	± 0.66	a	4.18	± 0.12	a	0.94	± 0.12	a	23.36	± 0.79	a	0.87	± 0.06	a	1.16	± 0.46	a
Non-irrigated (NIR)	24	38.68	± 1.24	b	1.28	± 0.04	b	4.17	± 0.22	a	1.12	± 0.05	b	19.14	± 0.76	b	4.01	± 0.14	a	0.93	± 0.14	a	22.04	± 0.55	a	0.71	± 0.03	b	0.89	± 0.34	b
IR/NIR (%)		105			105			104			109			109			104			101			106			123			130		
Terrain		All values are averaged over 6 planting materials and 2 terrain conditions																													
Undulating (U)	24	40.45	± 1.30	a	1.34	± 0.04	a	4.35	± 0.21	a	1.26	± 0.07	a	19.76	± 0.59	a	3.87	± 0.13	b	0.92	± 0.04	a	21.94	± 0.55	b	0.77	± 0.06	a	1.04	± 0.50	a
Terraced (T)	24	38.93	± 1.48	a	1.29	± 0.05	a	4.17	± 0.22	a	1.07	± 0.05	b	20.33	± 0.85	a	4.33	± 0.11	a	0.95	± 0.04	a	23.45	± 0.78	a	0.81	± 0.04	a	1.01	± 0.48	a
U/T (%)		104			104			104			118			97			89			97			94			95			102		
Planting Material		All values are averaged over 2 terrains and 2 irrigation conditions																													
FELDA Clone																														
Yangambi-Y103	8	31.21	± 0.87	b	1.04	± 0.03	b	3.21	± 0.19	c	0.90	± 0.03	c	17.00	± 0.54	b	3.86	± 0.23	a	1.11	± 0.04	a	21.07	± 0.68	b	0.62	± 0.04	b	0.81	± 0.34	c
NIFOR-N114	8	44.85	± 1.61	a	1.48	± 0.05	a	4.26	± 0.36	ab	1.22	± 0.08	ab	17.54	± 1.40	b	4.42	± 0.24	a	0.82	± 0.06	bc	21.45	± 1.35	b	0.99	± 0.15	a	1.13	± 0.86	ab
La Me-L110	8	43.36	± 0.66	a	1.43	± 0.02	a	4.72	± 0.35	a	1.44	± 0.11	a	22.17	± 0.69	a	3.93	± 0.16	a	0.76	± 0.04	c	23.55	± 1.26	ab	0.71	± 0.05	ab	1.04	± 0.66	b
AVROS-A122	8	31.95	± 1.15	b	1.06	± 0.04	b	3.63	± 0.29	bc	0.86	± 0.04	c	17.88	± 0.75	b	4.02	± 0.16	a	1.03	± 0.04	ab	21.51	± 0.70	ab	0.67	± 0.06	b	0.84	± 0.46	c
FELDA DxP																														
Yangambi-DQ8	8	41.30	± 1.66	a	1.36	± 0.05	a	4.58	± 0.37	ab	1.14	± 0.08	b	21.89	± 0.77	a	4.58	± 0.25	a	1.07	± 0.05	a	25.31	± 1.45	a	0.83	± 0.08	ab	1.06	± 0.77	b
Yangambi-SC3	8	45.48	± 1.13	a	1.50	± 0.04	a	5.16	± 0.21	a	1.45	± 0.06	a	23.80	± 0.84	a	3.80	± 0.22	a	0.82	± 0.03	bc	23.32	± 1.05	ab	0.90	± 0.05	ab	1.27	± 0.70	a
	df	ANOVA results																												
Irrigation (IR)	1	*			*			n.s.			*			n.s.			n.s.			n.s.			n.s.			**			**		
Terrain (TR)	1	n.s			n.s			n.s.			**			n.s.			*			n.s.			*			n.s.			n.s.		
Planting material (PM)	5	**			**			**			**			**			n.s.			**			*			**			**		
Interaction (IR x TR)	1	*			*			**			n.s.			n.s.			n.s.			n.s.			*			n.s.			n.s.		
Interaction (IR x PM)	5	n.s			n.s			n.s.			n.s.			n.s.			n.s.			n.s.			n.s.			n.s.			n.s.		
Interaction (PM x TR)	5	n.s			n.s			n.s.			n.s.			n.s.			n.s.			n.s.			*			n.s.			n.s.		
C.V (%)		7.83			7.68			14.95			13.32			11.80			14.33			15.20			11.08			25.36			12.01		

Note: n = number of replicate. * P<0.05, ** P<0.01, n.s P>0.05 (not significant). Degree of freedom are: irrigation 1, planting material 5, terrain 1, irrigation x planting material interaction 5, irrigation x terrain interaction 1, planting material x terrain interaction 5. ±S.E. n.s. – not significant.

