Acidification of volcanic ash soils under oil palm in Papua New Guinea: effects of fertiliser type and placement

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Abstract
Soil acidification is a widespread degradation problem, but little information is available for oil palm production systems. The aim of this work was to determine the effect of fertiliser type and placement on acidification of volcanic ash soils under oil palm in Papua New Guinea. A field trial, which had various combinations of N (114-120 kg N/(ha.year)) and K (329 kg K/(ha.year)) fertilisers applied over 13 years, was examined. Over that period, pH_{water} of the 0-0.2m layer declined by 0.38 units in the control treatment and 0.52-0.96 units in the fertilised treatments. Application of fertiliser and plant residues are not uniform in oil palm plantations, so the effect of placement was measured in another trial, which had been operating for 6 years. In the 0-0.05 m layer, the decrease in pH_{water} due to fertiliser addition (ammonium chloride plus kieserite) was least (0.52 units) when fertiliser was applied in the weeded circle and greatest (1.03 units) when it was applied in the frond pile. Soil pH buffer capacity was different between zones and fertiliser treatments, but the difference in acidification effect of fertiliser between zones was attributed primarily to differences in the water balance and N cycling rather than pH buffer capacity.

Key Words
Exchangeable cations, net acid addition rate, pH buffer capacity, nitrogen fertiliser, potassium fertiliser.

Introduction
Oil palm (*Elaeis guineensis* Jacq.) is grown on over 100 million ha in the humid tropics and the area is expanding in response to demand for vegetable oil. Being a perennial tree crop it is a good candidate for sustainable agricultural systems, but soil acidification is a potential soil degradation issue, especially since ammonium fertilisers came into use in the 1980s. There is a reasonable amount of information on soil acidification in a number of tropical agricultural systems (Moody and Aitken 1997), but there is little published information on soil acidification under oil palm, probably largely because of the tolerance of oil palm to acidic conditions. Research in Malaysia and Africa indicates substantial acidification due to fertiliser applications (Kee *et al*. 1996; Roth *et al*. 1986). In Papua New Guinea (PNG), most oil palm is grown on fertile recent volcanic ash soils. Nitrogen fertiliser (mostly ammonium-based) is used in most plantations due to large economic responses. High rainfall rates and permeable soils mean that nitrate losses by leaching can be considerable (Banabas *et al*. 2008a; 2008b), so soil acidification is likely. In addition, considerable removal of cations in produce could be expected to accelerate acidification. Most of these cations are returned to the field in by-products from the oil mill, but only to fields close to the mill, for economic and logistical reasons. In this work we set out to determine the rate of soil pH decline and acidification under oil palm grown on recent volcanic ash soils of PNG, using two fertiliser trials run by the PNG Oil Palm Research Association. The aims of the work were to determine a) the effect of fertiliser type on acidification, and b) the effect of fertiliser placement on acidification and pH buffering capacity.

Methods
Field trial descriptions
The effect of fertiliser type was measured in Ambogo plantation, Oro Province (Trial 309). The site has an annual average rainfall of 2,214 mm, and silty to sandy loam soil derived from alluvially deposited volcanic ash. The trial was a latin square design with 5 treatments, 5 replicates and 36-palm plots, of which the central 16 were monitored. Treatments were application (annual rates) of: no fertiliser; ammonium chloride (AC) alone at 3.2 kg/palm; ammonium sulphate (SOA) alone at 4.0 kg/palm; and SOA (4.0 kg/palm) together with potassium chloride (MOP) at 4.4 kg/palm or bunch ash (BA) at 8.8 kg/palm. The BA, which supplied the same amount of K as the MOP, was produced by burning the empty fruit bunches (EFB) that are a by-product of palm oil production. The trial was conducted in a field that had been planted in 1980 at 143 palms/ha, and treatments ran from 1990 until 2001. In 1989, before treatments were imposed, soil samples

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

were taken from each plot (0-0.2 m depth). Each sample was a composite of samples taken from 5 pits within each plot. The 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 receives some fertiliser, with most of the remainder falling on the frond pile (Figure 1). In 2002 soil samples were taken again, in the same way as the first sampling.

