Direct and Residual Effect of Rock Phosphate from Mali on Upland Rice Grown on Acid Soil of the Humid Forest Zone in Côte D'Ivoire

Diatta, S., Kotchi, V. and ***Sahrawat K.L.***

West Africa Rice Development Association (WARDA)01 BP 2551
Bouake 01, Côte d'Ivoire

Abstract: About 70% of the upland rice in West Africa is grown in the humid zone. Phosphorus deficiency is the major nutrient constraint to upland rice growing on acid soils in the humid forest zone of West Africa. Our research on soluble P management in upland rice showed that although upland rice responds well to the application of soluble P, its efficacy decreases rapidly over time. In an experiment with upland rice on an Ultisol, the residual value of fresh P from soluble P source was drastically reduced within two years of its application, indicating that the soluble P was rendered unavailable by its reactions with iron and aluminium oxides. The cost of imported P fertilizers is prohibitively high and there is a need to explore the use of natural phosphate rocks for direct application to upland rice grown on Ultisols of the humid forest zone. It was hypothesized that on Ultisols from the humid forest zone, the rock P solubility would increase with time and upland rice would be able to utilize P from rock phosphate. A long-term experiment was initiated in 1998 on an Ultisol in the humid forest zone of Côte d'Ivoire to evaluate the efficacy of Mali rock P with upland rice as the test crop. Results showed that direct and residual effects of Mali rock phosphate alleviated P deficiency and improved the productivity of upland rice in Ultisol grown on West Africa.
Keywords: rock Phosphate, soluble P, humid forest, upland rice, Ultisols, acid soil, fertilizer P

1 Introduction

Acid-related soil infertility is the major constraint to crop production on low-activity clay soils in the humid forest zone of West Africa. Phosphorus is one of the major constraints to upland rice production on Oxisols and Ultisols (Sanchez and Salinas, 1981; Fageria *et al*., 1988; Sahrawat *et al*., 1995, 1998). Application of P combined with N increased significantly yields of acid-tolerant upland rice cultivars on Ultisols deficient in P (Mokwunye *et al*., 1986; Sahrawat *et al*., 1995, 1999). Population pressure has forced upland-rice farmer to reduce fallow periods, and expanded into new areas wherever possible. The process has reduced production potential, mined soil fertility, increased erosion and provoked a build up of weeds and other crop pests. Most modern upland varieties yield less than local varieties under these conditions. Farmers hardly use chemical fertilizers because of their high costs.

There is a need to look for cheaper alternative fertilizers locally produced in the region. Rock P is widely produced in Burkina Faso, Mali, Niger, Nigeria, Senegal and Togo.

2 Material and methods

A field experiment was conducted during four years (1998—2001) on an Ultisol of the humid forest zone at the CNRA (Center National de Recherche Agronomique) research station near Man (7.2º N, 7.4º W; 500 m altitude), Côte d'Ivoire to evaluate immediate and residual responses of five upland rice cultivars developed by WARDA (called NERICAs) to rock P. The annual rainfall is 2000 mm within a monomodal rainy season. The rainfall received during the cropping period (June-October) is shown in Table 1. The experimental site was a four year bush fallow before the started of the experiment.

2.1 Soil

The soil at the experiment is an Ultisol (low activity clay soil) with low pH and low available P. Soil samples were collected at the surface (0 m—0.2 m) and sub-surface (0.2 m—0.4 m) before starting the experiment. Samples were air-dried and ground to pass 2 mm screen before analysis. To determine organic carbon, total N and total P, samples were ground to pass 0.25 mm screen. Soil pH was measured with a glass electrode using a soil to water or 1 M KCl solution ratio of 1:2.5. Organic C was determined with Walckey-Black method and total N with Bremmer and Mulvany methods. Available P was determined using Bray 1. Table 2 shows physical and chemical characteristics of the soil.

