Fertilizer Phosphorus Fractions and their Availability to Maize on different Landforms on a Vertisol in the Coastal Savanna Zone of Ghana

A. Abunyewa[1]*, E. K. Asiedu[2] and Y. Ahenkorah[3]
[1] *Savanna Agricultural Research Institute, P. O. Box 52, Tamale, Ghana. E-mail: akwasi_abunyewa@yahoo.com*
[2] *Soil Research Institute, Private Mail Bag, Kwadaso, Kumasi, Ghana*
[3] *Department of Soil Science, University of Ghana, Legon, Ghana*
**Corresponding author*

Abstract

A trial was conducted to investigate the fractionation and availability of fertilizer phosphorus to maize on a Vertisol on four different landform technologies in the coastal savanna zone of Ghana. The phosphorus fractions were determined through sequential extraction and correlated with bicarbonate extractable phosphorus and maize dry matter yield. Two main inorganic phosphate fractions, calcium bound phosphate which formed 75%, and iron bound phosphate, 2% of the total inorganic phosphate in the soil, were significantly influenced by the type of landform used. The calcium bound phosphate and the iron bound phosphate independently and significantly correlated with the total inorganic phosphate. The iron bound phosphate constituted the major phosphate fraction in the flat bed while calcium phosphate constituted the major phosphate fraction in the Ridge, Ethiopian and Camber beds. Addition of the fertilizer may have caused greater formation of iron-bound phosphate in the Flat and the Ridge beds than the Ethiopian and the Camber beds. Unlike aluminium-bound phosphate both calcium-bound and iron-bound phosphate independently correlated significantly with maize dry matter yield.

Introduction

The Vertisols of the Accra Plains, generally referred to as Tropical Black Earth, is classified as Calcic Vertisols (FAO/UNESCO, 1990). These soils occupy a total area of about 1,630 km^2 in the coastal savanna zone and 190 km^2 in the interior savanna of Ghana (Brammer, 1967; Adu & Stobbs, 1981). Though they constitute one of the productive soils, the major constraint affecting increased farming activities on these fertile soils include difficulty in tilling the soil, nutrient management problems and lack of technology for the conservation and the shedding of excess water.

The Vertisols in Ghana are derived from hornblende gneiss. The soil has total phosphorus (P_T) of 150-298 mg kg^{-1} and available phosphorus (P) content of 0.1-3.5 mg kg^{-1} (Acquaye & Owusu-Bennoah, 1989). Though Tandon & Kanwar (1984) considered Vertisols that contain less than 5.0 mg kg^{-1} $NaHCO_3P$ as deficient in available P, fertilizer trials on Vertisols in the coastal savanna zone of Ghana gave no significant response to P fertilizer application (Oteng, 1974). The lack of response to fertilizer P application on Vertisols could be attributed to various factors including high P sorption capacity of the soil, soil moisture conditions and, perhaps, P transformation into sparingly soluble forms.

To ensure successful cultivation of the Vertisols, various landform technologies have been developed (Jutzi & Abebe, 1987; Kanwar & Virmani, 1987). The landform technologies developed aim mainly at ensuring efficient drainage of excess water during the wet season and conserving adequate soil moisture for crop production. On the Vertisols of the coastal savanna zone of Ghana, improved crop yields were obtained on Camber bed (CB) and Ridge bed (RB) compared to Flat bed (FB) (Owusu-Bennoah & Dua-Yentumi, 1989; Dua-Yentumi *et al.*, 1992; Ahenkorah, 1995; Yangyuoru *et al.*, 2001).

