Long-term comparison of rock phosphate with superphosphate on crop yield in two cereal-legume rotations

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Choudhary, M., Peck, T. R., Paul, L. E. and Bailey, L. D. 1994. **Long-term comparison of rock phosphate with superphosphate on crop yield in two cereal-legume rotations.** Can. J. Plant Sci. **74**: 303–310. Monocropping and long-term use of highly water soluble commercial fertilizers may reduce crop yields and contaminate surface and ground water. A long-term experiment compared the effectiveness of rock phosphate (RP) with superphosphate (SP) on crop yields, soil tests, and leaf nutrient concentrations in two rotations with or without addition of N or lime in a strip-block design with phosphate as vertical factor and N or lime as horizontal factor applied over P treatments. Crops in rotation A (1952–1967) included oats (*Avena sativa* L.), alfalfa (*Medicago sativa* L.), corn (*Zea mays* L.) 1st yr and corn 2nd yr while crops in rotation B (1968–1983) included corn and soybean (*Glycine max* L.). Phosphate application as single source, RP and SP in combination, and RP with elemental sulphur ranged from 0 to 40 kg P ha^{-1} yr^{-1}. In rotation A, RP was applied once every 8 yr at eight times the annual rate; in rotation B it was applied at half the annual rate of rotation A. The SP was applied annually in both rotations. In both rotations, P treatments significantly increased crop yields. In rotation A, crop yields on RP treatments were similar to those on corresponding SP treatments except for oats. Similarly, yields of crops grown with RP alone were similar to those obtained with a mixture of RP with SP or S. But corn grown after alfalfa did not respond to N application nor did crop yields respond to lime application. In rotation B, at low lime, corn and soybean yields were similar on RP treatments to those on corresponding SP treatments, but at high lime, yields were significantly lower with RP than corresponding SP treatments. Further, crop yields on mixture of RP and SP were similar to yields with RP alone, and the RP and S combination produced lower soybean yields and similar corn yields than RP alone. In this long-term cropping sequence study, on acidic soil RP was equally as effective as SP in supplying P to crops.

Key words: Rock phosphate, superphosphate, legumes, lime, nitrogen

Choudhary, M., Peck, T. R., Paul, L. E. et Bailey, L. D. 1994. **Comparaison à long terme du phosphate naturel avec le superphosphate sur le rendement des cultures dans deux rotations céréales-légumineuses.** Can. J. Plant Sci. **74**: 303–310. La monoculture et l'utilisation à long terme des engrais chimiques très solubles dans l'eau peuvent réduire les rendements des cultures et contaminer les eaux de surface et les eaux souterraines. Une expérience de longue durée a permis de comparer l'efficacité du phosphate naturel (PN) avec celle du superphosphate (SP) sur le rendement des cultures, sur certains critères chimiques du sol et sur les concentrations de nutriments dans les feuilles, dans deux rotations avec ou sans apport d'azote (N) ou de chaux. On utilisait un dispositif en bandes croisées avec P comme facteur vertical et N ou la chaux comme facteur horizontal surimposé au traitement P. La rotation A (1952-1967), comprenait l'avoine (*Avena sativa* L.), la luzerne (*Medicago sativa* L.), le maïs (*Zea mays* L., deux ans), alors que la rotation B (1968-1983) ne comptait que le maïs et le soja (*Glycine max* L.). L'apport de phosphate: PN ou SP, PN et SP combinés et PN avec soufre élémentaire allait de 0 à 40 kg P ha^{-1}. Dans la rotation A, PN était apporté une fois tous les 8 ans à raison de 8 fois la dose annuelle, tandis que dans la rotation B il était apporté à la moitié de la dose annuelle utilisée dans la rotation A. SP était apporté chaque année dans les deux rotations. Dans les deux rotations, l'apport de P accroissait significativement le rendement. Dans la rotation A, le rendement dans les traitements PN était du même ordre que dans les traitements SP correspondants, sauf pour l'avoine. De même, le rendement des cultures sur PN seul était semblable à ceux obtenus avec la combinaison PN–SP ou PN–S. Par ailleurs, le maïs après luzerne ne réagissait pas à la fumure N et, d'autre part, le chaulage n'avait pas d'effet sur les rendements. Dans la rotation B, au niveau de chaulage bas, les rendements du maïs et du soja étaient du même ordre sur les traitements PN que sur les traitements SP correspondants, mais au niveau de chaulage élevé, ils étaient significativement plus bas sur les traitements PN que sur les traitements SP. En outre, les rendements sur le traitement PN–SP étaient les mêmes que sur PN seul. La combinaison PN–S produisait des rendements de soja inférieurs mais des rendements de maïs semblables à ceux obtenus sur PN seul. Dans cette étude de séquences culturales de longue durée, PN était aussi efficace que SP sur sol acide comme source d'alimentation des plantes en P.

