THE EFFECT OF ROCK PHOSPHATE ON SOIL NUTRIENT DYNAMICS, GROWTH, DEVELOPMENT AND YIELD OF OIL PALM IN THE SEMI-DECIDUOUS FOREST ZONE OF GHANA

I. Danso[1], B.N. Nuertey[1], T.E.O. Asamoah[1], F.M. Tetteh[2], F. Danso[1], P.A. Afari[1], E.Y. Safo[3] and V. Logah[3]
[1]CSIR-Oil Palm Research Institute, Box 74, Kade
[2]Soil Research Institute, CSIR, Academy Post Office, Kumasi.
[3]Department of crops and Soil science, Kwame Nkrumah University of Science and Technology, Kumasi

ABSTRACT
Field experiment was conducted at Oil Palm Research Institute, Kusi from 2002 to 2007 to assess the effect of Phosphate Rock (PR) on soil nutrient dynamics, growth, development and yield of oil palm. The study was carried out on the soils of Nzema series classified as Ferric Acrisols and Typic Hapludult. The oil palm trees selected were 8 year old tenera (DXP ex OPRI). Each plot measured 17.6 m x 17.6 m and had 6 palm trees. There were four treatments arranged in randomized complete block design with four replicates. The treatments included: 1). TSP - OPRI fertilizer recommendation - 222 kg of AS + 222 kg of TSP + 296 kg of MOP/ha/yr (control); 2). PR1 - PR 715 kg + 222 kg of AS + 296 kg of MOP/ha - Yr 1. PR 358 kg + 222 kg of AS + 296 kg of MOP/ ha – Yr 2. PR 358 kg + 222 kg of AS + 296 kg of MOP/ha – Yr 3; 3). PR2 - PR 1428 kg + 222 kg of AS + 296 kg of MOP/ha applied once in every 5 years; 4). PR3 - PR 142.85 kg/ha +222 kg AS/ ha + 296 kg of MOP/ha applied twice in every 5 years. Application of treatments influenced the soil chemical properties to a varying extent. Gradual increase in soil nutrient levels were more pronounced in RP treatments than Triple Super Phosphate (TSP) treatment (control). Soil pH increased from extremely acidic (3.73) to acidic (5.43) for treatment PR2. At the end of the study, available P recorded 9.55 mg/kg. The value is slightly below the medium range of available P for oil palm production. Significant increases were recorded by RP treatments for exchangeable Ca, Mg, K and ECEC. The results showed that treatment PR2 was effective and gave the highest oil palm yield of 62.8t/ha with TSP recording 53.7t/ha. For sustained levels of soil nutrients, growth, development and yield of oil palm, PR incorporation should be encouraged.

Keywords: *Phosphate Rock, nutrient dynamics, oil palm, triple super phosphate*

INTRODUCTION
With the current increase in cost of oil palm production subsequent reduction in farmer's income, there is the need to search for low input farming strategies such the use of Togo Phosphate Rock (TPR) with about 25.5% P_2O_5 (CSIR-OPRI Annual Report, 2007). This may reduce cost of oil palm production and improve the incomes of oil palm stakeholders, especially the small scale oil palm farmers. Some studies

have shown poor soil fertility status of most soils under oil palm production. At Bogoso in the Western region, Tetteh and Dedzoe (2004) and Tetteh *et al.,* (2002) evaluated the soil fertility levels of some benchmark soils under oil palm, cocoa and maize. According to the authors, soil fertility levels of most of the soils were very low. Most of the soils were found to be acidic (pH < 5.0), low in available P and exchangeable cations. Similar studies at Bawjiase in the Central Region also revealed similar results regarding soil fertility status (Dedzoe *et al.*, 2004). Studies carried out by Asamoah and Nuertey (2005) also revealed that areas climatically suitable for optimal oil palm production in Ghana have limitations including poor drainage, hazards of erosion, high acidity and low nutrients.

Phosphate Rock (PR) is a raw material that contains phosphate mineral for making superphosphate fertilizers. It can be utilized as direct application fertilizer in acid soils because of the low input cost and slow release of P to the soil (Sale and Mokwunye, 1993). In Brazil a single application of PR per ha of land deficient of P gave 100 percent yield increase in oil palm over a period of 6 years (Hartley, 1988). This agrees with the role PR play in increasing yield (ton / ha) by 58 percent of oil palm in Indonesia in a second year following implementation of best management practices (Griffiths and Fairhust, 2002). According to Zin *et al.,* (2005) PR fertilizers have a higher content of calcium ranging from 24 – 33 %. This makes PR beneficial in increasing soil pH and cation exchange capacity (CEC) resulting in yield increases of oil palm. Foster *et al.,* (1998) noted that the effects of direct application of PR in mature oil palm under Malaysia soil conditions have been very promising. Similarly, in phosphorus deficient soils of Brazil as pertains in tropical Africa, a large initial application of PR had a superior effect to annual doses of triple superphosphate (IRHO, 1974). Its incorporation ensures a steady supply of P over a long period and also provides a high rooting density to crops (Bolan *et al.*, 1990).