Table 1 Rainfall received during the growing period (June-October)

Year	Rainfall (mm)
1998	1,688
1999	2,260
2000	1,771
2001	1,857

Table 2 Chemical and physical characteristics of the soil at the experimental site at Man, Côte d'Ivoire at the initiation of the experiment in 1998

Soil characteristics	Soil depth (m)	
	0—0.2	0.2—0.4
pH (water)	4.9	4.8
pH (KCl)	4.0	4.0
Organic C ($g \cdot kg^{-1}$)	13.5	10.0
Total N ($mg \cdot kg^{-1}$)	950	780
Total P ($mg \cdot kg^{-1}$)	155	125
Bray 1 available P ($mg \cdot kg^{-1}$)	2.8	1.8

2.2 Field experiment

The experimental site was cleared and the slashed vegetation was removed from the plots. Five upland rice cultivars comprising a sativa check (V1 = WAB56-104) and four interspecific cultivars (NERICAs) newly bred by WARDA (V2 = WAB450-1-B-P-38-HB; V3 = WAB450-11-1-P-40-HB; V4 = WAB450-11-1-P-40-1-H; V5 = WAB450-24-3-2-P-18-HB) were used. Two P sources were applied: (1) Mali rock phosphate was applied once in 1998 at rates 0 $kg \cdot ha^{-1}$, 150 $kg \cdot ha^{-1}$, 300 $kg \cdot ha^{-1}$, 450 $kg \cdot ha^{-1}$ P and residual effect was measured in 1999, 2000, and 2001; (2) Triple super phosphate (TSP) a P fertilizer was applied every year in 1998, 1999, 2000, and 2001 at rates 0 $kg \cdot ha^{-1}$, 50 $kg \cdot ha^{-1}$, 100 $kg \cdot ha^{-1}$, 150 $kg \cdot ha^{-1}$ P. Nitrogen and potassium were applied annually at 100 $kg \cdot ha^{-1}$ in all plots to meet the plant needs. Nitrogen was applied in three splits at planting, tillering and booting stages of the crop. The plot size was 5 m $\times$ 3 m. A factorial trial (variety and P sources) with a randomized complete block design was used with three replications. Grain yield was recorded at 14% moisture content.

3 Results and discussion

3.1 Grain yield response to fertilizer P and its residues

Without P application the five rice cultivars gave yields ranging from 0.75 $t \cdot ha^{-1}$ to 1.71 $t \cdot ha^{-1}$ in 1998, 0.42 $t \cdot ha^{-1}$ to 1.16 $t \cdot ha^{-1}$ in 1999, 0.42 $t \cdot ha^{-1}$ to 0.99 $t\ ha^{-1}$ in 2000, and from 0.38 $t\ ha^{-1}$ to 0.92 $t \cdot ha^{-1}$ in 2001. During the first year, the five rice cultivars showed a significant response to rock phosphate with WAB450-11-1-P-40-I-H responding most (2.67 $t \cdot ha^{-1}$), followed by WAB450-1-B-P-38-HB (2.51 $t \cdot ha^{-1}$), WAB450-11-1-P40-HB (2.26 $t \cdot ha^{-1}$), WAB450-34-3-2-P-18-HB (2.13 $t \cdot ha^{-1}$), and the check WAB56-104 (1.38 $t \cdot ha^{-1}$) (Table 3). The response to first residual P (1999) after P application in 1998 was significant, but lower than the first-year response in all the four varieties except the check. The grain yield response to second residual P (year 2000) was very weak due to insect and disease attack. The response to third residual P (year 2001) indicated the same trend as in 1999 and the grain yield was more than 1 t ha^{-1} for all varieties. WAB450-11-1-P-40-HB gave the greatest yield, followed by WAB56-104, WAB450-B-P-38-HB, WAB450-34-3-2-P-18-HB, and WAB450-11-1-P-40-I-H. Three years after rock phosphate application on an acid soil, results show a positive and sustainable residual response of NERICAs to rock P residual effect. NERICAs gave higher yield than the check WAB56-104.