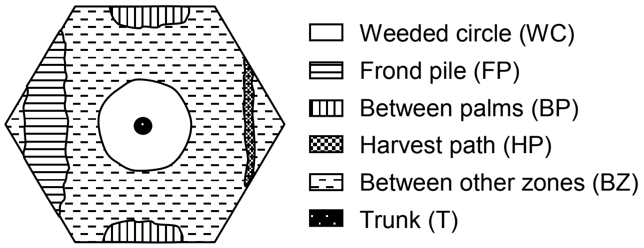

Figure 1. Surface management zones in the fertiliser trials. The hexagon, whose perimeter is defined by the midpoint between adjacent palms, represents the repeating unit in oil palm plantations. Empty fruit bunches (EFB) were applied to the BP zone in some treatments in Trial 129 but none in Trial 309.

The effects of fertiliser placement and EFB application were measured in Kumbango plantation, West New Britain Province (Trial 129). 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 randomised complete block design, with 4 replicates, 36-palm plots, of which the central 16 were monitored, and treatments involving placement of fertiliser in different locations; either on the 'weeded circle' (WC), the 'frond pile' (FP), or the 'between palms' (BP) zones (Figure 1). The BP zone had no EFB applied in some treatments and EFB applied in other treatments (50 t/(ha.year)). The fertiliser was AC (3 kg/palm) plus kieserite ($MgSO_4.H_2O$, 3 kg/palm) annually. The trial was conducted in a field that had been planted in 1994 at 135 palms/ha, and treatments were imposed from 1998 until 2004. In 2004, soil was sampled from all application zones at depth increments of 0-0.05 and 0.05-0.1 m. Each sample from each plot, zone and depth increment was a composite of 8 samples, which were taken from two points adjacent to 4 different palms.

Soil analyses and calculation of net acid addition rate and pH buffer capacity
In both trials, all soils were analysed for pH (pH_{water}, 1:2 soil:water for Trial 309 and 1:5 for Trial 129), exchangeable cations, cation exchange capacity (CEC) and organic C content, and selected samples were analysed for bulk density and pH buffer capacity by titration (pHBC, calculated by linear regression of titration curves). In Trial 309, net acid addition rate (NAAR) was calculated by multiplying the pH change by pH buffer capacity (24.6 mmol/(kg.pH unit)) and bulk density (1.14 Mg/m^3).

Results
In Trial 309, soil pH declined and exchangeable acidity increased in all treatments, with pH of the 0-0.2 m layer dropping by 0.38 units in the nil treatment and 0.52-0.96 units in the fertilized treatments (Figure 2). Addition of SOA or AC accelerated pH decline by 0.023 units/year compared to the control treatment. Addition of SOA together with MOP accelerated pH decline by 0.042 units/year compared to the control, whereas BA had an ameliorative affect on pH compared to SOA alone (Figure 2). There were substantial decreases in exchangeable Ca and Mg and CEC with time in all fertilised treatments except SOA+BA (Figure 1). NAARs for the top 0.2m were 1.6, 3.1, 2.5, 4.2 and 2.3 kmol/(ha.year) for the nil, AC, SOA, SOA+MOP and SOA+BA treatments, respectively. In the fertilised plots the NAARs were less than the potential NAAR calculated from nitrification and uptake or leaching loss of nitrate (8-17 kmol/(ha.year)), possibly because the 0-0.2 m depth layer of the BP zone was not representative of the whole field.

In Trial 129, pH and the effects of fertilisers on pH differed markedly between management zones (Table 1). Without fertiliser addition, pH was lowest in the WC, which had 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 0-0.05 m layer due to fertiliser addition was least (0.52 units) when fertiliser was applied in the WC and greatest (1.17 units) when fertiliser 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 pHBC. Soil pHBC did indeed differ between zones (Figure 3), in relation to their organic matter contents (Figure 4). The greatest decline in pH occurred in the FP and BP zones, despite them having high organic matter contents and pHBC. 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 fertiliser addition in Trial 129 was accompanied by large decreases in exchangeable cation contents, especially Ca (Table 1). Addition of EFB (without fertiliser) resulted in an increase in pH, CEC and exchangeable Mg and K, but a decrease in exchangeable Ca (Table 1).