Therefore the objective of this work is to conduct a detailed study to examine the effect of PR on soil nutrient dynamics, growth, development and yield of oil palm.

MATERIALS AND METHODS

Site description and experimental design

A field experiment was conducted between 2002 to 2007 at the Oil Palm Research Institute (OPRI), Kusi in the semi-deciduous forest zone of Ghana. The study was carried out on the soils of Nzema series classified as Ferric Acrisols (FAO, 1990) and Typic Hapludult (USDA, 1991). The area is in a zone characterized by relatively high rainfall, which falls in two seasons. The major rainy season occurs from April to July. The minor rainy season begins in September to the end of October/or mid November. Average annual rainfall is about 1425 mm. The oil palm trees selected were 8 year old tenera (DXP ex OPRI). Each plot measured 17.6 m x 17.6 m and had 6 oil palms trees. There were four treatments, consisting of: 1).Triple Super Phosphate - OPRI fertilizer recommendation - 222 kg of ammonium sulphate + 222 kg of triple super phosphate + 296 kg of muriate of potash/ha/yr (control); 2). PR1 - PR 715 kg + 222 kg of ammonium sulphate + 296 kg of muriate of potash/ha - Yr 1. PR 358 kg + 222 kg of ammonium sulphate + 296 kg of muriate of potash/ha – Yr 2. PR 358 kg + 222 kg of ammonium sulphate + 296 kg of muriate of potash/ha –Yr 3; 3). PR2 - PR 1428 kg + 222 kg of ammonium sulphate + 296 kg of muriate of potash/ha applied once in every 5 years; 4). PR3 - PR 142.85 kg/ha +222 kg ammonium sulphate/ha + 296 kg of muriate of potash / ha applied twice in every 5 years. The experimental design was randomized complete block with 3 replicates. Treatment plots were broadcast with appropriate straight fertilizers individually within the interrows and rings of palm trees (1.5 m radius around the palm).

Laboratory analysis

Composite soil samples (0-15 cm and 15-30 cm soil depth) were taken from experimental field before treatment application and subsequently annually from each plot. The composite soil samples were air dried for 24 hours and then sieved with a mesh of 2mm diameters for chemical analysis. Soil pH was measured with 1:2.5 soil:water suspension using a HI 9017 microprocessor pH meter. The Walkley and Black procedure as modified by Nelson and Sommers (1982) was used to assess the organic C content in the soils. Total N was determined by Kjeldahl digestion method. The available P was extracted with a HCl: NH_4F mixture method as described by Bray and Kurtz (1945) and determined colorimetrically using the molybdenum blue method at the wavelength using the molybdenum blue method at the wavelength of 636nm. Exchangeable bases (calcium, magnesium, potassium and sodium) in the soil were determined in 1.0 M ammonium acetate extract and exchangeable acidity (hydrogen and aluminium) was determined in 1.0 *M* KCl extract. The Effective Cation Exchange Capacity (ECEC) was calculated as the sum of exchangeable bases and exchangeable acidity (Table 1). Soil particle size was determined by using the hydrometer method (Bouyoucos, 1962).

Statistical analysis

All data obtained, were subjected to analysis of variance (ANOVA) using Genstat statistical package (Genstat, 1997). Separation of means was done using the least significant difference at P = 0.05

RESULTS

Pre-experimental soil characteristics

Some physical and chemical properties of the soil at the experimental site before imposition of treatments are presented in Table 1. The soil pH was extremely acidic at both depths. Effective cation exchange capacity (ECEC), total nitrogen, organic matter content and exchangeable potassium were low and the level of available phosphorus was below the deficiency

Table 1: Chemical and physical properties of soil at experimental site before application of treatments

	Soil Depth (cm)	
Soil Property	0-15	15-30
pH (1:2.5 H_2O)	4.42	4.13
Org. Carbon (%)	1.05	0.56
Organic matter (%)	1.81	0.97
Total N (%)	0.11	0.05
Avail. Bray's (mg/kg)		
P	0.80	0.20
K	69.20	131.30
Exchangeable bases (cmol/kg)		
Ca	2.88	1.44
Mg	1.60	0.64
K	0.06	0.07
Na	0.08	0.15
TEB	4.62	2.30
Exhangeable acidity (cmol/kg)	0.25	1.05
ECEC (cmol/kg)	4.87	3.35
Base saturation (%)	94.90	68.70
Particle size (%)		
Sand	68.00	60.00
Silt	27.00	32.00
Clay	5.00	8.00
Texture	Sandy loam	Sandy loam

threshold of 10mg/kg (Hartley, 1988) for plants. Exchangeable Ca and Mg values were below the critical values of 5.0 and 1.0 cmol/kg respectively, in both depths (Healed, 1965). Generally, the fertility of the soil was low and decreased with depth and crop response to the major nutrients especially P was expected.