The grain yields response functions for the five cultivars for different years were described by the following equations where Y is the yield kg· ha^{-1} and X the level of P rock phosphate (kg ha^{-1}) applied only in 1998. Equations 1 to 20 indicate that the response of all tested NERICA cultivars was described by a quadratic function with both fresh (1998) and residual P effect (1999, 2000, 2001). These results indicated that quadratic slopes of residual P effect decrease slowly. These slopes vary from one variety to another.

Cumulative effect of soluble P (TSP) was similar to fresh and residual effect of rock phosphate (Table 4). The grain yield functions were described by a quadratic equation for all varieties except WAB450-11-B-P-38-HB and WAB450-24-3-2-P-18-HB, which gave linear functions respectively in 1998 and 2001.

WAB56-104

1998: $Y = -0.0064X^2 + 4.1X + 795$ $R^2 = 0.86$ (1)

1999: $Y = -0.006X^2 + 3.94X + 1036$ $R^2 = 0.95$ (2)

2000: $Y = -0.0039X^2 + 2.3167X + 467$ $R^2 = 0.99$ (3)

2001: $Y = -0.0038X^2 + 2.5267X + 879$ $R^2 = 0.86$ (4)

WAB450-I-B-P38-HB

1998: $Y = -0.0086X^2 + 6.66167X + 1262$ $R^2 = 0.99$ (5)

1999: $Y = -0.0099X^2 + 6.35X + 607.5$ $R^2 = 0.93$ (6)

2000: $Y = -0.0059X^2 + 3.4967X + 484$ $R^2 = 0.92$ (7)

2001 : $Y = -0.0026X^2 + 1.8367X + 935$ $R^2 = 0.93$ (8)

WAB450-II-I-P40-HB

1998: $Y = -0.0048X^2 + 3.3833X + 1657$ $R^2 = 0.83$ (9)

1999: $Y = -0.0081X^2 + 5.8567X + 1108$ $R^2 = 0.93$ (10)

2000: $Y = -0.0033X^2 + 1.9X + 705$ $R^2 = 0.99$ (11)

2001 : $Y = -0.0048X^2 + 3.81X + 611$ $R^2 = 0.99$ (12)

WAB450-II-I-P40-I-H

1998: $Y = -0.005X^2 + 4.433X + 1696$ $R^2 = 0.99$ (13)

1999: $Y = -0.0149X^2 + 8.0467X + 952$ $R^2 = 0.94$ (14)

2000: $Y = -0.0044X^2 + 2.0133X + 767$ $R^2 = 0.92$ (15)

2001: $Y = -0.0063X^2 + 3.5633X + 729$ $R^2 = 0.95$ (16)

WAB450-34-3-2-P18-HB

1998: $Y = -0.0081X^2 + 5.8567X + 1103$ $R^2 = 0.97$ (17)

1999: $Y = -0.0087X^2 + 5.9133X + 467$ $R^2 = 0.93$ (18)

2000: $Y = -0.0044X^2 + 3.04X + 481$ $R^2 = 0.68$ (19)

2001: $Y = -0.0042X^2 + 3.82X + 403$ $R^2 = 0.98$ (20)

3.2 Residues and cumulative P sources (rock P and soluble P) effects on available P

Our results showed a positive effect of rock phosphate and soluble fertilizer P on concentration of available P in the soil (Table 5). In 1999 and 2000, there was a positive increase of available soil P following the applied P rates (Table 5), two to five times higher than in the check (1998). Rock phosphate was arithmetically higher than the cumulative soluble P in 1999. In 2000 and 2001, cumulative P fertilizer (TSP) gave higher available P soil content than residual rock phosphate (Table 5).

4 Conclusion

The residual effect of P rock phosphate was highly beneficial to grain yield and soil available P content. After three years, results indicate sustainable residual response of NERICAs to rock P. Rock phosphate can also be used as an alternative to improve Alfisol and Ultisols available P content in the humid forest zone.