Mots clés: Phosphate naturel, superphosphate, légumineuses, chaux, azote

Concerns have been raised recently about the adverse effects of agricultural production systems on environmental quality, particularly, on the extensive and more often excessive use of commercial N and P fertilizers in intensive monoculture of cereals. These practices have been associated with reduced crop yields and contamination of surface and ground water. Reduced yields in continuous corn compared to corn following hay or small grains have been reported for midwestern USA (Dick and Van Doren 1985; Sahs and Lesoing 1985). Gambrell et al. (1975) estimated the leaching of

Abbreviations: RP, rock phosphate; **SP**, superphosphate nitrate in the Coastal Plain of North Carolina to be 8% of applied fertilizer N in poorly drained soil and of 29% in well-drained soil. In fertilizer N studies during 1985–1987, Vereijken (1990) reported 4.3–11.2 mg N L^{-1} in drainage water. Unlike nitrate which has little affinity for soil particles, fertilizer phosphate is rapidly adsorbed, still some P may exist in the soil as dissolved orthophosphate form (Logan 1990). Nelson and Logan (1983) reported 0.07–1.1 kg P ha^{-1} yr^{-1} transported in stream flow from selected watersheds and 0.01–0.58 kg P ha^{-1} yr^{-1} lost from agricultural land in tile drainage. Substitution of RP, a sparingly soluble material, for commercial P fertilizer and inclusion of legumes in crop rotation to supply biologically fixed N may reduce water contamination. Sahs and Lesoing (1985) reported that reductions in inorganic fertilizers can be compensated for by using crop rotations, particularly legumes as a source of N. Miller and Larson (1990) reported that the annual biologically fixed N contribution from seed legumes and alfalfa to US crop land accounts for approximately 24% of total N contribution from all crop residue. Rock phosphate is reported to be potentially as effective as SP in increasing crop yields (Doll et al. 1960; Bationo et al. 1990; Kumar et al. 1992). Further, it is cheaper than SP, locally available, and some RP deposits are unsuitable for fertilizer P manufacturing due to its low P content. Dissolution of RP increases with decreasing pH (Chaudhary and Mishra 1980; Mackay and Syers 1986; Kanabo and Gilkes 1987; Robinson et al. 1992) and with increasing Ca sink (Kirk and Nye 1986). Thus, as a source of plant P, it is possible that RP may prove equal or even better than SP because P from RP is released slowly in acid soils. The agronomic effectiveness of RP is influenced by several soil, plant, and fertilizer factors which were extensively reviewed by Khasawneh and Doll (1978) and Hammond et al. (1986). Acid-forming fertilizers such as ammonium sulphate and urea increase dissolution of RP in soil and enhance plant P availability (Volk 1944; Terman et al. 1969). However, Hammond (1978) reported that liming may counteract the soil acidification associated with N fertilization. Chien (1978) reported that the P concentration of the soil solution would increase when the Ca concentration decreases. Depression in solubility of RP by liming may also be due to increased exchangeable Ca or Ca common ion effect (Welte 1978). Substitution of RP for SP and inclusion of legumes in crop rotation may be a viable alternative for sustainable agriculture. This paper reports a long-term crop rotation study in Illinois comparing RP with SP on yields of cereals and legumes, on soil tests, and on leaf nutrient concentrations.

