EFFECTS OF N, P AND K FERTILIZERS ON LEAF TRACE ELEMENT LEVELS OF OIL PALM IN SUMATRA

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ABSTRACT

Nine trials testing the application of N, P, K and Mg fertilizers to oil palm were carried out at different locations on mineral soils in both North and South Sumatra, and their effect on the contents of both major and minor elements were monitored. This article reports the effect of N, P and K fertilizers on the trace element status of the palms. In four of the trials on old palms in North Sumatra, urea fertilizer significantly reduced the leaf levels of both copper and zinc, in some cases below the established critical levels. In addition, superphosphate fertilizer significantly reduced leaf copper in four of these trials whilst muriate of potash fertilizer significantly depressed leaf zinc in two trials. In contrast, N and P fertilizers had no effect on leaf trace element levels in five trials on younger palms in South Sumatra, but in four of the trials, K fertilizer significantly reduced leaf zinc. There were no consistent effects of N, P and K fertilizers on leaf levels of B, Mn or Fe.

Changes in soil properties due to the fertilizer applications did not appear to explain these results. Furthermore, the effects of fertilizers on trace element levels were not generally seen in the rachis, suggesting that the uptake of trace elements into the palms was not significantly affected. The reduction in leaf copper and zinc levels may therefore have been due to a physiological effect of the fertilizer nutrients inside the palms which influenced the transfer of these trace elements to the leaves. Leaf concentrations of other trace elements were not generally affected by fertilizers, indicating that the results for copper and zinc were not due to a dilution effect resulting from increased growth.

In the trials on older palms in North Sumatra, yields had generally fallen with time, and Ganoderma *incidence had increased in the treatments where trace elements had been depressed by the major fertilizers. It is concluded that continuous application of N, P and K fertilizers is likely to have an adverse effect on the trace element status of oil palms, which if not corrected may result in reduced yields and increased disease incidence.*

Keywords: N, P, K fertilizers, trace elements, oil palm.

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INTRODUCTION

The recommendation for applying trace element fertilizers to oil palm on mineral soils is usually restricted to boron (Rajaratnam, 1976) although on exceptionally sandy soils the need for copper (Wanasuria and Gales, 1990) and manganese (Kee *et al.*, 1995) has been reported. In contrast, oil palm on peat soils typically becomes chlorotic and stunted unless both copper (Ng *et al.*, 1974) and zinc (Gurmit, 1988) fertilizers are supplied. Fertilizer trials on peat have indicated the tentative critical levels for leaf copper and zinc, corresponding to optimal yield levels (von Uexkull and Fairhurst, 1991).

A long-term fertilizer trial network on oil palm has been conducted by Sumatra Bioscience in

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North and South Sumatra since 1994 and 2000, respectively. The main objective of these trials is to determine oil palm requirements for N, P, K and Mg fertilizers, both in North and South Sumatra provinces. In the trials in North Sumatra, optimal fresh fruit bunch (FFB) yields initially exceeded 30 t ha^{-1} yr^{-1} but with time have fallen below this level, while the initial responses to the highest level of N fertilizer have declined or even disappeared. To determine if nutrients not supplied as fertilizer in the trials might be limiting yields, additional leaf analyses were carried out which revealed a significant depression of some trace elements in instances where high fertilizer rates had been continuously supplied. In some cases, the trace elements in the leaves had been depressed to below the commonly accepted critical levels.

This article reports the effects of N, P and K fertilizers on frond trace element levels in all the trials carried out in both North and South Sumatra, and discusses the possible implications of the results on oil palm performance and disease incidence.

MATERIALS AND METHODS

The results from the nine oil palm fertilizer trials implemented in different environments were used in this investigation. Three fertilizer trials were located on the soils derived from rhyolite parent material and one on a sandstone soil in North Sumatra province, whilst the remaining five trials were situated in South Sumatra province where the soils are formed from volcanic ash rich in dacite and the underlying claystone. Soil type and particle size distribution in the individual trials are presented in *Table 1*.

All trials were factorial (with higher order interactions confounded with blocks), testing combinations of NPKMg fertilizers at different rates as indicated in *Table 2*. Each plot in three of the trials in North Sumatra consisted of 7×7=49 palms of which the central 5×5=25 and 3×3=9 palms were recorded and analyzed. In trial 232 in which the plots were located on terraced slopes, each plot consisted of a minimum of 12 palms in a row along three parallel terraces, with eight palms from the middle and lower terraces having their data recorded. In the South Sumatra trials, each of the plots consisted of 8×8=64 palms from which the central 6×6=36 and 4×4=16 palms were recorded and analyzed.

