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Long Term Effects of Mineral Fertilisers, Phosphate Rock, Dolomite and Manure on the Characteristics of an Ultisol and Maize Yield in Burkina Faso

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Abstract

The effects of soil liming, mineral and organic fertilisation on soil characteristics and maize *(Zea mays)* productivity was studied in an Ultisol in the South Savannah zone of Burkina Faso. The experiments were carried out in Farakô-ba research station located in the South Sudanian zone at 11°6' N latitude, 4°20' W longitude and 405 m altitude. Two experimental designs were used. In a long-term experiment with different treatments of fertilizers, a single rate of 571 kg ha^{-1} of the local Kodjari phosphate rock (PR) containing 200 kg ha^{-1} CaO and 143 kg ha^{-1} P was applied the first year (1983). The liming effect of organic fertilisation was also evaluated with an application of 5 t ha^{-1} of manure every two years. In the second experiment, the liming effect of a local dolomitic limestone was tested with 3 rates of potassium (0, 30 and 60 kg ha^{-1} K_2O) in a split-plot design. The results of the long term experiment showed that mineral fertilisers might increase maize yield from 250 to 350% during the first 5 years indicating that nutrient deficiency is one of the main constraints that limit crop productivity. However, mineral fertilisers induced soil acidification and became less efficient after 5 years of cultivation. Manure increased and maintained mineral fertiliser effectiveness during 6 years of cultivation. Manure had a significant liming effect on soil acidity by increasing pH and reducing exchangeable acidity and Al saturation. PR increased exchangeable Ca, and base saturation. Soil liming with PR increased P availability, maize yield and mineral fertiliser effectiveness during 6 years of cultivation indicating that P deficiency is an important limiting factor in this soil. The critical soil fertility limit of available P (Bray I) for maize using Cate and Nelson graphical method was found to be 15.9 mg kg^{-1} soil. Dolomite also increased base saturation and soil pH and reduced Al saturation and exchange acidity. However, a significant interaction between dolomite and potassium fertiliser was observed. Dolomite effectiveness was affected by K rate. The higher yield of maize was obtained with 370 kg ha^{-1} of dolomite combined with 42 kg K ha^{-1} indicating that Ca, Mg and K ratios have to be considered when dolomite is used for soil liming.

Keywords: acidity, soil, phosphorus, manure, phosphate rock, dolomite, maize

Introduction

Agriculture in sub-Saharan Africa (SSA) is characterized by its poor productivity. Several factors related to soil fertility limit agricultural production. Many factors such as soil type, farmer's practices, crop residues and mineral fertilizers management influence crop yields. Alfisols, Oxisols and Ultisols dominate sub-Saharan Africa zones. The Sahel zone of West Africa is particularly covered with sandy acidic soils with low buffering capacities. Acidity in these soils is probably a consequence of parent sands derived from acid continental terminal deposits, strong paleoclimate and contemporaneous leaching and base-cycling processes (Wilding and Hossner, 1989). Majority of West African soils belong to the Alfisols soil order according to the United State Soil Taxonomy and Ferruginous tropical group in the French classification (Pieri, 1985). In the savannah zone with low rainfall (500 - 1000 mm annually), base leaching is limited; hence soils have relatively high soil pH and base saturation (Ssali *et al.*, 1985). Particularly Alfisols of

Savannah zone have a low inherent acidity (pH 6.0 to 6.5). Considering the pH values, West African soils are not excessively acid. However, soil acidity may rapidly increase with farmers cultural practices (Pieri, 1985). Traditional fallow system reduction due to population growth, intensive cropping, nutrient losses by erosion and runoff, cations Ca^{2+} and Mg^{2+} losses with nitrate leaching, all tend to induce acidification in low-buffered soils. So, the acidification of cultivated soils and P deficiency due to high P fixation could significantly affect crop yields.

Considering P deficiency and soil acidification induced by farmers practices, organic amendments, rock phosphates and dolomite are interesting alternatives that could be exploited to improve traditional farming system productivity in SSA. The objective of this study was to test PR and dolomite ability to alleviate both P deficiency and soil acidity constraints.