Though calcium is the predominant cation in the Vertisols of the coastal savanna zone, water log conditions due to poor internal drainage could contribute to the prevalence of aluminium and reduced iron in soil solution (Russell, 1973; Acquaye & Owusu-Bennoah, 1989). The primary orthophosphate ions ($H_2PO_4^{2-}$) and/or secondary orthophosphate ions (HPO_4^{2-}) from the applied fertilizer may react with these cations (Ca, Fe and Al) to form various phosphate fractions. Finck & Venkateswarlu (1982) argued that because Ca is the dominant cation in the exchange complex of Vertisols, added P is usually transformed into Ca-P. However, according to Russell (1973), under poorly drained soil condition, iron-bound phosphate (Fe-P) and/or aluminium-bound phosphate (Al-P) may also be formed.

One of the goals for the introduction of various landform technologies is to ensure effective drainage of excess water and conserve adequate soil moisture for crop production. These landforms could influence the relative distribution of phosphorus fractions and their availability to the crop. An understanding of these changes that take place in different landforms on a Vertisol in the zone will be very important in fertilizer management and efficient crop production.

The objective of the study was, therefore, to determine relative distribution of inorganic phosphate fractions from applied phosphorus fertilizer and the availability of these fractions to the maize crop on the four landform technologies: Flat bed, Ridge bed, Ethiopian bed and Camber bed on a Vertisol in the coastal savanna zone of Ghana.

Materials and methods

Landform preparation, planting and agronomic practices

The four landform technologies used for the study were Flat bed (FB), considered as control, Ridge bed (RB), Ethiopian bed (EB) and Camber bed (CB) (Fig. 1). A tractor was used to plough and harrow the land. The FB was then leveled; the RB was prepared by a ridger mounted on a tractor; the EB by a tractor tool carrier for shaping the bed and the CB by a polydisc mounted on a tractor. The FB measured 7.5 m length × 4.8 m width; RB, 7.5 m length × 0.4 m width × 0.45 m height; EB, 7.5 m length × 1.6 m width × 0.45 m height and CB, 7.5 m length × 4.8 m width × 0.45 m height at the apex and slopes gently to a furrow (Fig. 1). Each of the raised beds had a furrow between two beds. Three levels of fertilizer were applied *viz.* 0, 50% and 100% of the rate recommended by Ministry of Food and Agriculture for maize production in the coastal savanna zone of Ghana (250 kg ha^{-1} NPK 15:15:15 compound fertilizer and 125 kg ha^{-1} urea applied as top dress). The experimental design used was split-plot with landform as main plot (7.5 m × 4.8 m) and fertilizer levels as sub plot. There were four replications per treatment.

