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Evaluation of Soil Ameliorants on Immature and Mature Oil Palms in Acidic Peat

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Although peat soil has a low pH range of 3.2 to 3.8 units, it remains unclear whether this is a major constraint to oil palm cultivation, as the cultivar is known to tolerate fairly high levels of acidity without any serious adverse effects. Earlier work on liming and acidity correction has often given conflicting and sometimes, even negative results. In view of the latter, two trials were established to evaluate a number of soil ameliorants and their impact if any, on the growth and yield of newly planted and young mature palms in deep acidic peat. This paper summarises results over a 7- year evaluation period.

Of the four ameliorants evaluated on newly planted seedlings in trial no.1, limestone dust (LSD) was the most effective in correcting acidity, raising the soil pH from 3.6 to 5.4 - 6.1 units in the top 30 cm of soil. Despite the significant improvement in soil pH, no advantage in nutrient uptake, palm growth and fresh fruit bunch (FFB) yield was recorded over unlimed control plots. In contrast, oil palm bunch ash (BA), eucalyptus fly ash (EFA) and paddy husk ash (PHA) had a smaller impact on soil acidity, but increased FFB yield from 2 per cent to 9 per cent, of which BA was the most effective, especially at the higher rate of application (9.0 kg/palm/year).

One negative aspect of acidity amelioration is its impact on peat subsidence. Being highly caustic, application of LSD and BA accelerated decomposition and mineralisation of the peat, increasing subsidence rates by as much as 1.0 cm per annum.

In trial no.2 which evaluated two potash sources [muriate of potash (MOP) and BA] on young mature palms, only annual applications of BA significantly improved soil pH, requiring up to 9.0 kg per palm per year to improve and maintain top soil pH above 5.0 units. BA was also superior to MOP in improving soil fertility, particularly the levels of exchangeable potassium, calcium and magnesium and also significantly reduced the concentration of free aluminium ions and aluminium saturation to low or negligible levels. Although BA ameliorated soil acidity and significantly improved soil fertility, no significant differences in FFB yield were recorded between BA and MOP. With MOP, response to fertiliser inputs was linear, highest yield being achieved with 6.0 kg per palm per year. In contrast, no significant differences were recorded between the different BA rates applied, with 4.50 kg per palm per year producing the same yield response as the highest rate of 11.25 kg per palm per year. For peat soil, BA appeared to be the more efficient K source, as it could attain the same yield as MOP, but at lower K inputs.

As peat is reported to be very deficient in silica, it is suspected that any positive responses elicited by application of ash products (which have high silica content) could be a response to silica rather than correction in soil acidity. However, as no soil, foliar and product analysis was carried out for silica content in both trials, the latter will remain a hypothesis until proven otherwise. Trials are currently underway to evaluate the impact of silica on oil palm growth and yield in peat soils.

Keywords*: Acidity, bunch ash, oil palm, peat, soil amelioration.*

Due to its inherent physical and chemical properties, planting and cultivation of oil palm in peat soil greater than 3 m in depth, is difficult and costly. Limiting factors that have been cited by numerous researchers include low bulk density, high porosity, poor anchorage, rapid soil subsidence, leaning and lodging-over of palms, fluctuating water tables, high carbon to nitrogen ratios, low nutrient fertility and high acidity (Gurmit, 1987, 1999; Dolmat *et al*., 1996; Hasnol *et al*., 2005; Lim, 2006; Melling *et al*., 2011).

Although peat has a low pH range of 3.2 to 3.8 units, it remains unclear whether this is a major constraint, as oil palm is known to tolerate fairly high levels of acidity without any serious adverse effects. It is only under hyper-acidic conditions such as those found in acid sulphate soils where pH can drop below 3.0 units, are both palm growth and yield affected significantly (Poon & Bloomfield, 1977; Xavier *et al*., 2008). Nevertheless, as a precautionary measure, many plantation companies apply between 2-3 kg per palm of limestone dust (LSD) or ground magnesium limestone (GML) during the first 2 to 3 years of planting to correct soil acidity and to promote better rooting and growth of the palms and establishment of legume cover crops (Gurmit, 1999; Hasnol *et al*., 2005). Liming or soil amelioration is seldom done in mature palms, as the benefits of the latter practice remains unclear, with a number of trials giving contradictory and inconsistent results (Chang & Chan, 1982; Dolmat *et al*., 1996; Hasnol *et al*., 2005; Xavier *et al*., 2008).

To confirm the benefits (if any) of ameliorating peat soil acidity, two trials were established to evaluate the efficacy of several soil ameliorants on newly planted palms and young mature palms. This paper summarises the results of the latter two trials over a 7- year period.

METHODOLOGY

Both trials were established on a 2006 replant in deep peat (Typic Haplosaprists*)*, greater than 3.0 m depth in Labuhan Batu district, North Sumatra province, Indonesia. Land clearing, planting and maintenance were as per Asian Agri's standard operating procedures, which utilises the zero-burning land preparation technique and the concept of best management practices (BMP) for oil palm cultivation. In this particular case, no compaction of the peat was carried out, although all seedlings were planted out using the "hole-in-hole" method to minimise the impact of peat subsidence. All seedlings (Topaz D x P) were planted at a spacing of 8.80 m x 7.62 m, giving a density of 150 palms per hectare. In both trials, a randomised complete block design with three replications was used. Each treatment plot consisted of 64 (8 x 8) palms with the inner 16 (4 x 4) palms serving as the assessment core. The latter was bordered on each side by a pair of guard row palms to minimise fertiliser poaching.