MATERIALS AND METHODS

The study was initiated in 1952 on the University of Illinois Experimental Farm, DeKalb, Illinois. The soils used are predominantly Flanagan silt loam (fine, montmorillonitic, mesic Aquic Argiudoll) and Drummer silty clay (fine silty, mixed, mesic Typic Haplaquoll). Selected physical and chemical properties of the soils are given in Table 1. These soils were classified as medium and high in P and K supplying power, respectively (Illinois Agronomy Handbook 1987–1988). The experimental design consisted of four blocks with two replicates in a strip block with P as vertical factor and N or lime as horizontal factor. Each block was divided vertically into 12 plots and P treatments were assigned randomly to these plots. Each plot was subdivided horizontally into two subplots and used for N or lime application. The location of plots and treatments in this experiment remained the same throughout the study. In rotation A, cropping started with oats in 1952 in block 1, 1953 in block 2, 1954 in block 3, and 1955 in block 4 so that from 1955 onwards each block should have one crop and all four crops should be present each year (Table 2). There were 12 P treatments (Table 3). The mixture of RP and elemental S was used to supplement S to crops as RP does not contain any S while SP contains about 11.9% of sulphur. In rotation A, to determine the effect of N on P availability and use, half of the subplots in each block for the first 8 crop years received N fertilizer. This 8-yr sequence was designated as cycle 1 (Table 4). Similarly, to determine the effect of lime on P availability and use, half of the subplots (those previously treated with N) in each block in the remaining 8 crop years in block 1, 7 crop years in block 2, 6 crop years in block 3, and 5 crop years in block 4 in rotation A, were treated once with lime and were designated as cycle 2. In 1968, the cropping pattern was changed to corn-soybean (rotation B) to reflect the changes in Illinois cropping systems. In rotation B, each crop was grown in two blocks, alternated annually and designated as sequence I and II. To determine the effect of pH on RP dissolution, attempts were made to get two distinct pH levels in the beginning of rotation B by liming all plots at 2.24 t ha^{-1} and then applying additional lime at 6.72 t ha^{-1} to half of those subplots which had received lime in cycle 2 of rotation A.

In rotation A, Florida rock phosphate (RP) (13.1% P with 80% passed through a 200-mesh sieve) and elemental S were applied eight times the annual rate in 1952 in block 1, 1953 in block 2, 1954 in block 3, and 1955 in block 4. In the 9th year only RP was applied eight times the annual rate in 1959 in block 1, 1960 in block 2, 1961 in block 3, and 1962 in block 4. Superphosphate (SP) (0-18-0) was applied at twice the annual rate to oats (for oats and alfalfa) and at the annual rate for each year of corn. Alfalfa was seeded with oats. Nitrogen and K were applied as ammonium sulphate and KCl, respectively.

In rotation B, RP was applied 16 times the annual rate in 1968 in each block while SP (0-46-0) was applied annually

Table 1. Selected physical and chemical characteristics of the soil series used in this study

Characteristic	Flanagan	Drummer
pH	5.9 - 6.2	6.2
Clay g kg^{-1} (0–15 cm)	250	310
Organic C g kg^{-1} (0–15 cm)	26.1	34.8
CEC cmol kg^{-1} (0–15 cm)	28	35
Bray-1 P mg kg^{-1} (0–15 cm)	9 - 14	—
Bray-2 P mg kg^{-1} (0–15 cm)	10 - 18	—
Sub soil supplying rate of P	Medium	Medium
Sub soil supplying rate of K	High	High
Drainage class	Somewhat poor	Poor
Permeability	Moderate	Moderate

to each block. Nitrogen and K were applied as ammonium nitrate and KCl, respectively.

The pH of the soil was measured in a slurry using 1:1 soil water ratio. The Bray-1 P and Bray-2 P were determined as described by Bray and Kurtz (1945). Soil Ca was determined by equilibrating the soil with 1 *M* NH_4OAC and determining Ca in the extract using an atomic absorption spectrophotometer in the presence of Sr. Leaf sampling was done in the fall of 1980. Leaves were washed, dried, ground, and dry-ashed. Nitrogen was determined by standard Kjeldahl procedure using a Hg catalyst; P was analyzed with an emission spectrograph (Peck et al. 1969).

