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DIVISION S-8—FERTILIZER TECHNOLOGY AND USE

Rate of Phosphorus and Potassium Buildup/Decline with Fertilization for Corn and Wheat on Nebraska Mollisols[1]

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ABSTRACT

A 12-yr study was conducted on four Mollisols in Nebraska to evaluate response of corn (*Zea mays* L.) and wheat (*Triticum aestivum* L.) to P and K fertilizers and to determine the rate of buildup or decline of these nutrients in soil. Rates of P were 0, 11, 22, and 33 kg ha^{-1} applied annually or in less frequent applications of higher rates in order to maintain the same average seasonal amount, along with 27 and 54 kg annual K rates ha^{-1} in association with 22 kg P. The P and K fertilizers were broadcast and incorporated before planting with an appropriate blanket N treatment for the two crops. Positive yield response to applied P resulted when soil test P by Bray and Kurtz no. 1 procedure was below 15 mg kg^{-1} for corn and 22 mg kg^{-1} for wheat. No positive yield response to applied K was measured in these soils of high exchangeable K but rather a yield depression was observed at the high K rate. No significant differences in yield existed between annual applications of P and the heavier less frequent applications. Soil test P level was maintained by annual P rates of 4 to 13 kg ha^{-1} on the eastern soils, with none applied in the west, and was more than doubled on all soils at the end of the experimental period with 33 kg applied. Three of the soils evidenced distinct increases in soil test K without K application; the fourth a slight decline. Results from P fractionations of the test soils are reported to aid in interpreting the yield results.

Additional Index Words: Bray and Kurtz no. 1 soil P, extractable soil K, corn, wheat, P fractionation.

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A LIMITED NUMBER of long-term field experiments have been conducted for ascertaining the rate at which soil P and K build up or decline on specific soils with varied fertilizer rates under high level crop

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production. There is no substantial data base on the value to crops of residual P and K from prior fertilization with intensive crop production.

Residual P from a single broadcast fertilizer application of 40 kg P ha^{-1} was found to benefit yield and P uptake of dryland spring wheat (*Triticum aestivum* L.) in the Northern Great Plains and to maintain soil test P level above that of the check for up to 6 yr (Alessi and Power, 1980). A longer 16-yr study with dryland cropping in the Northern Plains revealed a progressive decline in soil test P from fertilizer broadcast only at initiation of the study until the eighth crop year when soil test P appeared to stabilize at a new, lower equilibrium level (Halvorson and Black, 1985). By the 11th yr only the highest P rate of 180 kg ha^{-1} was significantly greater in soil test P than the check. Residual P from a single moderate P rate afforded some yield increases of wheat and forage sorghum [*Sorghum bicolor* (L.) Moench] over a 5-yr period on Blackland Prairie soils of Texas of low soil test P level, but was much less efficient than equivalent amounts of P applied annually (Hipp, 1986). Residual P fertilizer studies with alfalfa (*Medicago sativa* L.) on irrigated calcareous soils of the Central High Plains during a 6-yr cropping period evidenced no yield responses from annual or periodic P applications despite decline of soil tests to expected deficiency levels (Havlin et al., 1984). From 1.7 to 1.9 times as much fertilizer P was required for maintaining soil test level as was removed in the crop. Similar evaluations with K in these experiments likewise found no yield response. Approximately 1.4 times as much fertilizer K was required as was removed by the crop for soil test maintenance on one soil. There was essentially no fertilizer requirement for maintenance on the other soil. In a 5-yr study on irrigated sandy soil in Nebraska, the 22 kg annual P ha^{-1} rate that produced maximum yield of corn (*Zea mays* L.) also increased soil test P by 1 mg kg^{-1} for each 9.6 kg P ha^{-1} applied (Rehm et al., 1984). This resulted in an approximate doubling of soil test P over the starting level. The same study found no yield increase to applied K during the 5 yr even when corn was harvested for silage and no change in soil test values for K with 34 or 68 kg ha^{-1} applied. The 102 kg ha^{-1} rate did increase soil K level by 1 mg kg^{-1} for each 28 kg applied when only grain was harvested.

Investigations on Coastal Plain and Piedmont soils that had been heavily fertilized in the past found residual P levels that could supply sufficient P for crops without P fertilization for several years (Novais and Kamprath, 1978). A 25-yr rotation study involving P rates on an Aquic Argiudoll soil of the Eastern Corn Belt found a linear relation between Bray and Kurtz P1 (Bray and Kurtz, 1945) and P applied less that removed by cropping (Barber, 1979). Furthermore, the soil test value in this study was increased 1 mg kg^{-1} for every 17 kg net P ha^{-1} applied. Grain yields of corn, soybean [*Glycine max* (L.) Merr.] and wheat peaked at yields of 8.6, 3.2, and 3.9 Mg ha^{-1}, respectively with an application of 22 kg P ha^{-1}. Extractable soil P decreased when P fertilization was stopped, the rate of decrease being greater the higher the soil P level at the time application ceased.

