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Response of maize to partially acidulated Mekrou phosphate rock on ferralitic soils in the Mono region in Southern Benin.

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Summary

In this study, the agronomic efficiency of acidulated Mekrou phosphate rock from Benin was compared with pure rock and simple superphosphate on ferralitic soils in the Mono region. Two experiments were laid out, one at Zouzouvou in 1987 and one at Tulehudji in 1988 on soils containing respectively 2 and 4 ppm Bray-1-P.

Two methods were used in this evaluation: classical analysis of covariance for the 1987 and 1988 results and the determination of the Relative Efficiency indexes (RAE) by comparison of the regression coefficients of the response curves for 1988.

The analysis of covariance showed a highly significant (1 %) response to P sources on the two sites, but interactions with doses were not significant at the 5 % level in the two cases.

The RAE-values of phosphate rock and acidulated phosphate rock were respectively 2.50 % and 61.61 % of that of simple superphosphate, but no significant difference existed between acidulated rock and simple superphosphate.

Further studies should go deeper in the economics of the synthesis and application of the acidulated phosphate rock and its interaction with different soils.

Samenvatting

In deze studie, waarin de bemestingswaarde van gedeeltelijk aangezuurde Mekroufosfaatrots uit Benin op ferralitische bodems in het Mono-gebied in Benin werd vergeleken met ruwe fosfaatrots en enkelvoudig superfosfaat, werden twee proeven uitgelegd: één in Zouzouvou in 1987 en één in Tulehudji in 1988. Het Bray-1 extraheerbaar P in deze bodems bedroeg respektievelijk 2 en 4 ppm P.

In deze evaluatie werden twee statistische methoden gebruikt: de klassieke covariantie-analyse voor de resultaten van 1987 en 1988 en de bepaling van de relatieve bemestingswaarde (RAE) door de methode steunende op de vergelijking van de regressiecoëfficiënten voor de resultaten van 1988.

De covariantie-analyse toonde een hoog significante invloed (niveau 1 %) van de drie fosfaatbronnen op de twee plaatsen, maar een niet significante interaktie aan het 5 % niveau tussen P bronnen en dosissen.

De relatieve bemestingswaarde van fosfaatrots en verzuurde fosfaatrots bedroeg respectievelijk 2.50 en 61.61 % van deze van enkelvoudig superfosfaat. Het verschil tussen de geacidulleerde rots en het enkelvoudig superfosfaat was echter niet significant.

Verdere studies moeten dieper ingaan in de ekonomie van de synthese en de toepassing van deze fosfaatbron en de interaktie met de verschillende bodemtypen in Benin.

Introduction

The People's Republic of Benin disposes of phosphate ore which could be exploited for fertilizer production. The most promising Perimetre of South Marakire proved to contain reserves to a depth of 30m of 3.3 million tonnes, averaging 25.1 % P205 and underlying an area of 0.225 km² (17).

The use of adiculated phosphatic ores has several advantages (14) due to the transformation of a portion of the P in plant available form and the remainder in a form which could enhance residual value. The amount of acid is limited and rocks that are less suitable for the production of superphosphate can still be used.

In the literature, different methods for the evaluation of the relative effectiveness of alternative phosphorus fertilizers have been reported: the determination of the substitution rate (5), the comparison of the regression coefficients (slopes) for the whole response curves in semi-log form (12,16) and the linear part (slopes) of the curves, up to a dose where the quadratic coefficients become significant (2). This last expression is particular by useful in developing countries where only low fertilizer doses have to be considered.

Hammond et al. (11) have evaluated the agronomic value of unacidulated and partially acidulated phosphate rock indegenous to the tropics.

In Africa, a more systematic study was undertaken by the International Fertilizer Development Center (13) from 1982 till 1984, but Benin was not included in the program.

As no results were available on the effectiveness of local acidulated Mekrou phosphate rock, the Faculty of Agronomy started a research program to synthetise and evaluate this fertilizer source. This study reports the results on the evaluation of non-acidulated and acidulated rockphosphate from Benin using the method of comparison of the regression coefficients.

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Materials and methods

Characterisation of the fertilizer sources

The Benin phosphate ore is composed primarily of phosphate pellets and is cemented by silica. The rock is approximately 71% apatite with 23% silica, 1% goethite, and 2% aluminophosphates.