Trial no.1 was established at the time of replanting (2006) and evaluates four ameliorants for their efficacy in improving soil pH and its subsequent impact on palm growth and yield. The four ameliorants comprised of LSD, oil palm bunch ash (BA), eucalyptus fly ash (EFA) and paddy husk ash (PHA). Details of the ameliorants and the rates applied over the 7-year period are summarised in *Appendices 1* and *2*. Each ameliorant was applied at two rates in conjunction with two rates of muriate of potash (MOP) fertiliser. There were also two control treatments without any ameliorants. All treatments also received standard rates of other macro and micro nutrient fertilisers (*Appendix 1*). All ameliorants and standard fertilisers were uniformly broadcast in the palm circles, commencing 15 cm from the seedling bole to edge of the weeded circle (maximum 2.0 m radius). Total dosage of each ameliorant was split equally and applied in two applications per annum. To monitor the impact of the ameliorants on soil fertility, palm nutrient status and palm growth, soil sampling (0 - 15 cm, 15 - 30 cm depth), foliar sampling and vegetative growth measurements were carried out prior to application of ameliorants (pre-treatment) and at 12-monthly intervals thereafter (post treatment). In addition, subsidence poles were installed in weeded circles at a density of two palms per plot, to monitor the effect of fertiliser and ameliorant application on the rate of peat subsidence. Harvesting commenced 30 months after field planting and recording of fresh fruit bunches (FFB) harvested was made at 10-day intervals.

Trial no.2 was established when the replant was 4 years old (2010) and evaluated two potash fertilisers (MOP and BA) applied at five levels of potassium (K). Details of trial treatments, standard fertilisers applied and frequency of application are given in *Appendix 3.* As in trial no.1, all fertilisers were uniformly broadcast over the weeded palm circles, commencing 30 cm from palm bole to the edge of the weeded circle (maximum 2.0 m radius). All parameters were assessed and their frequency of assessment were as for trial no.1. However, no annual growth measurements were carried out for trial no.2.

RESULTS AND DISCUSSION

Trial no. 1

The impact of applying soil ameliorants on soil fertility over a 7-year period is summarised in *Tables 1* and *2*. Of the four ameliorants evaluated, only LSD, BA and EFA significantly reduced soil acidity at both depths. PHA had no positive effect on soil pH. LSD was the most effective ameliorant raising soil pH from 3.7 to over 6.0 units in the top soil (0 - 15 cm). No significant differences in efficacy were recorded between the two rates. They were both equally effective. BA was better than EFA, but could only raise top soil pH to above 5.0 units with the higher rate. Although application of EFA could also raise soil pH by 0.7 to 1.0 unit, soil pH remained below 4.5 units. For all three ameliorants, correction of soil pH was stronger in the top soil compared to the lower depth (15 - 30 cm), indicating a slower and limited movement of the ameliorant down the soil profile. A strong correlation was also observed between improvement in soil pH and the reduction in free aluminium (Al) ions and levels of Al saturation. As both LSD and BA increased soil pH to above 5.0 units, the level of free Al ions and Al saturation declined to negligible levels, as free Al ions are rendered less soluble through precipitation reactions, at higher pH (Tisdale *et al*., 1985).

Application of the latter three ameliorants also resulted in significant changes in peat fertility levels (*Tables 1&2*). Although no differences in exchangeable K was recorded between the MOP control treatment and BA, as expected, due to its high calcium content (> 50 per cent), LSD increased soil Ca levels by more than 40 fold at both soil depths, followed by BA and EFA. All three ameliorants also significantly increased soil exchangeable Mg, whilst BA and EFA also increased available phosphate (P), manganese (Mn), zinc (Zn) and iron (Fe) levels. The increase in soil macro and micro nutrient levels can be partly attributed to the nutrient content of the ameliorants and partly to accelerated decomposition of the peat, due to the caustic nature of the latter three products. Only PHA had no positive effect on raising soil fertility in view of its low nutrient content (Hashim *et al.,* 1996).

Although application of LSD, BA and EFA significantly raised soil Ca, Mg, P and Fe levels, foliar levels of treated palms were not significantly different from those of control palms in all macro and micro nutrients assessed (*Table 3*). The commonly reported antagonism between Ca and K was not observed in this trial, probably because K inputs were adequate.

TABLE 1
EFFECT OF SOIL AMELIORANTS ON SOIL CHEMICAL PROPERTIES[1] AT 0-15 CM SOIL DEPTH (TRIAL NO.1)

Soil ameliorants	pH (Units)				Exchangeable cations (meq/100 g soil) K				Ca				Mg				H				Al			
	L1		L2		L1		L2		L1		L2		L1		L2		L1		L2		L1		L2	
	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m
MOP	4.1	3.9	3.6	3.9	0.46	5.77	0.32	6.48	9.76	2.75	7.56	1.85	7.76	0.36	5.95	0.25	1.13	2.95	1.80	3.32	0.07	0.44	0.13	0.38
LSD*	3.7	6.1	3.7	6.0	0.30	4.38	0.24	3.68	11.49	56.30	9.86	54.07	7.10	1.45	5.65	1.57	1.03	0.28	0.98	0.26	0.04	T	0.04	T
BA	4.0	4.6	3.8	5.0	0.33	5.48	0.32	7.86	13.47	10.43	12.42	14.63	5.41	5.40	6.09	10.56	0.84	0.74	0.84	0.50	0.02	T	0.05	T
EFA	3.6	4.3	3.5	4.5	0.36	5.52	0.42	5.72	8.27	7.81	7.76	8.18	5.27	1.19	5.68	1.42	1.17	0.95	1.40	0.75	0.31	0.91	0.14	0.98
PHA	3.9	4.0	3.8	4.0	0.42	6.52	0.40	6.43	16.66	2.38	10.70	1.38	6.27	0.31	5.72	0.31	1.61	2.96	1.26	3.30	0.18	0.50	0.06	0.70
LSD 5%	0.5	0.3	0.5	0.3	0.17	1.34	0.17	1.34	10.68	2.98	10.68	2.98	3.69	2.23	3.69	2.23	0.93	0.68	0.93	0.68	0.18	0.34	0.18	0.34

Soil ameliorants	Al saturation (%)				Avail.P (Bray 2) (ppm)			
	L1		L2		L1		L2	
	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m
MOP	0.4	3.6	0.8	3.1	140	75	103	105
LSD*	0.2	0	0.2	0	180	90	138	61
BA	0.1	0	0.3	0	219	119	207	186
EFA	2.0	5.6	0.9	5.7	121	353	159	425
PHA	0.7	1.3	0.3	5.8	294	81	153	17
LSD 5%	-	-	-	-	152	42	152	42