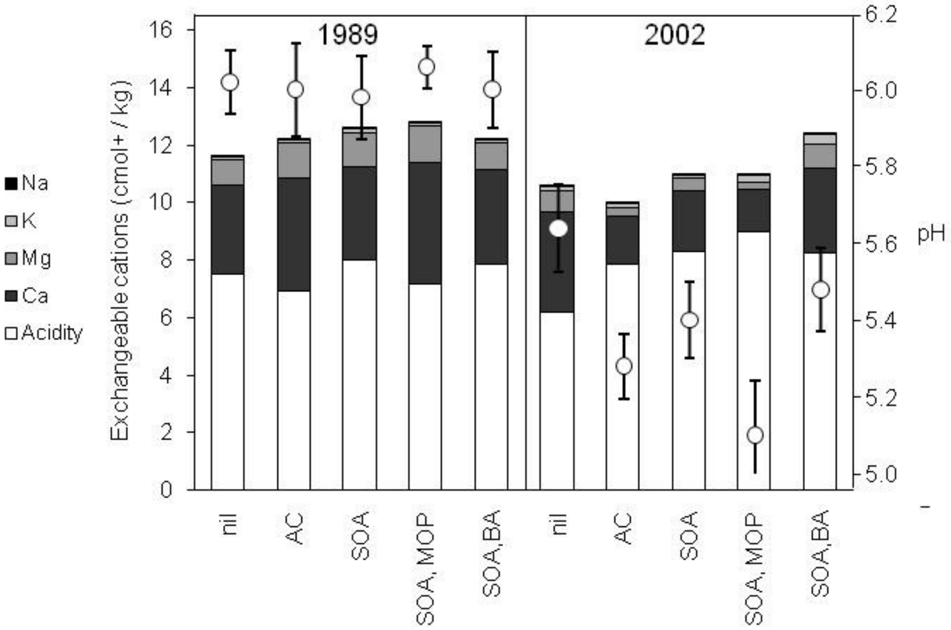

Figure 2. Mean exchangeable cation content (bars) and mean pH$_{water}$ (circles ±s.d.) of soil in the BP zone of Trial 309 (0-0.2 m depth). Order of cations in the bar graph is the same as in the legend.

Table 1. Effect of fertiliser application and placement on soil properties in Trial 129. Values are the mean of 4 replicates.

	0-0.05 m depth				0.05-0.10 m depth			
	WC zone	FP zone	BP (+EFB)	BP (-EFB)	WC zone	FP zone	BP (+EFB)	BP (-EFB)
pH$_{water}$ (- fert.)	5.52	5.98	6.01	5.82	5.74	6.01	6.45	5.92
pH$_{water}$ (+ fert.)	5.00	4.81	5.26		5.08	4.98	5.46	
Org. C (-fert.), %	3.9	10.4	11.4	4.0	2.7	4.9	5.1	3.1
Org. C (+fert.), %	3.3	9.3	14.4		2.6	5.1	6.1	
CEC (- fert.), cmol+/kg	6.5	28.4	26.5	10.1	5.7	16.5	18.5	7.6
CEC (+ fert.) , cmol+/kg	2.9	10.1	22.8		2.1	6.0	13.6	
Ex. Ca (- fert.), cmol+/kg	24.8	27.8	28.2	36.1	20.2	26.3	25.2	33.5
Ex. Ca (+ fert.), cmol+/kg	2.2	8.0	19.0		1.8	4.4	9.9	
Ex. Mg (- fert.), cmol+/kg	0.71	4.07	4.52	1.40	0.55	2.33	4.18	1.10
Ex. Mg (+ fert.), cmol+/kg	0.44	3.50	9.84		0.38	1.69	5.99	
Ex. K (- fert.), cmol+/kg	0.42	1.28	0.72	0.56	0.42	1.31	1.50	0.56
Ex. K (+ fert.), cmol+/kg	0.29	0.80	0.85		0.24	0.53	0.70	