TABLE 4. SUMMARY OF PALM OIL AND KERNEL OIL YIELDS (2008-2011)

Treatment	Mean oil yield product (t ha^{-1} yr^{-1})					
	FFB		Oil yield	Kernel oil yield		TEP
	t ha^{-1}	O/B (%)	t ha^{-1}	K/B (%)	t ha^{-1}	t ha^{-1}
Irrigation	**All values are averaged over 6 planting materials and 2 terrain conditions**					
Irrigated	29.91^{a}	32.88^{a}	9.83^{a}	4.96^{a}	1.48^{a}	10.72^{a}
Non-irrigated	29.48^{a}	31.39^{b}	9.26^{b}	5.09^{a}	1.50^{a}	10.16^{b}
Extra with irrigation (%)	1.5	4.7	6.2	-2.6	-1.1	5.6
Terrain	**All values are averaged over 6 planting materials and 2 irrigation conditions**					
Undulating	29.60^{a}	32.16^{a}	9.52^{a}	5.19^{a}	1.54^{a}	10.44^{a}
Terraced	29.80^{a}	32.11^{a}	9.57^{a}	4.86^{a}	1.45^{a}	10.44^{a}
Extra with undulating (%)	-0.7	0.2	-0.5	6.9	6.2	0.0
Planting Material	All values are averaged over 2 terrains and 2 irrigation conditions					
FELDA Clone						
Yangambi-Y103	29.86^{a}	34.29^{a}	10.24^{a}	6.23^{a}	1.86^{a}	11.35^{a}
NIFOR-N114	29.91^{a}	29.03^{b}	8.68^{b}	2.72^{c}	0.81^{c}	9.17^{c}
La Me-L110	29.74^{a}	33.38^{a}	9.93^{a}	3.24^{c}	0.96^{c}	10.50^{ab}
AVROS-A122	29.03^{a}	33.38^{a}	9.69^{ab}	6.45^{a}	1.87^{a}	10.81^{ab}
FELDA DxP						
Yangambi-DQ8	30.09^{a}	33.56^{a}	10.10^{a}	4.92^{b}	1.48^{b}	10.99^{a}
Yangmbi-SC3	29.53^{a}	29.18^{b}	8.62^{b}	6.59^{a}	1.95^{a}	9.78^{bc}
Trial Mean	**29.69**	**32.14**	**9.54**	**5.02**	**1.49**	**10.44**
	df			**ANOVA results**		
Irrigation	1	n.s	**	*	n.s	n.s	*
Terrain	1	n.s	n.s	n.s	n.s	n.s	n.s
Planting material	5	n.s	**	**	**	**	**
Interaction (IR x TR)	1	n.s	n.s	n.s	n.s	n.s	n.s
Interaction (IR x PM)	5	n.s	n.s	n.s	n.s	n.s	n.s
Interaction (PM x TR)	5	n.s	n.s	n.s	*	*	n.s

Note: Values with the same alphabets are not significantly different from each other.
O/B = oil to bunch; K/B = kernel to bunch.
Oil yield = O/B (%) x mean FFB yield (2008-2011).
Kernel yield = K/B (%) x mean FFB yield (2008-2011).
TEP (total economic product) = oil yield + (0.6) kernel oil yield.
* P<0.05, ** P < 0.01, n.s. – not significant.
FFB – fresh fruit bunch.
n.s – not significant.

concentrations of N, K, Ca and Cl but showed an opposite trend for their respective content in the rachis (*Table 3*). This is mainly due to growth rate expression in term of PCS and estimated rachis dry weight shown by different planting materials. Therefore, rachis nutrient contents assessment of the planting materials alone may not directly reflect the high yielding palms. Thus, the normal assessment of 'vigorous growth' to refer to healthy palm may not directly indicate good yielding palms.

Leaf K concentrations for DxP Yangambi-DQ8 have been reported to be consistently lower by 20% as compared to the AVROS-A122 (Lee *et al*., 2012). The present study revealed that the rachis K concentrations for both planting materials were comparable. However, D×P Yangambi-DQ8, retained higher rachis K contents (by 22%) due to larger PCS as compared to that of AVROS-A122 (*Figure 1*). Overall, rachis P and K concentrations for the two planting materials are above the critical

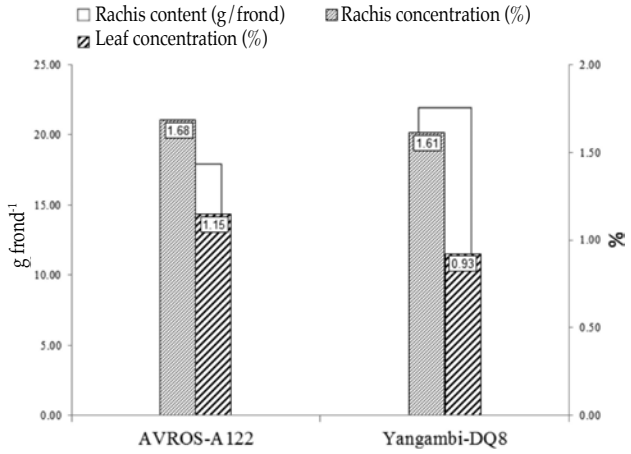

Figure 1. Comparison of leaf concentration and rachis concentration and content for K element of AVROS-122 and Yangambi-DQ8 planting material.

levels for rachis K (> 1.2%) and rachis P (>0.08%). Therefore, assessing the leaf concentration itself may not reflect the nutrition status. Incorporation of other parameters, such as rachis nutrient concentration and contents, are certainly useful.