Maize (*Zea mays* L.) was planted as a

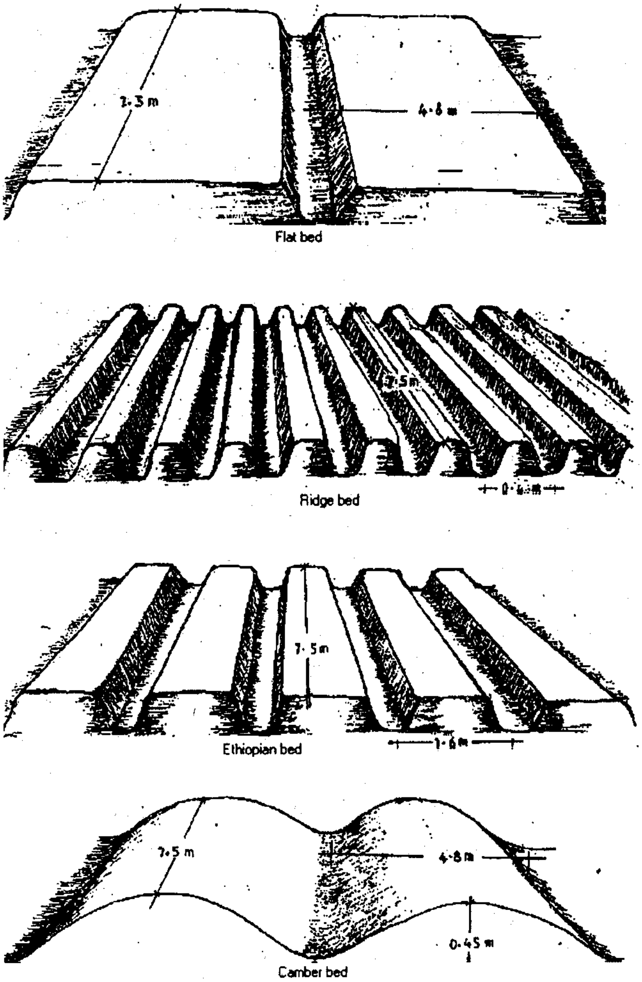

Fig. 1. Diagramatic representation of the four landforms on a Vertisol in the coastal savanna zone of Ghana.

test crop at a spacing of 80 cm × 40 cm. Two plants per hill were maintained after germination giving plant population of 62,500 plants ha^{-1}. The NPK fertilizer was applied 2 weeks after germination, and top-dressed with urea 8 weeks after germination by spot placement and covered with soil.

Chemical analyses

Soil samples were taken after land preparation (initial sampling) at maize tasselling stage and at harvest. The soil samples were air-dried and passed through a 2-mm mesh sieve. A 0.5-g sample of 2- mm sieved soil was digested with 4.4 ml digestion mixture (0.42 g selenium powder + 14 g lithium sulphate + 350 ml 30% hydrogen peroxide + 420 ml conc. sulphuric acid). The total N (N_T) and total P (P_T) concentration in the digest were determined as described in TSBF (1996). Soil organic phosphorus (P_O) was determined by the ignition method (Legg & Black, 1955). Soil available phosphorus was determined as described by Olsen *et al.* (1954). Soil inorganic phosphate fractions: calcium-bound phosphate (Ca-P), aluminium-bound phosphate (Al-P) and iron-bound phosphate (Fe-P) were determined as described by Chang & Jackson (1957). The phosphorus concen-tration in the various extracts were measured colorimetrically after Murphy & Riley (1962) as modified by Watanabe & Olsen (1965). Maize ear leaves were sampled at tasselling, while the stubble, cob and the grain were sampled at harvest. The maize samples were oven-dried at 70 °C for 48 h and stored separately. The oven-dried samples of maize grain were milled and 0.2 g sub-samples in duplicates were digested using sulphuric acid and hydrogen peroxide for the determination of total phosphorus as described in TSBF (1996).

Statistical analysis

Analysis of variance (ANOVA) was conducted on the data collected with the statistical programme MSTAT-C (Version

1.41, Michigan State University) and treatment means were separated where appropriate at $P < 0.05$ using least significant difference (LSD). Simple correlation and best subset regression analysis (Hocking, 1976) were used to establish association between yield and the phosphorus fractions.

Results and discussion

Soil physical and chemical properties

Initial analysis indicated that the soil was sandy clay (Table 1). The soil chemical properties were typical of Vertisols in the coastal savanna zone of Ghana (Brammer & Endredy, 1954; Acquaye & Owusu-Bennoah, 1989). The low level of organic carbon may be attributed to the low vegetative cover, the poor farming practices and the annual bush fire, which destroys the accumulated plant debris.

TABLE 1

Initial soil physical and chemical characteristics of a Vertisol in the coastal savanna zone of Ghana

Sand (%)	30.5
Silt (%)	18.7
Clay (%)	50.8
*p*H (0.01*M* $CaCl_2$	6.1
Organic carbon (%)	1.1
Total nitrogen (%)	0.131
Total phosphorus (mg kg^{-1})	362
Organic phosphorus (mg kg^{-1})	89.0
Available phosphorus (mg kg^{-1})	3.0
Calcium-bound phosphorus (mg kg^{-1})	23.5
Aluminium-bound phosphate (mg kg^{-1})	5.1
Iron-bound phosphate (mg kg^{-1})	0.24