From the results of particle size analysis, the content of sand, clay and silt were 68, 27 and 5% for 0-15cm soil depths and 60, 32 and 8% for sand, clay and silt respectively. Hence, the soil was classified as sandy loam in both depths.

Effect of treatments on soil pH

The effect of treatments on soil pH is shown in Table 2. Differences that were recorded during the test period were significant in 2004 and 2007 for both soil depths and 2006 in 0-15 cm soil depth only. Values of pH increased gradually from 2004 to 2007 for PR treatments in both soil depths. Soil pH values for the control (TSP) in the 0-15 cm soil depth gradually decreased from 2004 to 2006 but eventually increased by 0.87 units from 2006 to 2007. Soil pH values for control (TSP) in 15-30 cm soil depth remained constant (4.22) from 2004 to 2006. However, there was an increase of 0.51 units from 2006 to 2007 in soil depth 15-30 cm.

Effect of treatment on soil organic matter

Table 3 shows organic matter content of the soil as affected by treatments. Changes in organic matter content over the test period were not significantly influenced in both soil depths. Significant difference was rather observed among the treatments in 2004 at 15-30 cm soil depth. Organic matter levels were moderate to high and ranged from 1.56 to 5.33 % in the 0-15 cm. These values decreased with soil depth. A gradual increase in organic matter content from 2004 to 2007 during the period was recorded. However, from 2006 to 2007 in the PR2 treatments, both soil depths experienced organic matter reduction by 4.00 % and 15.00 % for 0-15cm and 15-30 cm, respectively.

Effect of treatment on total soil nitrogen

Total soil nitrogen values showed no significant difference among treatments for both soil depths (Table 4). Comparatively, total N values in 2004 were lower than 2007 values.

Increase in total N values in 2007 over 2004 were 28.0 and 51.0 % for 0-15 cm and 15-30 cm soil depths respectively. Values recorded in 2005 and 2006 for PR2 treatment in 0-15 cm

Table 2: Effect of treatment on dynamics of soil pH from 2004 to 2007

Treatment	2004	2005	2006	2007
	0 – 15 cm soil depth			
TSP	4.27a	4.12a	3.99b	4.86bc
PR1	4.22a	4.32a	4.43ab	5.08a
PR2	3.76b	4.42a	5.09a	5.37a
PR3	4.11a	4.33a	4.65ab	4.72c
CV (%)	5.9	5.6	9.8	3.4
LSD (5%)	0.48	0.47	0.88	0.34
	15 – 30 cm soil depth			
TSP	4.22a	4.22a	4.22a	4.73b
PR1	4.10a	4.49a	4.88a	5.09ab
PR2	4.13a	4.66a	5.18a	5.39a
PR3	3.76b	4.30a	4.85a	5.43a
CV (%)	4.1	9.8	15.6	3.9
LSD (5%)	0.32	0.86	1.49	0.39

Means followed by the same letter are not significantly different (P>0.05).

soil depth had the highest total N values and these were higher than the critical soil nutrient value of 0.2% (Hartley, 1988). However, by 2007 PR2 treatment in soil depth 0-15 cm had dropped by 20.0 %.

Effect of treatment on available phosphorus

Table 5 shows the available phosphorus levels as influenced by treatments. Differences that were recorded during the period were not significant in both soil depths. Available phosphorus values increased gradually from 2004 to 2006. However, from 2006 to 2007 there was a drop in available phosphorus values for treatments TSP (control) in 0-15 cm, PR1 in 0-15 cm and TSP (control) in 15-30 cm soil depth. The respective drops were 26.0, 31.6 and 6.5

Table 3: Effect of treatment on dynamics of soil organic matter (%) from 2004 to 2007

Treatment	2004	2005	2006	2007
	0 – 15 cm soil depth			
TSP	1.8a	2.07a	2.33a	2.96a
PR1	1.78a	2.07a	2.30a	3.12a
PR2	1.75a	3.54a	5.33a	2.74a
PR3	1.56a	2.13a	2.70a	3.25a
CV (%)	10.9	2.85	87.1	27.90
LSD (5%)	0.37	58.50	5.50	1.68
	15 – 30 cm soil depth			
TSP	1.05a	1.25a	1.45a	1.90a
PR1	0.92ab	1.05a	1.18a	2.05a
PR2	0.70b	1.37a	2.06a	1.75a
PR3	0.94a	0.99a	1.05a	1.84a
CV (%)	13.40	45.8	77.60	20.50
LSD (5%)	0.24	1.06	2.22	0.77