Soil ameliorants	Extractable micro-nutrients (in 25% HCl) B (mg/kg)				Mn (mg/kg)				Zn (mg/kg)				Cu (mg/kg)				Fe (mg/kg)			
	L1		L2		L1		L2		L1		L2		L1		L2		L1		L2	
	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m
MOP	4	15	5.0	14	46	25	33	22	8	117	7.0	82	4	170	2.0	168	967	1 783	633	1 451
LSD*	5	15	4	14	51	115	58	123	8	190	8	126	2	330	2	197	900	2 016	867	1 915
BA	4	15	4	16	101	150	66	192	16	158	10	231	3	175	3	131	1 367	1 698	1 067	1 913
EFA	5	13	5	12	55	129	56	189	8	121	9	119	2	158	2	245	900	3 238	967	4 289
PHA	4	11	5	12	134	39	65	34	13	90	10	72	3	201	3	136	1 533	1 506	833	1 569
LSD 5%	2	3	2	3	34	50	34	50	8	79	8	79	1	141	1	141	658	599	658	599

[1] At 0 month and 84 months after commencement of differential treatments
L1 and L2 = Level of soil ameliorants and MOP applied
T- trace, MOP - muriate of potash, LSD* - limestone dust, BA - bunch ash, EFA - eucalyptus fly ash, PHA - paddy husk ash

TABLE 2
EFFECT OF SOIL AMELIORANTS ON SOIL CHEMICAL PROPERTIES[1] AT 15-30 CM SOIL DEPTH (TRIAL NO.1)

Soil ameliorants	pH (Units)				Exchangeable cations (meq/100 g soil)																			
					K				Ca				Mg				H				Al			
	L1		L2		L1		L2		L1		L2		L1		L2		L1		L2		L1		L2	
	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m
MOP	3.7	3.7	3.6	3.7	0.34	4.36	0.33	5.36	6.30	2.31	6.92	1.59	6.42	0.34	5.10	0.25	1.76	3.22	2.49	3.62	0.13	0.60	0.21	0.53
LSD*	3.6	5.4	3.7	5.4	0.29	4.21	0.31	3.87	7.40	45.09	8.51	50.73	5.89	1.32	5.64	1.66	1.58	0.29	1.21	0.33	0.07	0.06	0.09	0.06
BA	3.8	4.2	3.6	4.5	0.39	4.36	0.32	6.05	9.54	7.98	7.87	8.43	5.12	4.15	4.86	5.91	1.39	1.04	1.63	0.79	0.04	0.12	0.17	0.08
EFA	3.6	4.2	3.5	4.1	0.36	5.18	0.43	5.11	8.92	6.85	4.98	6.04	5.88	1.16	4.35	1.11	1.44	1.06	2.37	1.23	0.10	0.75	0.26	1.21
PHA	3.6	3.8	3.6	3.8	0.40	5.87	0.42	5.36	7.27	2.41	8.08	1.35	4.88	0.38	5.37	0.29	1.37	3.06	1.30	3.20	0.13	0.46	0.08	0.57
LSD 5%	0.3	0.3	0.3	0.3	0.21	1.06	0.21	1.06	4.90	5.33	4.90	5.33	3.91	1.13	3.91	1.13	1.16	0.71	1.16	0.71	0.16	0.42	0.16	0.42

Soil ameliorants	Al saturation (%)				Avail.P (Bray 2) (ppm)			
	L1		L2		L1		L2	
	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m
MOP	0.9	5.6	1.4	4.5	103.0	37.2	88.3	66.1
LSD*	0.5	0.1	0.6	0.1	108.3	103.6	109.7	82.3
BA	0.2	0.7	1.1	0.4	169.2	155.0	104.0	246.9
EFA	0.6	5.0	2.1	8.2	107.3	355.9	84.3	364.0
PHA	0.9	3.8	0.5	5.3	124.7	78.6	116.7	23.1
LSD 5%	-	-	-	-	85	78	85	78

Soil ameliorants	Extractable micro-nutrients (in 25% HCl)																			
	B (mg/kg)				Mn (mg/kg)				Zn (mg/kg)				Cu (mg/kg)				Fe (mg/kg)			
	L1		L2		L1		L2		L1		L2		L1		L2		L1		L2	
	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m	0 m	84 m
MOP	4.37	17.84	3.06	16.02	26.3	20.77	16.3	19.10	5.56	92.1	3.53	72.7	2.10	122.0	1.86	119.6	667	1 458.6	433	1 156.5
LSD*	4.39	17.21	4.26	15.83	23.1	92.18	70.1	83.99	5.11	157.8	10.08	90.5	1.87	183.9	1.92	156.6	500	1 523.6	1 100	1 469.4
BA	4.13	14.68	3.83	16.71	51.7	95.04	31.1	101.59	8.15	118.0	4.88	151.0	2.28	130.1	2.30	87.1	867	1 371.0	633	1 376.7
EFA	4.76	14.88	2.11	13.67	33.6	111.56	26.2	114.68	7.45	110.1	4.60	91.7	2.73	130.0	2.01	152.7	633	2 680.4	700	2 854.8
PHA	4.50	12.29	3.83	10.39	45.2	43.70	35.6	30.04	6.98	95.2	7.28	64.0	2.31	169.4	2.56	94.6	667	1 508.6	700	1 354.4
LSD 5%	1.55	3.51	1.55	3.51	42.8	40.90	42.8	40.90	4.39	63.4	4.93	63.4	2.50	94.4	2.50	94.4	488	334.8	488	334.8

[1] At 0 month and 84 months after commencement of differential treatments
L1 and L2 = Level of soil ameliorants and MOP applied
MOP - muriate of potash, LSD* - limestone dust, BA - bunch ash, EFA - eucalyptus fly ash, PHA - paddy husk ash

In general, all macro and micro nutrient levels were at sufficient levels for palms of this age group (Sidhu *et al*., 2004).