Total phosphorus

The mean total phosphorus (P_T) content in the landforms during the growing period ranged from 380-418 mg kg^{-1} (Table 2). Neither the landform nor fertilizer application significantly influenced the P_T status of the Vertisol. Comparing P_T (between 830–920 kg ha^{-1} assuming plough layer of 2,200,000 kg soil ha^{-1}) to the level of fertilizer P applied, it was not surprising that fertilizer application did not influence P_T significantly. According to Ahmad & Jones (1969), P_T is more related to the parent material of the soils and, therefore, the variation in P_T observed between landforms may be due to the micro variability in the field. Apart from the soil organic phosphorus (P_O), which correlated significantly with P_T, the relationship between P_T and the inorganic P fractions were not significant (Table 3). The lack of significance between P_T and each of the various P fractions during the maize growing period could be attributed to the long period of time required for part of the P_T to mineralize and release P to the soil solution. The P_T content may, therefore, not be a good indicator of phosphorus availability to the maize crop on soils. This conforms to the non-significant correlation between P_T and maize dry matter yield (Table 4).

Organic phosphorus fraction

The soil organic phosphorus (P_O) constituted between 24-27% of the P_T, which falls within the range reported by Acquaye & Owusu-Bennoah (1989) on a similar Vertisol. At tasselling, P_O on the raised beds: Ridge bed (RB), Ethiopian bed (EB) and Camber bed (CB), were significantly higher than that of the Flat bed (FB) (Table 2). This may be due to the improved decomposition and mineralisation of organic residue as a result of improved aeration on the raised beds. The FB on the other hand experienced prolonged period of flooding, which may have resulted in poor aeration with subsequent reduction in decomposition and mineralisation. Though

TABLE 2

Soil phosphorus fractions in different landforms at maize tasseled and at harvest in a Vertisol at the coastal savanna zone of Ghana

Landform	P_T		P_O		Avail. P (mg kg^{-1})		Ca-P		Al-P		Fe-P	
	MT	MH	MT	MH	MT	MH	MT	MH	MT	MH	MT	MH
FB	398	399	92.44	96.86	3.66	3.13	27.93	23.90	5.39	5.50	1.09	0.31
RB	401	399	100.3	105.4	4.73	3.05	27.14	26.08	5.32	5.59	1.02	0.28
EB	380	418	97.50	97.88	4.67	3.23	28.47	24.17	5.45	5.42	0.89	0.26
CB	387	396	95.38	102.5	4.11	2.92	29.00	23.75	5.39	5.41	0.35	0.23
Mean	392	403	96.41	100.7	4.29	3.08	28.14	24.98	5.39	5.48	0.84	0.27
SE	8.799	8.374	1.291	1.522	0.151	0.103	0.566	0.336	0.076	0.043	0.036	0.019
CV (%)	6.93	13.92	4.85	8.05	11.38	22.92	12.14	7.39	6.26	10.50	22.31	35.22

P_T = Total phosphorus; P_O = Organic phosphorus; Avail. P = Available phosphorus;
Ca-P, Al-P and Fe-P = Calcium; Aluminum and Iron bound phosphate, respectively; MT = Maize tasseled, MH = Maize harvest

TABLE 3

Correlation matrix of soil phosphorus fractions in a Vertisol at tasseling age of maize in the coastal savanna zone of Ghana

	P_T	Avail. P	P_O	Ca-P	Al-P	Fe-P
P_T	-					
Avail. P	0.149	-				
P_O	0.418*	0.240	-			
Ca-P	0.205	0.319*	0.415*	-		
Al-P	-0.016	0.105	-0.025	0.045	-	
Fe-P	0.086	0.427*	-0.175	0.230	0.240	-

* Significant at $P < 0.05$
P_T = Total phosphorus; P_O = Organic phosphorus; Avail. P = Available phosphorus; Ca-P, Al-P and Fe-P = Calcium, Aluminum and Iron bound phosphate, respectively.

