Published March, 1990

Critical Phosphorus Levels for Corn and Cowpea in a Brazilian Amazon Oxisol

T. J. Smyth* and M. S. Cravo

ABSTRACT

Phosphorus soil test interpretations in the Brazilian Amazon currently do not account for differences in P requirements among crops and lack information on the changes in available soil P per unit of applied fertilizer P. A long-term P experiment in a Xanthic Hapludox near Manaus, Brazil was used to determine soil and leaf P critical levels for corn (*Zea mays* L.) and cowpea (*Vigna unguiculata* L.). A total of six corn crops were planted in annual rotation with five crops of cowpea during five consecutive years. Critical levels were established by a segmented linear regression, a linear plateau, of relative crop yields on soil test or leaf P concentrations for each crop species. Mehlich 1 (1:10) critical P levels were 6 and 8 mg kg^{-1} for corn and cowpea, respectively. Relationships between soil test P and crop yields were similar for fertilizer P placement as either broadcast and/or frequent bands. Fertilizer P required to raise the initial Mehlich 1 soil P to the critical levels were 41 and 60 kg P ha^{-1} for corn and cowpea, respectively. Higher amounts of P were extracted by Bray 1 than by Mehlich 1, but both extractants were effective in relating available soil P to yield and applied fertilizer P. Critical foliar P concentrations for corn and cowpea were 1.6 and 1.8 g kg^{-1}, respectively. Higher soil and leaf P critical levels for cowpea relative to corn were attributed to greater P requirements for plants depending on symbiotic N_2 fixation for their N supply.

LARGE AREAS OF THE AMAZON have soils with low P availability and the capacity to sorb large amounts of fertilizer P (Cochrane and Sanchez, 1982; Singh et al., 1983). Economic considerations often require judicious management of P fertilizer inputs to such soils. Fertilizer P recommendations depend on a knowledge of (i) the existing level of available soil P, (ii) the optimum level of soil P for the crop to be grown and (iii) the level of fertilizer which must be added to raise available soil P to the optimum level (Kamprath and Watson, 1980). Current recommendations for the Brazilian Amazon are based on a Mehlich 1 (1:10 soil/solution) critical P level of 30 mg P kg^{-1} (Cruz et al., 1982). Information is needed as to how this value changes among major crops and the quantities of fertilizer P required to achieve optimum P levels in different soils for the region. Long-term effects of P rates and placement on yields for 11 consecutive crops of corn and cowpea, grown in a Brazilian Amazon Oxisol, were described in a separate paper (Smyth and Cravo, 1989). In this paper we compare soil and leaf P critical levels among the two species, and determine the relationship between applied fertilizer P and available soil P for the Oxisol under investigation.

T.J. Smyth, Dep. Soil Sci., North Carolina State Univ., Raleigh, NC 27695-7619; and M.S. Cravo, EMBRAPA/UEPAE de Manaus, Manaus, Amazonas, Brazil. Joint contribution of the North Carolina Agric. Res. Serv. Journal Series no. 12071 and EMBRAPA/UEPAE de Manaus. This work was supported by EMBRAPA, the Potash & Phosphate Inst. Found. for Agric. Res., the Rockefeller Foundation and the U.S. AID. Received 23 Mar. 1989. *Corresponding author.

Published in Agron. J. 82:309–312 (1990).

MATERIALS AND METHODS

The experiment was conducted in a Xanthic Hapludox (clayey, kaolinitic, isohyperthermic) at the Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA) Experiment Station located 30 km north of Manaus, Amazonas. Following slash and burn clearing of the primary forest vegetation, Mehlich 1 extractable P was raised from 2 to 6 mg kg^{-1} (Smyth and Bastos, 1984). Treatments consisted of broadcast and banded rates of fertilizer P (as triple superphosphate) arranged in a split-plot factorial combination with four replications in a randomized complete block design. Main plots contained five broadcast P rates (0, 22, 44, 88 and 176 kg P ha^{-1}) applied once before planting the initial crop., Subplots contained four banded P rates (0, 11, 22 and 44 kg P ha^{-1}), applied to each crop 5 cm below the seed. Banded P applications were discontinued when total P by this placement method reached 176 kg ha^{-1}. Treatments with banded rates of 11, 22, and 44 kg P ha^{-1}, therefore, received 11, 8, and 4