Table 3 Response of four upland NERICAs and one sativa cultivar (WAB56-104) to fresh rock phosphate in 1998 and to residual P in 1999, 2000, and 2001 in a long-term experiment on an Ultisol of the humid forest zone in Côte d'Ivoire

P rate (kg· ha^{-1})	Grain yield (t· ha^{-1})				
	1998	1999	2000	2001	Mean
		WAB56-104			
0	0.75	1.01	0.47	0.85	0.77
150	1.40	1.57	0.72	1.26	1.24
300	1.31	1.60	0.82	1.21	1.24
450	1.38	1.62	0.72	1.28	1.25
LSD (0.05)	0.589	0.475	0.431	0.170	0.416
		WAB450-1-B-P-38-HB			
0	1.26	0.58	0.51	0.92	0.82
150	2.07	1.42	0.80	1.20	1.37
300	2.47	1.54	1.08	1.21	1.58
450	2.51	1.49	0.84	1.26	1.52
LSD (0.05)	1.134	0.740	0.430	0.382	0.672
		WAB450-11-1-P-40-HB			
0	1.61	1.16	0.71	0.60	1.02
150	2.20	1.65	0.90	1.11	1.02
300	2.10	2.29	0.99	1.29	1.51
450	2.26	2.05	0.88	1.37	1.64
LSD (0.05)	0.517	0.652	0.298	0.359	0.456
		WAB450-11-1-P-40-I-H			
0	1.71	0.99	0.78	0.71	1.05
150	2.21	1.71	0.93	1.18	1.51
300	2.62	2.14	1.01	1.17	1.49
450	2.67	1.52	0.76	1.07	1.50
LSD (0.05)	0.920	1.283	0.448	0.638	0.822
		WAB450-34-3-2-P-18-HB			
0	1.07	0.42	0.42	0.38	0.573
150	1.90	1.30	1.02	0.95	1.29
300	2.03	1.32	0.81	1.10	1.32

450	2.13	1.42	1.01	1.29	1.46
LSD (0.05)	0.875	0.464	0.570	0.652	0.640

Table 4 Response (t ha^{-1}) of four upland NERICAs and one sativa cultivar (WAB56-104) to cumulative soluble P fertilizer in a long-term experiment (1998—2001) on an Ultisol of the humid forest zone in Côte d'Ivoire

Prate (kg· ha^{-1})	Grain yield (t· ha^{-1})				
	1998	1999	2000	2001	Mean
			WAB56-104		
0	0.75	1.01	0.47	0.85	0.77
50	1.33	1.52	0.74	1.29	1.22
100	1.78	1.77	0.71	0.88	1.28
150	1.81	1.55	0.45	1.01	1.21
LSD (0.05)	0.306	0.712	0.383	0.496	0.474
			WAB450-1-B-P-38-HB		
0	1.26	0.58	0.51	0.92	0.80
50	2.06	1.81	0.95	1.11	1.48
100	2.25	1.71	0.74	1.29	1.50
150	2.62	2.04	0.99	1.37	1.76
LSD (0.05)	0.338	0.659	0.242	1.062	0.575
			WAB450-11-1-P-40-HB		
0	1.61	1.16	0.71	0.60	1.02
50	2.22	1.72	0.93	1.48	1.59
100	2.58	2.22	0.84	1.24	1.72
150	2.83	2.22	0.85	1.26	1.79
LSD (0.05)	1.012	1.144	0.432	0.522	0.780
			WAB450-11-1-P-40-1-HB		
0	1.71	0.99	0.78	0.71	1.047
50	2.10	1.76	0.73	1.10	1.42
100	2.61	2.46	0.68	1.15	1.73
150	2.61	1.77	0.72	1.11	1.55
LSD (0.05)	1.363	0.991	0.478	0.354	0.453
			WAB450-34-3-2-P-18-HB		
0	1.07	0.42	0.42	0.38	0.57
50	1.72	1.26	0.76	0.90	1.16
100	2.02	1.50	0.78	0.97	1.32
150	2.25	1.54	1.00	1.57	1.59
LSD (0.05)	1.083	0.391	0.316	0.422	0.553