Analyses of variance (ANOVA) of crop yields were performed using the ANOVA procedure of SAS (SAS Institute, Inc. 1985). In rotation A, ANOVA of crop yield was performed for each cycle on every crop separately. The analysis of variance of crop yield in rotation B was done for each crop separately. Since the effect of N on P availability in cycle 1 of rotation A was significant only in corn 2nd year and oats and the effect of lime on P availability was nonsignificant in cycle 2, the LSD values for crop yields were calculated on the average N and no N treatment in cycle 1 and on the average of lime and no lime in cycle 2. In rotation B, LSD values for crop yields were calculated to test

Table 2. Cropping sequence in rotation A from 1952–67 and in rotation B from 1968–83

Rotation A

Year	Block 1	Block 2	Block 3	Block 4
1952	Oats[z]	—	—	—
1953	Alfalfa	Oats[z]	—	—
1954	Corn 1st yr	Alfalfa	Oats[z]	—
1955	Corn 2nd yr	Corn 1st yr	Alfalfa	Oats[z]
1956	Oats	Corn 2nd yr	Corn 1st yr	Alfalfa
1957	Alfalfa	Oats	Corn 2nd yr	Corn 1st yr
1958	Corn 1st yr	Alfalfa	Oats	Corn 2nd yr
1959	**Corn 2nd yr**	Corn 1st yr	Alfalfa	Oats
1960	Oats[y]	**Corn 2nd yr**	Corn 1st yr	Alfalfa
1961	Alfalfa	Oats[y]	**Corn 2nd yr**	Corn 1st yr
1962	Corn 1st yr	Alfalfa	Oats[y]	**Corn 2nd yr**
1963	Corn 2nd yr	Corn 1st yr	Alfalfa	Oats[y]
1964	Oats	Corn 2nd yr	Corn 1st yr	Alfalfa
1965	Alfalfa	Oats	Corn 2nd yr	Corn 1st yr
1966	Corn 1st yr	Alfalfa	Oats	Corn 2nd yr
1967	Corn 2nd yr	Corn 1st yr	Alfalfa	Oats

Rotation B

Year	Block 1 and 2	Block 3 and 4	Year	Block 1 and 2	Block 3 and 4
1968	Soybean[y]	Corn[y]	1976	Soybean	Corn
1969	Corn	Soybean	1977	Corn	Soybean
1970	Soybean	Corn	1978	Soybean	Corn
1971	Corn	Soybean	1979	Corn	Soybean
1972	Soybean	Corn	1980	Soybean	Corn
1973	Corn	Soybean	1981	Corn	Soybean
1974	Soybean	Corn	1982	Soybean	Corn
1975	Corn	Soybean	1983	Corn	Soybean

Crops above and below underline in rotation A are included in cycle 1 and cycle 2, respectively.
[z] Year of rock phosphate and S application.
[y] Year of rock phosphate application only.

Table 3. Annual rate of phosphate (vertical factor) application

	Rotation A (1952–67)				Rotation B (1968–83)		
P Treatment	RP[z]	SP	S[z]	P Treatment	RP[z]	SP	S
	— kg P ha^{-1} —				— kg P ha^{-1} —		kg S ha^{-1}
Control	0	0	0	Control	0	0	0
SP1	0	5	0	SP1	0	5	0
SP2	0	10	0	SP2	0	10	0
SP4	0	20	0	SP4	0	20	0
SP8	0	40	0	SP8	0	40	0
RP1	5	0	0	RP0.5	2.5	0	0
RP2	10	0	0	RP1	5	0	0
RP4	20	0	0	RP2	10	0	0
RP8	40	0	0	RP4	20	0	0
RP4SP1	20	5	0	RP2SP1	10	5	0
RP4SP4	20	20	0	RP2SP4	10	20	0
RP4S	20	0	11	RP2S	10	0	0

[z] Calculated on annual basis.