The measurements which are discussed in this article include FFB yield per year, leaf and rachis trace element levels from frond 17 samples collected every year. Frond 17 was cut at the base and removed from the tree. The point on the rachis where the flat top changes to angular (which is about two-thirds along the frond from the base) was located, and at this point four adjacent leaflets from each side of the rachis (*i.e.* eight leaflets) were selected and detached from the rachis. The central one-third of each leaflet was then cut out and placed in a clean bag. A rachis sample was also collected from the same location as the leaflets. A short length of the rachis was removed by making two cuts approximately 10 cm apart, and all the rachis samples from one plot were bulked in one bag. The levels of trace elements in both leaf and rachis tissues were analyzed using the dry ashing method followed by uptake in HCl and HNO_3, whilst $CaCl_2$ 0.1 M was used to extract both soil Cu and Zn. Detailed yield results, vegetative growth parameters, major tissue nutrient levels measured and the characteristics of the different sites of the trials are found in the *Annual Reports of Bah Lias Research Station* (BLRS, 2008).

TABLE 1. SOIL TYPE AND PARTICLE SIZE DISTRIBUTION IN EACH TRIAL IN NORTH AND SOUTH SUMATRA

Trial No.	Soil Sub-group (USDA)*	Soil parent material	Slope (%)	Soil texture (%)		
				Sand	Silt	Clay
231	Typic Hapluudult	Rhyolite	3	23	31	46
232	Typic Dystrudepts	Sandstone	40	65	11	24
275	Oxic Dystrudepts	Rhyolite	3	62	14	24
277	Oxic Dystrudepts	Rhyolite	3	57	7	36
1403	Typic Hapluaquults	Dacite, claystone	3	49	30	21
1411	Typic Dystrudepts	Dacite, claystone	3	60	7	33
1412	Typic Dystrudepts	Dacite, claystone	3	65	12	23
1413	Typic Endoaquepts	Dacite, claystone	3	51	12	27
1414	Typic Dystrudepts	Dacite, claystone	3	57	22	21

Note: *Soil Survey Staff (1999). USDA: United States Department of Agriculture.

TABLE 2. PLANTING MATERIALS AND ANNUAL FERTILIZER TREATMENT RATES

Trial No.	Material[1]	Planting year	Density (palms ha^{-1})	Fertilizer rate (kg $palm^{-1}$ yr^{-1})											
				Urea			TSP[2] and CIRP[3]			MOP[4]			Kieserite and super dolomite[5]		
				0	1	2	0	1	2	0	1	2	0	1	2
231	Deli x Avros 1	1985	128	0	2	4	0	2	4	0	2.5	5	0	1.5	3
232	Deli x Avros 1	1985	128	0	2	4	0	2	4	0	2.5	5	0	1.5	3
275	Deli x Avros 1	1985	135	0	2	4	0	2	4	0	2	-	0	2	-
277	Deli x Avros 1	1985	128	0	2	4	0	2	4	0	2	-	0	2	-
1403	Deli x Avros 1	1996	143	0	2	4	-	2*	4*	0	2	4	0	2*	-
1411	Deli x Avros 2	1997	143	0	2	4	-	2*	4*	0	2	4	0	2*	-
1412	Deli x Avros 2	1997	143	0	2	4	-	2*	4*	0	2	4	0	2*	-
1413	Deli x Avros 2	1997	143	0	2	4	-	2*	4*	0	2	4	0	2*	-
1414	Deli x Avros 2	1997	143	0	2	4	-	2*	4*	0	2	4	0	2*	-

Note: [1]Planting material = Deli *Dura* x *Pisifera* Avros 1 and 2.
[2]TSP = Triple superphosphate (45% total P_2O_5).
[3]CIRP = Christmas Island rock phosphate (26%-36% total P_2O_5).*
[4]MOP = muriate of potash (60% K_2O).
[5]Super dolomite = (18%-22% MgO with more than 90% passing a 100-mesh sieve).*

