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Phosphorus Management

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PHOSPHORUS MANAGEMENT

Reduction of High Soil Test Phosphorus by Corn and Soybean Varieties

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ABSTRACT

Soils with high levels of P can contribute to excess P in runoff and subsequently pollute the surface water. Excess P in the soil can be removed from the system by harvesting crops. The objectives of this study were to evaluate corn (*Zea mays* L.) P removal effects on soil P reduction, and to evaluate various corn hybrids and soybean [*Glycine max* (L.) Merr.] varieties for differences in grain P concentration and P removal. Soil with varying P levels as a result of annual or biennial beef cattle (*Bos taurus*) feedlot manure or compost application was cropped to corn for 4 yr without any P addition. In other studies under various water and N regimes, corn hybrids and soybean varieties were evaluated for grain P concentration and P removal. Four years of corn production without P addition lowered surface soil (0–15 cm) extractable P level (Bray and Kurtz no. 1) from 265 mg kg^{-1} to 171 mg kg^{-1} in the biennial N-based compost treatment. Based on a decay equation, it would have required 10 yr of corn P removal to lower the soil P level to the original 69 mg kg^{-1} that existed before treatment application. The rate of decrease in extractable soil P was greater when soil P was higher and reduced with decreasing soil P level. Most of the P in the plants was absorbed from the 0- to 15-cm soil depth since no significant reduction in soil P level was observed from 1996 to 1999 in the 15- to 30-cm soil depth. Across 2 yr, there was as much as 54% difference among corn hybrids for grain P removal. The differences in P concentrations among corn hybrids indicated that hybrids could be selected for low P uptake when lower P level in ethanol production by-product or in animal ration and subsequently in manure is desired. Soybean grain P concentration was nearly twice that for corn but grain P removal was less for soybean than for corn. Crop P removal can significantly reduce soil P level with time.

Application of manure or composted manure can result in a significant accumulation of P in soil. Eghball and Power (1999) found that N-based applications of manure and composted manure resulted in a significant P increase in the soil while P-based applications maintained the soil P near the original level. High levels of plant-available P in the soil can result in significant P loss in runoff (Pote et al., 1996). How much soil test P influences the P loss in runoff depends on the time of P application. Eghball et al. (2002) showed that soil test P was not a significant factor in soluble P loss in runoff when application of manure or inorganic fertilizer was made just before simulated rainfall. In contrast, when manure or P fertilizer was applied a year earlier, a significant relationship was found between soluble P loss in runoff and soil test P. Eghball and Gilley (2001) found that erosion was the most important factor in loss of total and particulate P, whereas runoff amount, tillage, and P source were the important factors influencing loss of dissolved and bioavailable P in runoff. The soil test P levels in this study did not seem to be high enough (ranged from 25 to 101 mg kg^{-1} in the top 5 cm soil) to influence dissolved or bioavailable P in runoff.

Soils with high P test concentrations can be managed to reduce the soil test P level and the subsequent reduction for P loss potential in runoff. Crop, soil, and management factors can change soil test P (Pierzynski and Logan, 1993). Practices such as deep tillage to bury the high P containing surface soil, crop P removal, and P application strategies can be used to reduce soil P level. However, tillage can increase soil erosion and hence result in greater total P loss in runoff (Eghball and Gilley, 1999). The build-up and maintenance P application strategy can increase soil test P while the sufficiency strategy (apply only what is needed) can maintain soil test P near the original level (Olson et al., 1982). Crop removal can be an effective method of reducing soil test P. The amount of P removed by grain from the soil depends on the crop grown. McCallister et al. (1987) found that soil test P in surface layers (0–15 cm) of two Mollisols under irrigated corn decreased by 42% while soil test P in two other Mollisols under fallow–winter wheat (*Triticum aestivum* L.) did not decline following 20 yr of cropping without any P addition. McCollum (1991) showed that high soil test P (>50 mg kg^{-1}, Mehlich-1) could not be maintained by annual replacement of crop-removed P because P conversion to unavailable forms was a larger factor than crop removal in depleting the extractable P pool in an Ultisol. However, when P level was 20 to 24 mg kg^{-1}, soil test P was maintained by band application of crop-removed P. Grain P removal by corn, soybean, and winter wheat increased as the fertilizer P application rates increased from 0 to 54 kg ha^{-1}. This occurred even though yield was maximized at about 11 kg P ha^{-1} in a 25 yr P buildup–decline study, indicating luxury consumption of P by crop when soil test P was high (Barber, 1979). Genotypes of each crop can remove different amounts of P from the soil. Gordon et al. (1997) found differences among corn hybrids for total P uptake in a no-till rainfed system.

