Soil Acidification under Oil Palm: Rates and Effects on Yield

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Field experiments in Papua New Guinea have shown strong effects of fertilizer type and placement on soil acidification in oil palm plantations—a potential degradation issue that may eventually have an adverse effect on yields. However, measurements at four sites in Indonesia show that relatively high yields are possible on soils with a low pH, and that best management practices can actually increase pH at low values. It is concluded that current pH levels in major growing areas of oil palm in Southeast Asia can be managed such that they do not prevent relatively high oil palm yields.

Being a perennial tree crop, oil palm is an ideal plant for sustainable agricultural cropping systems. Since the introduction of ammonium fertilizers in the 1980s, however, soil acidification under oil palm has been a potential degradation issue. This study assumes a dual approach to understand the problem through 1) experimental work looking at effects of fertilizer on soil acidity on relatively high pH soils in Papua New Guinea (PNG) and 2) measurements of yield at low soil pH values (in Indonesia) typical of those used in large oil palm growing regions in Southeast Asia.

In PNG, most oil palm is grown on fertile volcanic ash soils with addition of N fertilizer (mostly ammonium-based). Because of high rainfall rates and permeable soils, nitrate losses are promoted by leaching and soil acidification is likely as a result of that leaching. In addition, removal of base cations in harvested product is expected to accelerate acidification. These cations are returned as by-products from the oil-mill only to fields close to the mill.

Results are presented here from two fertilizer trials designed to determine the rate of soil pH decline and acidification under oil palm grown on recent volcanic ash soils of PNG. The objectives of the trials were to determine a) the effect of fertilizer type on acidification, and b) the effect of fertilizer placement on acidification and pH buffering capacity (pH BC).

The fertile soils of PNG are not necessarily representative of the major growing areas of the crop in Southeast Asia. Mutert (1999) has estimated that about 95% of oil palms are grown on acid, low fertility soils in Southeast Asia. We therefore discuss the data from PNG within the wider context of Southeast Asia using information from a general literature review of pH values, and from preliminary results from plantations in major growing areas of Indonesia where the Southeast Asia Program (SEAP) of the International Plant Nutrition Institute (IPNI) has developed Best Management Practices (BMPs).

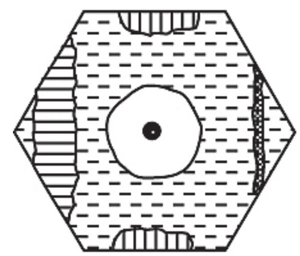

Figure 1. Surface management zones in the fertilizer trials. The hexagon, whose perimeter is defined by the midpoint between adjacent palms, represents the repeating unit in oil palm plantations. Empty fruit bunches (EFB) were applied to the Between palms (BP) zone in some treatments in Trial B, but none in Trial A.

Oil palm plantation managed under the BMP program developed by IPNI SEAP. The weeded circle surrounding the palm as well as the frond pile stack (on left) are clearly visible.

Papua New Guinea Sites

The effect of fertilizer type was measured at Ambogo plantation, Oro Province (Trial A), PNG. The site has an annual average rainfall of 2,214 mm with silt or sandy loam soil derived from alluvially re-deposited volcanic ash. The trial was a Latin square design with five treatments, five replicates, and 36-palm plots, of which the central 16 palms were monitored. Treatments included application of no fertilizer, ammonium chloride (AC) at 3.2 kg/palm/yr, ammonium sulfate (AS) at 4.0 kg/palm/yr, and AS (4.0 kg/palm/yr) together with either potassium chloride (KCl, 4.4 kg/palm/yr) or bunch ash (BA, 8.8 kg/palm/yr). The BA, which supplied the same amount of K as the KCl, was produced by burning empty fruit bunches (EFB). The trial was conducted in a field that had been planted in 1980 with 143 palms/ha, and treatments ran from 1990 until 2001. In 1989 and 2002 (before and after treatments), soil samples were taken from each plot (0 to 0.2 m depth). Each sample was a composite of five sub-samples. The sample pits were located in the corners and the middle of the plot, exactly between two palms (equivalent to the BP zone in **Figure 1**). This zone received some fertilizer, with most of the remainder falling on the frond pile (FP) **(Figure 1; Photo)**.

The effect of fertilizer placement and EFB application was measured at Kumbango plantation, West New Britain

Common abbreviations and notes: C = carbon; Ca = calcium; Mg = magnesium; N = nitrogen; Na = sodium.