The apatite is a carbonate fluorapatite (francolite) composition with a low degree of carbonate substitution and therefore low reactivity (2% NAC P_20_5). The liberation size of this ore should be approximately 0.09 mm. The silica gangue could be removed by a number of flotation processes. The low R_20_3 + MgO/P_20_5* ratio (0.06) and low chlorine levels indicate that the ore or concentrate has good potential for use in a number of fertilizer processes. Table 1 gives the chemical composition of the ore.

TABLE 1

Chemical analysis of the Benin phosphate ore

Constituents	Weight	Constituents	Weight	Constituents	Weight
	%		%		%
P_2O_5	29.30	MnO	0.02	SO_4^{2-}	0.10
CaO	41.50	Na_2O	0.09	S	0.10
F	2.80	K_2O	0.03	Cl	51 ppm
SiO_2	22.60	TiO_2	0.01	Org C	0.10
Al_2O_3	0.81	SrO	0.20	Free H_2O	0.5 ab
Fe_2O_3	1.00	BaO	0.03	L.O.I.	2.5 ac
MgO	0.01	CO_2	1.30	N.A.C. P_2O_5	1.9 ad

a: not included in totals
b: Free water determined by heating 1 hour at 105°C
c: L.O.I. (loss on ignition): determined by heating 1 hour at 105°C
d Neutral ammoniumcitrate - soluble P_2O_5.

Synthesis of acidulated phosphate rock

Ten kg of finely grounded phosphatic rock was treated with 1.8 liters of 70% sulphuric acid (which corresponds to 20 kg 100% acid for 100 kg of rock). The acid was previously heated to 80°C and carefuly mixed with the phosphate rock obtained from the Mekrou region. The acidulated product was dried at 60-70°C on a hot plate and stirred daily for 10 minutes during a period of 7 days.

The product was not granulated. The procedure employed is well explained in a report by the U.S. Department of Agriculture and Tenessee Valley Authority (20).

The amount of sulphuric acid needed for the maximum acidulation of phosphatic rock can be calculated from the chemical composition of the rock using the data in table 1 and the formula:

A (kg sulphuric acid 100% per 100 kg of rock) = $(1.749 \times \% CaO) + (0.962 \times \% Al_20_3) + (0.614 \times \% Fe_20_3) + (2.433 \times MgO) + (1.582 \times \% Na_20) + (1.041 \times \% K_20) - (0.691 \times \% P_2O_5) - (1.225 \times \% SO_3) = 53.88$ kg H_2SO_4 100%.

As 20 kg of sulphuric acid 100% was used in this experiment and 53.88 kg sulphuric acid is necessary for maximum acidulation, we can conclude that a partially acidulated product was obtained.

The products were immediately analyzed before application using the Official CEE method (9) for water soluble, citric acid 2% soluble and mineral acid soluble P. Results are given in table 2.

Although labelled as having a P_20_5 content of 19%, the commercial phosphate used in the 1987 trial contained less than 93% of the P content mentioned on the bag as a water soluble form, and did not meet the requirements (8) for superphosphate.

TABLE 2

Water soluble, citric acid 2% soluble and P soluble in mineral acids of the phosphate sources.

Fertilizer	Water sol. P	Citric acid sol. P	Mineral acid sol P
	%	%	%
Phosphate Rock	0.02	2.76	12.90
Acidulated Rock	3.82	4.90	11.30
Commercial P	4.30	5.54	9.68
Single Supers	8.30	-	8.60

Source: laboratory of Agrochemistry, University of Ghent, Belgium.

Variety of maize

The maize variety planted was Piersabak 7930 SR, an improved variety with white grain and a short cycle of 90 days. It is resistant to lodging, rust, helminthosporiosis and streak. Yields under controlled conditions in experimental stations amount to 4.5 - 5 tons/ha.

Soils

The soils were located at Zouzouvou in 1987 and Tulehudji in 1988 and can be classified as an Isohyperthermic, mixed, fine loamy Typic Rhodostult in the USDA Soil Taxonomy and as Ferralitic Soils in the French Classification System (7).

Some chemical and physical characteristics of the soils are given in table 3. The soils are characterised by a high sand content, slightly acid reaction and a low P content when 10 mg/kg of P Bray-1 is considered as the norm at which 90% of the optimum maize yield can be obtained.

TABLE 3

Chemical and physical characteristics of the soils (0-25 cm).

Location	O M %	pHw	pH KCl	Bray-1 P mg/kg	CEC meq/100g	Sand %	Silt %	Clay %
Zouzouvou	1.17	6.3	6.2	2	4.00	86.60	4.96	8.11
Tulehudji	1.22	6.4	4.9	4	6.00	75.59	5.62	16.41

Climate in the area

The annual rainfall in the area is about 1000 mm with a bimodal rainfall pattern: two rainy and two dry seasons. The first season is from March till July and the second one during September-October. This area is less suitable for maize production (3).