Clearly major differences exist in fertilizer P and K regimes required for maintaining yields and soil test levels among soils from different regions of the country. Variations in dominant native mineral types and amounts and subsoil nutrient reserves are likely responsible. Little information exists in the literature on maintenance requirements for these elements with soils that are inherently high in nutrient supplying capacity such as those in the Western Corn Belt. Accordingly, it was the objective of this investigation to determine the magnitude of P and K accumulation or depletion in representative Nebraska soils under fertilization and cropping practices in common use. The work would thereby give evidence of required P and K rates and application frequencies for maintaining sufficient levels of these nutrients in soil. The study was conducted in cooperation with the TVA as part of a coordinated research program of several state universities.

MATERIALS AND METHODS

This experiment has been conducted at three locations on four major Mollisols of Nebraska since 1973. Irrigated corn was grown on Sharpsburg silty clay loam (sicl) (fine, montmorillonitic, mesic Typic Argiudolls) and nonirrigated corn on a Moody-Nora silt loam (sil) (fine-silty, mixed, mesic Udic Haplustolls), both sites in eastern Nebraska, and winter wheat in a wheat-fallow rotation on Keith sil (fine, mixed, mesic Aridic Argiustolls) and on Rosebud sil (fine-loamy, mixed, mesic Aridic Argiustolls), both in western Nebraska. Routine analyses on these soils prior to initiation of the study included available P (Bray and Kurtz, 1945), available K, pH, and organic matter (Dahnke, 1980).

Phosphorus rates of 0, 11, 22, and 33 kg P ha^{-1} were applied annually or in larger amounts periodically at the same average annual rate along with annual K rates of 0, 27, and 54 kg K ha^{-1} in a randomized complete block design. The P and K treatments were broadcast and incorporated by the final tillage before planting. Nitrogen was uniformly applied on all corn plots at average rates of 200 kg N ha^{-1} for the irrigated corn, 90 kg for the nonirrigated, and was broadcast in the spring over all wheat plots at an average rate of 40 kg ha^{-1}.

Grain yields were measured at harvest and tillage layer soil samples (0–15 cm) were collected each spring to follow changes in soil test P and K from the respective treatments. Soil samples of 120 and 180 cm were collected on initiation of the study for measuring nutrient status of the rooting profile of soil at each site. Surface soil samples were collected from the corn experiment at the termination of the study in 1985 and were analyzed for P fractions (Olsen and Sommers, 1982) and for slowly available K using boiling 1 *M* HNO_3 (Knudsen et al., 1982).

EXPERIMENTAL RESULTS

Soil Profile Characteristics

Nutrient P and K, pH, and organic matter data for the rooting profile at the inception of the study at the four locations are presented in Fig. 1. Especially noteworthy is the very high P level of the Sharpsburg deep subsoil compared with the low subsoil P levels of the other soils, a result of their calcareous nature (note pH); and the high exchangeable K of the Sharpsburg and Moody-Nora profiles (eastern Nebraska) and extremely high K of the Keith and Rosebud profiles (western Nebraska). The organic matter levels are representative for relatively noneroded soils in the two