Despite the significant improvement in soil acidity and fertility, application of LSD did not significantly improve growth of oil palm seedlings (*Table 4*) nor their early yields (*Table 5*). Although not statistically significant, the remaining three ameliorants increased annual FFB yield by 2 per cent to 9 per cent, of which BA was the most effective, when applied at the higher level. The positive responses elicited by BA, EFA and PHA is likely to be due to factors other than correction of soil acidity. Being predominantly organic, peat has very low levels of silica (Goh, 2014). Due to its high silica content, application of paddy husk ash has been found to significantly increase rice yields and is now a practice that is commonly adopted in many rice growing nations in Asia (Hashim *et al*., 1996). It is suspected that it is the silica content in BA (and other ash ameliorants) that induces an increase in yield in oil palm rather than the correction in soil acidity. However, as no soil, foliar and product content analysis for silica was carried out during the duration of the trial, the latter will remain a hypothesis until proven otherwise. In addition, there has been no published data to date on the impact of silica application on oil palm yields, although trials are underway. In earlier trials exploring the need for liming and soil acidity correction in peat, Chang and Chan (1982) observed that magnesium limestone application lowered oil palm FFB yield through depression of palm K leaf status. Dolmat *et al.* (1996) also found that liming suppressed oil palm yield especially in the early years of cropping and suggested it was due to the overriding influence of Ca - K antagonism and had masked positive effects of lime, if any. Xavier and Gurmit (1999) reported that liming in excess of 2.0 kg per palm per year was not advantageous and could cause reduction in yield, bunch number and foliar contents of P and Mg. They also suggested that where BA is used routinely, lime applications can be reduced or even omitted, as over liming could adversely affect K uptake as well as availability of micronutrients.

Although the subsidence of peat is dependent on a number of factors primarily fluctuating water levels (Gurmit, 1999; Lim, 2005), results from the current trial indicate that acidity amelioration could also have a negative impact on peat subsidence. Being highly caustic, application of LSD and BA over a 7-year period, accelerated the decomposition and mineralisation of peat, resulting in an increased subsidence rate of 0.4 cm to 1.0 cm per annum respectively, the effect being greater at the higher dosage (*Table 6*). The latter increase could be significant, considering that the annual subsidence rate of mature peat varies from only 2.0 - 3.0 cm per annum (Lim, 2005).

Trial no.2

The impact of applying MOP and BA on soil fertility also over a 7-year period is summarised in *Table 7*. Of the two K sources, only annual applications of the ameliorant BA significantly improved soil pH. MOP application appeared neutral, having no effect on soil acidity. Although all rates of BA reduced soil acidity, it required up to 9.0 kg per palm per year to improve and maintain soil pH above 5.0 units in the top 15 cm of soil. At lower depths (15 – 30 cm), the ameliorating effect of BA was less, with pH not improving beyond 4.4 units, even with the highest application rate of 11.25 kg per palm per year.

Both sources of K fertiliser significantly improved soil exchangeable K. The improve-

TABLE 3

EFFECT OF SOIL AMELIORANTS ON OIL PALM LEAF NUTRIENT LEVELS (TRIAL NO.1)

Soil ameliorants	Leaf nutrient levels (% on dry matter)																													
	N						P						K						Ca						Mg					
	L1			L2			L1			L2			L1			L2			L1			L2			L1			L2		
	P1*	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
MOP	2.79	2.49	2.61	2.85	2.47	2.65	0.232	0.168	0.180	0.250	0.168	0.179	1.58	0.80	1.00	1.67	0.85	1.09	0.40	0.81	0.66	0.41	0.82	0.67	0.35	0.46	0.36	0.34	0.46	0.34
LSD*	2.80	2.51	2.71	2.84	2.49	2.66	0.213	0.164	0.174	0.222	0.162	0.178	1.50	0.85	1.07	1.63	0.81	1.07	0.48	0.91	0.71	0.49	0.98	0.75	0.35	0.41	0.31	0.34	0.43	0.32
BA	2.86	2.42	2.65	2.82	2.49	2.64	0.222	0.168	0.187	0.218	0.172	0.194	1.62	0.88	1.09	1.61	1.03	1.15	0.42	0.81	0.76	0.39	0.69	0.69	0.34	0.42	0.35	0.34	0.40	0.33
EFA	2.84	2.53	2.63	2.79	2.42	2.68	0.217	0.168	0.183	0.220	0.163	0.184	1.51	0.85	1.06	1.58	0.90	1.12	0.45	0.78	0.67	0.42	0.81	0.64	0.38	0.42	0.34	0.35	0.42	0.33
PHA	2.91	2.59	2.75	2.82	2.56	2.60	0.248	0.172	0.186	0.243	0.172	0.183	1.65	0.87	1.06	1.63	0.90	1.13	0.42	0.85	0.69	0.42	0.83	0.67	0.37	0.45	0.36	0.34	0.43	0.32
LSD 5%	0.22	0.23	0.14	0.22	0.23	0.14	0.025	0.013	0.030	0.025	0.013	0.030	0.14	0.11	0.15	0.14	0.11	0.15	0.09	0.13	0.11	0.09	0.13	0.11	0.05	0.54	0.05	0.05	0.54	0.05

Soil ameliorants	Leaf nutrient levels (ppm on dry matter)																							
	B						Cu						Zn						Fe					
	L1			L2			L1			L2			L1			L2			L1			L2		
	P1*	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
MOP	12	16	17	12	18	17	5	4	3	5	4	3	15	11	15	15	11	14	68	69	76	65	64	82
LSD*	12	15	16	12	17	17	5	5	4	3	4	3	15	12	15	16	11	14	69	68	71	60	62	75
BA	12	17	17	13	17	17	6	4	4	6	5	3	15	12	15	14	12	13	63	61	75	63	60	71
EFA	11	16	17	12	17	18	6	5	4	6	4	4	14	12	14	14	11	14	68	62	73	67	63	71
PHA	12	18	18	12	17	18	4	3	3	5	4	3	14	11	14	15	11	14	65	62	75	66	64	72
LSD 5%	2	3	3	2	3	3	2	1	1	2	1	1	1	1	2	1	1	2	11	9	13	11	9	13