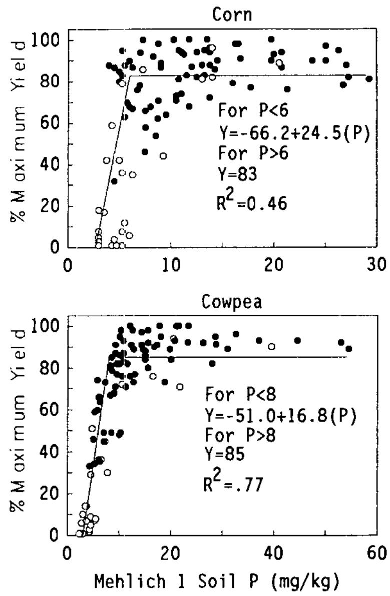

Fig. 1. Observed (symbols) and predicted (lines) relationships between yields and Mehlich 1 soil P for five crops each of corn and cowpea. Open and solid symbols denote fertilizer P placement as either broadcast or band and band plus broadcast, respectively.

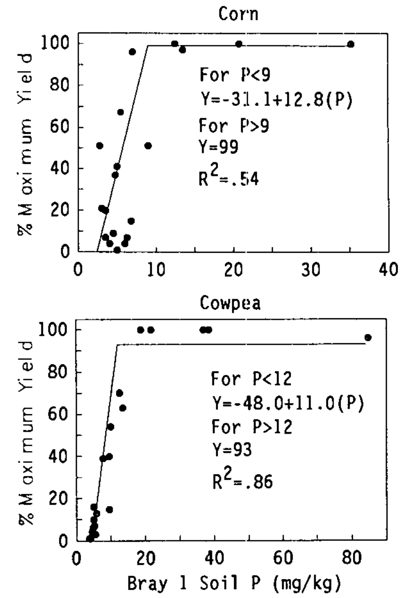

Fig. 2. Observed (symbols) and predicted (lines) relationships between yields for four crops each of corn and cowpea and Bray 1 soil P in five rates of broadcast P.

applications, respectively, during the course of the experiment.

Eleven crops of an annual corn-cowpea rotation were planted during the period of December 1981 to March 1987. Applications of lime, N, K and micronutrients to corn and cowpea crops, and further experimental details are reported elsewhere (Smyth and Cravo, 1989).

In all crops, soil samples (0–15 cm) were taken from each plot at either corn silking or cowpea midflowering stage. Each sample contained 10 random subsamples from the central 3- by 6-m plot area. Mehlich 1 P was measured in all samples by the procedure as used in Brazil (0.05 *M* HCl + 0.05 *M* H_2SO_4, 1:10 soil to solution ratio, 5 min shaking). Bray 1 P (Olsen and Dean, 1965) was only measured in samples from treatments without banded P.

In all crops, except corn and cowpea in 1986, leaf samples were collected from the same plot area and at the same time as soil samples. Samples consisted of 10 and 20 leaves for corn and cowpea, respectively. The leaf sampled for corn was immediately below and opposite to the ear leaf. Leaves for cowpea were fully expanded trifoliates at the top of the plant canopy. Leaves were digested by wet ashing with H_2O_2 and H_2SO_4. Phosphorus was measured in all samples and N was determined by micro-Kjehldal distillation (using Se as a catalyst) in samples from the 1985 cowpea crop. Phosphorus in both soil and plants was determined colorimetrically by the Murphy and Riley (1962) procedure.

Analysis of variance and regression procedures in the Statistical Analysis System (SAS Institute, 1985) were used to analyze the data. Critical soil and foliar P levels were established using linear-plateau models as described by Anderson and Nelson (1987). Yield trends as a function of rates and placement of fertilizer P during the 11 consecutive crops of corn and cowpea were described in a separate paper (Smyth and Cravo, 1989). Initial corn crop yields were severely affected by disease problems and were not used for evaluating critical P levels. A single broadcast application of 176 kg P ha^{-1} provided near maximum yields for the five initial corn crops. During the final corn crop, yields for this broadcast P rate were increased by 0.8 t ha^{-1} when combined with the residual effects from 176 kg ha^{-1} of banded P. In three of the five cowpea crops, yields for the highest broadcast P rate were increased by as much as 40% when P was also applied in bands. These results precluded the designation of yields for the 176 kg P ha^{-1} broadcast treatment as the absolute maximum when calculating relative yields for individual crops. Therefore, relative yields used in relationships with Mehlich 1 soil P and leaf P were based on the highest yielding treatment in each crop.

RESULTS AND DISCUSSION

Mehlich 1 and Bray 1 Critical Soil Phosphorus Levels

Mehlich 1 critical P levels were greater for cowpea than for corn (Fig. 1). The use of a crop rotation with different spacings between rows and tillage practices contributed to a progressive mixing of band-applied P throughout the surface soil layer. Soil test P, consequently, detected residual effects of frequent localized P applications. The absence of differences among P placement methods in yield responses to soil test P indicated that banded fertilizer P availability was adequately measured by this extractant.