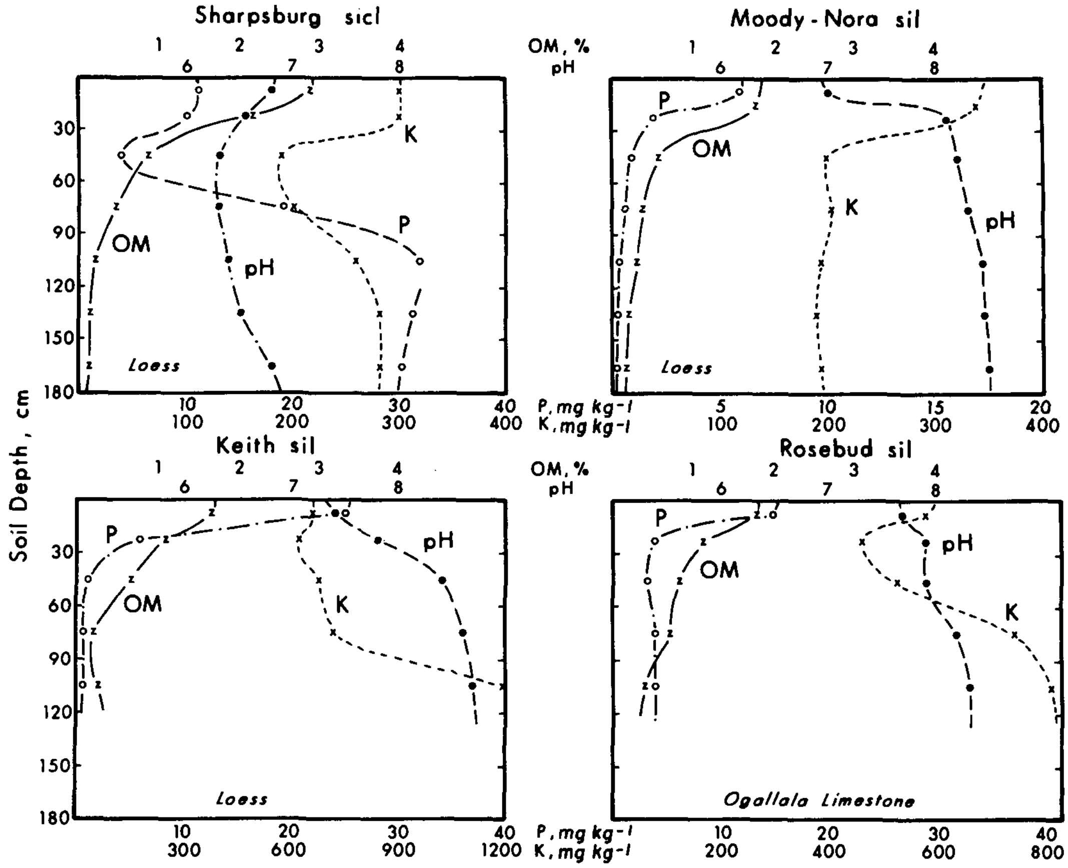

Fig. 1. Some chemical properties of the rooting profile of soils employed in the investigation (soil parent material shown in parentheses).

Table 1. Average annual grain yields of irrigated corn on Sharpsburg sicl over the first and second 6-yr periods and the complete 12-yr period. Agricultural Research and Development Center, Mead, NE.

Treatment‡	df	1973–1978	1979–1984	1973–1984
		Years		
		Mg ha^{-1}		
1. Check		10.04	9.77	9.90
2. 11 P annual		10.27	9.60	9.93
3. 22 P annual		10.51	10.19	10.35
4. 33 P annual		10.48	10.18	10.33
5. 22 P alternate yr		10.04	9.85	9.95
6. 33 P every 3rd yr		10.32	10.15	10.23
7. 66 P alternate yr		10.12	10.14	10.13
8. 66 P every 6th yr		9.89	9.66	9.77
9. 22 P-27 K annual		10.59	10.16	10.37
10. 22 P-54 K annual		9.98	10.03	10.01
11. 22 P-27 K annual row		9.82	9.97	9.90
	df	ANOVA and associated contrasts		
		$P > F$		
Treatment	10	†	NS	**
Contrasts				
P rate linear	1	†	*	**
P rate Quad	1	NS	NS	NS
Treatment 3 vs. 9	1	NS	NS	NS
3 vs. 10	1	*	NS	*
9 vs. 10	1	*	NS	*
2 vs. 8	1	NS	NS	NS
4 vs. 7	1	NS	NS	NS
2 vs. 6	1	NS	NS	NS
Residual error	31			
CV, %		4.0	3.8	2.5

*,**,† Significant at the 0.05, 0.01, and 0.10 probability levels, respectively.
‡ Nitrogen was uniformly sidedressed on all plots at an average 200 kg ha^{-1} rate.

Table 2. Average annual grain yields of nonirrigated corn on Moody-Nora soil over the first and second 6-yr periods and the complete 12-yr period. Northeast Research and Extension Center, Concord, NE.

Treatment‡	df	1973–1978	1979–1984	1973–1984
		Years		
		Mg ha^{-1}		
1. Check		6.63	7.06	6.85
2. 11 P annual		7.15	7.41	7.28
3. 22 P annual		7.32	7.76	7.54
4. 33 P annual		7.19	7.65	7.42
5. 22 P alternate yr		6.82	7.40	7.11
6. 33 P every 3rd yr		6.97	7.47	7.22
7. 66 P alternate yr		7.08	7.82	7.45
8. 66 P every 6th yr		7.12	7.42	7.27
9. 22 P-27 K annual		7.21	7.58	7.40
10. 22 P-54 K annual		6.87	7.43	7.15
	df	ANOVA and associated contrasts		
		$P > F$		
Treatment	9	†	*	**
Contrasts				
P rate linear	1	**	**	**
P rate Quad	1	*	†	*
Treatment 3 vs. 9	1	NS	NS	NS
3 vs. 10	1	*	†	*
9 vs. 10	1	0.13	NS	0.12
2 vs. 8	1	NS	NS	NS
4 vs. 7	1	NS	NS	NS
2 vs. 6	1	NS	NS	NS
Residual error	27			
CV, %		4.4	3.4	3.1

*,**,† Significant at the 0.05, 0.01, and 0.10 probability levels, respectively.
‡ Nitrogen applied preplant to all plots at an average 90 kg ha^{-1} rate.

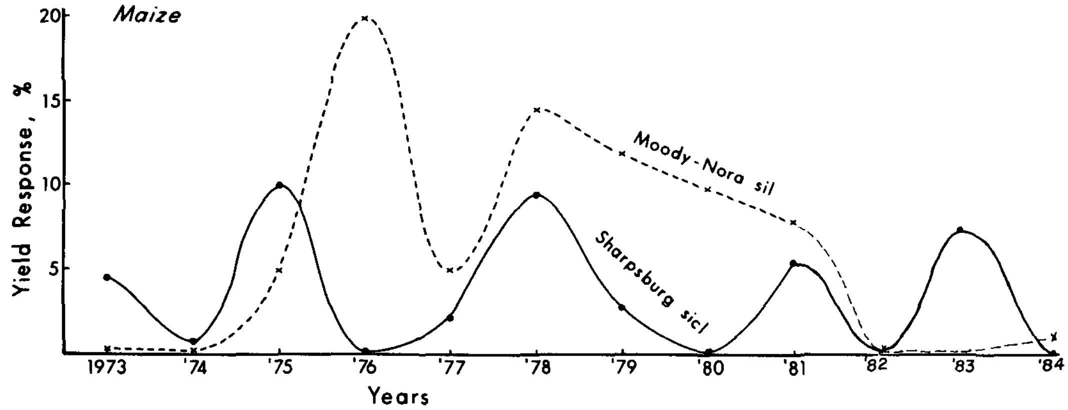

Fig. 2. Periodicity of corn yield response from 22 kg P ha^{-1} fertilizer rate relative to check on the Sharpsburg and Moody-Nora soils.

