Oil Palm Bulletin 68 (May 2014) p. 8-15.

Persistence of Mineral Fertility Carried over from the First Crop Cycle in Two Oil Palm Plantations in South America

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ABSTRACT

In South America, factorial fertilisation trials were set up on oil palm estates managed by Palmeras de los Andes in Ecuador and Indupalma S.A. in Colombia to control fertilisation during the two oil palm crop cycles. These experiments were designed to determine the optimal leaf contents of N, P, K, Mg and Cl, in recent planting materials and to assess the impacts of the first crop cycle on the following cycle.

In the two presented trials, nitrogen and chlorine treatments were found to have the greatest impact on production after 10 years of monitoring. The observed leaf N and Cl deficiencies resulted in a significant effect on the average bunch weight, but these differences did not lead to significant differences in yield. However, after 10 years of monitoring, it was found that the yield differences between the highest and the lowest nitrogen rates (N2-N0) and between the highest and the lowest chlorine rates (Cl2-Cl0), increased steadily until reaching a threshold at which some authors consider that supplementary fertilisation is required. In both experiments, soil mineral reserves had not been tapped during the first oil palm crop cycle, which had benefitted from mean rational fertiliser rates of 3 - 5 kg palm^{-1} yr^{-1}. These reserves were sufficient to limit a yield decline in the non-fertilised treatments. We also noted that it took a long time for the differences in leaf mineral content and yields to become significant, thus confirming that these are long-term effects. Hence, in a suitably fertilised plantation, it is very unlikely that the effects of fertiliser applications during previous years could be reflected by inter-annual yield variations. However, there is no reason to consider that the depressive effect of poor climatic conditions, such as prolonged drought, could be overcome by increasing early fertilisation.

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ABSTRAK

Di Amerika Selatan, kajian pembajaan faktorial telah dijalankan di ladang sawit di bawah pengurusan Palmeras de los Andes di Ecuador dan Indupalma SA di Colombia bagi menyelia pembajaan dalam tempoh dua kitaran hayat sawit. Kajian ini direka untuk menentukan kandungan daun optimum N, P, K, Mg dan Cl dalam bahan tanaman terkini serta untuk menilai impak kitaran tanaman pertama pada kitaran berikut.

Setelah 10 tahun pemantauan, keputusan dua kajian tersebut menunjukkan nitrogen dan klorin mempunyai impak terbesar dalam pengeluaran hasil. Kekurangan N dan Cl dalam daun telah menyebabkan kesan yang ketara terhadap purata berat tandan tetapi tidak membawa kepada perbezaan hasil yang ketara. Walau bagaimanapun, selepas 10 tahun pemantauan, didapati bahawa perbezaan hasil antara kadar yang tertinggi dan yang terendah bagi nitrogen (N2-N0) dan klorin (Cl2-Cl0) meningkat dengan ketara sehingga mencapai suatu ambang yang memerlukan pembajaan tambahan. Kandungan rizab mineral dalam tanah didapati tidak digunakan semasa sawit dalam kitaran hayat yang pertama, yang mana sawit telah mendapat manfaat daripada kadar purata baja yang dibekalkan sebanyak 3 - 5 kg pokok^{-1} thn^{-1}. Simpanan mineral ini mencukupi untuk menghadkan penurunan hasil sepertimana dalam plot tanpa rawatan baja. Kajian menunjukkan bahawa perbezaan dalam kandungan mineral daun dan hasil mengambil masa yang lama untuk menjadi ketara, sekali gus mengesahkan bahawa ini adalah kesan jangka panjang. Oleh itu, adalah sukar untuk membuktikan variasi hasil tahunan adalah terhasil daripada kesan pembajaan tahun-tahun sebelumnya. Namun begitu, pelaksanaan pembajaan awal bukanlah langkah yang perlu dipertimbangkan bagi mengatasi masalah yang boleh merendahkan hasil seperti kemarau yang berpanjangan.