TABLE 3. OPTIMAL FERTILIZER COMBINATIONS AND YIELDS IN NORTH SUMATRA TRIALS AT DIFFERENT PERIODS

Period	Trial 231		Trial 232		Trial 275		Trial 277	
	NPKMg level	FFB yield (t ha^{-1} yr^{-1})	NPKMg level	FFB yield (t ha^{-1} yr^{-1})	NPKMg level	FFB yield (t ha^{-1} yr^{-1})	NPKMg level	FFB yield (t ha^{-1} yr^{-1})
1998-2001	1222	29.11	2122	28.84	2110	32.34	2200	33.64
2002-2004	0222	32.12	2122	27.01	1211	29.41	1210	31.29
2005-2007	2211	32.63	2122	24.04	1211	27.13	0210	28.97

RESULTS

Over 1998-2001, most of the North Sumatra trials responded to the high rate of N fertilizer, and achieved optimal FFB yields of around 30 t ha^{-1} yr^{-1} with the fertilizer treatments shown in *Table 3*. However, over 2002-2004, trials 275 and 277 only responded to the lower fertilizer rate, while over 2005-2007, trial 277 did not respond to N fertilizer at all. Furthermore, the optimal yields from these two trials declined over the last two periods, indicating the influence of some limiting factor.

In contrast, in only two of the five much younger South Sumatra trials there was initially (over 2002-2004) a response to the higher rate of N fertilizer, but over 2005-2007 all five trials responded to the higher rate of N fertilizer, and generally recorded higher yields in this latter period (*Table 4*).

Application of the three major fertilizers significantly increased their corresponding leaf and rachis nutrient levels in almost all the fertilizer trials carried out in Sumatra. However, further analyses showed that N fertilizer application to the older trials in North Sumatra also significantly

TABLE 4. OPTIMAL FERTILIZER COMBINATIONS AND YIELDS IN SOUTH SUMATRA TRIALS

Period	Trial 1403		Trial 1411		Trial 1412		Trial 1413		Trial 1414	
	NPKMg level	FFB yield (t ha^{-1} yr^{-1})	NPKMg level	FFB yield (t ha^{-1} yr^{-1})	NPKMg level	FFB yield (t ha^{-1} yr^{-1})	NPKMg level	FFB yield (t ha^{-1} yr^{-1})	NPKMg level	FFB yield (t ha^{-1} yr^{-1})
2002-2004	2221	37.87	1220	31.41	2220	26.30	0220	25.46	0110	29.77
2005-2007	2120	36.80	2220	31.16	2220	32.35	2221	28.25	2110	31.86

TABLE 5. MAIN EFFECT OF N FERTILIZER ON LEAF TRACE ELEMENT LEVELS IN NORTH SUMATRA OVER 2006-2008

Trial	N level	Leaf trace element level (µg g^{-1})									
		2006			2007			2008			
		B	Cu	Zn	B	Cu	Zn	Cu	Zn	Fe	Mn
231	N0	9.2	5.7	17.1	8.9	3.9	19.9	6.6	25.4	132.1	512.0
	N1	8.5	4.6*	14.3*	8.8	3.4	17.7*	5.9	25.5	128.5	565.8
	N2	8.8	4.1*	14.0*	8.9	2.8*	17.2*	4.8*	22.3*	137.5	605.8
232	N0	10.2	4.6	11.2	9.3	3.6	11.0	3.8	14.1	176.6	111.5
	N1	10.8	4.3	10.9	9.1	2.8	10.0	3.1	12.5*	155.9	101.6
	N2	10.5	3.7*	10.0*	8.9	2.1*	9.4*	2.7*	11.4*	144.2	106.4
275	N0	9.1	5.1	15.6	7.8	5.0	25.7	3.4	15.0	97.0	638.8
	N1	9.7	4.5	13.8	7.4	4.6	18.4*	2.8	12.6*	103.1	540.7
	N2	9.1	4.1*	10.3*	7.3	4.1*	15.8*	2.9	12.8*	105.0	643.4
277	N0	10.5	4.4	17.7	8.5	4.0	23.5	3.1	23.9	113.7	552.8
	N1	10.0	4.0	17.8	8.4	3.9	17.2*	2.6	20.1	142.7	463.0
	N2	9.5*	3.8*	14.5*	8.7	2.8	15.8*	2.5	17.2*	127.5	531.0