regions of the state. These profile data would project modest response to P on the Moody-Nora and Rosebud sites, slight response to P on the Sharpsburg and Keith sites, but no likelihood of response to K on any of the soils.

Grain Yield Response to Applied P and K

Corn grain yield increased by an average of 0.45 Mg ha^{-1} for the experimental period from 22 kg P ha^{-1} applied to the irrigated Sharpsburg soil, with average yield at the 10 Mg ha^{-1} level (Table 1). Similarly, corn grain yield increased by an average of 0.69 Mg ha^{-1} for that P rate on the nonirrigated Moody-Nora soil, with an average yield at the 7.5 Mg ha^{-1} level (Table 2). Eleven kg P ha^{-1} was not sufficient for maximum yield, and no benefit accrued from applications >22 kg ha^{-1}. Since no factorial arrangement was present, the statistical evaluation of response to P fertilization was determined using treatments 0, 11, 22, and 33 kg P ha^{-1} (designated as 1, 2, 3, and 4, respectively, in Tables 1-4), respectively. A significant linear response to P fertilization for corn was found from these treatments at both locations and a significant quadratic response was found on the Moody-Nora soil. No significant differences existed between annual P applications and less frequent applications of the same total amount, i.e., contrasts of treatments 2 vs. 8, 4 vs. 7, and 2 vs. 6. A striking seasonal periodicity of response is apparent and a trend of declining yield response over time is also evident, presumably due to increasing soil P levels of treated plots (Fig. 2).

Because of climatic problems (hail and drought) only 4 yr of yield data are recorded for the wheat-fallow locations (Table 3). General indication for these sites is that 22 kg P ha^{-1} was adequate for top yields in those four years, and no real difference existed between annual and periodic P application.

As the soil profile data of Fig. 1 would predict, there were no significant yield increases derived from applied K at any site. Rather, a significant yield reduction from the 54-kg K rate was registered for three of the four sites (contrast treatment 3 vs. 10, Tables 1, 2, and 3), and an even greater reduction resulted from the more efficient row application of 27 kg K ha^{-1} (treatment 3 vs. 11 in Table 1). Such depressions in yield have been measured before on high K soils in

Table 3. Treatment means for average annual grain yields of summer fallow wheat on Keith and Rosebud soils of the High Plains Ag Lab (four harvests in 1975, 1977, 1979, 1985), Sidney, NE.

		Soil type	
Treatment‡		Keith	Rosebud
		Mg ha^{-1}	
1. Check		2.98	2.39
2. 11 P annual		3.23	2.48
3. 22 P annual		3.15	2.65
4. 33 P annual		3.58	2.72
5. 22 P alternate yr		3.31	2.35
6. 33 P every 3rd yr		3.38	2.33
7. 66 P alternate yr		3.35	2.63
8. 66 P every 6th yr		3.35	2.77
9. 22 P-27 K annual		3.42	2.60
10. 22 P-54 K annual		3.46	2.33
ANOVA and associated contrasts			
	df	$P > F$	
Treatment	9	**	**
Years	3	**	**
Contrasts			
P rate linear	1	**	*
P rate quad	1	NS	NS
Treatment 3 vs. 9	1	NS	NS
3 vs. 10	1	NS	*
9 vs. 10	1	NS	†
2 vs. 8	1	NS	NS
4 vs. 7	1	NS	NS
2 vs. 6	1	NS	NS
Residual error		25.3	29.2
CV, %		11.34	16.2
Mean yield		3.32	2.52

*,**,† Significant at the 0.05, 0.01, and 0.10 probability levels, respectively.
‡ Nitrogen applied to all plots in spring of cropped year at an average 40 kg N ha^{-1} rate.

Nebraska for which no precise explanation has been given. Essentially no interference with crop Mg nutrition nor with N, P, K and Ca was apparent (F. Miany, 1980). One possible explanation is that K^+ derived from the fertilizer was adsorbed on the soil exchange complex with subsequent release of other cations such as Al^{3+}, Ca^{2+}, and Mg^{2+}. Upon release of these cations, especially Al^{3+}, insoluble complexes with P would form reducing the amount of plant available P from the fertilizer source (Bray, 1942; Nye et al., 1961). The yield depression thereby might be explained as a result of marginal P deficiency. Subsequent soil P data give some substance to this hypothesis.