Materials and Methods

Two trails were established in the research station of Farakô-ba in Burkina Faso. The site is located in the South Sudanian zone at 11°6' N latitude, 4°20' W longitude and 405 m altitude. The average annual rainfall varies from 900 to 1000 mm. Ultisols and Alfisols are the main soil types of Farakô-ba. The two experiments were established on Ultisols. These soils have a low inherent acidity (pH 6.0 to 6.5), which may rapidly increase with cultural practices. The major properties of the soil are presented in Table 5.6. Before the establishment of the experiments, the land was under several years of fallow.

The dolomite effectiveness was studied in a randomised block design in a split-plot arrangement with six replications. The main plot treatments were four levels of dolomite (0, 100, 200 and 400 kg CaO ha^{-1}). The potassium was applied in the sub plots. Three levels of K (0; 21 and 42 kg K ha^{-1}) were applied. All plots received 16 kg P ha^{-1} in the form of triplesuperphosphate except the control. A uniform rate of 90 kg N ha^{-1} was applied on all subplots except the control. The N was applied in the form of urea and was split. Three splits were applied, with one third at the sowing, one-third 30 days after planting (DAP) and the last third 60 DAP. An improved maize variety SR 22 (120 days) was used at the recommended planting density of 62500 plants ha^{-1}.

PR liming effect was studied in a long-term experiment started in 1983. The experimental design was a randomised complete block design in a split-plot treatment arrangement with six replications. The main plot treatment was six levels of mineral, organic and organo-mineral fertilisers. The PR was applied in the sub plots. Two levels of mineral fertilisers (weak annual mineral fertilizer: 60N-10P-10K-6S-1B (fm) and high annual mineral fertiliser: 90N-15P-36K-9S-1.5B (FM) was applied alone or in combination with 5 tonnes ha^{-1} of manure every two years (fmo and FMO). The nutrients P, K, S and B were applied as NPKSB fertiliser and KCl. Nitrogen in the form of urea and NPKSB fertiliser was split. Three splits were applied, with one third at the sowing, one-third 30 days after planting (DAP) and the last third 60 DAP. Each main plot was split in two subplots and one of them received a basal application (1983) of 571 kg ha^{-1} of PR corresponding to 200 kg ha^{-1} CaO and 62 kg ha^{-1} P. The main characteristics of PR are presented in Table 5.1. On the two experiments all fertilisers were broadcast and incorporated.

An improved maize variety, IRAT 171 (120 days) was used at the recommended planting density of 62,500 plants ha^{-1}. The dates of planting varied according to the start of the rains. In general, plating was in June and harvesting occurred in November. The monthly rainfall distribution during the experimentation is showed in Table 5.2. Maize gain and stover yield were measured. Consistent with traditional practices, the crop residues were removed each year.

Table 5.1: Element content (%) of phosphate rock and dolomite

	Phosphate rock *	Dolomite
P_2O_5	25.5	-
Al solubility (HCl)	3.1	-
Fe_2O_3solubility HCl	3.4	-
CaO	34.5	35.5
F	2.5	-
SiO_2	26.24	-
MgO	0.27	19.0

* Source: Mc Clellan *et al* (1986)

Table 5.2: Monthly rainfall (mm) distribution during the crop cycle of the experiments

	Month						
Year	May	June	July	August	September	October	Total
1983	122	104	166	194	131	3	720
1984	102	104	123	274	157	13	773
1985	112	290	272	429	169	57	1329
1986	118	83	215	233	168	53	870
1987	43	151	199	372	74	22	861
1988	83	99	194	196	305	62	939
1989	59	126	155	366	144	41	891

In 1989, soil samples were taken after harvest from the top 20 cm depth of all subplots for chemical characterisation. Organic carbon was measured by the procedure of Walkley & Black (1934). Soil pH was measured in 1 N KCl using 2:1 solution to soil ratio and exchangeable acidity was measured using McLean method (1982). Exchangeable bases (Ca, Mg and Na) were displaced with NH_4O. Ca and Mg were determined by atomic absorption spectrometry, while K and Na were determined using flame photometry. The data were analysed as split-plot with SYSTAT using analysis of variance.