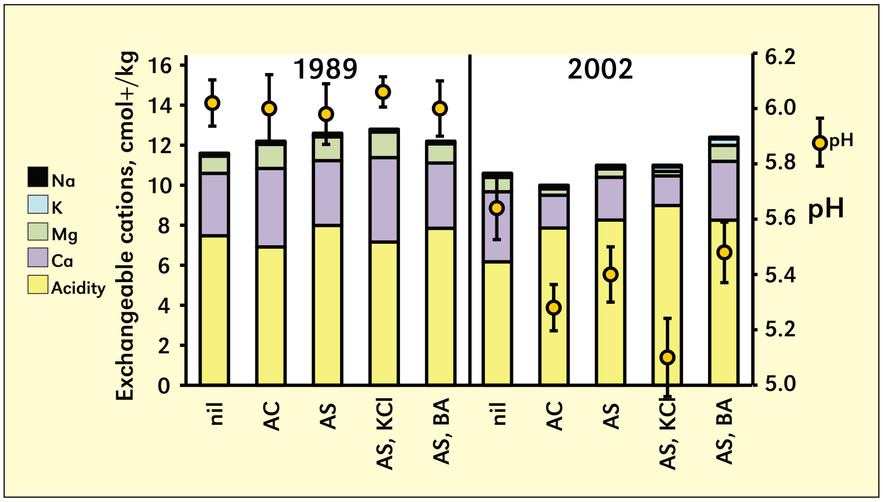

Figure 2. Mean exchangeable cation content (bars) and mean pH_{water} (circles ±s.d.) of soil in the BP zone of Trial A (0 to 0.2 m depth).

Province (Trial B), PNG. The site has an annual average rainfall of 3,248 mm, and clayey recent volcanic ash soils with some inter-bedded pumice. The trial was a randomized complete block design, with four replicates of 36-palm plots, of which the central 16 were monitored. Treatments included placement of fertilizer onto the 'weeded circle' (WC), the 'frond pile', or in the 'between palms' (BP) zones **(Figure 1)**. The BP zone had EFB applied (50 t/ha/yr) in some plots and not in others. The fertilizer applied was AC (3 kg/palm/yr) plus kieserite ($MgSO_4 \cdot H_2O$, 3 kg/palm/yr). The trial was conducted in a field that had been planted in 1994 with 135 palms/ha, and treatments were applied from 1998 until 2004. In 2004, soil was sampled from all application zones at depth increments of 0 to 0.05 and 0.05 to 0.1 m. Each sample from each plot, zone, and depth increment was a composite of eight samples taken from two points adjacent to each of four different palms.

In both trials, soils were analyzed for pH (1:2 soil to water for Trial A and 1:5 for Trial B), exchangeable cations, cation exchange capacity (CEC) and organic C content. Selected samples were analysed for bulk density and pH BC by titration (calculated by linear regression of titration curves). In Trial A, net acid addition rate (NAAR) was calculated by multiplying the pH change by pH BC (24.6 mmol/kg per pH unit) and bulk density (1.14 Mg/m^3).

Indonesian Sites

The Indonesian results were generated at sites that IPNI SEAP uses to develop BMPs for sustainable intensification of oil palm. IPNI SEAP developed the BMP concept as a management tool for yield gap correction and yield intensification in mature oil palm plantations (Donough et al. 2010). In this concept, a set of site-specific BMPs are identified and implemented in a number (five minimum) of full-sized management blocks representative of a plantation. A parallel set of comparable blocks under standard practice are monitored as reference (REF) blocks for comparison. Measurements of soil pH were taken at the beginning and at the end of a 4 year BMP implementation cycle in four plantations in major growing areas of Southeast Asia (i.e. two sites in north Sumatra, one site in south Sumatra, and one site in west Kalimantan). In these plantations, N is predominantly applied as urea within the weeded circles of the REF blocks, and partially as AS in the BMP blocks. Timely pruning contributes a consistent source of nutrients and organic matter (Goh and Härdter, 2003).

Results

In Trial A in PNG, soil pH declined and exchangeable acidity increased in all treatments, with pH of the 0 to 0.2 m layer dropping by 0.38 units in the nil fertilizer treatment and 0.52 to 0.96 units in the fertilized treatments **(Figure 2)**. Addition of AS or AC accelerated pH decline by 0.023 units/year compared to the control treatment (nil fertilizer). Addition of AS together with KCl accelerated pH decline by 0.042 units/year compared to the control, whereas BA had an ameliorative effect on pH compared to AS alone. There were substantial decreases over time in exchangeable Ca and Mg and effective CEC (sum of cations) in all fertilized treatments except AS+BA. NAARs for the top 0.2 m were 1.6, 3.1, 2.5, 4.2, and 2.3 kmol/ha/year for the nil, AC, AS, AS+KCl, and AS+BA treatments, respectively. In the fertilized plots, the NAARs were less than the potential NAAR calculated from nitrification and uptake or leaching loss of nitrate (8 to 17 kmol/ha/yr), possibly because the 0 to 0.2 m depth layer of the BP zone was not representative of the whole field.

