Direct and residual effects of phosphate fertilizer on maize (*Zea mays* L.) grown on an Ultisol in Kumasi, Ghana

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SUMMARY
Long-term field experiments were conducted for 13 cropping seasons on a Typic Paleustult in Ghana to study response of maize (*Zea mays* L.) to P fertilization, evaluate the relative efficiency of broadcast versus band applications, estimate residual effects of applied P and determine the critical P level for maize. The results showed no significant direct effect of P fertilization on maize yield for the first four crops. Thereafter, grain yields consistently and significantly increased due to the residual effects of applied P and the effects increased as the broadcast rates increased but decreased when banded P rates increased. The overall residual effect of the banded P was significantly superior to the broadcast application. The critical P level for maize on this soil was estimated to be 12-16 ppm Bray 1 P. There was a significant direct effect of applied P on grain yield for the tenth through the thirteenth crops when the available P level in the soil was below the critical level.

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RÉSUMÉ
KWAKYE, P. K. & NYAMEKYE, A. L.: *Effets direct et résiduel de l'engrais du phosphate sur le maïs* (Zea mays *L.*) *cultivé dans un Ultisol à Kumasi.* Des expériences du champ de très longues durées ont été faites pour treize saisons sur un Typic Paleustult au Ghana pour étudier la résponse du maïs (*Zea mays* L.) à l'engrais du phosphate, l'efficience relatif d'application à la volée par rapport à l'application en bande, d'estimer des effets résiduels du phosphate appliqué et de déterminer le niveau critique du phosphate pour le maïs. Les résultats montrent que il n'y a pas d'effet direct significatif du phosphate sur le rendement du maïs pour les quatre prémières cultures. Par la suite, les rendements du grain ont régulièrement et significativement augmenté, grace à des effets résiduels du phosphate appliqué et les effets se sont intensifiés avec l'augmentation de taux d'application en volée maïs ont diminué avec l'augmentation de taux du phosphate appliqué en bande. L'effet résiduel total du phosphate appliqué en bande était significativement supérieure au phosphate appliqué à la volée. Le niveau critique du phosphate pour le maïs dans ce sol à été estimé à 12 - 16 ppm (Bray1P). Il y'a eu d'effet direct significatif du phosphate appliqué sur le rendement du maïs de la dixième à la treizième culture quand le niveau du phosphate disponible dans le sol était au-dessous du miveau critique.

Introduction

Phosphorus has been established to be the most limiting plant nutrient in Ghana soils (de Endredy & Montgomery, 1954; Nye & Bertheux, 1957). Phosphorus fertilization is, therefore, necessary for increased crop production on these soils.

One advantage of phosphate fertilization is its long residual effect (Younge & Plucknett, 1966; Kamprath, 1967; Fox, Plucknett & Whitney, 1968; Ofori, 1968; Wagar, Stewart & Moir, 1986; Widjaja-Adhi, Sudjadi & Silva, 1986; Hipp, 1986). However, this benefit is usually not realized in farming under shifting cultivation. A crop may not respond significantly to phosphorus fertilization in the season of application but may show a significant residual effect. For instance, Ofori (1968) obtained no significant direct effect from phosphorus (14-59 kg P/ha) on maize grown on three P-deficient soils in Ghana, but there were persistent high residual effects during the following three continuous cropping seasons.

The efficiency of applied phosphorus, to a large extent, is influenced by the method of its application and the magnitude of its fixation. The advantages of band over broadcast application of phosphorus have been reported by several researchers (Prummel, 1957; Van Wijk, 1963; Kafkafi, 1963). In contrast to the widely held view favouring band placement of phosphates, Barber (1958) reported results showing the superiority of broadcast application over band placement. The divergent results reported by various authors on the efficiency of applied phosphorus might have been influenced by soil properties, mainly P fixation.

The clay fraction of most tropical soils is dominated by hydrous oxides and oxides of iron and aluminium (Soil Survey Staff, 1975). These minerals fix large amounts of phosphorus. The magnitude of P fixation will depend on the dominant mineral present in the soil. Kamprath (1972) found that the largest amounts of phosphorus are fixed by amorphous hydrated oxides of iron and aluminium, followed by gibbsite, goethite and kaolinite. The Ultisol on which this experiment was conducted is mainly kaolinitic (Acquaye, 1973), suggesting possible high P fixation capacity.