Results and Discussions

The effects of fertilisers and PR on maize yield are presented in Tables 5.3 and 5.4. Compared to the control, all treatments increased the maize yields. All Fertilisers improved maize grain and stover yields during the eight years of experimentation. The mineral fertilisers highly increased maize grain and stover yields particularly during the first four years. The highest yields of maize were obtained with the application of mineral fertilisers associated with organic manure. As showed by other works (Berger *et al.*, 1987; Pichot *et al*, 1981; Sedogo, 1981; Bationo and Mokwunge 1991; Bado *et al.*, 1997) these high responses to fertilisers may be explained by the poverty in nutrients and the low content in organic mater of west African weakly acidic Ultisols. So, all additions of fertilisers or high quality organic mater can significantly increase crop yields. As showed on Table 5.6, mineral fertilisers reduced soil base saturation and pH. They increase exchangeable acidity and Al saturation. Mineral fertilisers not only increased nutrients availability in soil but also increased soil acidity at the same time. This acidification effects of the mineral fertilisers are reduced or suppressed when manure was simultaneously applied with mineral fertilisers (Table 5.6), explaining the beneficial effect of organic and mineral fertilisers on soil fertility and maize yields. Similar results relative to the beneficial effect of the simultaneous application of organic amendments and mineral fertilisers on crop yields were also obtained by Sedogo (1981) and Bado *et al.* (1997).

The basal application of PR in the first year (1983) had a significant effect (<0.01) on maize grain yield, particularly during the first two years (Table 5.3). The PR also increased maize stover yield during the first three years (Table 5.4). The beneficial effect of the PR on maize yields may probably be due to it's effect on P availability and soil acidity. PR application involved an increasing of soil available P (Table 5.6). As indicated by the relationship between soil available P and maize yield calculated in 1989 using the data of all treatments, maize yield was significantly affected by soil P availability (Figure 5.1). Maize yields and P-Bray are related by positive correlations (<0,01) indicating that 94 % of maize yield variations were due to soil P availability. By using the graphical methodology of Cate and Nelson (1965) we saw that the critical limit of P-Bray I for maize production in this soil was 15.9 mg P kg^{-1} and 16.5 mg P kg^{-1} respectively for grain and stover yield indicating that P is an important limiting factor for maize yield in this soil as shown by Saharawat *et al* (1997) in Côte d'Ivoire.

Table 5.3: Effect of organic and mineral fertilizers and basal application of rock phosphate (only in 1983) on maize grain yield over six years (1983-1989)

		Organic and mineral fertilisers				
Year		Control	Weak mineral fertiliser (fm)	High mineral feriliser (FM)	fm + 5 t ha^{-1} manure	FM + 5 t ha^{-1} manure
	0 PR	505	1766	2159	1566	2175
1983	571 kg PR	1353	2413	1889	1775	2230
	PR (a)			*		
	Fertiliser(b)			**		
	a*b			*		
	0	294	2036	1901	1812	2486
1984	PR	1185	2730	3089	2397	3240
	PR*(a)			**		
	Fertiliser(b)			**		
	a*b			ns		
	0	847	2276	2994	2861	3242
1985	PR	1386	2247	2903	3224	3641
	PR*(a)			NS		
	Fertiliser(b)			**		
	a*b			ns		
	0	679	2413	2543	2758	3538
1986	PR	1263	2233	2985	2873	3428
	PR*(a)			NS		
	Fertiliser (b)			**		
	a*b			ns		
	0	453	2285	2796	1673	2857
1987	PR	1022	2310	3223	1867	2708
	PR*(a)			NS		
	Fertiliser (b)			**		
	a*b			ns		
	0	64	1108	1734	1308	2923
1988	PR	284	1160	2438	1745	3024
	PR*(a)			**		
	Fertiliser (b)			**		
	a*b			ns		
	0	35	472	869	479	1069
1989	PR	227	657	878	733	1203
	PR*(a)			NS		
	Fertiliser (b)			**		
	a*b			ns		