Keywords: oil palm, yield response, mineral deficiency, mineral reserves.

INTRODUCTION

Crop fertilisation has always been a key issue in oil palm plantations due to fertiliser costs. Crop needs are determined through the mineral contents of leaf and rachis samples collected in commercial plantations. The results are compared to optimal mineral contents that are determined at each site through fertilisation trials.

Oil palm replanting operations, which are conducted every 25 - 30 years, provide an opportunity to assess the relevance of applying the same fertilisation decision-making rules for a new oil palm crop cycle. This concern is well founded due to the on-going improvement in oil palm planting materials with constantly increasing fresh fruit bunch (FFB) and oil yields and whose needs could differ, and also considering that the first crop cycle — via the farming practices that have been implemented for around three decades — may have modified the physico-chemical characteristics of the soil. These concerns are especially relevant since the land use patterns before the first oil palm crop cycle can vary markedly in terms of biomass inputs, with previous vegetation covers ranging from grazing lands to forests. After 30 years of cropping, soil mineral reserves should be assessed while keeping in mind that massive nutrient recycling takes place as a result of crop replanting operations. Khalid *et al.* (1999) estimated that 6.5 t ha^{-1} of conventional fertiliser minerals were available when a 23-year old palm stand was felled in Malaysia, which corresponds to several years of fertilisation depending on the mineral elements.

In Latin America, the sustainability of oil palm plantations was questioned when the second crop cycle began in the 1980s. Replantation fertilisation experiments were thus set up with the aim of testing the hypotheses outlined above. Oil palm estates managed by Palmeras de los Andes (PDA) in Ecuador and Indupalma S.A. in Colombia were mostly planted on land with a previous history of secondary forest stands (PDA) and grazing land (Indupalma). Fertilisation during the first oil palm crop cycle involved what could be considered as 'modest' fertiliser rates which, for mature stands, were estimated to be 2-4 kg $palm^{-1}$ yr^{-1} at PDA and 3-5 kg $palm^{-1}$ yr^{-1} at Indupalma. The main fertilisers applied were urea, KCl, $MgSO_4$ or $MgCl_2$ depending on the period, and occasionally triple superphosphate (TSP).

This article discusses the impact of persistent soil mineral reserves carried over from the first crop cycle on the expression of nutrient deficiencies induced by treatments applied over a 10-year period in two replantation fertilisation experiments.

MATERIALS AND METHODS

Study Site and Experimental Layout

Two fertilisation experiments were set up, one each in Ecuador (TTCP08) and Colombia (SACP10). Both trials involved oil palm replantings (in 1997 and 1996, respectively) following a first crop cycle of 21 and 31 years, respectively. Both plantations had equivalent annual rainfall levels (*Table 1*), but the rainfall was less favourable in Ecuador because of longer dry seasons. The mean sunshine measured with a Campbell-Stokes heliograph was high in Colombia, but low in Ecuador. The mean yields recorded in Ecuador were therefore lower than those logged in the Colombian plantation.

The soil in Ecuador was developed from Quaternary volcanic material, whereas the Colombian soil was developed on Magdalena River alluvial silt (also from the Quaternary period). The soil characteristics differed markedly between experiments with respect to texture and pH (*Table 2*). At both sites, the soils had a high calcium content in the exchange complex, representing around 70% of the CEC and up to 72% and 78% of the total base cations of the soils at Ecuador and Colombia, respectively.

Several factors were studied at two or three levels of fertiliser rates in both experiments, with the lowest always being a non-fertilised control. Yields obtained under the highest fertiliser rates could thus be compared with those obtained in the non-fertilised control treatment.