Means followed by the same letter are not significantly different (P>0.05)

Table 4: Effect of treatment on dynamics of total nitrogen (%) from 2004 to 2007

Treatment	2004	2005	2006	2007
	0 – 15 cm soil depth			
TSP	0.10a	0.11a	0.11a	0.15a
PR1	0.11a	0.11a	0.11a	0.15a
PR2	0.10a	0.22a	0.27a	0.13a
PR3	0.11a	0.12a	0.13a	0.16a
CV (%)	6.80	66.00	90.00	30.20
LSD (5%)	0.01	0.18	0.28	0.09
	15 – 30 cm soil depth			
TSP	0.04a	0.06a	0.07a	0.10a
PR1	0.05a	0.17a	0.04a	0.10a
PR2	0.02a	0.06a	0.10a	0.08a
PR3	0.03a	0.04a	0.05a	0.01a
CV (%)	40.70	132.60	45.70	25.80
LSD (5%)	0.03	0.22	0.10	0.05

Means followed by same letter are not significantly different (P>0.05)

%. Generally, available phosphorus values decreased with depth.

Effect of treatment on available potassium

Available potassium as influenced by treatments is shown in Table 6. There was a gradual increase in available potassium from 2004 to 2007 for all treatments in both depths. Available potassium values were generally low to high and ranged from 31.50 to 121.60 mg/kg and 19.50 to 125.6 mg/kg in the 0-15 cm and 15-30 cm depths respectively. However, increased values from 2006 to 2007 were more pronounced. Treatment differences that were recorded during the test period were not significant in both soil depths.

Effect of treatment on exchangeable calcium

Table 7 shows the effect of treatments on the dynamics of exchangeable calcium. Values of exchangeable calcium increased from 2004 to 2007. However, from 2006 to 2007 a drop in in

Table 5: Effect of treatment on dynamics of available phosphorus (mg/kg) from 2004 to 2007

Treatment	2004	2005	2006	2007
	0 – 15 cm soil depth			
TSP	0.36a	2.97a	5.60a	4.14a
PR1	0.41a	4.63a	8.85a	6.05a
PR2	0.50a	5.59a	9.50a	9.32a
PR3	0.43a	2.93a	5.44a	5.70a
CV (%)	35.30	40.50	42.60	47.20
LSD (5%)	0.30	3.25	6.50	5.94
	15 – 30 cm soil depth			
TSP	1.07a	1.99a	2.91a	2.72a
PR1	0.33a	1.53a	2.74a	4.43a
PR2	0.48a	1.54a	2.60a	4.46a
PR3	0.36a	1.37a	2.38a	4.05a
CV (%)	74.90	42.30	51.20	46.20
LSD (5%)	0.84	1.35	2.71	3.61

Means followed by same letter are not significantly different (P>0.05)

Table 6: Effect of treatment on dynamics of available potassium (mg/kg) from 2004 to 2007

Treatment	2004	2005	2006	2007
	0 – 15cm soil depth			
TSP	31.50a	33.60a	35.80a	94.90a
PR1	39.90a	41.50a	43.10a	108.2a
PR2	37.40a	39.90a	42.30a	68.60a
PR3	35.80a	37.20a	38.40a	121.60a
CV (%)	20.40	23.80	28.20	27.10
LSD (5%)	14.72	18.06	22.47	53.10
	15 – 30 cm soil depth			
TSP	41.30a	38.90a	36.50a	111.60a
PR1	22.20a	24.60a	27.00a	93.70b
PR2	22.70a	25.40a	28.10a	125.6a
PR3	19.50a	19.90a	20.30a	93.70b
CV (%)	43.00	29.60	19.90	26.60
LSD (5%)	22.69	16.09	11.12	56.43

Means followed by same letter are not significantly different (P>0.05)

values were recorded in treatments PR2 and PR3 in both soil depths. The drop from 2006 to 2007 in 0-15 cm soil depth for treatments PR2 and PR3 were 58.1 % and 33.0 % respectively. The drop in exchangeable calcium from 2006 to 2007 in 15-30 cm soil depth was about 38 % and 39 % for treatments PR2 and PR3 respectively.