* P1 = Average of 6 and 12 months analysis (frond 3)
P2 = Average of 18 and 24 months analysis (frond 9)
P3 = Average of 36, 48, 60, 72 and 84 months analysis (frond 17)
L1 and L2 = Level of soil ameliorants and MOP applied
MOP - muriate of potash, LSD* - limestone dust, BA - bunch ash, EFA - eucalyptus fly ash, PHA - paddy husk ash

TABLE 4
EFFECT OF SOIL AMELIORANTS ON OIL PALM GROWTH ANNUAL INCREMENT[1] (TRIAL NO.1)

Soil ameliorant	*Annual growth increment*					
	Frond length (m)		*Frond dry weight (kg)*		*Petiole CSA (cm^2)*	
	L1	*L2*	*L1*	*L2*	*L1*	*L2*
MOP	0.31	0.32	0.22	0.23	2.04	2.24
LSD*	0.33	0.30	0.26	0.26	2.54	2.50
BA	0.31	0.27	0.22	0.24	2.13	2.36
EFA	0.31	0.31	0.24	0.27	2.37	2.65
PHA	0.28	0.30	0.19	0.22	1.88	2.11
LSD 5%	0.06		0.09		0.46	

[1] Average annual growth increment from 36 to 84 months
L1 & L2 = Level of soil ameliorants and MOP applied
CSA - cross section area, MOP - muriate of potash, LSD* - limestone dust, BA - bunch ash, EFA - eucalyptus fly ash, PHA - paddy husk ash

ment was linear with rate applied and occurred at both soil depths. Irrespective of soil depth, BA was superior to MOP, for each equivalent rate applied. In addition, BA also significantly improved soil exchangeable magnesium and calcium despite K being antagonistic to both latter nutrients and cation displacement at exchange sites is known to occur (Tisdale *et al*., 1985). As in trial no.1, the improvement in Mg and Ca concentration can be attributed to BA being a valuable source of the latter two cations and through accelerated decomposition of the peat, as BA is highly caustic (pH > 10). Likewise, an improvement in soil acidity brought about by BA application also significantly reduced the concentration of free Al ions and Al saturation to negligible levels in the top 15 cm of soil and to a lesser extent at the lower depth. MOP on the other hand, had no effect on soil acidity and minimal impact on reducing free Al ion concentration and Al saturation (*Table 7*).

Both MOP and BA applications significantly improved palm leaf K levels, the effect being linear with the applied dosage. However, no significant differences were recorded between the two potash sources (*Table 8*). No positive or negative correlations were obtained with leaf N, P and Ca but as expected, both K fertilisers depressed leaf Mg and boron (B) levels, the effect being more consistent and linear with increasing MOP fertiliser rate.

On average, both potash fertilisers improved FFB yields by 2.0 tonnes per hectare per year (8 per cent). Despite the considerable improvement in soil acidity by BA, no significant differences were recorded between BA and MOP. With MOP, response to fertiliser inputs was linear, highest yield being achieved with 6.0 kg per palm per year and no advantage was gained with any further increase in MOP fertiliser rate (*Table 9*). In contrast, no significant differences were recorded between the different BA rates applied, with 4.50 kg per palm per year producing the same yield response as the highest rate of 11.25 kg per palm per year. For both potash fertilisers, improvement in FFB yield was achieved through an improvement in

TABLE 5
EFFECT OF SOIL AMELIORANT APPLICATION ON OIL PALM YIELD PARAMETERS

Treatments	L 1						L 2					
	Year 1	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Average*	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Average*
Yield/ha (t FFB)												
MOP	14.5	25.4	31.0	23.0	28.5	24.5 (100)	15.4	25.1	28.4	23.1	29.6	24.3 (99)
LSD*	15.0	26.1	30.4	22.4	29.5	24.7 (101)	26.2	26.2	30.4	23.4	29.2	24.8 (101)
BA	17.4	27.8	32.0	22.9	29.0	25.8 (106)	26.8	26.8	25.0	25.0	31.6	26.6 (109)
EFA	15.0	25.1	31.1	24.3	32.6	25.6 (105)	26.8	26.8	22.7	22.7	30.5	25.8 (105)
PHA	16.2	27.1	32.8	23.0	28.1	25.0 (102)	27.7	27.7	25.4	25.4	31.7	26.1 (107)
LSD 5%	4.3	5.1	3.9	3.7	5.1	3.1	4.3	5.1	3.9	3.7	5.1	3.1
Number of bunches/palm/year												
MOP	16.3	25.6	22.2	17.3	16.8	19.6 (100)	17.1	26.0	21.2	18.1	18.1	20.1 (103)
LSD*	18.2	28.1	22.6	17.8	18.3	21.0 (107)	16.7	26.3	22.2	18.0	18.0	20.2 (103)
BA	18.6	26.9	22.1	17.0	16.3	20.2 (103)	19.9	27.5	23.1	18.8	18.3	21.5 (110)
EFA	16.8	26.4	21.8	18.6	19.2	20.6 (105)	17.7	25.9	22.2	16.9	17.4	20.2 (103)
PHA	17.9	27.3	23.4	17.6	17.7	20.8 (106)	18.0	27.1	28.3	18.9	18.8	22.2 (113)
LSD 5%	3.1	3.7	2.2	2.4	3.0	2.1	3.1	3.7	2.2	2.4	3.0	2.1
Average bunch weight (kg)												
MOP	5.9	6.5	9.3	8.9	11.3	8.4 (100)	5.9	6.1	8.9	8.5	10.9	8.1 (96)
LSD*	5.5	5.9	8.9	8.4	10.7	7.9 (94)	5.9	6.6	9.2	8.7	10.8	8.2 (98)
BA	6.3	6.7	9.7	8.9	11.9	8.7 (104)	5.9	6.3	9.3	8.9	11.5	8.4 (100)
EFA	5.9	6.1	9.5	8.7	11.3	8.3 (99)	6.1	6.6	9.8	8.9	11.7	8.6 (102)
PHA	6.0	6.4	8.8	8.7	10.6	8.1 (96)	5.9	6.7	7.6	9.0	11.1	8.0 (95)