TABLE 1. ANNUAL CLIMATE CHARACTERISTICS AT THE TRIAL SITES (1996 - 2010 period)

	Ecuador TTCP08	Colombia SACP10
Rainfall (mm)	2 786	2 515
Sunshine (hr)	954	2 133
Min T (°C)	21.5	22.7
Max T (°C)	31.0	33.8
Dry season (rainfall < 150 mm)	6 months (June to November)	4 months (December to March)
Coordinates	0° 13′ N - 79° 25′ W	7° 41′ N - 73° 26′ W

TABLE 2. MAIN SOIL CHARACTERISTICS AT EACH SITE

Trial	Depth (cm)	pH (H_2O)	Clay	Silt	Sand	OM (%)	CEC	K	Ca	Mg	Na	Al+H	TC [a]	Ca/TC[b]
				(%)							(cmol kg^{-1})			
TTCP08	0-30	5.1	32	31	36	3.1	9.1	0.6	6.4	1.8	0.1	0.2	8.8	72%
TTCP08	30-60	5.4	33	32	35	1.7	10.7	0.5	7.8	2.1	0.1	0.2	10.5	74%
SACP10	0-20	5.8	21	45	34	4.4	20.4	0.3	19.0	5.0	0.2	-	24.4	78%
SACP10	20-40	6.4	19	46	35	2.3	16.9	0.2	15.1	3.8	0.2	-	19.3	78%

Note: [a] Total cation contents, [b] Ca as % of TC.
Soil analyses were conducted by Agrobiolab in Ecuador and Cenipalma in Colombia.

The TTCP08 trial was designed especially to test chlorine (Cl)and magnesium (Mg) nutrition at three levels each since their leaf contents were low in the region. Nitrogen (N) and phosphorus (P) treatments were added in presence/absence tests. A factorial design (Cl3xMg3xN2xP2) without replication was used, on experimental plots containing 12 trees. The fertiliser rates were increased from the beginning of the trial at three years to account for tree growth. The maximum fertiliser rates for each factor are specified in *Table 3*.

The SACP10 trial was designed to test nitrogen and chlorine nutrition at three levels each; chlorine fertiliser was applied in three forms (NaCl, KCl and a blend). A 3x3x3 design was used without replication on experimental plots containing 16 palms. The maximum fertiliser rates applied at the end of the trials are specified in *Table 4*.

Statistical Analysis

An analysis of variance was conducted to test the effects of the treatments on yields and mineral element rates. A regression was performed to assess yield differences between extreme fertilisation levels in relation to age by modelling random variations in each test plot by a first-order autoregressive process.

RESULTS

In the TTCP08 trial, the treatments had no significant effects on the annual fresh fruit bunch (FFB) yield per palm up to 13 years old. KCl fertilisation significantly increased the average bunch weight (ABW) twice and urea tended to improve the ABW during the last five years. *Table 5* summarises the effects of KCl and urea applications at the end of the trial when the differences were at maximum.

The annual leaf analyses highlighted a positive effect of KCl on the Cl content (*Figure 1*, significant as of three years old) and of urea on the N content (*Figure 2*, significant as of five years).

In the SACP10 trial, the treatments had no significant effects on the annual FFB yield per tree

TABLE 3. HIGHEST FERTILISER RATES APPLIED IN THE TTCP08 TRIAL FROM 2004 TO 2009

Fertiliser	KCl (60% K_2O, 50% Cl)	Kieserite (27% MgO)	Urea (46%N)	TSP (45% P_2O_5)
Rate (kg $palm^{-1}$ yr^{-1})	3	2	3	1.5

TABLE 4. HIGHEST FERTILISER RATES APPLIED IN THE SACP10 TRIAL FROM 2005 TO 2009

Fertiliser	Urea (46%N)	NaCl (60% Cl)	KCl (60% K_2O, 50% Cl)
Rate (kg $palm^{-1}$ yr^{-1})	4	3.5	4.2

TABLE 5. MAXIMUM TREATMENT EFFECTS AT THE END OF THE TTCP08 TRIAL (age 10-13)

	N0	N1	P-value	Cl0	Cl1	Cl2	P-value
ABW (kg)	19.69	19.94	0.109	18.87	20.11	20.48	0.078
FFB (kg $palm^{-1}$ yr^{-1})	165	170	0.853	164	170	169	0.699

Note: ABW – average bunch weight. FFB – fresh fruit bunch.