Effect of treatment on exchangeable magnesium

Exchangeable magnesium as influenced by treatments is shown in (Table 8) for 0-15 cm and 15-30 cm depth respectively. Values increased gradually from 2004 to 2007 in 0-15 cm depth for TSP and PR1. Treatments PR2 and PR3 dropped from 2006 to 2007 by 1.1 and

Table 7: Effect of treatment on dynamics of soil exchangeable calcium (cmol/kg) from 2004 to 2007

Treatment	2004	2005	2006	2007
	0 – 15 cm soil depth			
TSP	2.37a	2.63a	2.90a	2.90a
PR1	1.70a	2.36a	3.00a	3.84a
PR2	3.32a	6.68a	10.10a	4.23a
PR3	2.33a	3.19a	4.00a	2.68a
CV (%)	34.70	77.2	100.03	38.9
LSD (5%)	1.68	5.73	10.03	2.16
	15 – 30 cm soil depth			
TSP	2.27ab	2.22a	2.1a	2.89a
PR1	1.57b	1.81a	2.05a	2.76a
PR2	3.38a	4.32a	5.25a	3.25a
PR3	2.04ab	2.64a	3.25a	1.96a
CV (%)	28.90	47.10	61.60	37.40
LSD (5%)	1.33	2.58	3.91	2.03

Means followed by same letter are not significantly different (P>0.05).

Table 8: Effect of treatment on dynamics of soil exchangeable magnesium (cmol/kg) from 2004 to 2007

Treatment	2004	2005	2006	2007
	0 – 15 cm soil depth			
TSP	0.74a	0.59a	0.44a	0.93a
PR1	0.70a	0.82a	0.93a	1.15a
PR2	1.21a	1.63a	2.05a	0.98a
PR3	0.99a	1.35a	1.74a	0.93a
CV (%)	84.90	18.70	89.20	56.30
LSD (5%)	1.54	1.87	2.30	1.12
	15 – 30 cm soil depth			
TSP	0.35a	0.46a	0.58a	0.71a
PR1	0.35a	0.80a	1.24a	1.07a
PR2	0.32a	1.36a	1.40a	2.36a
PR3	0.41a	1.23a	2.04a	0.76a
CV (%)	53.60	72.90	88.00	96.00
LSD (5%)	0.38	1.40	2.78	2.35

Means followed by the same letter are not significantly different (P>0.05).

0.8 units, respectively. For the 15-30 cm depth, a drop in values from 2006 to 2007 were 15.8 and 168 % respectively for PR1 and PR3.

Effect of treatment on exchangeable potassium

More than 80 % of values recorded were below the deficiency threshold of 0.15 cmol/kg (IRHO, 1960) by 2006 (Table 9). There were fluctuations in the values of exchangeable potassium from 2004 to 2007 in the 15-30 cm depth. However, values increased gradually from 2004 to 2007 in the 0-15 cm soil depth.

Effect of treatment on soil exchangeable acidity

Table 10 shows soil exchangeable acidity as influenced by treatments. Differences that were recorded during the test period were not significant in both soil depths. Soil exchangeable

Table 9: Effect of treatment on dynamics of soil exchangeable potassium (cmol/kg) from 2004 to 2007

Treatment	2004	2005	2006	2007
0 – 15cm soil depth				
TSP	0.03a	0.02a	0.03a	0.93a
PR1	0.01a	0.01a	0.02a	1.15a
PR2	0.02a	0.02a	0.03a	0.98a
PR3	0.02a	0.02a	0.03a	0.93a
CV (%)	76.50	71.4	57.00	56.30
LSD (5%)	0.03	0.03	0.03	1.12
15 – 30 cm soil depth				
TSP	0.02bc	0.02a	0.02bc	0.11a
PR1	0.01c	0.01c	0.01c	0.10a
PR2	0.34a	0.34a	0.02bc	0.10a
PR3	0.01a	0.01c	0.20a	0.07a
CV (%)	86.00	286.40	42.3	46.00
LSD (5%)	0.03	0.55	0.010	0.09

Means followed by the same letter are not significantly different (P>0.05).

Table 10: Effect of treatment on dynamics of soil exchangeable acidity (A+H) (cmol/kg) 2004 to 2007

Treatment	2004	2005	2006	2007
0 – 15cm soil depth				
TSP	0.26a	0.66a	1.07a	0.21a
PR1	0.26a	0.32a	0.39a	0.26a
PR2	0.24a	0.28a	0.31a	0.20a
PR3	0.28a	0.34a	0.41a	0.28a
CV (%)	6.60	55.80	82.90	23.60
LSD (5%)	0.03	0.44	0.91	0.11
15 – 30cm soil depth				
TSP	1.07a	1.20a	1.35a	0.18b
PR1	1.08a	0.73a	0.39a	0.23a
PR2	1.26a	0.75a	0.23a	0.20a
PR3	1.19a	0.82a	0.46a	0.28a
CV (%)	13.70	39.20	112.0	21.30
LSD (5%)	0.31	0.68	1.35	0.09

Means followed by the same letter are not significantly different (P>0.05).

acidity values ranged from 0.20 to 1. 07 cmol/kg and 0.18 to 1.35 cmol/kg for 0-15 cm and 15-30 cm soil depth respectively. Values that were recorded in 2004 for both soil depths were higher than values obtained at the end of the study (2007).