L 1 and L 2 = Level of soil ameliorants and MOP applied
Figures in parantheses is treatment yield expressed as a percentage of control yield
MOP - muriate of potash, LSD* - limestone dust, BA - bunch ash, EFA - eucalyptus fly ash, PHA - paddy husk ash

TABLE 6
EFFECT OF SOIL AMELIORANT APPLICATION ON PEAT SUBSIDENCE (TRIAL NO.1)

Soil ameliorants	*Peat subsidence rate (cm/year)* L1	L2
MOP	2.1	1.9
LSD	2.5	2.9
BA	3.0	3.1
EFA	2.5	2.3
PHA	2.3	2.2

L 1 and L 2 = Level of soil ameliorant and MOP applied.
MOP - muriate of potash, LSD - limestone dust, BA - bunch ash, EFA - eucalyptus fly ash, PHA - paddy husk ash.

average bunch weight rather than in an increase in bunch number (*Table 10*).

Similar results were recorded by Dolmat *et al.* (1996) in their trial on peat comparing MOP with BA. Although BA improved soil acidity and a positive yield response was obtained by both potash fertilisers over the 7-year evaluation period, no significant differences were recorded between the two fertiliser types. Yield response to MOP was consistent up to the highest level tested (6.0 kg/palm/year) whilst no further advantage in FFB yield was gained beyond the second level (6.4 kg/palm/year) of BA applied. Both these trials indicate that although no significant differences in yield were recorded between MOP and BA, on peat, BA was the more efficient fertiliser as the same yields were achieved by a lower level of K input. In contrast, Hasnol *et al.* (2005) evaluating three potash sources on peat in Sarawak, Malaysia, found BA to be clearly superior to MOP and SOP (sulphate of potash). They recorded a 23 per cent increase in FFB yield, with optimum yield being attained with 8.0 kg BA per palm per year. On the other hand, applications of MOP and SOP only increased yield by 4 per cent to 5 per cent and was statistically not significant. They attributed the better efficacy of BA due to its ability to ameliorate soil acidity, as application of BA had significantly improved soil pH from 4.25 to 4.48 units whilst both MOP and SOP had no effect on soil pH, even at the highest rate of application (Hasnol *et al.*, 2005). Based on the lack of response or a negative response in earlier liming trials, it is likely that the positive response to BA application observed by Hasnol *et al.* (2005) could be due to factors other than improvement in soil acidity which was small (0.23 units). The lack of response of oil palm to improvement in soil acidity was further highlighted by Xavier *et al.* (2008). Despite raising the top soil pH from 3.7 to 5.1 units after ten consecutive years of lime application on acid sulphate soils, no positive effect on yield was recorded. Instead, the limed plots experienced an average yield decline of 5- 8 per cent over the 11-year trial period. They found that liming markedly hindered P and K uptake, causing foliar levels of the latter two nutrients to drop close to or below the deficient thresholds (Xavier *et al.*, 2008).

CONCLUSION

Based on the results of the above two trials and previous trials conducted by other researchers, the following conclusions can be drawn:

i. Oil palm is generally tolerant to acidic soil conditions provided soil pH does not decline below 3.2 units (hyper - acidity). Unlimed plots in both trials achieved FFB yields more than 30 tonnes per hectare despite being established on acidic deep peat (pH: 3.5 - 3.7 units),

TABLE 7
EFFECT OF POTASSIC FERTILISER APPLICATION ON SOIL CHEMICAL PROPERTIES[1] (TRIAL NO.2)

Fertiliser treatments	*pH (units)*	*Exchangeable cations (meq/100 g soil)*					*Al saturation (%)*	*Avail.P (Bray 2) (ppm)*
		K	*Ca*	*Mg*	*Na*	*Al*		
0 - 15 cm soil depth								
Zero potassic fertiliser	3.6	0.26	3.25	0.23	0.07	3.82	50.1	30.4
MOP - 3.00 kg	3.6	1.06	2.54	0.22	0.07	3.21	45.2	187
MOP - 4.50 kg	3.6	1.30	2.67	0.28	0.08	3.50	44.7	214
MOP - 6.00 kg	3.8	1.98	2.29	0.21	0.08	3.45	43.1	153
MOP - 7.50 kg	3.6	2.33	2.07	0.23	0.07	4.16	47.0	292
BA - 4.50 kg	4.1	2.17	6.69	3.53	0.08	1.09	8.1	216
BA - 6.75 kg	4.9	3.60	7.19	4.75	0.08	0.39	0.5	218
BA - 9.00 kg	5.1	4.85	10.40	6.12	0.10	0.25	2.4	198
BA - 11.25 kg	5.6	6.60	11.62	7.22	0.10	0.12	1.2	243
LSD 5%	0.4	1.14	2.21	1.08	0.02	0.71	8.9	8.9
15 - 30 cm soil depth								
Zero potassic fertiliser	3.5	0.31	2.66	0.25	0.09	4.74	58.9	193
MOP - 3.00 kg	3.5	0.95	2.37	0.28	0.08	4.65	55.8	137
MOP - 4.50 kg	3.4	1.20	2.54	0.29	0.09	4.69	53.2	96
MOP - 6.00 kg	3.4	1.61	2.58	0.27	0.11	5.16	53.0	142
MOP - 7.50 kg	3.4	1.60	2.19	0.20	0.10	4.80	54.0	115
BA - 4.50 kg	3.6	1.64	3.46	1.38	0.08	3.19	32.7	218
BA - 6.75 kg	4.2	2.80	4.34	3.09	0.09	2.62	20.2	161
BA - 9.00 kg	4.2	2.78	5.32	3.29	0.10	2.21	16.1	169
BA - 11.25 kg	4.4	3.93	6.38	4.49	0.11	1.17	7.3	209
LSD 5%	0.3	1.33	1.72	1.21	0.02	0.91	10.9	75

[1] At 7 years after commencement of differential fertiliser treatments
MOP = muriate of potash, BA = bunch ash