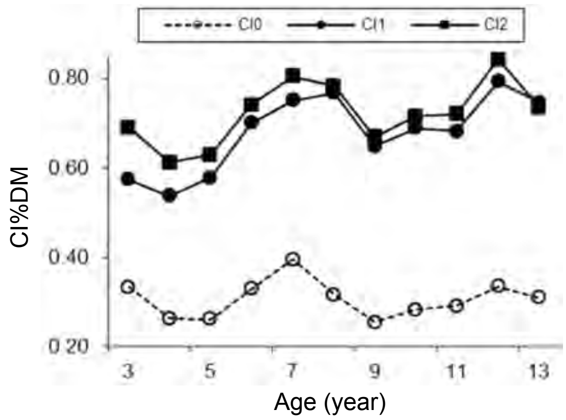

Figure 1. Chlorine content in Frond 17 in relation to KCl application and palm age in the TTCP08 trial.

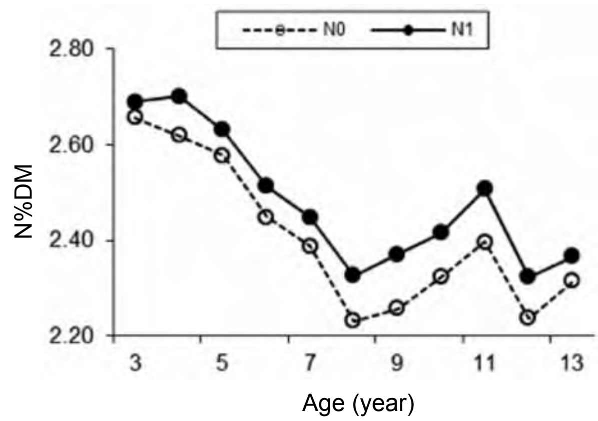

Figure 2. Nitrogen content in Frond 17 in relation to urea application and palm age in the TTCP08 trial.

up to 14 years old. The ABW was significantly increased by urea and chlorine applications as of 11 years old. *Table 6* summarises the effects of the treatments at the end of the trial when the differences were at maximum.

The leaf N contents increased significantly with urea applications as of 9 years old, and the effect was especially marked between 12 and 14 years old (*Figure 3*).

As of 6 years old, the leaf Cl contents in the Cl2 treatment were significantly higher than those of the control (*Figure 4*).

In addition to the separate yearly ANOVA tests, we assessed variations in yield differences between extreme treatments in each trial over time. *Table 7* gives the linear regression slopes calculated to fit the FFB ha^{-1} yr^{-1} and ABW differences between treatments with and without fertilisation. These fits were highly significant for ABW, which increased from 60 to 200 g yr^{-1} according to the trial and treatment. In the SACP10 trial, the FFB differences showed a significant trend, whereas the N and Cl treatments had no effects in the TTCP08 trial. In both trials, there were no marked variations in the difference in the number of fruit bunches per tree (data not shown).

Figures 5 and *6* illustrate the differences in FFB palm^{-1} yr^{-1} between Cl2 and Cl0 in both trials according to the palm age.

Figures 7 and *8* illustrate the differences in FFB palm^{-1} yr^{-1} between N1 and N0 for the TTCP08 trial and between N2 and N0 for the SACP10 trial.