Effect of treatment on Effective Cation Exchange Capacity (ECEC)

Table shows effective cation exchange capacity (ECEC) as influenced by treatments. Values of ECEC decreased with depth. The highest ECEC of 12.6 cmol/kg occurred in PR2 at a depth 0-15 cm in the year 2006 with the lowest of 3.23 cmol/kg recorded by PR1 in 2004 at a depth of 0-15 cm. A gradual decrease in ECEC from 2004 to 2007 in the 0-15 cm for TSP treatment (control) was recorded. By the end of the study individual PR treatments recorded higher values than TSP (control) in both soil depths.

Effect of treatment on leaf area development

Figure 1 shows the effect of treatment on leaf area. Treatments did not significantly affect leaf area throughout the experimental period. Over the period, the highest and the lowest leaf area values of 8.52 and 6.45 m^2 were recorded by treatment PR2 and TSP respectively. Mean leaf area per palm in 2004 was 6.84 m^2. This increased to 9.0, 7.1 and 14.2 m^2 in 2005, 2006 and 2007 respectively.

Effect of treatment on oil palm yield (t/ha)

The yield of oil palm defined as the product of the number of bunches and weight of bunches per ha from 2004 to 2007 is shown in Table 12. Fresh fruit bunches per ha was not significantly different among treatments except in 2006. The highest fresh fruit bunches per ha of 18.88 t/ha was recorded in 2006 for PR2 whilst the lowest of 9.92 t/ha was recorded in 2007 for TSP (control). In calculating the relative yield increase (R1) of PR treated plots, TSP treated plots were used as standard treatment. The RI during the early stages of the trial (2004) for PR1, PR2 and PR3 were 6.0, 2.0 and 25.0 % respectively. By 2007 the values had increased to 17.5 and 28.9 % for PR1 and PR2 respectively with PR3 recording a decreased value of 13.1%. For the years 2004 and 2007, RI were in the order of PR3 > PR1 > PR2 and PR2 > PR1 > PR3 respectively

Table 11: Effect of treatment on dynamics of Effective Cation Exchange Capacity (cmol/kg) from 2004 to 2007

Treatment	2004	2005	2006	2007
		0 – 15 cm soil depth		
TSP	4.94a	4.74a	4.60a	4.35a
PR1	4.99a	4.75a	4.50a	5.50a
PR2	4.56b	8.69a	12.60a	7.52a
PR3	4.46c	5.43a	6.40a	6.04a
CV (%)	3.50	50.20	82.90	49.50
LSD (5%)	0.33	5.91	11.63	5.78
		15 – 30 cm soil depth		
TSP	3.52a	3.90a	4.28a	4.06a
PR1	3.23a	3.51a	3.79a	4.31a
PR2	3.26ab	5.42a	7.59a	6.05a
PR3	3.43ab	4.70a	5.97a	3.21a
CV (%)	3.60	39.80	63.3	49.50
LSD (5%)	0.24	3.48	6.84	4.35

Means followed by same letter are not significantly different (P>0.05).

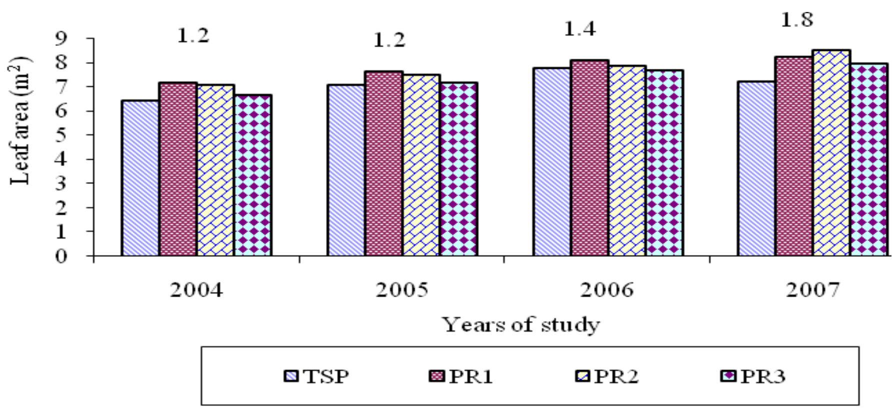

Fig. 1: Effect of treatment\s of palm leaf area

Figures on bars represent lsd values. Where Lsd = p < 0.05

DISCUSSION

Pre-experimental soil characteristics

The low pH values of soil were similar to those reported for some Ghanaian soils by Adu and Tenadu (1979). Strong leaching of the basic cations out of the top soil contributed to low pH values. It is expected that this factor will affect the dynamics of all nutrients and especially phosphate because the available P depends to a large extent on interactions with constituents carrying a variable charge (Quang *et al.,* 1996).