For the poorer yielding planting materials, such as NIFOR-N114 and D×P Yangambi-SC3, the ability to retain Mg, Cl and Ca concentrations in the leaflets (Lee *et al.*, 2012) and rachis was obviously very low, and resulted in a poor FFB yield. These three nutrition elements are related to biochemical functions of photosynthesis (Von Uexkull, 1985; 1990; Goh and Hardter, 2003) and their complementary roles to each other deserve further investigations.

The present study revealed that FFB production was not significantly different between the planting materials, and this trend was reported in the previous papers (Lee *et al.*, 2005; 2011; 2012). Generally, the oil to bunch ratio (O/B) of the elite planting materials remains higher than the standard control (Yangambi D×P, SC3), resulting in 14.0%-17.5% higher oil yield and 6.1%-13.5% more TEP. At prime age, these elite palms are able to produce more than 10.5 t TEP ha^{-1} yr^{-1} and show an improvement of over 24%, an increment of almost more than 2.0 t TEP ha^{-1} yr^{-1}, as compared to the ascending yielding stage (Lee et *al.*, 2011). There is a great concern on palm nutritional status, particularly on leaf nutrient concentrations, to sustain this high oil yield. Some researchers have advocated the use of additional N and K fertilisers of up to 30% more in order to sustain growth and to obtain even higher yields (Zin, 1996). However, based on the results of the present study, the management is contented with the current fertiliser regime which is capable of producing 10.5 t of TEP ha^{-1} yr^{-1}. There is, therefore, no requirement for additional fertiliser input.

CONCLUSION

The present study clearly showed that palms grown under favourable growing environment, such as by the implementation of irrigation or grown on an undulating terrain, will be able to retain much higher rachis nutrient concentrations, larger PCS and higher rachis nutrient contents. The high yielding planting materials (Yangambi-Y103, AVROS-A122, LaMe-L110 and Yangambi-DQ8) have high rachis concentrations of N, K, Ca and Cl, but showed an opposite trend for their content in rachis. This is mainly due to growth rate expression in terms of PCS and estimated dry rachis weight shown by the different planting materials. Thus, normal assessment of 'vigorous growth' which usually refers to healthy palm may not directly indicate good yielding palms. We also concluded that the present fertiliser regime is sufficient for the palms to produce over 10.5 t TEP ha^{-1} yr^{-1}. The elite planting materials also have higher nutrient use efficiency and giving 9%-14% higher TEP compared to the standard control D×P Yangambi SC3.

In contrast, poor yielding planting materials, such as NIFOR-N114 and D×P Yangambi-SC3, have the lower ability to retain substantial rachis nutrition concentration of rachis Mg, Cl and Ca resulting in poorer oil yield, and this should deserve further investigation. Understanding the rachis nutrient concentrations and contents of each planting material over the prime production period is crucial for sustainable oil yield in oil palm.

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THE USE OF MANNOSE SELECTION SYSTEM FOR GENE TRANSFER IN TOBACCO PLANTS (*Nicotiana tabacum* L.), A MODEL PLANT FOR OIL PALM TRANSFORMATION

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ABSTRACT

A mannose selection system was evaluated for its potential application as a selectable marker in tobacco using biolistic transformation. The above system uses pmi gene isolated from Escherichia coli *that helps transgenic plants expressing it to convert mannose-6-phosphate (from mannose) into a metabolisable carbon source, fructose-6-phosphate. The ability to utilise mannose allows the transformed cells to survive on the medium containing mannose as compared to the untransformed cells. This was achieved by transforming the tobacco leaf discs using a construct carrying the pmi and β-glucuronidase (gusA) genes which were driven by 35S cauliflower mosaic virus (CaMV35S) promoter. The tobacco leaf discs were cultured on medium supplemented with 30 g litre^{-1} mannose for callus induction, proliferation and regeneration. The presence of the pmi gene was proven by PCR analysis and β-glucuronidase (gusA) activity confirmed the expression of gusA gene. Results showed that this procedure might be efficient in tobacco and other plants. The transformation procedure presented here, PMI/mannose system for selection of transgenic plants, represents an alternative for the production of transgenic plants under conditions that are safe for human health and the environment.*

Keywords: phosphomannose isomerase (PMI), mannose, biolistics, tobacco.

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INTRODUCTION

The process of plant improvement involves the delivery of a foreign gene of interest and a selectable marker gene to effectively and exclusively select transformed cells, calluses and embryos. The most frequently used selectable markers are genes that include the *nptII* gene conferring resistance to antibiotics like kanamycin, neomycin and G-418; the *hph* gene conferring antibiotic hygromycin resistance; and the *bar* gene conferring resistance to the herbicides containing phosphinothricin as an active compound such as Basta or Bialaphos (Tuteja *et al*., 2012). However, these common selectable marker genes in transgenic plants can generate environmental and consumer concerns regarding the possible impact of these markers (Zechendorf, 1994). Therefore, alternative selection systems have been developed.

PMI has been shown to be a useful marker in a variety of crops as it enables selection of transgenic cells that have a metabolic advantage over non-

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