The final corn and cowpea crops were excluded from evaluations of the Bray 1 critical soil P levels to maximize conditions wherein maximum yields were approached with broadcast P alone. The critical soil P level with this extractant also was higher for cowpea than for corn (Fig. 2). Bray 1 critical soil P levels were also estimated by a linear regression established across all sampling dates with the Mehlich 1 extractant in treatments containing only broadcast P. The regression equation, based on 60 observations, was as follows

$$\text{Bray 1 P} = -4.75 + 2.23(\text{Mehlich 1 P})$$
$$\text{with an } r^2 = 0.92.$$

Both regression coefficients were significant at the 0.001 probability level. Based on this equation, the Bray 1 critical P levels corresponding to levels established in Fig. 1 for the Mehlich 1 extractant were 9 and 13 mg kg^{-1} respectively for corn and cowpea. These calculated values compared favorably with the

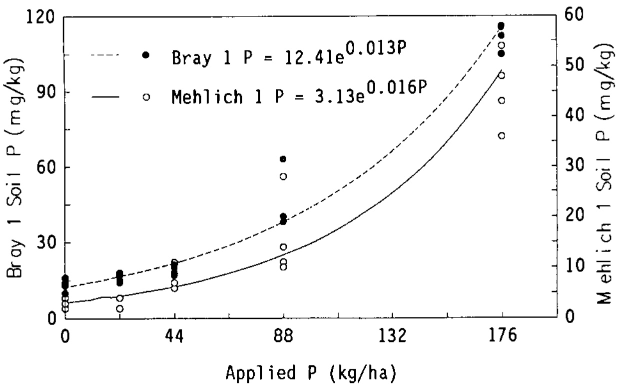

Fig. 3. Bray 1 and Mehlich 1 soil test P as a function of P rates, 62 d after fertilizer P was broadcast applied. Coefficients of determination (r^2) were 0.99 and 0.98 for the Bray 1 and Mehlich 1 extractants, respectively.

critical levels of 9 and 12 mg P kg^{-1} established for corn and cowpea with data from the broadcast P treatments (Fig. 2).

Soil test interpretations in the Brazilian Amazon are currently based on a Mehlich 1 critical P level of 30 mg kg^{-1} for all crops (Cruz et al., 1982). Critical levels for corn and cowpea in this Oxisol were less than one-half of this value and differed among crops. The critical level established for corn with the Mehlich 1 extractant was also lower than values reported in other regions of Brazil. In a clayey Oxisol from the Cerrado region, Yost et al. (1981) determined the critical level as 10 to 15 mg P kg^{-1} soil. A level of 9 mg P kg^{-1} soil was recommended for soils with >40% clay in southern Brazil (Kochhann et al., 1982). The lower critical level for the present study may be associated with a higher clay content (76%) and reduced P extraction due to exhaustion of the acid extractant or readsorption of extracted P (Kamprath and Watson, 1980). Mehlich 1 critical P levels for soybean trials in three Cerrado soils declined fourfold as clay content increased from 12 to 63% (Lins et al., 1985).

The Bray 1 critical P level for corn was similar to values reported for an Ultisol in Indonesia and an Oxisol in Hawaii (Widjaja-Adhi and Silva, 1986) but lower than the value recommended for midwestern U.S. soils (Thomas and Peaslee, 1973). The Bray 1 critical level for cowpea was considerably higher than the value of 1.1 mg P kg^{-1} which Cassman et al. (1981) found for maximum dry matter yield at 90 days after emergence for a clayey Ultisol in Hawaii.

Relationships between P additions and extractable soil P are essential for predicting amounts of fertilizer P required to raise soil P availability to a given level. In samples taken 62 d after broadcast P was applied to this Oxisol, both Mehlich 1 and Bray 1 soil extractable P increased exponentially with increasing fertilizer P rates (Fig. 3). The equation for the Mehlich 1 extractant indicated that applications of 41 and 60 kg P ha^{-1} were required to achieve the respective critical soil P levels established for corn and cowpea.

Critical Leaf Phosphorus Concentrations

Relationships between yield and foliar P levels were based on all broadcast and banded P treatment combinations (Fig. 4). Critical leaf P levels were ranked in the same order as critical soil P levels: cowpea > corn.