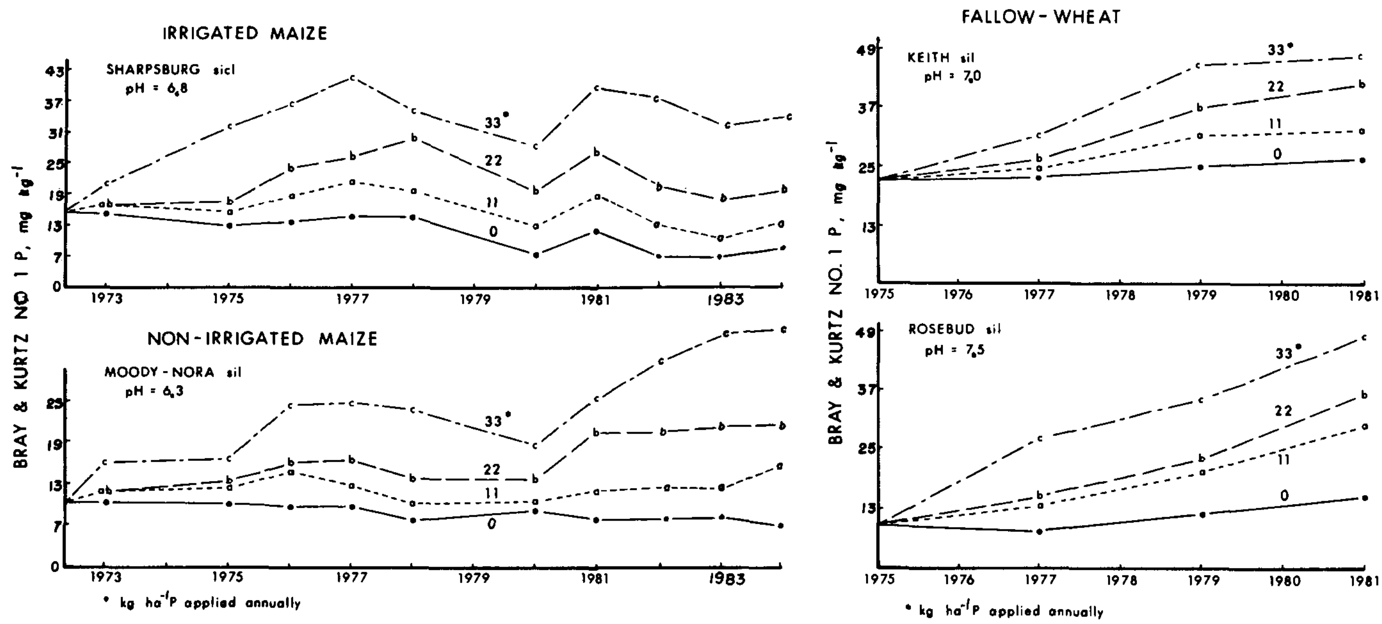

Fig. 3. Soil test P levels of the four soils through the years as influenced by the four fertilizer P rates employed.

Impact of Treatments on Soil Test P and K

Soil test P declined only slightly on check plots of Sharpsburg and Moody-Nora during the 12 yr of corn production and did not decline at all on the Keith and Rosebud (Fig. 3). The annual fluctuations in soil test P values are to be expected in view of the known seasonal effects imposed by weather factors (Olson et al., 1954, Sharpley, 1985) and the probabilities of occasionally procuring samples containing residual fertilizer particles. Twenty-two kilograms of P per hectare (treatment 3) increased soil test levels substantially, and 33 kg P ha^{-1} (treatment 4) more than doubled P level relative to the check plots at all sites. The 22-kg rate increased residual P in all cases above the level at which yield response to applied P would be expected. Approximately 4 kg of applied P ha^{-1} annually was required for the Moody-Nora soil and 13 kg P for the Sharpsburg (with its high corn yields) to maintain soil test P at its initial level. No applied P was required for maintenance on the fallowed Keith and Rosebud soils. Clearly, P is being released at a rapid rate from

Table 4. Means and analysis of variance for P fractions of Sharpsburg and Moody-Nora soils.