Discussion

It is difficult to accurately assess acidification of soil under oil palm, due to the large spatial variability in throughfall, water uptake, fertiliser 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). The NAARs that we measured over a 13-year time period were quite low compared to the values calculated for various tropical agricultural systems by Moody and Aitken (1997). That difference could be due to several factors. Firstly, NAAR was calculated for the 0-0.2 m layer only. Deeper in the profile there were also differences in soil pH between treatments (results not reported here), but the deeper analyses were carried out in 2002 only, so could not be used to calculate NAAR. Secondly, it is possible that NAAR is lower under oil palm than other crops, due to the large net primary productivity and high rates of recycling of organic matter. Thirdly, it is possible that the measurements made in the BP zone did not properly account for NAAR over the whole field, due to localised acidification in certain places. Certainly, acidification rates, as determined in the 6-year old trial, were highly variable spatially.

The relatively low acidification rate in the WC is likely to result from low losses of nitrate by leaching in that zone. Nitrate loss is a function of deep drainage loss, which is likely to be low in the WC due to low throughfall and high uptake in this zone. In contrast, the FP and BP zones have higher throughfall and lower uptake (Banabas *et al*. 2008a; Nelson *et al*. 2006). In addition, differences in acidification rates between zones would have been influenced by differences in the area over which fertiliser was spread.

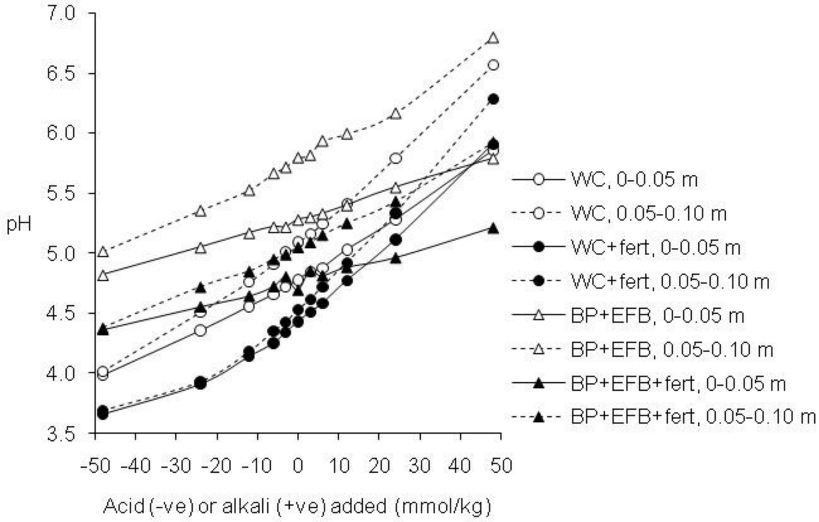

Figure 3. pH buffering titration curves of soil from selected zones in Trial 129.

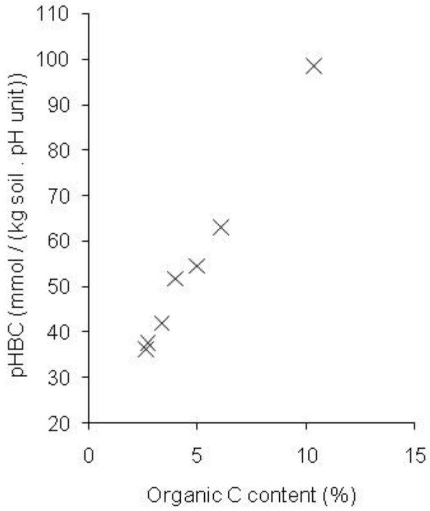

Figure 4. pHBC as a function of organic C content (Trial 129).

Conclusions

Under oil palm, there was significant acidification of volcanic ash soil with time, with or without fertiliser application, despite the soil's relatively high CEC and organic matter content. Addition of ammonium-based fertilisers significantly accelerated pH decline, with combined addition of MOP enhancing the decline. The effect of fertiliser addition on acidification was spatially variable, being greatest when fertiliser was applied in the FP and BP zones, probably due to a high proportion of the N being lost by leaching in those zones.

Acknowledgments

This work was funded by PNG Oil Palm Research Association and the Australian Centre for International Agricultural Research (SMCN-2000-046).

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