DISCUSSION

This study revealed that differences in ABW between the Cl2 and Cl0 treatments and between the N2 and N0 treatments increased significantly

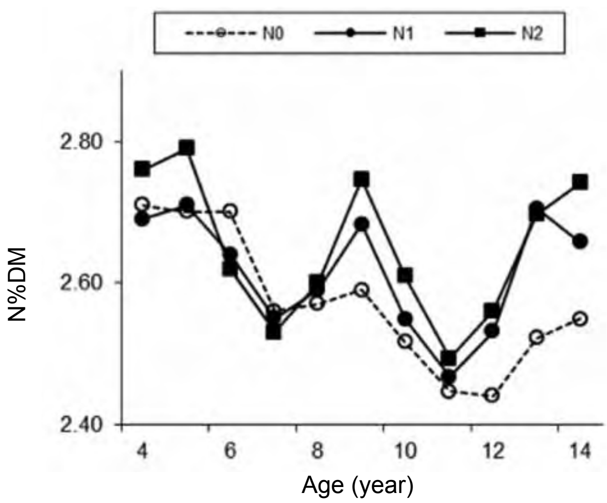

Figure 3. Nitrogen content in Frond 17 in relation to urea application and palm age in the SACP10 trial.

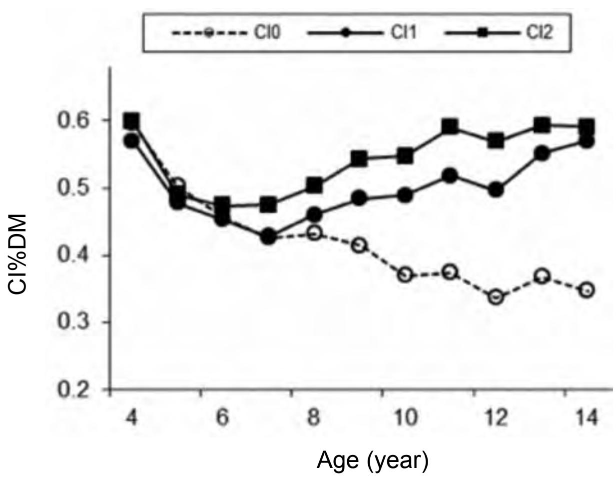

Figure 4. Chlorine content in Frond 17 in relation to KCl application and palm age in the SACP10 trial.

over the years. In terms of yield, although the findings were not significant, the differences observed between the N and Cl fertilised and non-fertilised treatments, increased in both trials. At the beginning, due to the random distribution, these differences were in favour of the non-fertilised treatments (*Figures 5* to *8*), but they became gradually positive. This trend could be explained by the onset of N and Cl deficiencies associated with the N0 and Cl0 treatments.

Although KCl was used as chlorine source, K deficiency was avoided because, paradoxically, the K contents declined in both trials with KCl fertilisation. K contents in the Cl0 treatments were therefore always higher than those in the Cl2 treatments. A detailed analysis of the SACP10 findings (Dubos *et al.*, 2011) showed that K was not deficient in the absence of potassium fertilisation and that soil K reserves from the soil origin were sufficient. Conversely, Cl contents in the Cl0 control

TABLE 6. MAXIMUM TREATMENT EFFECTS AT THE END OF THE SACP10 TRIAL (age 11-14)

	N0	N1	N2	P-value	Cl0	Cl1	Cl2	P-value
ABW (kg)	16.0	16.8	16.9	0.059	16.2	17.1	16.5	0.079
FFB (kg palm^{-1} yr^{-1})	224	227	233	0.433	222	232	230	0.410

Note: ABW – average bunch weight. FFB – fresh fruit bunch.

TABLE 7. LINEAR REGRESSION BETWEEN YIELD AND AGE OF TRIALS AND BETWEEN AVERAGE BUNCH WEIGHT (ABW) AND AGE OF TRIALS

		SACP10		TTCP08	
	Treatment	N	Cl	N	Cl
FFB (kg palm^{-1})	Slope	1.45	1.66	0.95	1.28
	P-value	0.162	0.114	0.283	0.240
ABW (kg)	Slope	0.11	0.06	0.13	0.19
	P-value	**0.000**	**0.003**	**0.044**	**0.016**

Note: P-value: significant results are shown in bold.