Welch *et al.* (1966), however, obtained a higher efficiency of applied phosphorus in a combined broadcast-band application at the rate of 38 kg P/ha. At lower rates (10 and 19 kg P/ha), they reported higher yields when all the phosphorus was banded. In an experiment with maize conducted in the humid zone of Nigeria, Fox & Kang (1978) observed the advantages of banded phosphate only at the sub-optimal rate of 8-16 kg P/ha. At higher rates of 24-32 kg P/ha, they obtained the best results when the phosphorus fertilizer was broadcast and incorporated into the soil.

In West Africa, there is paucity of information on residual effect of applied P. Furthermore, the effectiveness of P fertilizers in relation to method of application is ill-defined in the sub-region. More importantly, the critical P level for maize, a staple food crop in the forest zone of Ghana, has not been established. In view of the increasing use of P fertilizers on the soils of West Africa, it is imperative to generate and document information on P fertilization. This paper reports the results of a long-term field experiment evaluating the direct and residual effects of broadcast and band applications of phosphorus fertilizer on maize grain yield and critical P level in the humid zone of Ghana.

Materials and methods

The experiment was conducted on an Ultisol (Typic Paleustult, coarse, kaolinitic, hyper-isothermic) located at the Soil Research Institute Experiment Station, Kwadaso, near Kumasi in the moist semi-deciduous rain forest zone of Ghana. The surface soil (0-15cm) had a *p*H of 6.4; organic matter, 5.3 per cent; Bray 1P, 10.8 ppm; CEC, 10.32 me/100 g; Al saturation, 3 per cent.

A randomized complete block design comprising five rates of P (0, 70, 105, 140, 175 kg/ha) as triple superphosphate and two application methods broadcast and band with five replicates, were used in the study. Each experimental plot measured 12 m × 4.8 m. In the broadcast treatments, all the P fertilizer was evenly mixed with the top soil by hoeing at the beginning of the experiment in 1975. There was no further P broadcast application during the next eight consecutive crops. In the band treatments, a quarter of each of the broadcast rates (17.5, 26.25, 35, 43.75 kg P/ha) was banded per season to only the first four crops. The P fertilizer was placed about 8 cm away from the planting row and covered with soil. Each plot received an annual basal dressing of 50 kg K/ha as muriate of potash broadcast and 100 kg N/ha as urea with half applied broadcast at planting and the remaining top-dressed at 1 m high of the maize plants.

Maize (*Zea mays*, var. Composite-4) was planted at a density of 37, 000/ha. After harvesting each crop, soil samples (0-23 cm) were collected from the control (Po) and the P broadcast plots and analysed for available P using the Bray I method to assess the P status of the soil with time and to allow estimation of critical P level for maize. Crop residues were removed after each harvest and the site was hoed before planting the next crop. After the fourth cropping season, the residual effects of the applied P were evaluated.

Following the ninth crop the experimental site was ploughed and harrowed the second time. Phosphorus fertilization was repeated and the same maize variety was sown twice a year for 2 years.

Using the method of Cate & Nelson (1965), the relative yields of the first nine crops were plotted against the soil test values for P to estimate the critical level of P for maize on this soil.

Results and discussion

Direct effect

Grain yields as influenced by increasing amounts of P broadcast and banded are shown in Table 1. There was no significant direct effect of P applied broadcast at beginning of cropping. The second crop was adversely affected by severe drought immediately after tasselling resulting in decreased and poor cob formation. Total dry matter yield was, therefore, presented for discussion. The 140 kg P/ha broadcast once at the initiation of the experiment gave the highest yields for the second, third and fourth crops. Grain yields obtained with the various P rates applied banded were essentially the same for the first, third and fourth crops. The content of available phosphorus (Bray 1) in the surface soil was below the critical level of 12 ppm P estimated in this study suggesting that significant response of maize to P application on this soil was likely. However, neither increasing rate of phosphorus applied broadcast to the first crop alone nor the small amounts of P banded seasonally to each of the first four crops showed a significant direct effect on grain yield.