		Sharpsburg extract‡				Moody-Nora extract			
Treatment		A	B	C	D	A	B	C	D
		mg P kg^{-1} soil							
1. Check		26.8	23.5	41.6	45.6	23.9	27.8	59.2	220.0
2. 11 P annual		30.2	23.2	59.5	37.4	28.2	44.1	66.8	235.0
3. 22 P annual		37.9	25.6	66.8	43.8	33.3	41.9	64.4	271.9
4. 33 P annual		40.2	30.3	64.8	45.6	35.8	39.7	66.8	279.4
5. 22 P alternate yr		27.3	16.3	36.4	38.8	24.1	25.6	54.2	254.4
6. 33 P every 3rd yr		26.4	18.8	56.7	35.0	25.9	32.8	51.8	345.0
7. 66 P alternate yr		31.3	20.6	61.6	43.1	43.9	57.8	66.8	265.6
8. 66 P every 6th yr		24.5	18.5	56.7	48.1	20.2	28.2	69.6	336.0
9. 22 P-27 K annual		39.9	30.3	62.0	50.0	36.2	50.6	62.0	243.0
10. 22 P-54 K annual		40.5	32.8	67.2	43.8	32.8	38.0	64.4	228.0
		ANOVA and associated contrasts							
Source of error	df	probability > *F*							
Rep	3	**	NS	NS	*	*	NS	†	**
Treatment	9	**	NS	†	†	†	**	NS	NS
Contrasts									
P rate linear	1	**	NS	*	NS	†	NS	NS	NS
P rate quadratic	1	NS	NS	NS	NS	NS	†	NS	NS
Treatment 3 vs. 9	1	NS	NS	NS	NS	NS	NS	NS	NS
Treatment 3 vs. 10	1	NS	NS	NS	NS	NS	NS	NS	NS
Treatment 9 vs. 10	1	NS	NS	NS	NS	NS	†	NS	NS
Treatment 2 vs. 8	1	NS	NS	NS	NS	NS	*	NS	†
Treatment 4 vs. 9	1	†	NS	NS	NS	NS	*	NS	NS
Treatment 2 vs. 6	1	NS	NS	NS	NS	NS	†	NS	*
Check vs. others	1	†	NS	*	NS	NS	*	NS	NS
Residual error	27								
CV, %		19.0	35.4	26.5	27.8	35.0	24.8	24.0	27.3

*,**,† Significant at the 0.05, 0.01, and 0.10 probability levels respectively; NS indicates not significant.

‡ Extract A = nonoccluded Fe and Al-bound P (0.1 *M* NaOH); extract B = carbonate-sorbed P (1 *M* NaCl and citrate-bicarbonate); extract C = occluded Fe-P (citrate-bicarbonate-dithionite); extract D = Ca-bound P (1 *M* HCl). All extractions by method of Olson and Sommers (1982).

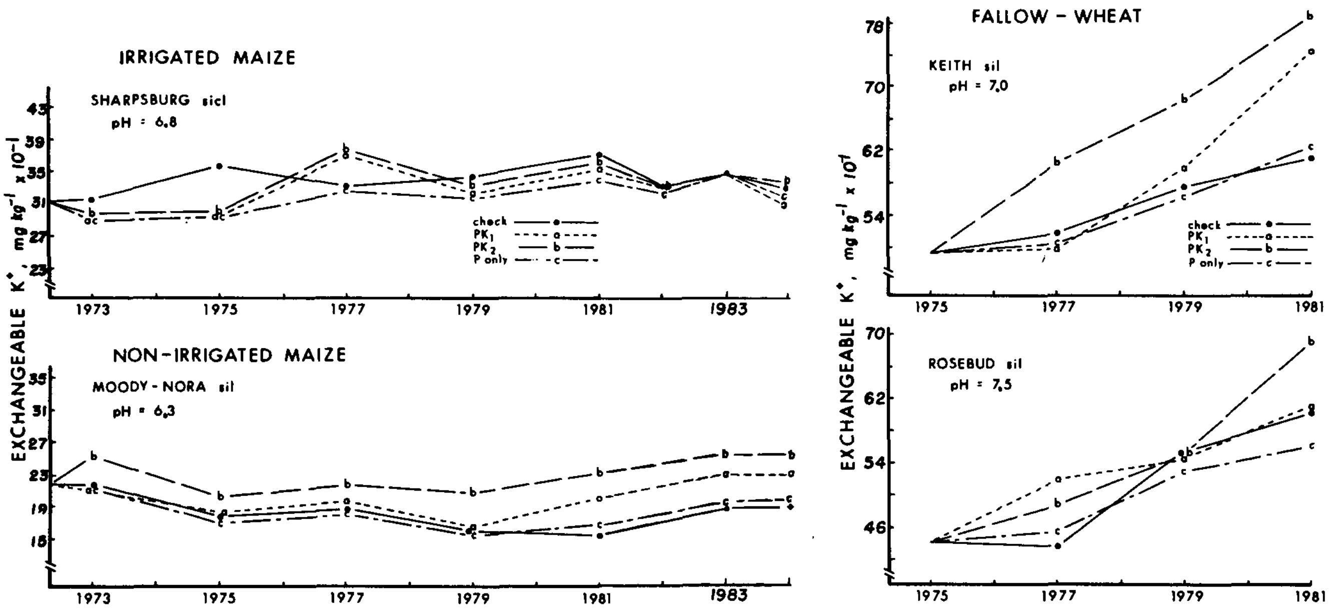

Fig. 4. Exchangeable soil K_+ of the four soils through the years as influenced by the three fertilizer K rates employed.

native soil minerals and from subsoil reserves in all of these soils.

Results obtained from P fractionations by sequential extraction of soil samples collected from the Sharpsburg and Moody-Nora sites in 1984 (Table 4) generally paralleled the yield data already discussed. Both the nonoccluded Al and Fe-bound P (A extract) and occluded Fe and Al-bound P (C extract) in the Sharpsburg soil, and the A extract of the Moody-Nora soil showed a positive, linear response to the rate of P applied. A quadratic effect also appeared in the carbonate-sorbed P (B extract) of the Moody-Nora soil. The increases in the A extract fractions that coincide with increasing P rates can be explained as follows. The soil samples are from the surface zone, and based on their pH values (Fig. 1), would be expected to have at least some Fe and Al coatings that are capable of sorbing phosphate ions. It appears that the slightly more acid Sharpsburg has more occluded crystalline Fe and Al materials that are also involved in P retention. Although the Moody-Nora surface soil is not calcareous in the usual sense, there may be some microcrystalline carbonates present. These then would contribute to the quadratic response to the rate of applied P in the B extract of the Moody-Nora soils.