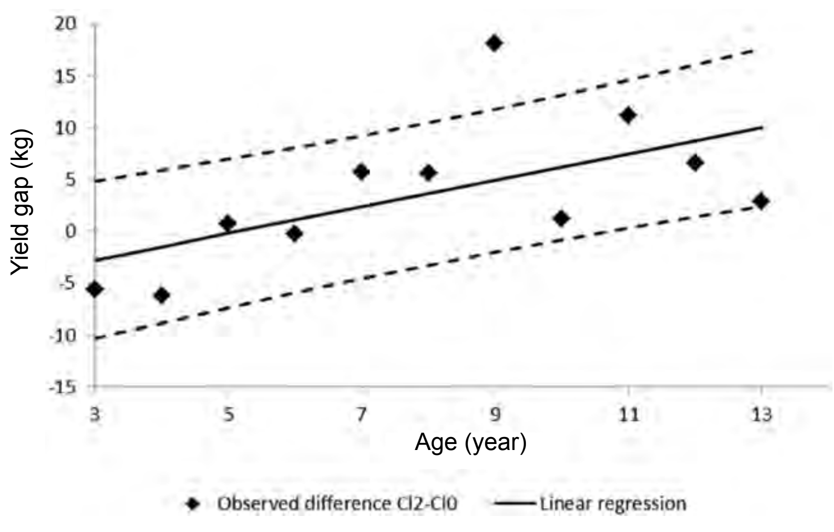

Figure 5. Yield differences (kg palm^{-1} yr^{-1}) between Cl2 and Cl0 in relation to palm age in the TTCP08 trial. Dashed lines correspond to confidence limits of the regression.

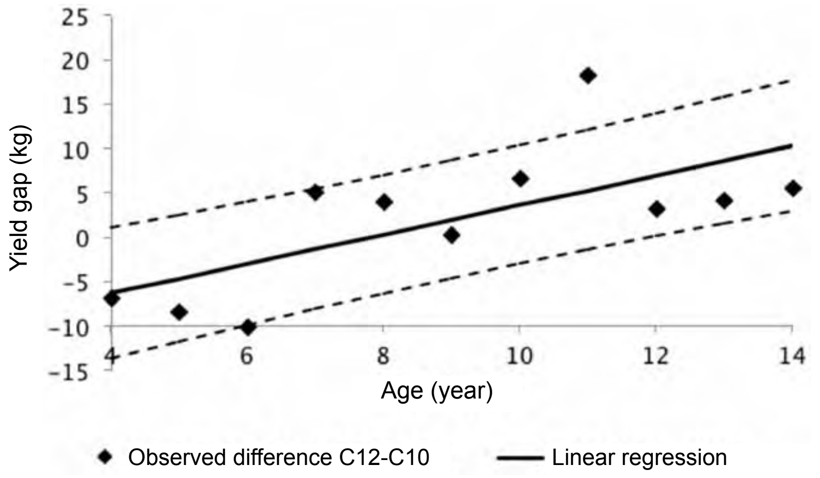

Figure 6. Yield differences (kg palm^{-1} yr^{-1}) between Cl2 and Cl0 in relation to palm age in the SACP10 trial. Dashed lines correspond to confidence limits of the regression.