*, **, ns: indicate significant at 0.05, 0.01 probability or not significant (> 0.05)

Table 5.4: Effect of organic and mineral fertilizers and basal application of rock phosphate (only in 1983) on maize stover yield over six years (1983-1989)

		Organic and mineral fertilisers				
Year		Control	Weak mineral fertiliser (fm)	High mineral feriliser (FM)	fm + 5 t ha^{-1} manure	FM + 5 t ha^{-1} manure
	0 PR	1595	3328	3762	3086	4099
1983	571 kg PR	3424	4581	4292	3617	3906
	PR (a)			**		
	Fertiliser(b)			**		
	a*b			**		
	0	1109	3376	2893	2894	3906
1984	PR	1591	4003	3810	3231	3762
	PR*(a)			**		
	Fertiliser(b)			**		
	a*b			ns		
	0	1254	4128	4417	4552	4630
1985	PR	2083	4109	4900	4687	5112
	PR*(a)			*		
	Fertiliser(b)			**		
	a*b			ns		
	0	-	-	-	-	-
1986	PR	-	-	-	-	-
	PR*(a)	-	-	-	-	-
	Fertiliser (b)	-	-	-	-	-
	a*b		-	-	-	-
	0	1234	4687	4784	3974	4321
1987	PR	2180	4649	5035	3569	5343
	PR*(a)			NS		
	Fertiliser (b)			**		
	a*b			ns		
	0	249	1742	2656	2098	3583
1988	PR	532	1835	3351	2264	3313
	PR*(a)			NS		
	Fertiliser (b)			**		
	a*b			NS		
	0	260	1138	1428	776	1726
1989	PR	583	1205	1755	1635	2030
	PR*(a)			**		
	Fertiliser (b)			**		
	a*b			ns		

*, **, ns: indicate significant at 0.05, 0.01 probability or not significant (P> 0.05)

On the soil acidity parameters, the basal application of PR significantly reduced aluminium saturation (Table 5.6). The basal application of PR in 1983 had a residual effect on the reduction of Al saturation until 1989. By using the data of all treatments we found that soil pH and soil exchange acidity are related by a significant ($P<0.05$) exponential relationship (Figure 5.2).

Figure 5.1: Relationship between P-Bray I and maize grain yield

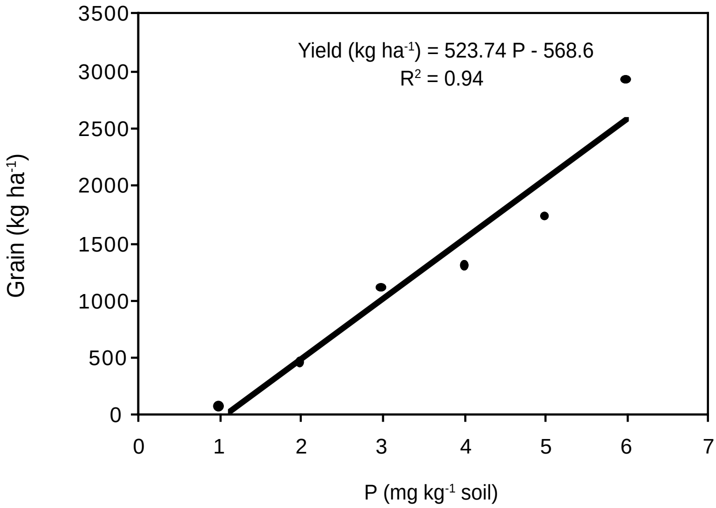
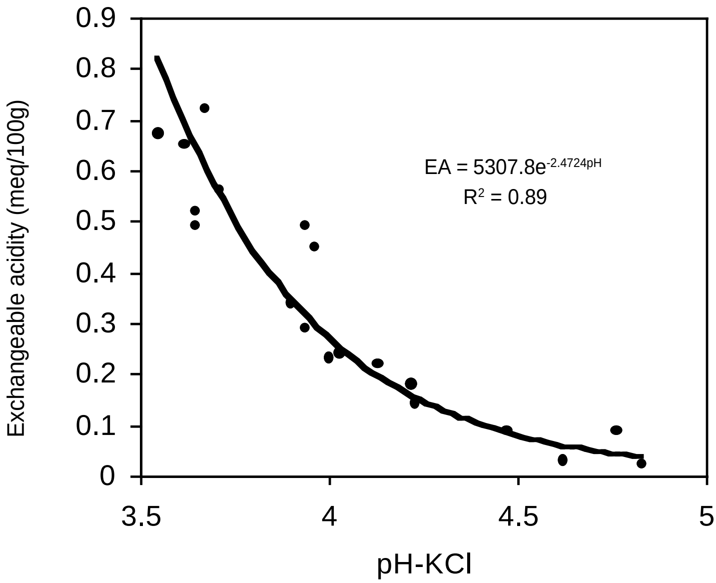