Few of the other single degree of freedom contrasts showed significant trends. As expected, the zero P (check) soil was lower in P than all other treated soils for the Sharpsburg A and C extracts and the Moody-Nora soil B extract. There is no overall treatment effect in the Moody-Nora Ca-bound P (D extract), so the contrast showing significantly lower P concentrations of the zero P soil than in all other treated soils cannot be relied upon. Other contrasts suggest that there is more P "stored" in the soil when the P is applied annually than at a less frequent, but equivalent, rate. This is seen for the Sharpsburg soil where P in the A extract is higher in the 33-kg annual application than in the 66-kg biennial application; in the Moody-Nora soil where P in the B extract is higher in the 11-kg annual application than in both the 33-kg triennial and 66-kg every sixth year applications. The only inconsistency is with the 33-kg annual treatment of the Moody-Nora soil where the B extract P is lower than in the 66-kg biennial treatment. Without knowing the plant availability of these sorbed P fractions, it is difficult to interpret the data conclusively. If the nonoccluded Fe and Al-sorbed P is still relatively accessible to the growing plant, the smaller, more frequent applications would appear to be preferable to the less frequent applications because of the greater P retention by the former. In any case, these differences in P fractions within the soils due to frequency of fertilizer application do not correspond in any direct way to yield differences in the time interval involved (Tables 1 and 2).

The effect of the higher K rate in depressing corn yield is paralleled in one of the P fractionations. Phosphorus in the Moody-Nora B extract is higher for the soil with 27 kg K ha^{-1} applied than with 54 K (Table 4). This difference is similar to the difference in yield of the same treatments (Table 2). Thus excess K application may be related to lower P availability and correspondingly lower yield.

Soil test K presents quite a different story from that of P. Only the Moody-Nora soil declined in exchangeable K through the years on the plots that received no K, requiring about 15 kg K ha^{-1} annually to maintain soil test K at the initial levels. The other three soils evidenced substantially increased exchangeable K without K applied (Fig. 4). It is impossible to explain the source of this additional K from the data available. We can conjecture that it came from fixed K in the clay minerals released by the added NH_4^+ in N fertilizer or was translocated from subsoil horizons by root action. Translocation appears to be more likely because no differences were detected in "slowly available" K among treatments as measured by extraction with boiling 1 *M* HNO_3 (Table 5). This is true irrespective of P and K applied, crop grown, or cropping sequence (i.e., annual cropping vs. crop-fallow rota-

Table 5. Nitric acid-extractable K in soils of long-term fertility studies.†

Treatment	Corn studies		Wheat studies	
	Sharpsburg	Moody-Nora	Keith	Rosebud
	—— mg K kg^{-1} soil ——			
1. Check	1208	807	1953	1542
2. 11 P annual	1188	811	1947	1699
3. 22 P annual	1215	815	1994	1755
4. 33 P annual	1172	855	1944	1470
5. 22 P alternate yr	1220	870	1956	1670
6. 33 P every 3rd yr	1192	809	1860	1624
7. 66 P alternate yr	1168	831	1932	1722
8. 66 P every 6th yr	1230	822	1947	1538
9. 22 P-27 K annual	1231	835	1931	1577
10. 22 P-54 K annual	1256	919	1869	1733
11. 22 P-27 K annual row	1211	--	--	--
LSD (0.05)	NS	NS	NS	NS

† Extracted from 2.5 g of soil after 10 min boiling 1 *M* HNO_3 (Knudsen et al., 1982).

tion) and can be attributed to the high native mineral content of the soils, mainly as hydrous micas.

Statistical analysis of the soil P and K data in Table 6 for 1978 and 1984 (end of the 6- and 12-yr cycles of the corn experiments) show linear increases from fertilizer rates. The fact that soil P tends to be lower in plots with K treatment and common P rate (treatment 3 vs. 9 and 3 vs. 10) gives further credence to a K–P interaction deleterious to P availability that may explain the recorded yield depressions from applied K on these high K level soils.

CONCLUSIONS

This study affords added information, for the Western Corn Belt at least, for resolving philosophical differences that exist in soil test interpretation between university and many commercial soil testing laboratories. Most of the former have developed calibration schemes for the soils and crops of their respective states based on a "sufficiency" concept. Specifically, soils testing above some established level with a given nutrient receive no fertilizer recommendation (McLean, 1977; Olson et al., 1982). Many commercial organizations, however, espouse a "maintenance" and/or "cation balance" approach to recommendations. By this approach, fertilizer rate equivalent to the amount of nutrient a planted crop is likely to remove is advocated, without regard to the soil test results. Additional amounts of fertilizer may be proposed for building up the soil test level or for creating a presumed ideal cation balance.