TABLE 4

Correlation coefficient of soil phosphorus fractions at tasseling on dry matter yield at harvest on a Vertisol in the coastal savanna zone of Ghana

P fractions	Leaf	Stubble	Cob	Grain
P_T	0.017	0.120	0.125	0.063
Avail. P	0.345*	0.349*	0.386*	0.377*
P_O	-0.206	0.033	0.040	0.102
Ca-P	0.373*	0.422*	0.631*	0.656*
Al-P	0.145	0.144	0.120	0.207
Fe-P	0.717*	0.608*	0.579*	0.510*

*Significant at $P < 0.05$
P_T = Total phosphorus; P_O = Organic phosphorus; Avail. P = Available phosphorus; Ca-P, Al-P and Fe-P = Calcium, Aluminum and Iron bound phosphate, respectively.

P_O was far greater than soil available P (bicarbonate extractable P), it did not correlate significantly with maize dry matter yield (Table 4). This is because P_O is released to soil solution after mineralisation and could contribute to maize uptake if P mineralisation and availability coincided with the crop's growing period. The apparent high P_O observed at harvest may be due to the presence of rootlets and other plant debris incorporated into the soil during weeding.

Inorganic phosphorus fractions

The soil available P was low (Table 1) and the application of fertilizer P resulted in significant increase in soil available P in all the landforms (Fig.2). Contrary to expectation, the highest soil available P in all the landforms at the tasselling age of maize occurred with the 50% fertilizer application (Fig. 2). According to Tisdale *et al.* (1990), concentrated phosphorus solution may cause the release of reactive cations such as Fe^{3+}, Al^{3+}, Mn^{2+}, Ca^{2+} and Mg^{2+}. The phosphorus in the solution reacts with these cations forming active inorganic phosphate fractions with varying solubility. The observed relatively lower soil available P at 100% fertilizer application may have resulted from higher P concentration in soil solution leading to higher P sorption and formation of more P complexes with the dissolved cations. Thus, higher rate of application of fertilizer phosphorus may lead to inefficient utilization as a high proportion of the applied