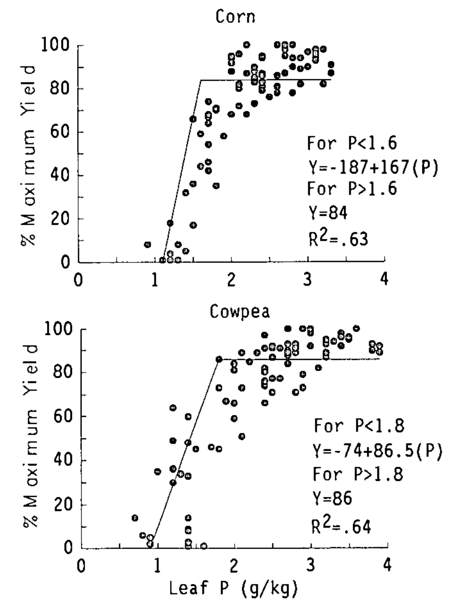

Fig. 4. Observed (symbols) and predicted (lines) relationships between yields and leaf P concentrations at midflowering stage for 20 fertilizer P treatments during four crops each of corn and cowpea.

The similarities in predicted mean relative yields above the critical leaf and Mehlich 1 P levels (Fig. 1 and 4) suggested a close correspondence between soil and plant assessments of P availability throughout the course of this experiment. Critical leaf P concentrations for corn in this study are below the range of recommended values reported in other investigations (Jones and Eck, 1973; Small and Ohlrogge, 1973). Critical leaf P level for cowpea in our experiment was considerably lower than the foliar P concentration (4.7 g kg^{-1}) associated with maximum aboveground dry matter yields in a Hawaiian Ultisol (Cassman et al., 1981).

Cowpea nodulation was assessed during the 1983 crop on treatments receiving only broadcast P (Empresa Brasileira Pesquisa Agropecuaria, 1984). Measurements at flowering on 20 plants plot^{-1} showed that nodule number increased up to the rate of 44 kg P ha^{-1} whereas nodule mass, N uptake and final grain yield increased to the highest rate of broadcast P. Fol-

Table 1. Effect of P rates and placement on leaf N concentration for the 1985 cowpea crop in the Brazilian study.

P Broadcast in 1981	Total Banded P (kg ha^{-1})† 0	88	176	176	Broadcast means
kg ha^{-1}			g N kg^{-1}		
0	43	37	40	44	41
22	45	33	34	44	39
44	41	38	39	40	39
88	39	39	38	43	40
176	40	42	44	45	43
Band means	42	38	39	43	
LSD (0.05)					
Broadcast			NS		
Band			4		
Broadcast × band			NS		

† Total banded P corresponds to the respective rates of 0, 11, 22 and 44 kg P ha^{-1} crop^{-1}. All crops received banded applications of 11 kg P ha^{-1}. Banded P rates of 22 and 44 kg P ha^{-1} crop^{-1} were applied to the first eight and four crops, respectively.

iar N concentrations for the 1985 cowpea crop (Table 1) also suggested that soil P availability influenced plant N status. With broadcast applications of 0 to 88 kg P ha^{-1}, decreases in leaf N at the lowest band rate reflected a dilution effect as yields were increased by 2 to 20 times relative to broadcast P alone. Yield responses to higher rates of residual or fresh banded P applications were lower but leaf N content continued to increase.

These data suggested that part of the cowpea response to applied P resulted from increased N_2 fixation and N supply. Studies with soybean have shown that external P requirements were higher for N-fixing plants than for plants supplied with fertilizer N (Cassman et al., 1981). Subsequent investigations indicated that this difference was related to a higher internal P requirement for symbiotic N_2 fixation rather than to differences in the ability of roots to absorb P under different N regimes (Israel, 1987). A higher P requirement for symbiotic N_2 fixation would be in agreement with the higher critical soil P levels for cowpea than for corn in the present study.

CONCLUSIONS

Critical levels for both soil extractable and foliar P were greater for cowpea than for corn. Relationships between applied P and Mehlich 1 soil P during the initial crop indicated that 60 and 41 kg P ha^{-1} were required to raise initial soil P to the respective critical levels for cowpea and corn. These recommendations represent a substantial reduction in P fertilizer inputs relative to the current soil test interpretations used in the region. Although the Mehlich 1 extractant, at a 1:10 soil/solution ratio, is used extensively by soil testing laboratories throughout the Brazilian humid tropics, Bray 1 extractable P was equally effective in relating soil P to crop yields and fertilizer P.

With increasing soil P availability, leaf N concentration increased in the legume crop. The higher soil and leaf P critical levels for cowpea relative to corn, in this study, support previous observations of higher internal P requirements for plants dependent on symbiotic N_2 fixation.