Note: * Significant at 5% probability.

depressed leaf Cu and Zn levels as shown in *Table 5*. Meanwhile, P fertilizer application also significantly depressed Cu levels in all the trials in North Sumatra although not in every year as shown in *Table 6*. *Table 7* shows that K fertilizer application significantly depressed leaf Zn levels in trials 231 and 232, both of which showed a significant yield response to K fertilizer, but there was no significant effect of K fertilizer on yields or leaf trace element levels in the other two trials. Meanwhile N, P and K fertilizer application had only few effects on both Fe and Mn levels as shown in *Tables 5* to *7*. In the South Sumatra trials, N and P had no significant effects on leaf trace element levels, but K fertilizer significantly reduced leaf Zn in four out of the five trials, as well as leaf Cu and B in one trial each as shown in *Table 8*.

Fertilizer treatments on rachis trace element levels shown in *Tables 9* and *10* for North and South Sumatra, respectively, indicate few significant effects, suggesting that the fertilizers were not influencing the uptake of trace elements into the palms. This tentative conclusion is supported by the effects of the fertilizer treatments on the soil chemical properties shown in *Table 11*. N fertilizer significantly reduced the topsoil pH and exchangeable Ca, and increased exchangeable Al in all the trials in North Sumatra, which would have tended to increase rather than reduce the availability of the trace elements. N and P fertilizer applications both significantly reduced soil organic matter in trials 231 and 275, which could have reduced available trace elements, but this effect was not seen in the other two trials in North Sumatra. Further investigation into trial 275 as shown in *Table 12* revealed that both N and P fertilizer applications did not significantly reduce available trace elements.

DISCUSSION

The application of N and P fertilizers on old palms in North Sumatra clearly depressed both leaf Cu and Zn levels, and in some cases below the tentative critical levels. For example, leaf Cu in trials 231 and 232 in 2007 was below 3 µg g^{-1} which is the critical level for mature palms (von Uexkull and Fairhurst, 1991). The results for Cu are similar to the previous findings by Wanasuria and Gales (1990) on a very sandy soil in Riau where the incidence of Cu deficiency was positively related to the applied

TABLE 6. MAIN EFFECT OF P FERTILIZER ON LEAF TRACE ELEMENT LEVELS IN NORTH SUMATRA OVER 2006-2008

Trial	P level	Leaf trace element level (µg g^{-1})									
		2006			2007			2008			
		B	Cu	Zn	B	Cu	Zn	Cu	Zn	Fe	Mn
231	P0	8.5	4.9	13.9	8.8	3.6	17.5	7.1	24.8	144.0	523.3
	P1	8.7	5.1	15.4	9.3	3.4	19.8	5.2*	23.9	132.1	607.4
	P2	9.3	4.3	16.2*	8.5	3.0*	17.5	5.0*	24.4	122.1	552.8
232	P0	10.2	4.6	11.3	9.0	3.3	10.9	3.4	12.9	164.3	100.3
	P1	10.4	3.9	9.9*	9.3	2.7*	10.0	3.2	12.1	155.9	106.8
	P2	10.9	4.2	10.8*	9.0	2.6*	9.5	3.0	12.9	156.4	112.4
275	P0	9.1	5.3	14.5	7.5	4.6	19.3	2.8	13.6	97.2	500.2
	P1	9.1	4.3*	12.4	7.5	4.4	21.1	3.5	13.8	106.4	640.1*
	P2	9.6	4.2*	12.8	7.5	4.7	19.5	2.7	13.1	101.5	682.6*
277	P0	9.7	4.3	17.2	8.3	3.8	18.6	3.0	20.0	141.7	434.7
	P1	10.4	4.0	16.5	8.7	3.5	17.8	2.6	21.0	116.0	561.7
	P2	9.8	3.8*	16.2	8.6	3.5	20.0	2.6	20.2	126.2	550.4

Note: * Significant at 5% probability.