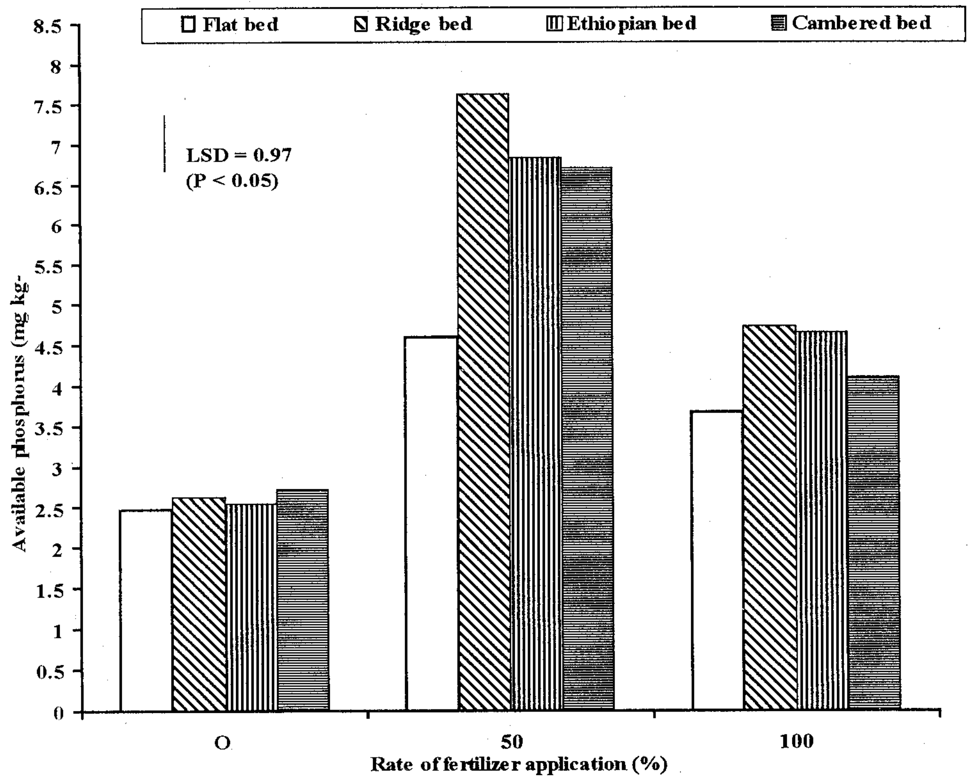

Fig. 2. Effect of different landforms and fertilizer application rate on soil available phosphorus at tasseling age of maize on a Vertisol in the coastal savanna zone of Ghana

P may be transformed to sparingly soluble forms and will not be readily available for the crop uptake (Abekoe & Sahrawat, 2003).

In general, not withstanding the fertilizer levels, the drop in available P at maize harvest was 17% in the FB, 55% in the RB, 45% in the EB and 41% in the CB over the corresponding levels at tasselling stage of maize. This trend indicates that the drop was more than two times in the raised beds than in the FB. Since P movement is minimal in soils, the drop in P levels could be attributed primarily to uptake by the maize crop and high P sorption capacity (Oteng, 1974; Tisdale *et al.*, 1990). In the raised beds, as a result of improved drainage, root development was enhanced resulting in higher P uptake, better growth and increase dry matter yield (Dua-Yentumi *et al.*, 1992; Abunyewa, 1996; Yangyuoru, *et al.*, 2001). At tasselling stage of maize, the soil available P correlated significantly ($P < 0.05$) with calcium-bound phosphate (Ca-P) and iron-bound phosphate (Fe-P) fractions (Table 3) and with dry matter yield (Table 4). Since Ca-P and Fe-P were not significantly correlated (Table 3), it can be argued that these two phosphate fractions contributed independently to the inorganic P in soil solution and also constituted the main source of P to the maize crop on Vertisols of coastal savanna zone of Ghana. The rainfall pattern during the growing period may account for the varying contribution of Ca-P and Fe-P to the inorganic P in soil on various landforms.

The soil Ca-P constituted 75% of the inorganic P fractions. Since Ca is the predominant cation on the exchange complex of these soils, most of the fertilizer P was transformed into Ca-P (Acquaye & Owusu-Bennoah, 1989). The soil Ca-P in the raised beds was significantly ($P < 0.05$) higher than that of the FB at all levels of fertilizer application (Fig. 3). Though differences in Ca-P in the raised beds were not significant, they follow a decreasing order of CB > EB > RB. This pattern follows closely what was observed in the efficiency of drainage and moisture conservation on a similar Vertisol (Asiedu, 1996). This suggests that soil P fractions may be influenced more by the landform than by any other factor. The soil Ca-P correlated significantly with dry matter yield of maize (Table 4), suggesting the significant role of Ca-P in maize nutrition on Vertisols. The fertilizer phosphorus applied may have been converted to soluble monocalcium phosphate $Ca(H_2PO_4)_2$ and other sparingly soluble calcium phosphate forms. The improved drainage and aeration on the raised beds ensured better root growth and development, which led to improve P uptake for higher dry matter yield. This may account for the relatively lower Ca-P at harvest in all the landforms (Table 2).

Soil Al-P was the next highest active inorganic P fraction after Ca-P, forming 16% of the total inorganic phosphate in the soil and varied slightly in content over the entire growing season (Table 2). Considering the fact that Al-P did not change significantly throughout the maize growing period and the weak correlation between Al-P and the dry matter yield (Table 4), this inorganic P fraction did not contribute to maize nutrition.