The very low organic carbon content and low exchangeable bases particularly calcium reflected the generally highly weathered soils in the humid rainforest agro-ecological zone of the country (Owusu-Bennoah *et al.,* 2000). This property of the soil is attributed mainly to the excessive leaching of the soils caused by high rainfall associated with oil palm growing areas in Ghana and constant plant nutrient uptake by the crop. The low ECEC values could be attributed to the low organic matter and to the fact that the clay fraction is dominated by low activity clays (kaolinite) (Owusu-Bennoah *et al.,* 1996). The high build up of available K in the 15-30 cm depth could be attributed to

Table 12: Effect of treatments on fresh fruit bunches and relative yield increase (RI) from 2004 to 2007

Treatment	Yield (t/ha)				R1%			
	2004	2005	2006	2007	2004	2005	2006	2007
TSP	13.5	13.53	16.76	9.93	-	-	-	-
PR1	16.0	14.70	18.61	11.67	6.0	8.6	1.1	17.5
PR2	13.8	17.30	18.88	12.80	2.0	27.8	12.6	28.9
PR3	16.9	12.6	17.56	11.23	25.0	6.0*	4.8	13.1
CV (%)	25.8	17.1	1.6	23.9				
LSD (5%)	N.S	N.S	0.58	N.S				

** indicates relative decrease in yield (t/ha) as compared to TSP in 2005* movement of K minerals due to leaching. The available P content of 0.8 and 0.2 mg/kg for the depths 0-15 and 15-30 cm depth respectively indicated that the soil was extremely low in P. According to Hartley (1988), the threshold deficiency for P is 10 mg/kg. This could be attributed to the advanced stage of weathering of the parent rocks which lacked primary weatherable minerals necessary for nutrient recharge (Charreau, 1974).

Although all inorganic P cannot be considered sorbed P, these findings together with the Bray P results strongly suggested deficiency of P in the soil and hence, the need for P fertilizer application.

Soil nutrient dynamics

Soil nutrients were concentrated in the top 0-15 cm and tended to decrease with depth, suggesting that a greater part of these nutrients may be associated with organic matter present in the top soil (Aweto, 1988). While superphosphate application generally leads to a reduction of soil organic matter in the top soil, PR applied with other inorganic fertilizers resulted in significant increases in total organic C, available-P, soil respiration, microbial biomass and enzyme activities (Melero *et al.,* 2006). The results of this study showed that, PR treatments in the 0-15 cm depth were comparatively higher in organic matter content and available-P than TSP treatment of the same depth. The reduction in organic matter after 2006 for both two soil depths in treatment PR2 could be attributed to mineralization. This is consistent with reports by Azeez *et al.* (2007) that mineralization of organic matter takes place during cropping season after fertilizer application. The maintenance of high organic matter levels in the top soil is therefore very important for sustainable soil fertility and for enhancing oil palm productivity.

The pH of the soil at the start of the experiment was extremely acid (pH 4.42 and 4.13 for the 0-15 and 15-30 cm soil depths respectively). The RP treated plots reached a suitable range of pH of 5.0-5.5 (strongly acidic) for optimum oil palm nutrient uptake except PR3 in soil depth 0 -15 cm. These results on pH confirm the findings by Zin *et al.* (2005) that PR fertilizers have a higher content of Ca (ranging from 24-33 %) which could increase soil pH and effective cation exchange capacity (ECEC) and positively affect yield of oil palm. The high acidity recorded in TSP treated plots compared to the PR plots at the end of the experiment was due to the low content of Ca in TSP and the remnants of phosphoric acid used in the manufacture process of the triple superphosphate fertilizers.