TABLE 7. MAIN EFFECTS OF K FERTILIZER ON LEAF TRACE ELEMENT LEVELS IN NORTH SUMATRA OVER 2006-2008

Trial	K level	Leaf trace element level (µg g^{-1})									
		2006			2007			2008			
		B	Cu	Zn	B	Cu	Zn	Cu	Zn	Fe	Mn
231	K0	9.0	5.3	17.2	9.7	3.3	20.3	5.5	26.7	130.1	584.3
	K1	8.5	4.5	14.0*	8.6	3.7	18.4	5.7	22.8*	135.9	549.5
	K2	9.0	4.6	14.3*	8.3	3.1	16.0*	6.2*	23.6*	132.2	549.8
232	K0	11.9	4.6	11.7	10.2	3.0	10.6	3.7	13.9	140.5	128.1
	K1	10.1	3.9	10.2*	8.7*	2.9	10.1	2.9*	12.3	166.0	97.7*
	K2	9.5*	4.2	10.1*	8.3*	2.7	9.8*	2.9*	11.7*	170.3	93.7*
275	K0	9.6	4.7	13.9	7.8	4.5	19.5	2.8	13.8	99.2	578.6
	K1	9.0	4.5	12.6	7.2	4.6	20.4	3.2	13.2	104.2	636.7
277	K0	10.0	4.0	17.5	8.5	3.5	19.0	2.9	21.7	117.5	479.8
	K1	10.0	4.2	15.8	8.5	3.6	18.6	2.6	19.1	138.4	551.4

Note: * Significant at 5% probability.

TABLE 8. MAIN EFFECTS OF NPK FERTILIZERS ON LEAF TRACE ELEMENT LEVELS IN SOUTH SUMATRA IN 2006

NPK level	Leaf trace element level (µg g^{-1})														
	1403			1411			1412			1413			1414		
	B	Cu	Zn	B	Cu	Zn	B	Cu	Zn	B	Cu	Zn	B	Cu	Zn
N0	11.0	4.9	12.8	10.9	5.3	13.0	10.4	4.4	13.4	11.1	4.7	12.9	11.2	4.2	11.0
N1	10.9	5.4	13.5	10.8	5.9	13.5	10.3	4.3	13.6	10.9	4.5	11.7	11.0	4.6	12.7*
N2	11.2	5.2	13.2	10.0	5.8	12.6	11.4	4.4	13.3	10.8	4.5	12.2	10.8	4.3	11.7
P1	10.6	5.1	12.8	10.4	5.7	13.4	10.3	4.3	13.1	10.9	4.6	12.2	11.0	4.3	11.7
P2	11.4	5.2	13.5	10.7	5.6	12.7	11.2	4.4	13.7	11.0	4.6	12.3	11.0	4.4	11.8
K0	11.9	5.7	14.7	12.0	5.6	14.3	10.4	4.5	14.2	10.8	4.9	13.2	10.4	4.6	13.3
K1	10.0*	4.8*	12.4	10.0*	5.7	11.9*	11.5	4.4	13.5	10.8	4.5	12.4*	11.3	4.1	11.0*
K2	11.2	5.0	12.5	9.6*	5.7	12.9*	10.3	4.1	12.5*	11.2	4.4	11.2*	11.4	4.4	11.0*

Note: * Significant at 5% probability.

TABLE 9. MAIN EFFECTS OF NPK FERTILIZERS ON RACHIS TRACE ELEMENT LEVELS IN NORTH SUMATRA IN 2006

NPK level	Rachis trace element level (μg g^{-1})											
	Trial 231			Trial 232			Trial 275			Trial 277		
	B	Cu	Zn	B	Cu	Zn	B	Cu	Zn	B	Cu	Zn
N0	5.5	2.2	7.6	4.5	1.8	4.2	5.9	2.1	8.8	5.2	2.2	12.5
N1	5.2	2.0	7.5	4.6	1.9	3.8	6.5	1.8	8.8	5.2	1.8	13.8
N2	5.4	2.0	7.7	4.4	1.8	3.2*	5.5	2.2	8.3	5.0	2.2	13.5
P0	5.1	2.1	7.5	4.6	1.9	4.0	6.0	2.4	9.9	5.3	2.3	13.9
P1	5.3	2.1	8.3	4.3	1.7	3.4	5.7	1.9*	8.2	5.1	1.9	13.0
P2	5.7	2.0	6.9	4.6	1.9	3.8	6.1	1.9*	7.8*	5.0	2.1	12.9
K0	5.6	1.9	8.5	4.5	1.9	5.3	5.7	1.9	9.5	5.4	2.1	13.1
K1	5.4	2.3	6.5	4.5	1.8	3.1*	6.2	2.2*	7.8*	4.8	2.1	13.4
K2	5.2	2.0	7.7	4.5	1.8	2.9*	-	-	-	-	-	-

Note: * Significant at 5% probability.