The soil Fe-P at tasselling was significantly ($P < 0.05$) influenced by both the landform and the fertilizer application (Fig. 4). At zero fertilizer application, the Fe-P in the FB and RB were significantly higher than that in EB and CB. At tasselling stage of maize, high rainfall and poor drainage on the FB and RB led to flooding and water logged

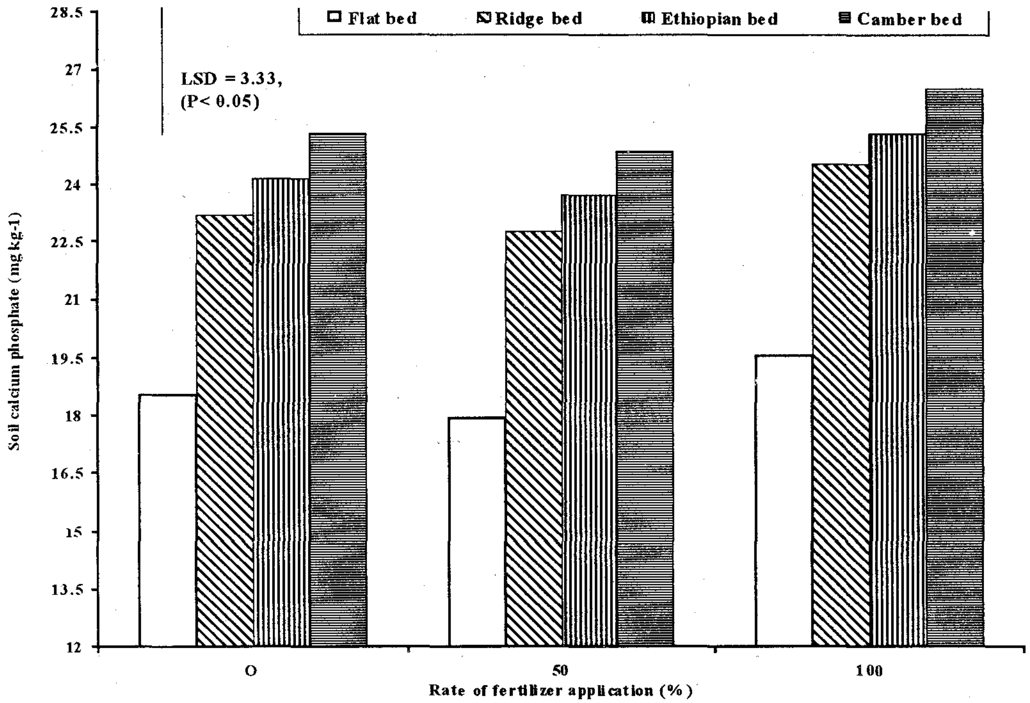

Fig. 3. Effect of different landforms and fertilizer application rate on soil calcium phosphate at tasseling age of maize on a Vertisol in the coastal savanna zone of Ghana

condition on these beds. This created poor soil aeration resulting in condition favorable for greater ferrous phosphate formation in the FB and RB compared to EB and CB. According to Russel (1973), under water logged condition crops make use of ferrous phosphate. However, the poor root growth and development on FB and RB at zero fertilizer application resulted in low nutrient uptake and stunted growth. On the other hand, addition of fertilizer ensured nutrient availability for improved root growth and development resulting in higher P uptake and dry matter production in all the landforms (Abunyewa, 1996). This may account for the significant ($P < 0.05$) drop of P in all the landforms with fertilizer application (Fig. 4).

Though rainfall was high at tasseling, the improved drainage on the EB and CB resulted in increased redox-potential with corresponding increase in aeration and oxidation, hence the low Fe-P in the two landforms (EB and CB). The improved root growth and development in the EB and CB which resulted in increased P uptake with the corresponding increase in dry matter yield may also have contributed further to the low Fe-P in these two beds. The low Fe-P at harvest could be attributed to uptake and perhaps the formation of insoluble ferric phosphate. The result of the Best subset regression analysis indicated that Fe-P was the second single best predictor variable ($R^2 = 13.7$) after landform which influenced dry matter production. These two variables (landform and soil Fe-P) accounted for 38% of the observed variations in grain