Table 4. Rate of N, K, and lime application over P treatments (horizontal factor)

Rotation	N			K	Lime		Nutrients applied
	Oats+ Alfalfa	Corn 1st yr	Corn 2nd yr	Each crop	Each crop		
Rotation A	kg ha^{-1} yr^{-1}				t ha^{-1} once		
Cycle 1	35	47	94	56	None		N to half of the subplots and K to all plots
Cycle 2	35	47	94	56	2.24		N and K to all plots and lime to half of the subplots
Rotation B		N		K	Lime		Nutrients applied
		Corn		Each crop	Each crop		
		kg ha^{-1} yr^{-1}			t ha^{-1} once		
		270		111	2.24 (Low lime)	8.96 (High lime)	N and K to all plots and high lime to half of the subplots

Table 5. Influence of phosphate treatments on crop yield in cycle 1 of rotation A (averaged over N and no N fertilizer) and analyses of variance

P Treatment	Corn 1st yr	Corn 2nd yr	Oats	Alfalfa
	Yield (kg ha^{-1})			
Control	5618	4741	1957	6680
SP1	5861	5039	2084	6946
SP2	6093	5214	2183	7507
SP4	6250	5470	2168	7948
SP8	6393	5545	2113	8396
RP1	5688	4865	1944	6970
RP2	5975	5074	2053	7532
RP4	6152	5260	2042	7745
RP8	6298	5344	2087	8474
RP4SP1	6049	5230	2093	7868
RP4SP4	6206	5497	2253	8149
RP4S	6096	5148	1994	7815
$LSD_{0.05}$[z]	209	281	153	530

Analyses of variance of crop yield

Source	df	Error term used	Corn 1st yr	Corn 2nd yr	Oats	Alfalfa
			F ratio and significance level			
P	11	Block × P	10.59**	6.41**	2.99**	7.58***
N	1	Rep × N (Block)	0.90	9.71*	17.24**	0.40
P × N	11	Block × P x N	0.51	2.28*	0.94	1.22

[z]Calculated using Block × P as an error term.
*, **, ***Significant at p = 0.05, 0.01, and 0.001 levels, respectively.

the difference between P treatments at a given lime level and between lime levels at a given P treatment for each crop (Satterthwaite 1946). The appropriate error terms used to calculate F ratio and LSD values of crop yields in both rotations are mentioned in the appropriate tables. The effect of lime on leaf N and P concentrations was non-significant. The LSD values were therefore calculated on average values of high and low lime levels. Soil Ca concentrations were significantly different at different lime levels. Hence, LSD was calculated at each lime level separately.

RESULTS AND DISCUSSION

The P treatments significantly increased crop yields in both rotations (Tables 5, 6, and 7). In cycle 1 of rotation A, the highest yields were found for corn on SP8 treatment, oats on RP4SP4 treatment, and alfalfa on RP8 treatment (Table 5). Yield of all crops responded similarly to both RP and SP, in general increasing with increasing rates of P. The addition of S with RP or RP and SP combination (RP4S or RP4SP4 treatment) had no significant effect on crop yields when compared with RP4 except for oats when yields were

Table 6. Influence of phosphate treatments on crop yield in cycle 2 of rotation A (averaged over lime and no lime) and analyses of variance

P Treatment	Corn 1st yr	Corn 2nd yr	Oats	Alfalfa
	Yield (kg ha^{-1})			
Control	5784	5674	2730	5395
SP1	6369	6383	3008	6609
SP2	6700	6978	3121	7326
SP4	7235	7441	3341	8883
SP8	7371	7732	3416	9810
RP1	6272	6237	2824	6051
RP2	6570	6705	2981	7220
RP4	6970	6847	3180	8286
RP8	7180	7358	3250	9342
RP4SP1	7045	7194	3160	8460
RP4SP4	7315	7482	3345	9482
RP4S	6878	6845	3087	8052
$LSD_{0.05}$[z]	422	416	147	851

Analyses of variance of crop yield

Source	df	Error term used	Corn 1st yr	Corn 2nd yr	Oats	Alfalfa
			F ratio and significance level			
P	11	Block × P	7.13***	12.86***	16.71***	20.03***
Lime	1	Rep × Lime (Block)	0.00	0.81	2.05	2.22
P × Lime	11	Block × P × Lime	0.75	0.37	1.09	0.64

[z]Calculated using Block × P as an error term.
***Significant at $p = 0.001$ level.