On an intensively cropped Ultisol with a mean available P (Bray 1) content of 6 ppm, Ofori (1973) observed significant responses of maize to low annual application rates of 9.8 kg P/ha in Ghana. The lack of significant direct phosphate effect on this soil in the first four cropping seasons might be due to increased available P resulting from mineralization of organic P in surface litter and small roots mixed with the soil as earlier reported by Cunningham (1963).

TABLE 1

Maize Yield (kg/ha) as Influenced by Rate and Method of Phosphorus Application

Amount of P applied (kg/ha)	*Grain yield*			*Total dry matter*
	Crop			
	1	3	4	2
Control	4790	4710	1060	5700
Broadcast for first crop only				
70	5710	4990	1340	6140
105	5940	5210	1330	5020
140	5680	5800	1740	6440
175	7540	5460	1400	6360
Mean	5770	5365	1500	5990
Banded each year				
17.50	5235	5580	1770	6895
26.25	5830	5740	1600	6370
35.00	5620	5140	1500	6640
43.75	5560	5730	1400	6955
Mean	5560	5730	1570	6715
LSD 0.05	NS	NS	NS	NS

Phosphorus status of the soil and residual effect of applied P

Continuous cropping was accompanied by a reduction in the level of available P in the soil (Fig. 1) although there were initial increases of P on the P treated plots at the end of the second cropping season. The decline in P availability on the 0, 70 and 105 kg P/ha broadcast plots was gradual especially on the control plots (Po) while the reduction resulting from the application of 140 and 175 kg P/ha was rather sharp. This trend could be explained by the 'A' - value concept (Fried & Dean, 1952) that the quantities of P absorbed from two sources (soil and fertilizer) will be in direct proportion to the amounts available. This indicates that more P would be expected to be taken up by the maize plant from the P fertilized plots, particularly those treated with higher than the lower rates as shown in Fig. 1. The available P increased initially at the end of the second cropping season by 20, 39, 150 and 233 per cent due to broadcasting 70, 105, 140 and 175 kg P/ha, respectively. This increase is possibly associated with the release of available P from mineralization of organic P contained in the litter and dead roots mixed with the surface soil as reported by Cunningham (1963). The trend observed could be also due to increased P concentration from the applied soluble monocalcium phosphate. Also, during the second cropping season, severe drought damaged the crops and could not probably absorb and utilize optimum amount of both the native and fertilizer phosphorus.

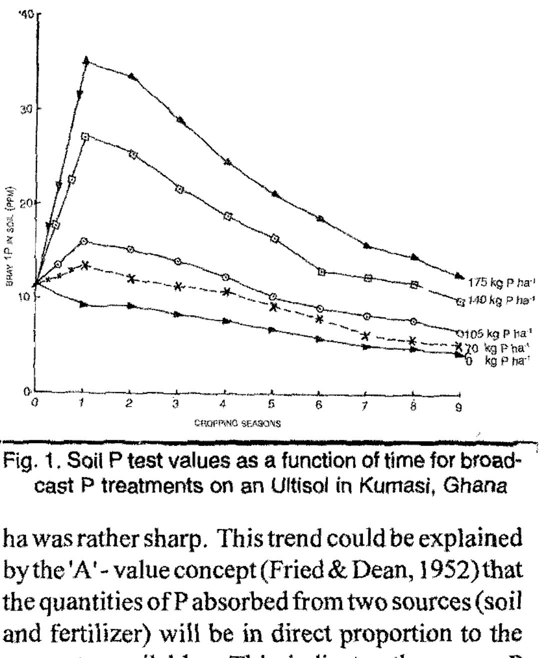

Fig. 1. Soil P test values as a function of time for broadcast P treatments on an Ultisol in Kumasi, Ghana

The initial increase in the available P was followed by sharp decline on the plots which received comparatively higher rates of P. Several reasons could be responsible for the rapid decline in P. Firstly, high levels of fertilization lead to increase in crop growth. There is thus increased uptake of P into both grain and straw. The P taken up was lost to the soil through crop harvest and crop residue removal at each harvest. Secondly, there might have been increased microbial growth resulting in immobilization of P. Thirdly, the occasional heavy rainfall at the experimental area could result in some P loss through leaching over a long period as the applied P was water-soluble. In addition, the exposure of the soil to high temperatures following clearing of the forest apparently accelerated the rate of organic matter decomposition leading to loss of available P through plant uptake and leaching.