TABLE 8
EFFECT OF POTASSIC FERTILISER APPLICATION ON LEAF NUTRIENT LEVELS[1] (TRIAL NO.2)

Fertiliser treatments (kg/palm/year)	*Percentage on dry matter (%)*						*ppm on dry matter*		
	N	*P*	*K*	*Mg*	*Ca*	*Cl*	*B*	*Cu*	*Zn*
Zero potassic fertiliser	2.68	0.165	1.00	0.40	0.69	0.50	27	7	17
MOP - 3.00 kg	2.64	0.162	1.04	0.37	0.68	0.49	24	7	16
MOP - 4.50 kg	2.59	0.163	1.11	0.36	0.67	0.54	25	7	17
MOP - 6.00 kg	2.63	0.164	1.13	0.35	0.70	0.54	23	7	16
MOP - 7.50 kg	2.64	0.164	1.12	0.35	0.66	0.56	22	7	16
BA - 4.50 kg	2.67	0.169	1.11	0.37	0.66	0.53	24	7	17
BA - 6.75 kg	2.63	0.166	1.11	0.39	0.65	0.51	27	7	17
BA - 9.00 kg	2.64	0.169	1.14	0.38	0.64	0.51	24	6	16
BA - 11.25 kg	2.68	0.170	1.14	0.38	0.65	0.49	23	7	17
LSD 5%	0.14	0.010	0.11	0.05	0.07	0.06	4	1	2

[1] Average of 7 years
MOP = muriate of potash, BA = bunch ash

ii. Application of LSD for seven consecutive years, successfully raised soil pH from 3.6 to 5.4 - 6.1 units in the top 30 cm of soil. Despite correction of soil acidity, no advantage in nutrient uptake, palm growth and FFB yield was recorded over unlimed plots,
iii. Of the four ameliorants evaluated, oil palm bunch ash appeared to be the most effective. As its impact on soil pH was of lower magnitude than limestone dust, it is likely that the positive response to bunch ash application could be due to factors other than correction of acidity. As deep peat is deficient in silica, it is suspected that the high silica content in ash products could be a contributing factor, and
iv. Although no significant differences were recorded between BA and MOP in both trials, BA appeared to be the more efficient K source for peat soils, as it could attain the same yields as MOP, but at lower K inputs.

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TABLE 9
EFFECT OF POTASSIC FERTILISER APPLICATION ON OIL PALM FFB PRODUCTION (TRIAL NO.2)

Fertiliser level	*Fertiliser type*[1]	*Fertiliser rate kg/palm/year*	*Average yield/ha (tonnes ffb)*									
			PRT[2]	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Year 6*	*Year 7*	*Average*[3]	
Ko	Nil	0	10.2	8.7	19.5	26.6	25.9	24.4	24.2	27.5	22.4	(100)[4]
K^1	MOP	3.00	10.2	8.0	24.3	25.7	28.6	25.6	24.5	29.0	23.7	(106)
K^2	MOP	4.50	10.3	9.2	22.3	28.6	30.2	26.6	25.1	27.0	24.1	(108)
K^3	MOP	6.00	10.7	10.2	24.8	31.1	33.0	25.6	26.4	29.4	25.8	(115)
K^4	MOP	7.50	11.5	9.0	22.4	32.1	27.7	30.3	26.2	29.7	25.3	(113)
Average	MOP	-	10.7	9.1	23.5	29.4	29.9	27.0	25.6	28.8	24.7	(110)
K^1	BA	4.50	10.7	8.9	21.0	28.3	28.3	27.8	27.0	30.0	24.5	(109)
K^2	BA	6.75	10.9	9.4	19.3	29.0	28.8	26.6	27.6	29.3	24.3	(109)
K^3	BA	9.00	10.2	7.7	19.6	29.2	27.0	31.0	23.3	31.8	24.2	(108)
K^4	BA	11.25	11.7	9.2	23.2	28.2	28.2	26.0	28.5	27.0	24.3	(109)
Average	BA		10.9	8.8	20.8	28.7	28.1	27.8	26.6	29.5	24.3	(109)
LSD 5%			2.8	2.9	4.3	3.7	4.9	4.5	5.5	6.4	3.1	

[1] MOP = muriate of potash, BA = bunch ash
[2] Pre-treatment yield
[3] 7 years post treatment yield average
[4] Figures in parentheses is treatment yield expressed as a percentage of control yield

TABLE 10
EFFECT OF POTASSIC FERTILISER APPLICATION ON OIL PALM FFB YIELD COMPONENTS
(TRIAL NO.2)

Fertiliser level	*Fertiliser type*[1]	*Fertiliser rate (kg/palm/year)*	*Average bunch number/palm/year*								
			PRT[2]	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Year 6*	*Year 7*	*Average*[3]
Ko	Nil	0	20.0	13.5	16.1	21.0	13.4	13.9	9.7	10.8	14.1 (100)
K^1	MOP	3.00	19.5	12.7	17.4	18.9	14.5	12.6	9.6	11.7	13.9 (99)
K^2	MOP	4.50	18.9	12.5	14.9	19.3	14.1	12.9	9.6	10.8	13.4 (95)
K^3	MOP	6.00	19.2	14.5	18.8	22.2	17.6	13.2	10.6	11.4	15.5 (110)
K^4	MOP	7.50	20.6	13.7	15.2	21.2	14.8	14.6	10.6	12.3	14.6 (104)
Average	MOP	-	19.6	13.4	16.6	20.4	15.3	13.3	10.1	11.6	14.4 (102)
K^1	BA	4.50	20.2	15.0	16.3	20.8	14.6	13.1	11.0	12.0	14.7 (104)
K^2	BA	6.75	19.1	13.7	14.7	19.9	15.5	13.3	10.5	12.1	14.2 (101)
K^3	BA	9.00	21.1	12.7	13.5	20.2	14.2	14.9	10.3	11.9	14.0 (99)
K^4	BA	11.25	20.9	13.4	17.4	20.7	14.6	12.1	11.2	11.2	14.4 (102)
Average	BA	-	20.3	13.7	15.5	20.4	14.7	13.4	10.8	11.8	14.3 (101)
LSD 5%			3.7	3.9	3.7	3.1	2.6	2.6	2.4	2.7	2.1