Table 7. Influence of phosphate treatments on grain yield in rotation B and analyses of variance

P Treatment	Corn Low lime	Corn High lime	Soybean Low lime	Soybean High lime
	Yield (kg ha^{-1})			
Control	6674	7528	2448	2565
SP1	8422	8760	2757	2875
SP2	8995	9210	2778	2936
SP4	9503	9696	2881	2998
SP8	9750	9882	2942	2999
RP0.5	7631	8029	2610	2678
RP1	8458	8497	2695	2742
RP2	8905	8783	2818	2848
RP4	9334	9130	2890	2894
RP2SP1	9074	9087	2804	2883
RP2SP4	9598	9652	2972	3014
RP2S	8770	8650	2737	2761
$LSD_{0.05}$[z] between P treatments	223	223	62	62
$LSD_{0.05}$[y] between lime levels	192		43	

Analyses of variance of crop yield

Source	df	Pooled error term used	Corn	Soybean
			F ratio and significance level	
P	11	Sequence × P + Block × P (Sequence)	85.9***	30.1**
Lime	1	Sequence × Lime + Block × Lime (Sequence)	11.8**	11.0**
P × Lime	11	Sequence × P × Lime + Block × P × Lime (Sequence)	7.0***	3.5**

[z]Calculated from a weighted average of Block × P (Sequence) and Block × P × Lime (Sequence) with weighted degrees of freedom (Satterthwaite 1946).
[y]Calculated from a weighted average of Block × Lime (Sequence) and Block × P × Lime (Sequence) with weighted degress of freedom (Satterthwaite 1946).
,*Significant at $p = 0.01$ and 0.001 levels, respectively.

higher with RP4SP4 than with RP4. Kumar et al. (1992) also reported that, on acidic soil, the residual effectiveness of North Carolina RP to increase the yields of wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) was similar to that of applied SP.

Corn 1st year did not respond to N application. The corn crop, grown after alfalfa, may have received adequate N from the residual N fixed by alfalfa. Corn 2nd year and oats responded positively to fertilizer N application (Table 5). The average yields of corn 2nd year with N and no N application over P treatments were 5387 and 5016 kg ha^{-1} ($LSD_{0.05}$ = 281 kg ha^{-1}) whereas the average yields of oats with N and no N application over P treatments were 2214 and 1948 kg ha^{-1} ($LSD_{0.05}$ = 136 kg ha^{-1}). Part of this response may have been due to the solubilization of rock phosphate by acid produced by nitrification of ammonium fertilizer to nitrate. In other studies at DeKalb, IL, similar response of corn to N fertilizer has been reported (Illinois Agronomy Handbook 1987–1988).

In cycle 2 of rotation A, the highest yields for all crops were obtained on SP8 (Table 6). But yields of corn and alfalfa on the RP treatments were similar to those on corresponding SP treatments except the yield of corn 2nd yr with RP4 treatment when it was lower than SP4 treatment. Oat yields were lower on the RP treatments than those on corresponding SP treatments except for the RP2 treatment when both RP and SP produced similar yields. The addition of S tended to reduce yields but the effect was not significant. Addition of small amounts of SP with RP did not increase yield (RP4SP1 vs. RP4) and yield responses to combination of equal amounts of RP and SP were no better than that obtained with an equivalent amount of RP (RP4SP4 vs. RP8). Liming did not change soil pH (Table 8, fall 1963) and yield responses to lime were not significant. These results are similar to those reported by Chien (1978).