Table 5 Effect of rock phosphate and soluble P fertilizer on available P (Bray 1) in an Ultisol in the humid forest zone in Côte d'Ivoire

Year	Available P soil content (ppm) at 0—20 cm depth									
	Rock phosphate (residual effect 1999)					Triple super phosphate (cumulative effect)				
	0	150	300	450	Mean	0	50	100	150	Mean
1998	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
1999	4.3	8.3	13.5	9.5	8.9	4.3	7.5	12.0	8.5	8.1
2000	5.4	8.4	12.3	16.5	10.6	5.4	10.5	19.7	23.4	14.7

2001	5.1	10.7	11.5	16.7	11.00	5.1	10.7	20.1	28.1	16.00
Mean	4.4	7.5	12.3	11.4	8.9	4.4	7.9	13.6	15.7	10.4

References

[1] Sanchez, P.A., Salinas, J.G. 1981. Low Input Technology for Managing Oxisols and Ultisols in Tropical America. Adv. Agron. 34, 280-406.

[2] Mokwunye, A.U.; Chien, S.H.; Rhodes, E. 1986. Phosphate Reactions with Tropical African Soils. In Management of Nitrogen and phosphorus in Sub-Saharan Africa; Mokwunye, A.U.; Vlek, P.L.G. eds. Martinus Nijoff: The Hague, 253-281.

[3] Sahrawat, K.L., Jones, M.P., Diatta, S. 1995. Response of Upland Rice to Phosphorus in an Ultisol in the Humid Forest Zone of West Africa. Fert.Res41, 11-17.

[4] Sahrawat, K.L., Jones, M.P.; Diatta, S. 1999. Phosphorus, Calcium, and Magnesium Fertilization Effect on Upland rice in an Ultisol. Commun. Soil Sci. Plant Anal. 30, 1201-1208.

[5] Sahrawat K.L., Jones, M.P.; Diatta, S. 1999. Phosphorus, Calcium, and Magnesium Fertilization Effects on Upland Rice in an Ultisol. Comun. Soil Sci. Plant Anal. 320, 1201-1208.

[6] Sahrawat K.L., Jones, M.P., Diatta, S. 2000. The Role of Tolerant Genotypes and Plant Nutrients in the Management of Acid Soil Infertility in Upland Rice. Management and Conservation of Tropical Soils for Sustainable Crop Production, Proceedings of a Consultants Meeting Organized by Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, Vienna, March 1-3, 1999, IAEA-TECHDOC1159; International Atomic Energy Agency (IAEA): Vienna, Austria, 29-43.

[7] Sahrawat, K.L., Jones, M.P., Diatta, S. 1997. Extractable Phosphorus and Rice Yield in an Ultisol of the humid Forest Zone in West Africa. Comun. Soil Sci. Plant Anal. 28, 711-716.

[8] Sahrawat, K.L., Jones, M.P.; Diatta, S. 1998. Plant Phosphorus and Rice Yield in an Ultisol of the Humid Forest Zone in West Africa. Comun. Soil Sci. Plant Anal. 29, 997-1005.

[9] Sahrawat, K.L., Jones, M.P., Diatta, S. 2001. Response of Upland Rice to Fertilizer Phosphorus and its Residual Value in an Ultisol. Comun. Soil Sci. Plant Anal. 32 (15 & 16), 2457-2468.

[10] Bremner, J.M., Mulvaney, C.S. Nitrogen-Total. In Methods of Soil Analysis, Part 2; Page, A.L., Miller R.H., Keeney, D.R. eds. Agron. N_0 9, American Society of Agronomy: Madison WI, 1982, 403-430.

[11] WARDA, 1990. Soil Nutrient Deficiency Studies, Annual Report 1990; West Africa Rice Development Association (WARDA): Bouaké, Côte d'Ivoire, 24-25.