Figure 5.2: Relationship between soil pH and exchangeable acidity



The effects of dolomite and potassium on maize yields are presented in Table 5.5. Dolomite increased maize yields. The efficiency of dolomite was affected by potassium rates. When potassium wasn't applied, the highest yield of maize was obtained with 200 kg CaO ha^{-1}. Potassium had a significant effect on maize yield when it was applied at 42 kg K ha^{-1} indicating that Ca, Mg and K ratios are to be considered for a better use of dolomitic limestone as observed by Bado *et al*. (1993). The best combination of dolomite and potassium providing highest yield is 100 kg ha^{-1} CaO as dolomite combined with 42 kg K ha^{-1}.

Table 5.5: Effect of dolomite and potassium on maize grain yield (kg ha^{-1})

	Potassium (kg K ha^{-1})		
Dolomite (kg CaO ha^{-1})	0 kg ha^{-1}	21 kg ha^{-1}	42 kg ha^{-1}
0	3557 a	3284 a	3143 a
100	3831 a	3509 a	4736 b
200	4286 b	4293 b	3309 a
400	4140 b	4234 b	4493 b

Yields affected by the same letter are significantly different (P< 0.05).

Table 5.6: Effects of organic and mineral fertiliser and phosphate rock on soil characteristics after 9 years of maize cultivation.

	P-Bray I	pH-KCl	Al+H	Al sat. (%)	Ca	Mg	K	Bases	CEC
Control	4.9	4.2	0.22	11	0.38	0.32	0.12	0.98	1.20
Control + PR	10.5	4.2	0.16	8	0.40	0.28	0.12	0.96	1.12
fm	13.1		0.32		0.32	0.21	0.11	0.82	1.14
fm + PR	15.7		0.20		0.33	0.17	0.10	0.77	0.97
FM	19.4	3.8	0.38	26	0.18	0.19	0.14	0.68	1.06
FM+PR	23.2	3.8	0.35	20	0.33	0.21	0.16	0.86	1.20
fmo	14.5		0.22		0.32	0.27	0.14	0.91	1.13
fmo+PR	25.1		0.17		0.41	0.27	0.16	1.00	1.18
FMO	16.1	4.0	0.24	13	0.30	0.26	0.23	0.96	1.20
FMO+PR	24.4	4.1	0.20	8	0.39	0.29	0.18	1.00	1.23
Original Soil	4.4	4.3	-	9	0.63	-	-	1.48	1.71

Conclusion

In this weakly acid soil, low organic matter content and low nutrient content soil, particularly for P, mineral and organic fertilisers are the main constraints limiting maize yield. This explains the good response of maize to mineral fertilisers and organic manure applications. Mineral fertilizers alone may induce soil acidification, a decrease in exchangeable cations and an increase in aluminium dissolution. Thus, the decrease in productivity is associated to soil acidification as a consequence of soil organic matter declining due to long-term cultivation and crop residues exportation, bases absorption by plants and bases leaching over years. To solve these problems, an economic solution may be to use local agro mineral resources (rock phosphate and dolomite) to supply P and to correct soil acidification over time.

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