Fertiliser level	*Fertiliser type*[1]	*Fertiliser rate (kg/palm/year)*	*Average bunch weight (kg)*								
			Year 1	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Year 6*	*Year 7*	*Year 8*	*Average*[3]
Ko	Nil	0	3.4	4.3	8.1	8.5	12.9	11.8	16.7	16.9	10.3 (100)
K^1	MOP	3.00	3.5	4.2	9.2	9.1	13.1	13.4	16.9	16.5	10.9 (106)
K^2	MOP	4.50	3.6	4.9	10.1	9.9	14.3	13.7	17.4	16.3	11.7 (114)
K^3	MOP	6.00	3.7	4.7	8.8	9.4	12.5	13.0	16.6	16.9	10.9 (106)
K^4	MOP	7.50	3.7	4.4	9.9	10.2	12.6	13.8	16.5	16.1	11.2 (109)
Average	MOP	-	3.6	4.6	9.5	9.7	13.1	13.5	16.9	16.5	11.2 (109)
K^1	BA	4.50	3.5	4.0	8.6	9.0	12.9	14.1	16.7	16.6	10.8 (105)
K^2	BA	6.75	3.8	4.6	8.3	9.7	12.4	13.1	17.6	16.6	11.1 (108)
K^3	BA	9.00	3.2	4.0	9.8	9.6	12.7	13.9	15.2	17.5	11.3 (110)
K^4	BA	11.25	3.7	4.6	8.9	9.1	12.9	14.4	16.7	16.4	11.1 (108)
Average	BA	-	3.6	4.3	8.9	9.4	12.7	13.9	16.6	16.8	11.1 (108)
LSD 5%			0.5	0.9	1.6	1.1	2.3	2.0	2.7	2.0	1.0

[1] MOP = muriate of potash, BA = bunch ash
[2] Pre-treatment yield
[3] 7 years post treatment yield average

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APPENDIX 1
DETAILS OF TRIAL TREATMENTS (TRIAL NO.1)

Treatments	*Fertiliser/ ameliorant*	*Application dosage (kg/palm/year)*[1]						
		0-12 m[2]	*13-24 m*	*25-36 m*	*37-48 m*	*49-60 m*	*61-72 m*	*73-84 m*
MOP 1	MOP	1.30	2.00	3.00	4.00	4.00	4.00	4.00
MOP 2	MOP	1.30	2.00	3.00	6.00	6.00	6.00	6.00
LSD 1 + MOP 1	LSD	2.00	3.00	4.50	6.00	6.00	6.00	6.00
LSD 2 + MOP 2	LSD	2.00	3.00	4.50	9.00	9.00	9.00	9.00
BA 1	BA	2.00	3.00	4.50	6.00	6.00	6.00	6.00
BA 2	BA	2.00	3.00	4.50	9.00	9.00	9.00	9.00
EFA 1 + MOP 1	EFA	2.00	3.00	4.50	6.00	6.00	6.00	6.00
EFA 2 + MOP 2	EFA	2.00	3.00	4.50	9.00	9.00	9.00	9.00
PHA 1 + MOP 1	PHA	2.00	3.00	4.50	6.00	6.00	6.00	6.00
PHA 2 + MOP 2	PHA	2.00	3.00	4.50	9.00	9.00	9.00	9.00
Common fertiliser (all treatments)								
Ammonium sulphate		1.275	2.20	3.00	3.00	3.00	3.00	3.00
Rock phosphate		0.70	0.80	0.50	0.50	0.50	0.50	0.50
Copper sulphate		0.175	0.15	-	-	-	-	-
Copper EDTA		-	-	0.04	0.04	0.04	0.04	0.04
Zinc sulphate		0.065	0.15	-	-	-	-	-
Zinc EDTA		-	-	0.04	0.04	0.04	0.04	0.04
High grade fertiliser borate		0.03	0.06	0.15	0.15	0.15	0.15	0.15

[1] For first 3 years, L1 and L2 received the same rates. Differential rates for soil ameliorants commenced from 4th year onwards

[2] months

MOP - muriate of potash, LSD - limestone dust, BA - bunch ash, EFA - eucalyptus fly ash, PHA - paddy husk ash

APPENDIX 2
NUTRIENT ANALYSIS OF SOIL AMELIORANTS APPLIED IN TRIALS 1 AND 2

Ameliorant	*pH (units)*	*Nutrient content (%)*				*Nutrient content (ppm)*				
		K_2O	*P_2O_5*	*MgO*	*CaO*	*B*	*Cu*	*Zn*	*Mn*	*Fe*
Trial No.1										
Limestone dust (LSD)	7.70	trace	trace	2.07	51.4	-	-	-	-	-
Oil palm bunch ash (BA)	10.30	39.40	3.50	5.50	5.40	2 784	158	382	918	1 374
Eucalyptus fly ash (EFA)	10.90	1.11	trace	0.70	8.29	88	50	125	1 249	13 900
Paddy husk ash (PHA)	9.00	0.51	trace	0.10	0.18	trace	7	33	168	4 035
Trial No.2										
Oil palm bunch ash (BA)	10.70	39.80	3.00	4.00	5.30	2 386	175	370	1 118	1 399

APPENDIX 3
DETAILS OF TRIAL TREATMENTS
(TRIAL NO.2)

Fertiliser treatment	*Fertiliser dosage (kg/palm/year)*
Zero potash fertiliser	0
L 1 - MOP	3.00
L 2 - MOP	4.50
L 3 - MOP	6.00
L 4 - MOP	7.50
L 1 - BA	4.50
L 2 - BA	6.75
L 3 - BA	9.00
L 4 - BA	11.25
Common fertiliser (all treatments)	
Ammonium sulphate	3.00
Rock phosphate	0.50
Copper sulphate	0.50
Zinc sulphate	0.50
High grade fertiliser borate	0.15

MOP = muriate of potash, BA = bunch ash