In Trial B in PNG, pH and the effects of fertilizers on pH differed markedly between management zones **(Table 1)**. Without the addition of fertilizer, pH was lowest in the WC (which had the lowest organic matter content of all the zones) and highest in the FP and BP+EFB zones (which had the highest organic matter contents). In all zones pH was lowest in the surface layer. The decrease in pH of the 0 to 0.05 m layer due to fertil-

Table 1. Effect of fertilizer (fer.) application and placement on soil properties in Trial B (Values are the mean of four replicates).

	Values in 0 to 0.05 m depth				Values in 0.05 to 0.10 m depth			
	WC	FP	BP+EFB	BP-EFB	WC	FP	BP+EFB	BP-EFB
pH water (-fer.)	5.5	6.0	6.0	5.8	5.7	6.0	6.4	5.9
pH water (+fer.)	5.0	4.8	5.3		5.1	5.0	5.5	
Org C (-fer.), %	3.9	10.4	11.4	4.0	2.7	4.9	5.1	3.1
Org C (+fer.), %	3.3	9.3	14.4		2.6	5.1	6.1	
CEC (-fer.), $cmol_+/kg$	6.5	28.4	26.5	10.1	5.7	16.5	18.5	7.6
CEC (+fer.), $cmol_+/kg$	2.9	10.1	22.8		2.1	6.0	13.6	
ExCa (-fer.), $cmol_+/kg$	24.8	27.8	28.2	36.1	20.2	26.3	25.2	33.5
ExCa (+fer.), $cmol_+/kg$	2.2	8.0	19.0		1.8	4.4	9.9	
ExMg (-fer.), $cmol_+/kg$	0.7	4.1	4.5	1.4	0.6	2.3	4.2	1.1
ExMg (+fer.), $cmol_+/kg$	0.4	3.5	9.8		0.4	1.7	6.0	
ExK (-fer.), $cmol_+/kg$	0.4	1.3	0.7	0.6	0.4	1.3	1.5	0.6
ExK (+fer.), $cmol_+/kg$	0.3	0.8	0.8		0.2	0.5	0.7	

Table 2. Yield and pH values measured at four plantation sites in "Best Management Practices (BMP)" blocks and "Estate Reference Practices (REF)" blocks.

			-------- Soil pH (KCl) Frond Pile[1] --------			------ Soil pH (KCl) Weeded Circle[1] ------		
T[2]	Area[3]. ha	FFB[4]. kg/ha	Start (S) Avg	End (E) Avg	E-S[5]	Start (S) Avg	End (E) Avg	E-S
BMP 1	158.8	26,338	3.9	4.5	0.6	3.8	4.2	0.4
REF 1	162.7	23,123	3.9	4.3	0.4	3.8	4.2	0.4
BMP 2	177.7	27,360	3.8	4.1	0.2	3.8	4.0	0.2
REF 2	171.1	23,042	3.8	4.2	0.4	3.8	4.1	0.3
BMP 3	164.3	25,950	3.8	4.1	0.3	3.7	3.9	0.2
REF 3	162.7	22,442	3.7	4.1	0.4	3.7	4.0	0.4
BMP 4	183.6	25,430	3.7	4.1	0.4	3.7	4.1	0.3
REF 4	193.3	22,859	3.8	4.2	0.5	3.8	4.1	0.3
BMP 5	135.5	27,187	3.6	4.0	0.4	3.6	4.0	0.4
REF 5	157.7	23,488	3.6	4.1	0.4	3.6	4.0	0.4
BMP All	819.9	26,453	3.8	4.1	0.4	3.7	4.0	0.3
REF All	847.5	22,991	3.7	4.2	0.4	3.7	4.1	0.4

[1] Soil pH determined at start (July 2006) and end (= final = July 2010); Average values for 0 to 20 and 20 to 40 cm depth, representing four blocks from four locations.
[2] Treatments include five "Best Management Practices (BMP)" blocks and five control "Estate Reference Practices (REF)" blocks at each of the four plantation sites
[3] Aggregated areas for each respective BMP and REF treatment from four plantation sites: two in north Sumatra, one in south Sumatra and one in west Kalimantan
[4] Fresh Fruit Bunch weight, annual average data of four years data
[5] Average at End minus Average at Start
General notes: Years of planting between 1994 and 2001 at site 1, 1992 and 1998 at site 2, 1989 and 1992 at site 3, and 1998 and 1999 at site 4; 134 palms per hectare (average across sites and blocks); Seed material included LonSum, Dami, SocFin at site 1, Marihat, SocFindo at site 2, Marihat, Dami at site 3, and DxP Hybrid seeds from ASB Costa Rica at site 4.

izer addition was least (0.52 units) when fertilizer was applied in the WC and greatest (1.17 units) when fertilizer was applied in the FP. The difference in pH decline between zones may have been due to differences in N transformations and fluxes, or to differences in pH BC. Soil pH BC did indeed differ between application zones; it was highly correlated with organic matter content. The greatest decline in pH occurred in the FP and BP zones, despite their high organic matter content and pH BC. Therefore, the difference in acidification rates between zones appears to have been primarily due to differences in N cycling processes. The pH decline due to fertilizer addition in Trial B was accompanied by large decreases in exchangeable cation contents, especially Ca **(Table 1)**. Addition of EFB (without fertilizer) resulted in an increase in pH, CEC, and exchangeable Mg and K, but in a decrease in exchangeable Ca **(Table 1)**.