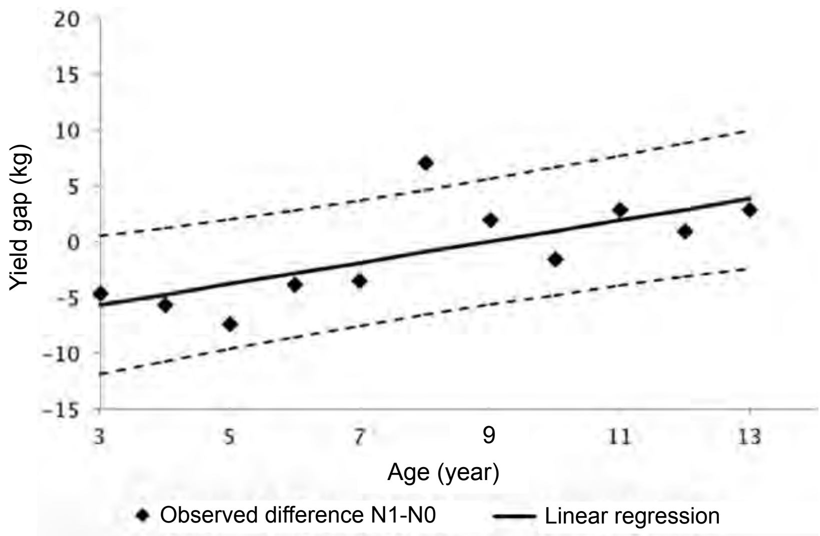

Figure 7. Yield differences (kg palm^{-1} yr^{-1}) between N1 and N0 in relation to palm age in the TTCP08 trial. Dashed lines correspond to confidence limits of the regression.

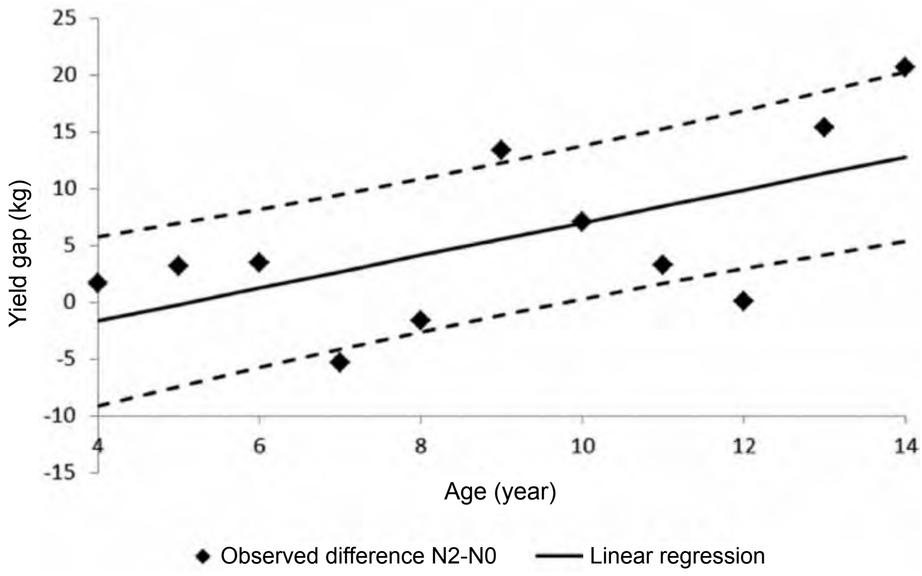

Figure 8. Yield differences (kg palm^{-1} yr^{-1}) between N2 and N0 in relation to palm age in the SACP10 trial. Dashed lines correspond to confidence limits of the regression.

in the TTCP08 trial were close to 0.30% DM from the outset (*Figure 2*) and remained under 0.40% DM for 13 years. Cl contents in the Cl0 control in the SACP10 trial (*Figure 4*) remained under 0.40% DM as of 10 years. Cl contents in the Cl2 treatment remained above 0.60% DM in the TTCP08 trial and 0.50% DM in the SACP10 trial, while it is generally assumed that the Cl deficiency threshold is between 0.50 and 0.60% DM (Ollagnier, 1971).

We found that N and Cl deficiencies gradually emerged when the crop was not fertilised. After 10 years, the FFB differences were estimated according to the cumulated linear regression slopes over this interval (*Table 7*). In the TTCP08 trial, at a planting density of 143 palms per hectare, the differences reached 1.4 and 1.8 t FFB ha^{-1} yr^{-1} for the N2-N0 and Cl2-Cl0 treatments, respectively, whereas in the SACP10 trial the differences were 2.1 and 2.4 t FFB ha^{-1} yr^{-1} for the N2-N0 and Cl2-Cl0 treatments, respectively. When expressed as a percentage of the mean yield between 10 and 13 years (*Table 5*) or between 11 and 14 years (*Table 6*), the differences represented 5.6% and 7.6% of the yield in the TTCP08 trial and 6.3% and 7.3% in the SACP10 trial.