Although grain yields following the fourth crop were substantially reduced, significant residual responses of maize to P application were obtained (Table 2). The very low level of the native P (control) and the relatively high content of the available P on the P treated plots might have accounted for the significant residual effect for the fifth, seventh, eighth and the ninth crops. The high residual effect of the broadcast P might be connected with the low P fixation capacity of the Kumasi Ultisol. Lathwell (1979), investigating the P responses on Ultisols, found out that the quantity of P required to give the Ghanaian Ultisol soil solution concentration of 0.1 ppm was low and ranged from 35 - 61 μg/g, indicating low P fixation capacity of the soil.

The lack of significant effect of the applied P on the sixth crop could be attributed to poor rainfall (290 mm) and its distribution during the growing period of the plants as against the normal rainfall (582 mm) for the eighth crop which was also a minor

TABLE 2

Residual Response of Maize (kg/ha) to Phosphorus Application

Kg P/ha applied	*Grain yield*					
	Crop					
	5	*6*	*7*	*8*	*9*	*Mean*
Control	2387 (0)a*	315 (0)a*	2133 (0)a*	1027 (0)a*	2099 (0)a*	1592 (0)a**
Broadcast						
70	2752 (365)ab	452 (137)a	2437 (403)abc	1167 (140)a	2336 (237)a	1734 (142)a
105	2922 (535)abc	495 (180)a	2306 (173)ab	1309 (282)ab	2445 (346)ab	1826 (234)ab
140	3271 (884)bcd	655 (340)a	2816 (683)bcd	1819 (792)bc	2978 (879) bcd	2308 (715)cd
175	3173 (786) bcd	565 (250)a	2762 (629)bcd	1996 (969)c	2873 (774)bcd	2274 (681)cd
Banded						
70	3708 (1321)d	693 (378)a	3083 (950)d	1854 (827)bc	2653 (554)abc	2398 (806)cd
105	3439 (1052)cd	760 (445)a	3029 (896)d	1980 (953)c	3418 (1319)d	2525 (933)d
140	3418 (1031)cd	768 (453)a	2818 (685)bcd	1485 (458)abc	3179 (1080)cd	2334 (741)cd
175	3084 (697)bc	486 (171)a	2606 (473)abcd	1527 (500)abc	2688 (589)bc	2078 (486)c

*, ** Means in a column followed by the same letter are not significantly different at 5 and 1per cent levels respectively.
( ) Figures in brackets denote yield increases over controls.

season crop.

At the end of the sixth crop, the level of the available P on the plots which received 70 and 105 kg P/ha broadcast had reduced below the critical level of 12 - 16 ppm estimated for maize in this study (Fig.1). This explains the relatively low residual effect with these treatments. When the P fertilizer was banded, the residual effect decreased as the rate increased but not significantly.

As the rate of P banded increased, the volume of soil phosphated should have correspondingly been increased to maintain approximately optimum P concentration in the soil solution. The same volume of soil receiving increasing amounts of P obviously created high P concentrations at the higher rates of application. The high P concentration in the fertilizer band could result in P toxicity and/or imbalance in NPK ratio which probably reduced the magnitude of the nutrients absorbed by the maize plants and consequently causing yield decline. Yost *et al.* (1979) in Brazil found large decreases in P uptake by maize when the volume of soil phosphated was only 12.5 per cent.

At comparatively lower rates of application (70 and 105 kg P/ha), the P banded showed significantly higher residual effect than when equal amounts of the fertilizer were broadcast. The overall residual effect of banded P was significantly superior to the broadcast application ($P = 0.01$). The reason for the above trend, according to Grunes (1959), is that when equal amounts of P are applied banded and broadcast, the concentration per unit of soil mass will be higher in the fertilizer band providing greater nutrient-supplying power than the broadcast fertilizer.