In contrast to PNG, Indonesia's low soil pH values are typical of those used for most oil palm production. Information from the four sites is summarized in **Table 2**. The data provide no evidence that application of fertilizer to relatively low fertility soils leads to further acidification or yield reduction. Relatively high yields are obtainable on soils with pH values lower than those reported for the PNG trials. Furthermore, during the 4 year implementation cycles, pH values increased on average by almost half a unit in BMP and REF blocks. Parallel yields in the BMP blocks also increased substantially. BMPs were strictly adhered to in these plantations, and while these practices are likely to have contributed to differences in pH values, the BMP work has just been concluded and no specific explanation for these trends can be provided prior to detailed analysis of the entire dataset.

It is difficult to accurately assess acidification of soil under oil palm, due to the large spatial variability in through fall, water uptake, fertilizer application, and organic matter content (due to placement of pruned fronds in FP, prevention of understory growth in the WC, and application of EFB to the BP zone in some plantations). Yet, the results of the PNG trials outline clear trends:

1. Under oil palm in PNG, there was significant acidification of volcanic ash soil with time, with or without fertilizer application, despite the soil's relatively high CEC and organic matter content.
2. Addition of ammonium-based fertilizers significantly accelerated pH decline, with combined addition of KCl enhancing the decline. However, the degree of acidification can be reduced by adding bunch ash to the fertilizer applications.
3. Application of the fertilizers in Trial B was accompanied by a decrease in exchangeable cation content. Except for Ca, bunch ash application reversed this trend.
4. The effect of fertilizer addition on acidification was spatially variable, being greatest when fertilizer was applied in the FP and BP zones, probably due to a high proportion of N being lost by leaching in those zones.

However, the trends identified here merit careful consideration to avoid making assumptions about oil palm production systems elsewhere, where soil properties differ. Furthermore, the management practices that resulted in the reported reduction in pH value are similar to those developed by IPNI SEAP for sustainable yield intensification in oil palm plantations using BMP (Donough et al. 2010). Specifically, the BMP concept promotes (Rankine and Fairhurst, 1998):

1. Placing of pruned palm fronds between rows and in the space between palms within rows,
2. Applying AS over the edge of the weeded palm circles and the adjoining frond stacks,
3. Spreading urea evenly within the weeded palm circle,
4. Applying straight and compound P fertilizers over the edge of the weeded palm circles and over the inter-row spaces,
5. Spreading straight and compound K fertilizers in a wide band around the weeded palm circles, and
6. Using EFB as organic fertilizer to replace bunch ash.

One might deduce from the results of the fertilizer studies in PNG that the listed BMPs may contribute to a reduction in pH over time. If evidence exists for such change, the BMP implementation process should address it so as not to jeopardize sustainable yield intensification. However, the fact that pH of the Indonesian soils did not decline over time suggests that they have reached a pH at which pH BC is effectively infinite (Nelson and Su, 2010) and little or no further decline in pH will occur under normal agricultural practices.

Based on an extensive literature review, we conclude that oil palm can tolerate fairly low values in pH. Commonly reported pH values in the range between 4 and 5 are considered favorable for commercial oil palm production in Southeast Asia (von Uexkull and Fairhurst, 1991; Goh 1995; Mutert 1999; Corley and Tinker, 2003; Paramananthan, 2003). Mutert (1999) listed eight representative soil types commonly used for oil palm in Southeast Asia and he further stated that all of these soils have a pH less than 5.0, six of the eight soils have low to very low contents of N, available P, and exchangeable K, and half of the soils have low to very low content of exchangeable Mg, when evaluated for oil palm fertility parameters.

Conclusions

Experiments in PNG have shown a strong acidifying impact of fertilizer application in oil palm plantations, alerting practitioners to the potential risk of adverse impact on yields. However, a literature review and preliminary data from BMP implementation at four sites in Indonesia illustrate that relatively high yields are obtainable on soils with a low pH. Plantation managers are advised to monitor and evaluate soil fertility characteristics in both the weeded circles and frond deposition areas to determine the relationship between acidification and yield trends. BC

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