TABLE 10. MAIN EFFECTS OF NPK FERTILIZERS ON RACHIS TRACE ELEMENT LEVELS IN SOUTH SUMATRA IN 2006

NPK level	Rachis trace element level (μg g^{-1})														
	Trial 1403			Trial 1411			Trial 1412			Trial 1413			Trial 1414		
	B	Cu	Zn	B	Cu	Zn	B	Cu	Zn	B	Cu	Zn	B	Cu	Zn
N0	8.0	1.7	4.8	3.1	2.0	4.4	7.4	2.8	5.2	5.2	1.4	4.7	2.8	2.0	4.9
N1	7.7	1.9	5.9	3.4	2.1	4.3	7.1	2.5	5.2	5.9	1.5	4.5	3.4	1.9	4.9
N2	7.6	1.9	5.0	3.4	2.0	4.0	7.2	2.2	5.5	5.3	1.9*	4.7	3.6	2.1	4.7
P1	7.9	1.9	5.4	3.5	2.1	4.2	7.1	2.5	5.3	5.5	1.7	4.4	2.7	2.0	4.8
P2	7.6	1.8	5.1	3.1	2.0	4.3	7.4	2.5	5.4	5.4	1.5	4.8	3.8*	2.0	4.8
K0	8.0	2.0	7.1	3.3	2.0	4.5	6.4	2.4	5.7	5.4	1.6	4.9	3.1	2.1	6.0
K1	7.5	1.7	4.1*	3.4	2.1	4.1	7.3*	2.7	6.0	5.2	1.6	4.6	4.1	1.9	4.1*
K2	7.9	1.8	4.6*	3.1	2.0	4.1	8.0*	2.4	4.3*	5.8	1.6	4.3	2.6*	2.0	4.3*

Note: * Significant at 5% probability.

rate of N and P fertilizers. Marschner (1995) added that when nitrogen supply is high, application of Cu fertilizer is required, whilst Mengel and Kirkby (1987) noticed that excess phosphate results in metabolic disorder and may lead to Zn deficiency. In contrast, N and P fertilizers had no effect on leaf trace element levels in the five trials on younger palms in South Sumatra, particularly leaf Cu and Zn. It is assumed that this is because the palms were still relatively young and that it takes a long time for the effects to become significant. The results in South Sumatra also explain why the depressive effect of N and P fertilizers on trace elements had not been generally reported because it would not occur on palms of average age but only in a limited number of old palms in a plantation.

Apart from the effect of N and P fertilizers, it was noticed that in two trials in North Sumatra and four trials in South Sumatra K fertilizer application also depressed leaf Zn levels. This may probably be due to physiological processes in the oil palm. Dibb and Thompson (1985) explained that the interaction of K with Zn varies with different plants, and that it could be positively or negatively related.

Further investigation revealed that application of N and P fertilizer in general had changed some soil chemical properties such as soil pH and exchangeable Ca. However, changes in soil properties due to fertilizer application seemed to have nothing to do with leaf trace element status as there was no significant correlation observed between leaf trace element and analyzed soil properties. Additionally, the effects of fertilizers on leaf trace element levels were not generally seen in the rachis, suggesting that uptake into the palms was not significantly affected. These findings confirm that the reduction in leaf Cu and Zn levels may therefore be due to a physiological effect of the fertilizer nutrients inside the palms which influenced the transfer of these trace elements to the leaves. Mengel and Kirkby (1987) noticed that N may increase the plant's requirement for Cu