The band will, therefore, be more effective in maintaining optimum concentration of P in the soil solution. However, the results of this study have shown that the superiority of band to broadcast P is limited to only low rates of application as earlier observed by Welch *et al.* (1966) and Fox & Kang (1978).

Second direct effect of applied P

The results of grain yield reported in Table 3 showed highly significant direct effect of phosphorus applied broadcast to the tenth crop, but differences in yields among rates were not significant. The fertilizer applied banded seasonally to each crop for four continuous crops resulted in a highly significant effect. Again, increasing P rates did not significantly influence yield. This suggests low P requirement for maize on this soil.

Determining critical level for soil P

The relationship between extractable P and yields for the broadcast P treatments is shown in Fig. 2. According to Cate & Nelson's method (1965), the critical level of P for maize on this soil was estimated to be 12 ppm for the Bray 1. The broadcast rates of 70 and 105 kg P/ha supplied less than the critical level of P in the fifth and subsequent crops, while the higher rates of P maintained levels greater than the critical level for the same period. A similar observation was made by Yost *et al.* (1979) working with maize on a very P deficient Oxisol in Brazil. This study shows that at least 70 kg P/ha is needed to provide the critical P level for the first crop, while about 140 kg P/ha is required to maintain soil P above the critical soil test level to support nine consecutive crops. The above observation might have accounted for the higher residual effect with the 140 and 175 kg P/ha rates than the 70 and 105 kg P/ha rates applied broadcast.

It is concluded that this soil has a low P requirement for maize. Either an initial application rate of 70 kg P/ha broadcast once in four seasons or a low seasonal application rate of 17.5 kg P/ha banded to each of the first four crops may produce a mean yield of at least 90 per cent of maximum at 40 per cent of the fertilizer cost. However, it would require 140-175 kg P/ha broadcast once or 17.5 - 26.25 kg P/ha seasonally banded to each crop for four seasons to maintain adequate P in the soil if long residual effect of applied P is expected.

TABLE 3

Maize Yield (kg/ha) as Influenced by Rate and Method of Phosphorus Application

P levels (kg/ha)	*Crop*				
	10	*11*	*12*	*13*	*Mean*
Control	1214a*	2073a**	1701a**	1375a*	1591a**
Broadcast for first crop only					
70	2981b	3408b	2644bc	2098b	2783b
105	3489b	3568b	3022bc	2555bc	3158b
140	3462b	3443b	3221bc	3171c	3324b
175	3925b	3711b	3487c	3227c	3588b
Banded each year					
17.50	3137b	3466b	3322c	3130	3264b
26.25	3298b	3530b	3158bc	2517bc	3126b
35.00	3633b	3498b	2942bc	2327bc	3100b
43.75	3620b	3736b	2488ab	2958bc	3200b

* ** Means in a column followed by the same letter are not significantly different at 5 and 1per cent levels respectively.

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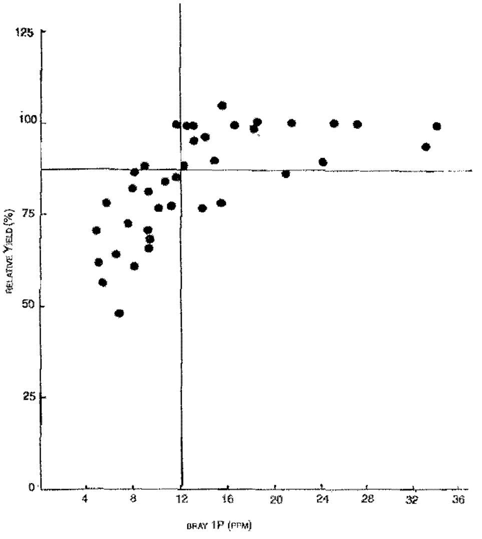

Fig. 2. **Critical level for Bray 1 extractable P based** on the broadcast treatment yields of nine consecutive maize crops on an Ultisol in Kumasi, Ghana.

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