Foster (2003) considered that at 0.5 t FFB ha^{-1} yr^{-1}, the difference between two treatments became worthwhile, and that corrective fertilisation was essential beyond 2 t FFB ha^{-1} yr^{-1}. The optimal content interval for a given mineral may be determined on the basis of these two thresholds, depending on the current palm oil market conditions. According to these criteria, the yield differences measured in this study reached the levels that are not economically acceptable any more, after 10 years without any N or Cl fertilisation.

These results also confirmed that omitting fertiliser applications for a long time should not be recommended because the mineral deficiency effects increased over time in both trials - this trend must be curbed in commercial plantations. Moreover, many authors (Patrick Ng *et al.*, 1999) agreed that suitable fertilisation management on plantations should be focused on reducing the risk of depleting soil mineral reserves (mining effect). Our findings indicated that mineral reserves carried over from the first crop cycle helped offset a yield decline in the non-fertilised treatments.

Our study confirmed that there was no severe depletion of soil mineral reserves after the first suitably fertilised oil palm crop cycle, and that it took several years before the onset of mineral deficiencies without fertilisation. The fertilisation management strategy adopted during the first crop cycle prior to setting up the experiments could thus be considered sustainable even though moderate fertilisation rates were applied.

The inertia due to soil mineral reserves was reflected by substantial time lags before leaf mineral contents dropped significantly, and the yield effects were limited because of a lag of several years with respect to the observed mineral content deficiencies. In South-east Asia, yield differences of over 50% between trials with and without fertilisation have been reported (Foster and Prabowo, 2002; Tarmizi *et al.*, 1990). The time and extent of crop reactions to mineral deficiencies can therefore differ between sites depending on the available soil mineral reserves and the presence of factors that contribute to mineral leaching.

Consequently, when soil mineral reserves are considered substantial, as in our study, interannual yield variations observed in a sufficiently fertilised plantation could not reasonably be explained by mineral content variations noted during the previous two years. In addition to soil reserves, minerals are also stored in the leaves and stems. In mature crops, Dufrêne (1989) estimated stem and leaf biomass at 42 t ha^{-1} in 10 year old palms in Ivory Coast, while Khalid *et al.* (1999) estimated this biomass at 85 t ha^{-1} in 23 year old trees in Malaysia. All of these factors contribute to markedly boosting mineral reserves, thus explaining why no direct relationships were noted between fertilisation applied during a crop season and yields recorded during the following years. Hence, any conclusion to the contrary would certainly not be correct.

The slowness of crops, especially mature palms, in taking advantage of available nutrient supplies offers interesting prospects for cover crop management. Risks of mineral leaching could likely be reduced by not limiting cover crop development beyond agricultural needs, while also promoting the build up of mineral reserves as this organic matter could then be tapped by the palm crop.

CONCLUSION

These fertilisation experiments, which were set up after the first crop cycle, enabled us to confirm that soil mineral fertility management in the two plantations included in this study was not diminished by crop mineral uptake. Moderate fertilisation of 3 - 5 kg $palm^{-1}$ yr^{-1} was compatible with sustainable soil mineral management, with yields remaining satisfactory. This is an important finding when considering the ever increasing cost of fertilisation. We observed substantial lags between the beginning of the non-fertilised treatments and their negative effects on mineral nutrition. This indicated that, contrary to annual crops, high mineral reserves in the soil and plants have a buffer role that neutralises all short-term effects of fertilisation on yields. Setting up experiments is an effective way of assessing the sustainability of mineral reserves and determining overall crop fertilisation needs. This experimental approach facilitates decision-making while awaiting the clarification of plant mineral uptake mechanisms through long-term studies.

ACKNOWLEDGEMENT

The authors wish to thank Dr R D Lizarralde, General Manager of INDUPALMA S A and Dr S Gutt, General Manager of Palmeras de los Andes, for their support in our research activities.

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