TABLE 11. MAIN EFFECTS OF N AND P FERTILIZERS ON SOIL CHEMICAL PROPERTIES IN NORTH SUMATRA IN 2006

Trial	NP level	pH	Organic matter (%)	P Bray 2 (μg g^{-1})	Exchangeable cation [cmol (+) kg^{-1}]			
					Al+H	K	Mg	Ca
231	N0	4.76	6.49	1.98	1.24	0.20	0.17	0.82
	N1	4.60*	6.38	3.61*	1.54*	0.18	0.16	0.50*
	N2	4.49*	5.90*	3.48*	1.73*	0.20	0.14*	0.51*
	P0	4.56	6.54	0.92	1.76	0.19	0.17	0.47
	P1	4.58	6.53	2.16*	1.50*	0.19	0.15	0.55*
	P2	4.72*	5.70*	5.99*	1.24*	0.20	0.15	0.81*
232	N0	4.91	4.58	38.44	1.37	0.18	0.21	0.76
	N1	4.76*	4.52	30.01	1.62*	0.16	0.18	0.68*
	N2	4.65*	4.59	28.77	1.78*	0.16	0.15*	0.62*
	P0	4.79	4.54	4.29	1.73	0.18	0.17	0.51
	P1	4.78	4.67	31.46*	1.50	0.16	0.18	0.64*
	P2	4.76	4.48	61.47*	1.54	0.15	0.19	0.91*
275	N0	5.01	4.46	3.43	0.71	0.19	0.18	1.19
	N1	4.81*	4.36	7.39	0.78	0.22	0.21	1.01
	N2	4.70*	4.03*	5.88	1.01*	0.21	0.15	0.73*
	P0	4.84	4.56	1.72	0.87	0.23	0.18	0.79
	P1	4.80	4.20	3.89	0.80	0.18	0.19	1.20*
	P2	4.88	4.10*	11.09*	0.83	0.20	0.17	0.93
277	N0	4.89	3.72	2.45	0.50	0.29	0.30	3.28
	N1	4.71	3.76	10.84	0.55	0.45	0.31	2.81*
	N2	4.52*	3.98	4.55	0.85*	0.34	0.27	2.20*
	P0	4.71	3.83	0.35	0.63	0.38	0.32	2.69
	P1	4.66	3.78	7.35	0.64	0.34	0.28	2.74
	P2	4.75	3.85	10.13*	0.62	0.35	0.28	2.86

Note: * Significant at 5% probability.

TABLE 12. MAIN EFFECTS OF N AND P FERTILIZERS ON SOIL COPPER AND ZINC IN TRIAL 275 IN 2008

Treatment	Soil trace element (μg g^{-1})	
	Cu	Zn
N0	0.38	2.36
N1	0.45	2.58
N2	0.36	2.21
P0	0.39	2.72
P1	0.40	2.18
P2	0.37	2.41

by apparently retarding the translocation of Cu from old to young leaves, whilst Marschner (1995) noticed that high P contents in the soils do not always influence Zn solubility in the soils.

In this initial investigation, it was also noticed that N, P and K fertilizer in general did not affect leaf B, Mn or Fe levels, both in young and older palms. This clearly indicates that the reduction of Cu and Zn levels was not due to a dilution effect resulting from increased growth.

As leaf Cu and Zn were in some cases depressed below the accepted critical levels (von Uexkull and Fairhurst, 1991), it would seem quite likely that this may have had an effect on yield. This could be the explanation for the decline in yields noted in two trials (275 and 277) in North Sumatra over the last 10 years as shown in *Table 3*. In all the North Sumatra trials, it was noticed that over the last 20 years, N fertilizer application significantly increased leaf N levels up to the highest rate tested. Consequently, as shown in a typical North Sumatra trial (trial 275), yields at nine years were increased up to the highest tested rate of N fertilizer and at 13 years as well. However, at 17 and 20 years, there was only a response to the lower rate of N fertilizer, with the highest rate actually depressing the yield as shown in *Figure 1*. This trend also occurred in another typical North Sumatra soil (trial 277). It appears that in old palms, N fertilizer at a high rate was inducing some limiting factor. Marschner (1995) noted that, when nitrogen supply is high, the application of Cu fertilizer is required for maximum yield whilst Zn deficiency may inhibit both plant growth and yield.

Further investigation into trial 275 in North Sumatra where *Ganoderma* incidence was very high revealed that both N and P fertilizer applications significantly increased the number of dead palms due to *Ganoderma* incidence as shown in *Table 13*.