In fact only in the first season where rainfall is superior to potential evaporation maize cultivation is possible without too much risk. Table 4 gives the mean monthly rainfall during the period 1950-1980 taken at Ouidah, 75 km South of the trial area. For the trial area itself at Djakotomey (5 km South of Zouzouvou) and Toviklin (5 km North of Tulehudji) only annual data are available. These data are given in table 5.

* $R_20_3 = Al_20_3 + Fe_20_3$

TABLE 4

Mean monthly rainfall at Ouidah from 1950 till 1980

Month											
J	F	M	A	M	J	J	A	S	O	N	D
mm											
12.2	26.5	81.4	120.6	180.1	331 9	134.8	46.6	75.7	126.5	40.1	13.2

Source: Chaillard H., 1985 (4).

TABLE 5

Yearly rainfall data for Djakotomey and Toviklin.

District	Aplohoue (Djkakotomey)		Kloukanme (Toviklin)	
Years	mm	number of days	mm	number of days
1978	1331	72	995	57
1979	1379	90	1256	71
1980	1169	67	1066	44
1981	921	67	1131	49
1982	796	62	824	47
1983	1102	64	—	—
1984	1222	76	986	74
1985	1126	70	1377	82
1986	903	61	927	70
Mean	1105		1070	
Stand.dev.	187		168	

Source: Carder Mono

Cultural Techniques

The design used is a complete randomised block design, replicated three times. No fertilizer has been applied to the soil for the last three years. It was freshly tilled at the moment of sowing to a depth of 10 cm with a hoe and pulverised which facilitates banding and covering of the fertilizer near the planting line. In fact minimum tillage has several advantages (1,6,15). Plot sizes were 5 × 5m.

At the sowing time, 30 kg N as urea (46% N) and 60 kg K_2O as potash muriate (50% K_2O) were applied as side-dressing (5 cm besides the sowing line and 5 cm deep). The four phosphate sources were applied at rates of 0,30,60 and 90 kg P_2O_5/ha in the same furrow.

As recommended (10,19), the N dose was split and 30 kg of N as urea was applied 45 days later in a furrow at the other side of the first fertilizer applications. As no estimations of volatile ammonia losses are known in the area, the fertilizer was each time covered.

Statistical analysis of the results

The differences between the different sources were evaluated with classical analysis of covariance, studying the interaction sources × linear and sources × quadratic effect.

A semilog function was used to describe the relationship between yield and rate of P_2O_5 applied from the various P-sources as follows:

$$Y_i = b_o + b_1 \, Ln \, x > o$$

To compare the relative agronomic affectiveness (RAE) to the various sources with respect to SSP, the RAE was defined as the ratio of the two slopes, i.e.,

$$RAE \, \% = \frac{b_i}{b_{SSP}} \times 100$$

$$t = \frac{b_1 - b_2}{\sqrt{(SE_1^2 + SE_2^2}} \quad \text{with 26 df.}$$

SE is the standard error on the regression coefficients.

The regression coefficients of the semi-log response functions were obtained by multiple linear regression using dummy variables.

Results and Discussion

Mean yields for the 1987 and 1988 season are given in table 6. As one treatment differs in 1987 and 1988 it is impossible to combine the results in the analysis of covariance.

TABLE 6

Mean yields of maize in kg/ha (14% moisture) as a function of phosphate sources and doses.

Source	0	30	60	90
1987				
Rock phosphate	2173	2491	2438	2597
Com. phosphate	-	3551	3710	3710
Acidul. phosph.	-	3419	3657	3366
1988				
Rock phosphate	2369	2121	2304	2268
Acidul. phosph.	-	2790	3005	3115
Single Supers	-	3172	3559	3810

Fertilizer effectiveness as evaluated by analysis of covariance

Analysis of covariance for the two years are given in table 7. In 1987 and 1988 no significant interactions between sources and linear and quadratic effects are observed, which means that there is no difference in the response functions of the three fertilizer sources at the 5% level, and one response function can be calculated, combining the three sources, although in 1988 the interaction S × L is significative at the 10% level. Further research might lead to significant interactions at the 5% level.

This analysis is very valuable because the whole response curve is considered.

The method that follows allows the calculation of an index for the relative fertilizer effectiveness (RAE) by comparison with a standard fertilizer, in this case simple superphosphate as in 1988.

Fertilizer effectiveness as calculated from regression coefficients.