The available P (Bray P) at the start of the experiment was low and agreed with that reported by Ankomah *et al*. (1995) in similar Ghanaian soils. Thomas and Peaslea (1973) suggested that most soils containing extractable P of less than 15 mg/kg as determined by Bray 1 method could be defined as being deficient in available P for optimal plant growth. These are similar to the values suggested by Olson and Engelsted (1972) and Menon *et al.* (1995). By the end of the experiment the highest available P was still below the medium range of 10-20 mg/kg (Hartley, 1988). The results obtained for this study confirmed the findings of Pieri (1986) that P is one of the most limiting nutrients for crop growth in tropical soils. Available P reported in PR treated plots were promising than values obtained for TSP treated plots. According to Sale and Mokwunye (1993), PR applied to P-deficient acid soils encounted in humid forest zone dissolve slowly to sustain soil levels and plant growth. Allen *et al.* (1995) also observed slow release of P to the soil by PR. As a result, Adam *et al.* (1987) suggested that PR should be used on perennial crops rather than annual crops and research must focus on treating PR to increase solubility. Studies by Hammond *et al.* (1986) and Chien and Menon (1995) have shown that partial acidulation of PR (PAPR) is one way to increase water solubility and agronomic effectiveness of PRs at a lower cost than would be required to manufacture the conventional, fully acidulated fertilizers as Single Superphosphate or TSP. The low

P values recorded in the 15-30 cm could possibly be due to P-fixation by aluminosilicates, since clay generally accumulates in the subsoil of tropical soils (Obeng, 1990).

The status of N was relatively low, both at the beginning and at the end of the study as well. Values of N decreased with depth and almost all the N values recorded were below the medium range of 0.1-0.2 % (Hartley, 1988). Continual supply of N is necessary since it is very difficult to build large N reserves.

Lower soil P levels as experienced in this study, could prevent the uptake and the use of available potassium (Hartley, 1988). This and the fact that K was applied annually might have given rise to the general increase in available K as experienced from 2006 to 2007 in this study. This could also be due to the replenishment from the potassium pool at the end of the experiment. The build up of available K in the 15-30 cm soil depth in 2007 may indicate the movement of K fertilizers due to leaching. This observation supports that of Weerasinghe and Premalal (2002) who observed a build up of K in deeper soil layers indicating the movement of K fertilizers due to leaching.

The low pH in TSP treated plots resulted in a smaller proportion of exchangeable Ca and Mg (Roy *et al.,* 2006). According to Havlin *et al.* (1999), the availability of K^+ is generally dependent on its concentration relative to that of Ca^{2+} and Mg^{2+}. Thus, K^+ uptake increases as concentrations of Ca^{2+} and Mg^{2+} decline in the soil solution and vice versa. This may explain the yearly variation in almost all the soil nutrients analyzed.

In a study of soil nutrient dynamics, Roy *et al.* (2006) observed that the content of available nutrients and their degree of availability and accessibility was not a static condition but an ever-changing and very dynamic process due to the various inorganic and biochemical processes that take place in soils.

Growth, development and yield of oil palm

It has been found that there is superior residual effect of PR compared to water soluble P (TSP) more especially in acidic soils (Sale and Mokwunye, 1993). Bolan *et al.* (1990) noted that incorporation of PR into the soil ensured a sustainable supply of P over a long period and also created a high rooting density for better nutrient exploration. This resulted in increased yield of 16.9 % (PR2) over TSP treated plots. Research done on PR in the United States provides an idea of the duration of the effect from residual P on a soil (Tisdale *et al.,* 1985). They provided data to show that irrespective of the rate of P, there was a residual effectiveness up to the seventh crop and response to initial and residual P increased with increasing rates. A similar observation was made in this trial where single application rate of 1428 kg PR + 222 kg AS +296 kg of MOP once in 5 years (PR2) gave promising results both morphologically and reproductively. Similarly, in Brazil, a single application of PR per ha of land deficient of P gave 100 percent yield increase in oil palm over a period of 6 years (Hartley, 1988).

Decrease in yield in TSP plots (control) could be attributed to very acidic conditions of soil. In 2007, PR treated plots (PR2) recorded a moderately acidic values of pH which made the crop better adapted for effective nutrient uptake resulting in good growth, development and yield of oil palm. Jacquemard (1998) observed that the oil palm can cope with acidic soils but is better adapted near to neutral soil pH values.

The overall response of oil palm to P fertilizers showed a higher fresh fruit bunch yield and development where PR was applied to the soil and was statistically better than the fresh fruit bunches yield produced by TSP (Table 12 and Fig. 1). This is in agreement with Sale and Mokyunye (1993) that, PR applied to the soil (such as P-deficient acidic Ferralsols encounted in the humid forest zone), dissolves readily to sustain plant growth.

CONCLUSION

The physico-chemical properties of the soil before the application of treatments indicated that, the soil is highly acidic, low in available phosphorus and low in organic matter all leading to low effective CEC. This could be attributed to excessive leaching and constant nutrient uptake by oil palm trees. The use of PR positively influences chemical properties of the soil especially increasing exchangeable cations and available P in the soil. Application of PR at the rate of 1428 kg per ha once in every 5 years gave the highest yield. The study has clearly shown that agronomically it is sound to use PR under oil palm.

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