In rotation B, corn yields were higher by more than 30% compared to those in rotation A (Table 7). This may be due to one or more of several factors including the residual effect of P, improved genetic plant material, higher plant population, and higher rates of N application. In this rotation, the highest corn and soybean yields were obtained on SP8 and RP4SP4 treatments, respectively. Nevertheless, at low lime level corn and soybean yields on the RP treatments were similar to those on the corresponding SP treatments except for soybean on RP1 when yield was lower than on SP1. As in cycle 2 of rotation A, the addition of elemental S with RP reduced soybean yields and addition of small amounts of SP with RP at low lime did not change yields compared to RP alone. However, yields were significantly larger with RP2SP4 than with RP4. Unlike the low lime treatment, corn and soybean yields for the high lime treatment were lower on RP than for corresponding SP rates. In general, crop response to lime application was favourable with SP and was unfavourable with RP application. Similar findings were reported by Bauer et al. (1945). Better yield response to RP at low lime than at high lime may have been due to low soil pH and low soil Ca concentration (Table 8) which are the driving forces of rock phosphate dissolution (Robinson et al. 1992). At high lime, apart from higher soil pH, soil Ca concentration (Table 8) was also larger than at low lime and may have depressed the solubility of RP due to the low level of proton and to Ca common ion effect (Welte 1978). Using North Carolina rock phosphate, Khasawneh (1977), cited in Khasawneh and Doll (1978), reported decreasing corn dry matter yield with increasing rates of lime at each level of rock phosphate applied and the yield reduction was more than 75% at the highest level of lime.

Soil pH levels in the spring of 1971 and fall of 1980 of rotation B were little affected by application of RP and SP (Table 8). The main changes in soil pH came from application of lime in 1968. This is in agreement with the work of John (1962), showing that when plots were treated with limestone, application of relatively high rates of RP and SP had no significant effect on soil pH. The application of

Table 8. Changes in soil pH and soil Ca concentration as influenced by lime and P application

P	Fall 1963		P	Spring 1971		Fall 1980		Soil Ca concentration in fall 1980 after soybean	
Treatment	NL[z]	L[y]	Treatment	LL[x]	HL[w]	LL	HL	LL	HL
	— pH —			— pH —				— μg g^{-1} soil —	
Control	6.0	6.0	Control	6.0	6.7	5.6	6.2	2158	2476
SP1	6.0	6.1	SP1	6.1	6.7	5.8	6.3	2158	2490
SP2	5.8	6.1	SP2	6.0	6.7	5.7	6.4	2385	2422
SP4	5.8	6.0	SP4	6.1	6.7	5.6	6.4	2290	2530
SP8	5.7	5.9	SP8	6.0	6.6	5.6	6.2	2331	2475
RP1	6.0	6.0	RP0.5	6.1	6.7	5.7	6.3	2329	2583
RP2	6.0	6.0	RP1	6.1	6.7	5.8	6.4	2330	2558
RP4	6.0	6.1	RP2	6.1	6.7	5.8	6.3	2210	2436
RP8	6.0	6.1	RP4	6.1	6.8	6.0	6.2	2544	2756
RP4SP1	5.9	5.9	RP2SP1	6.1	6.7	5.7	6.3	2250	2424
RP4SP4	5.7	5.9	RP2SP4	6.0	6.7	5.6	6.3	2344	2636
RP4S	5.9	5.9	RP2S	6.1	6.6	5.7	6.4	2278	2464
							$LSD_{0.05}$	339	277

[z,y] No lime and lime application, respectively.
[x,w] Low lime and high lime application, respectively.

Table 9. Leaf nutrient concentration in fall 1980

P Treatment	N Corn	N Soybean	P Corn	P Soybean
	g kg^{-1} leaf dry wt			
Control	33	47	2.4	3.5
SP1	31	46	2.7	3.9
SP2	32	48	2.5	3.8
SP4	31	48	2.8	4.2
SP8	31	47	2.8	4.0
RP0.5	32	47	2.1	3.7
RP1	—	—	—	—
RP2	—	—	—	—
RP4	32	48	2.6	4.2
RP2SP1	—	—	—	—
RP2SP4	—	—	—	—
RP2S	—	—	—	—
$LSD_{0.05}$	1.2	NS[z]	0.3	0.4

[z]Nonsignificant.

the two P sources had no significant effect on leaf N and P concentrations (Table 9).

CONCLUSION

Application of RP and SP increased crop yields over 32-yr in this experiment. Rock phosphate was equally effective as SP in increasing corn, soybean and alfalfa yields, particularly in low lime soils (low pH) and following the application of N fertilizer or after a legume crop such as alfalfa. The results indicate that RP is an effective source of plant-available phosphorus that can be used to enhance crop yields on acidic soils and when used in combination with N fertilizer or following a legume crop.

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