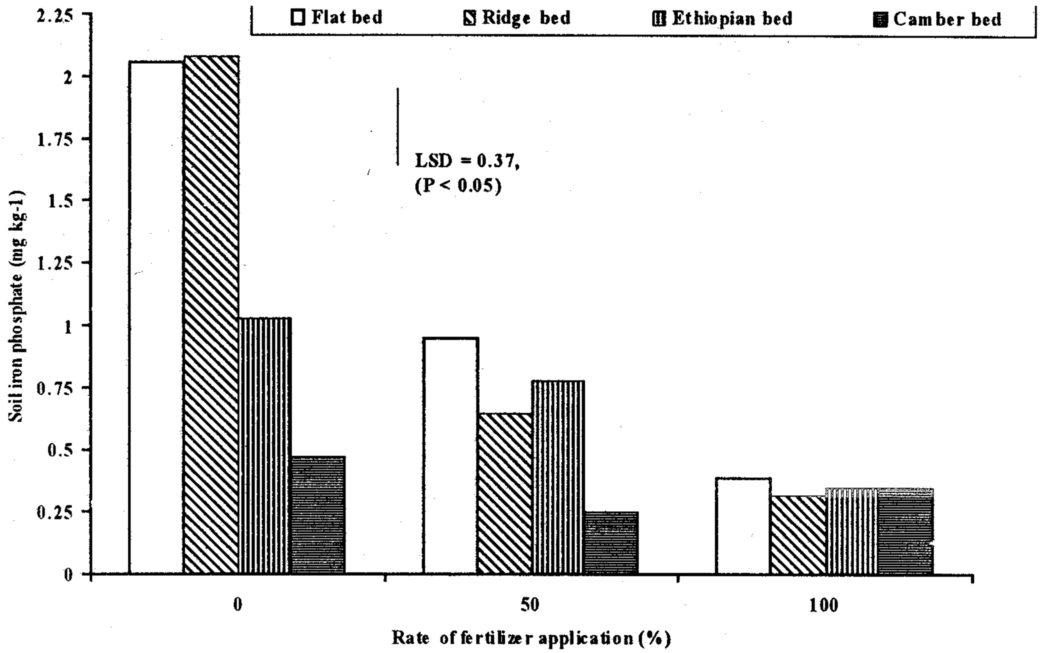

Fig. 4. Effect of different landforms and fertilizer application rate on soil iron phosphate at tasseling age of maize on a Vertisol in the coastal savanna zone of Ghana

yield (Table 5).

Conclusion

An appropriate landform to drain off excess water and conserve adequate soil moisture for plant growth and development could improve maize yield significantly. The improved soil moisture situation could reduce wastage in fertilizer P application, improve P uptake and ensure efficient nutrient utilization by the maize crop. From the study, landforms significantly influenced P fractions and their availability. The Camber bed (CB) had the highest amount of applied fertilizer phosphorus in solution for maize uptake, growth and development followed

TABLE 5

Best subset regression of maize grain yield on nine predictor variables at tasseling age of maize on a Vertisols in the coastal savanna zone of Ghana

Best subset of selected variables	*R^2 of selected variables*
Landform	14.3
Fe-P	13.7
Landform and Fe-P	37.6
Landform, Fe-P, fertilizer rate, avail. P, P_O, Ca-P	54.6
Landform, fertilizer rate, avail. P, P_O, P_T, Ca-P, Fe-P, Al-P.	54.7

P_T = Soil total phosphorus; P_O = Soil organic phosphorus; Avail. P = Soil available phosphorus; Ca-P, Al-P and Fe-P = Calcium, Aluminum and Iron bound phosphate, respectively.

by the Ethiopian bed (EB) with the Ridge bed (RB) and the Flat bed (FB) following in that order. For upland crops such as maize, CB at 50% recommended fertilizer would ensure efficient fertilizer P uptake and utilization for increase crop yield.

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