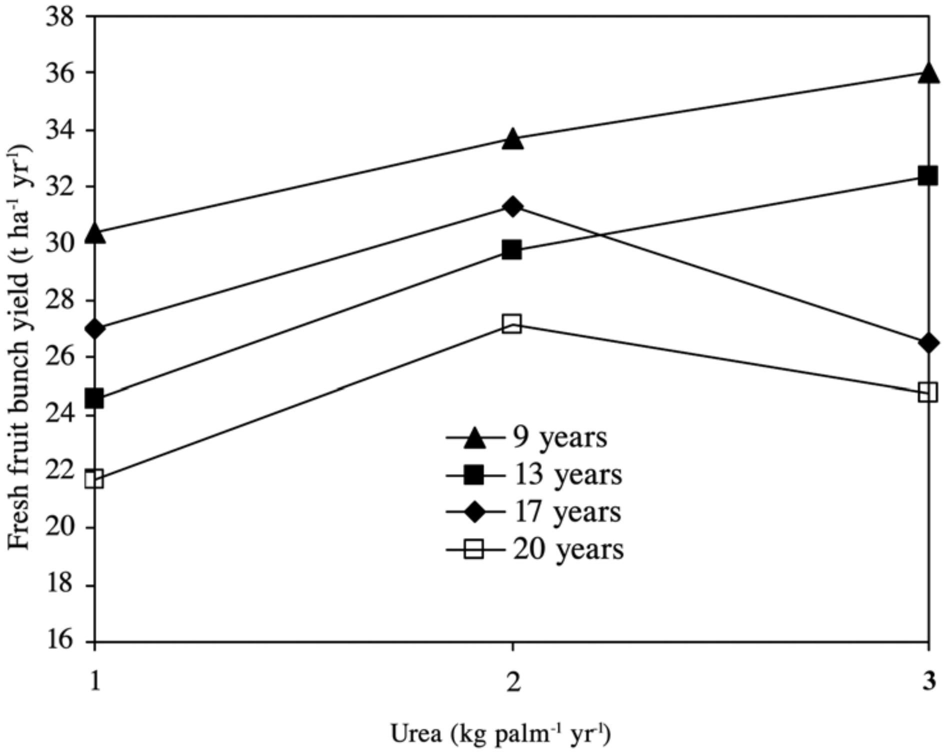

Figure 1. Oil palm yield response (t ha^{-1} yr^{-1}) to urea fertilizer at different times (at optimal rates of other fertilizers) in trial 275 in North Sumatra.

TABLE 13. MAIN EFFECTS OF NPK FERTILIZERS ON DEAD PALMS IN TRIAL 275 OVER 2006-2008

Treatment level		Number of dead palms ha^{-1}		
		2006	2007	2008
N	0	21	25	29
	1	47*	56*	59*
	2	37*	43*	46*
P	0	22	24	26
	1	36*	43*	46*
	2	47*	57*	63*
K	0	37	46	49
	1	32	37	41

Note: * Significant at 5% probability.

This effect of N and P fertilizers on *Ganoderma* has also been shown in a number of trials in Malaysia (Tayeb and Hamdan, 2000). It is possible that this effect of N and P fertilizers on *Ganoderma* was a consequence of the reduction of leaf Cu and Zn levels.

CONCLUSION

The trials on old palms in North Sumatra showed in all cases that N fertilizer significantly depressed leaf Cu and Zn levels whilst P fertilizer in all cases depressed leaf Zn levels. It is possible that this is the cause of the yield decline and reduced response to N fertilizer observed in later years in these trials. It might also be the explanation for the increase in *Ganoderma* incidence caused by N and P fertilizers as seen in trial 275.

In the trials on young palms in South Sumatra, N and P fertilizers did not affect leaf trace element levels, but K fertilizer in most cases significantly reduced leaf Zn levels. However, the latter effect did not appear to have affected yields to date.

The reduction in leaf trace element levels due to N, P and K fertilizer application did not seem to be due to a reduced uptake of trace elements by the palms because rachis trace element levels were not generally affected, and the changes in chemical soil properties did not support this theory. Furthermore, leaf concentrations of other trace elements (B, Mn and Fe) were not generally affected by fertilizers, indicating that the results for Cu and Zn were not due to a 'dilution' effect resulting from increased growth. It is therefore concluded that the reduction in leaf trace elements was probably due to a physiological effect of the nutrients supplied by the fertilizers which hindered the transfer of the trace elements into the leaves.

To prove whether or not trace element deficiencies induced by major fertilizers on mineral soils in Sumatra do significantly reduce the yield of older palms and influence disease incidence, a series of fertilizer trials testing the application of trace elements to oil palm has recently been established on a range of mineral soils in Sumatra.

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