REFERENCES

Anderson, R.L., and L.A. Nelson. 1987. Linear-plateau and plateau-linear-plateau models: Usefulness in evaluating nutrient responses. North Carolina State Univ. Tech. Bull. 283.

Cassman, K.G., A.S. Whitney, and R.L. Fox. 1981. Phosphorus requirements of soybean and cowpea as affected by mode of N nutrition. Agron. J. 73:17–22.

Cochrane, T.T., and P.A. Sanchez. 1982. Land resources, soils and their management in the Amazon region: A state of knowledge report. p. 137–209. *In* S. Hecht (ed.) Amazonia: Agriculture and land use research. CIAT, Cali, Colombia.

Cruz, E.S., W.S. Couto, R.F. Oliveira, and S. Dutra. 1982. Adubacao fosfatada na regiao Norte. p. 297–326. *In* A.J. Oliveira (ed.) Adubacao fosfatada no Brasil. Empresa Brasileira de Pesquisa Agropecuaria, Brasilia, Brazil.

Empresa Brasileira de Pesquisa Agropecuaria. 1984. Biologia do solo. p. 113–121. *In* Relatorio tecnico bienal de Unidade de Execucao de Pesquisa de Ambito Estadual de Manaus. Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA), Manaus, Brazil.

Israel, D.W. 1987. Investigation of the role of phosphorus in symbiotic dinitrogen fixation. Plant Physiol. 84:835–840.

Jones, J.B., and H.V. Eck. 1973. Plant analysis as an aid in fertilizing corn and grain sorghum. p. 349–364. *In* L.M. Walsh and J.D. Beaton (ed.) Soil testing and plant analysis, Rev. ed. SSSA, Madison, WI.

Kamprath, E.J., and M.E. Watson. 1980. Conventional soil and tissue tests for assessing the phosphorus status of soils. p. 433–469. *In* F.E. Khasawneh et al. (ed.) The role of phosphorus in agriculture. ASA, CSSA, and SSSA, Madison, WI.

Kochhann, R., I. Anghinoni, and J. Mielniczuk. 1982. A adubacao fosfatada no Rio Grande do Sul e Santa Catarina. p. 29–60. *In* Oliveira, A.J. (ed.) Adubacao fosfatada no Brasil. Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA), Brasilia, Brazil.

Lins, I.D.G., F.R. Cox, and J.J. Nicholaides. 1985. Optimizing phosphorus fertilization rates for soybeans grown on Oxisols and associated Entisols. Soil Sci. Soc. Am. J. 49:1457–1460.

Murphy, J., and J.R. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta. 27:31–36.

Olsen, S.R., and L.A. Dean. 1965. Phosphorus. *In* C.A. Black et al. (ed.) Methods of soil analysis. Agronomy 9:1035–1049.

SAS Institute, Inc. 1985. SAS user's guide: Statistics. SAS Institute, Inc., Cary, NC.

Singh, R., M.R.F. Moller, and W.A. Ferreira. 1983. Caracteristicas da sorcao do fosforo relacionadas com propriedades selecionadas de solos dos tropico umidos da Amazonia. Rev. Bras. Cienc. Solo 7:233–241.

Small, H.G., and A.J. Ohlrogge. 1973. Plant analysis as an aid in fertilizing soybeans and peanuts. p. 315–327. *In* L.M. Walsh and J.D. Beaton (ed.) Soil testing and plant analysis, Rev. ed. SSSA, Madison, WI.

Smyth, T.J., and J.B. Bastos. 1984. Alteracoes no fertilidade de um Latossolo Amarelo alico pela queima da vegetacao. Rev. Bras. Cienc. Solo 8:127–132.

Smyth, T.J., and M.S. Cravo. 1989. Phosphorus management for continuous corn-cowpea production in a Brazilian Amazon Oxisol. Agron. J. 82:305–309 (this issue).

Thomas, G.W., and D.E. Peaslee. 1973. Testing soils for phosphorus. p. 115–132. *In* L.M. Walsh and J.D. Beaton (ed.) Soil testing and plant analysis. Rev. ed. SSSA, Madison, WI.

Widjaja-Adhi, I.P.G., and J.A. Silva. 1986. Calibration of soil phosphorus tests for maize on Typic Paleudults and Tropeptic Eutrustox. p. 32–39. *In* Pembr. Pen. Tanah Dan Pupuk no. 6. Center for Soils Research, Bogor, Indonesia.

Yost, R.S., E.J. Kamprath, G.C. Naderman, and E. Lobato. 1981. Residual effects of phosphorus applications on a high phosphorus adsorbing Oxisol of Central Brazil. Soil Sci. Soc. Am. J. 45:540–543.