The already high and increasing soil test values for K in soils of this region clearly do not support a purely maintenance approach to fertilizer recommendations. It is also apparent that the sufficiency approach of calibrated soil test values for P is more rational than the maintenance concept for these soils of the Western Corn Belt since soil P levels are actually increasing with no more P added than that needed periodically for most economic yield. Although there was only a nonsignificant trend for greater yield response to P applied annually than to a higher rate applied less frequently, the higher soil test values would indicate the probability of yield benefit eventually from annual treatment.

Table 6. Analysis of variance and associated contrasts for soil test variables for the Sharpsburg and Moody-Nora soils.

		Sharpsburg				Moody-Nora			
		Soil P		Soil K		Soil P		Soil K	
	df	1978	1984	1978	1984	1978	1984	1978	1984
		$P > F$							
Treatment	9	**	**	**	†	**	**	**	**
Contrasts									
P rate linear	1	**	**	**	NS	**	**	**	NS
P rate quad	1	NS	NS	NS	†	NS	NS	NS	NS
Treatment									
3 vs. 9	1	NS	NS	NS	**	**	NS	NS	NS
3 vs. 10	1	*	NS	*	**	NS	†	**	**
9 vs. 10	1	NS	NS	NS	NS	†	NS	**	**
2 vs. 8	1	*	NS	**	NS	NS	NS	†	NS
4 vs. 7	1	**	*	NS	NS	**	**	†	NS
2 vs. 6	1	†	NS	*	NS	**	NS	†	NS
Check vs. rest	1	**	†	**	NS	**	*	**	NS
Residual error	27								
CV, %		14.8	49.3	3.2	14.6	14.3	36.2	5.5	10.0

*,**,† Significant at the 0.05, 0.01, and 0.10 probability levels, respectively; NS = nonsignificant.

REFERENCES

Alessi, J., and J.F. Power. 1980. Effects of banded and residual fertilizer phosphorus on dryland spring wheat yield in the Northern Plains. Soil Sci. Soc. Am. J. 44:792–796.

Barber, S.A. 1979. Soil phosphorus after 25 years of cropping with five rates of phosphorus application. Commun. Soil Sci. Plant Anal. 10:1459–1468.

Bray, R.H. 1942. Ionic competition in base exchange reactions. J. Am. Chem. Soc. 64:954–963.

Bray, R.H., and L.T. Kurtz. 1945. Determination of total organic, and available forms of phosphorus in soils. Soil Sci. 59:39–45.

Dahnke, W.D. (ed). 1980. Recommended chemical soil test procedures for the North Central Region. North Central Regional Pub. 221. North Dakota State University, Fargo.

Halvorson, A.D., and A.L. Black. 1985. Long-term dryland crop responses to residual phosphorus fertilizer. Soil Sci. Soc. Am. J. 49:928–933.

Havlin, J.L., D.G. Westfall, and H.M. Golus. 1984. Six years of phosphorus and potassium fertilization of irrigated alfalfa on calcareous soils. Soil Sci. Soc. Am. J. 48:331–336.

Hipp, B.W. 1986. Wheat and forage sorghum response to residual phosphorus in Blackland soils. Agron. J. 78:117–120.

Knudsen, D., G.A. Peterson, and P.F. Pratt. Lithium, sodium, and potassium. *In* A.L. Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agronomy 9:225–246.

McLean, E.O. 1977. Contrasting concepts in soil test interpretation: Sufficiency levels of available nutrients versus basic cation saturation ratios. p. 39–54. *In* T.R. Peck et al. (ed.) Soil testing: Correlating and interpreting the analytical results. Spec Pub. 29. American Society of Agronomy, Madison, WI.

Miany, F. 1980. Crops and soil response to applied P and K in a long term buildup/depletion study. M.S. thesis. Univ. of Nebraska, Lincoln.

Novais, Roberto, and E.J. Kamprath. 1978. Phosphorus supplying capacities of previously heavily fertilized soils. Soil Sci. Soc. Am. J. 42:931–935.

Nye, P., D. Craig, N.T. Coleman, and J.L. Ragland. 1961. Ion exchange equilibria involving aluminum. Soil Sci. Soc. Am. Proc. 25:14–17.

Olsen, S.R., and L.E. Sommers. 1982. Phosphorus. *In* A.L. Page et al., (ed.) Methods of soil analysis, part 2. 2nd ed. Chemical and microbiological properties. Agronomy 9:403–430.

Olson, R.A., K.D. Frank, P.H. Grabouski, and G.W. Rehm. 1982. Economic and agronomic impacts of varied philosophies of soil testing. Agron. J. 74:492–499.

Olson, R.A., M.B. Rhodes, and A.F. Dreier. 1954. Available phosphorus status of Nebraska soils in relation to series classification, time of sampling and method of measurement. Agron. J. 46:175–180.

Rehm, G.W., R.C. Sorensen, and R.A. Wiese. 1984. Soil test values for phosphorus, potassium and zinc as affected by rate applied to corn. Soil Sci. Soc. Am. J. 48:814–818.

Sharpley, A.N. 1985. Phosphorus cycling in unfertilized and fertilized agriculture soils. Soil Sci. Soc. Am. J. 49:905–911.