As stated by McCune (18) comparison of the regression coefficients constitutes the most appropriate way to (i)see if the crop response to a fertilizer nutrient is significant or not, (ii) compare whether there are significant differences in crop responses to various fertilizer sources, and (iii) calculate the relative agronomic effectiveness (RAE).

After a logaritmic transformation of the doses has been done, a multiple linear regression was tested using dummy variables. Results are given in table 8. This equation gives three linear equations with common intercept, which are given in table 9.

TABLE 7
Analysis of covariance for the 1987 and 1988 results

Source	Year 1987 Sum of Squares	D.F.	Mean square	F-ratio	Year 1988 Sum of Squares	D.F	Mean Square	F-ratio
Treatment	10041472	9	1115719	4.5**	9075514	9	1008390	30.1**
Check vs. rest	2932810	1	2932810	11.9**	774092	1	774092	23.1**
Betw.sources (S)	6873200	2	3436600	13.9**	7461170	2	3730585	111.3**
Linear eff.(L)	22827	1	22827	0.1ns	605000	1	605000	18.0**
Interaction S x L	36749	2	18375	0.1ns	196553	2	98277	3.0ns
Quadratic eff.(Q)	37604	1	37604	0.2ns	35267	1	35267	1.1ns
Interaction S x Q	138200	2	69130	0.3ns	3427	2	1714	0.1ns
Block	1363501	2	681751	2.8	185786	2	92893	2.7
Error	4448205	18	247122		603486	18	33527	
Total	15853179	29			9864787	29		
				5% *	1% **			
			F(1.18) =	4.4	8.3			
			F(2,18) =	3.6	6.0			
			F(9.18) =	2.5	3.6			

TABLE 8
Calculation of the multilinear regression

Yi = B0 + B1 1nX1 + B2 1nX2 + B3 1nX3

Term	Coeff	St.Err	T.stat *	Part.Corr	Contr.R-sq
B0	2235.4	152.7	14.6	...	...
B1	0.737	44.2	0.02	0.01	0.00
B2	185.2	44.2	4.19	0.63	0.14
B3	299.1	44.2	4.76	0.80	0.36

*t = 2.05
27 0.05

	Sum SQ	Deg Fr	Mean SQ
Due to regression	7882236	3	2627412
About regression	2026108	26	77927.21
Total	9908343	29	341667

R-SQ: 0.80 Corrected R-SQ: 0.77
F-test: 33.7** St.Err. of Regr.. 279.2
**F3.26 - 0.05 = 2.96

TABLE 9
Response equations and RAE

Source	Equation	RAE ***
P.R.	Y1 = 2235 + 0.74 1n X1	2.50 b
A.F.	Y2 = 2235 + 185.18 1n X2	61.91 a
SSP.	Y3 = 2235 + 299.13 1n X3	100.00 a

***t 26 0.05 = 2.06

From table 8 follows that only the coefficients B2 and B3 are significantly different from 0 as indicated by the t-statistic. (t 27, 0.05) = 2.05, which indicates definite responses for the acidulated phosphate rock and simple superphosphate.

The F-test for the multiple linear regression indicates a significant multiple regression model. (F 3,26 0.05) = 2.96.

When comparing the regression coefficients B3 and B2 a «t» value of 1.82 is calculated. This value is not significant at the 5% level and 26 degrees of freedom (2.06).

The analysis indicates that the regression coefficients for acidulated phosphate and SSP are not significantly different, but these two are significantly different from the raw phosphate rock which means that the effectiveness of acidulated phosphate rock in terms of increasing crop yield per unit of P applied is equal in effectiveness to SSP but raw phosphate rock is only 2.50% effective when compared to SSP, independant of the level of P applied in the interval studied.

When comparing the raw rock phosphate with the acidulated one, we can conclude that a larger RAE goes along with a larger amount of citrate soluble P (table 2), which is in accordance with the observations of Leon et al. (16).

The results obtained are in agreement with those published by IFDC (13) for maize in West Africa on Ultisols. Finely grounded, untreated phosphate rock from Togo gave lower yields than acidulated rock phosphate using 50% of the acid required for maximum acidulation (PA50) and superphosphate, the latter two being equal in effectiveness. With 25% acidulation an intermediary product between phosphate rock and PA50 was obtained.

Conclusions

The results indicate that with simple means and less sulphuric acid than required for maximum acidulation, a very effective phosphatic fertilizer can be synthetised from local Mekrou phosphate rock in Benin. The acidulated product was superior to the unacidulated rock in 1988.

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