The objectives of this study were (i) to evaluate corn grain P removal effects on soil test P in a soil with a history of manure and composted manure applications and (ii) to evaluate differences among corn hybrids and soybean varieties for grain P concentration and removal.

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Table 1. Composted and noncomposted manure P applications in 4 yr at Mead, NE.

Treatment	Phosphorus				
	1992	1993	1994	1995	Total
	kg P ha^{-1}				
Manure for N†	104	74	42	36	256
Manure for P	63	25	23	7	118
Manure for N/2y	208	–	127	–	335
Manure for P/2y	125	–	69	–	194
Compost for N	141	112	104	139	496
Compost for P	63	23	22	11	119
Compost for N/2y	282	–	312	–	594
Compost for P/2y	126	–	66	–	192
Fertilizer	26	26	26	26	104
Check	–	–	–	–	–

† N and P indicate applications to meet N or P needs of corn, respectively, and 2y indicates biennial application.

MATERIALS AND METHODS

Manure and Compost Study

Manure or Compost Application

The experiment was initiated in 1992 on a Sharpsburg silty clay loam soil (fine, smectitic, mesic Typic Argiudolls) under rainfed conditions (1993–1996 growing seasons) at the University of Nebraska Agricultural Research Center near Mead, NE. Growing season rainfall from 1 May to 15 October was 773, 558, 307, and 425 mm in 1993, 1994, 1995, and 1996, respectively. Average rainfall during this period in the last 30 yr was 493 mm. The Sharpsburg series consists of deep, moderately well-drained soils formed in loess on uplands and high benches. Permeability is moderately slow in the upper part of the subsoil and moderately slow in the lower part and in the substratum. The study area had a Bray and Kurtz no. 1 soil P test of 69 mg kg^{-1}, a $pH_{1:1}$ of 6.2, a soil organic matter content of 31 g kg^{-1}, and clay, silt, and sand contents of 25, 67, and 8%, respectively, in the top 15-cm soil depth before the initiation of the experiment in 1992. The 15- to 30-cm soil depth had a soil P test of 32.5 mg kg^{-1}, a $pH_{1:1}$ of 6.3, and clay, silt, and sand contents of 23, 69, and 8%, respectively.

The experimental design was a randomized complete block with four replications. The 10 treatments applied (Table 1) included annual or biennial manure or compost application based on N or P removal by corn (151 kg N ha^{-1} and 25.8 kg P ha^{-1} for an expected yield level of 9.4 Mg ha^{-1}) and inorganic fertilizer and unfertilized checks. Fertilizer application was made in the spring each year from 1993 to 1996. The inorganic fertilizer plots received N as NH_4NO_3 (34–0–0, N–P–K) and P as superphosphate (0–20–0) in 1993 and diammonium phosphate (18–20–0) in 1994, 1995, and 1996. If necessary, the P-based treatments (annual or biennial application) were supplemented with N fertilizer as NH_4NO_3 in the spring so that a total of 151 kg N ha^{-1} was available to the crop. Biennial manure or compost applications were made to provide 151 kg N ha^{-1} for N-based and 25.8 kg P ha^{-1} for P-based rates in the second year after application. Over-application of N and P were made in the first year of biennial manure and compost treatments.

Manure or compost application was made in late autumn after corn harvest. Manure and compost were applied by hand to plots 12.2 m long and 4.6 m wide (six corn rows). The characteristics of manure and compost applied from 1992 to 1995 are given in Table 2. Beef cattle manure was collected from the feedlot pens in late spring each year and composted for about 4 mo using active composting with turning. Beef cattle feedlot manure (collected in the autumn) and composted feedlot manure were applied from 1992 to 1995. The P application rates in 4 yr are given in Table 1. Manure and compost were applied and incorporated into the top 10-cm soil depth by disking within 2 d after application. The experimental area was disked to 10-cm soil depth again in the spring before planting. Additional information regarding corn yield, N and P uptake, and soil properties from 1993 to 1996 are reported in Eghball and Power (1999) and Eghball (2002). The soil P level increase during the years of manure and compost applications are given in Eghball and Power (1999).

Residual Effects

For the 1997, 1998, and 1999 growing seasons, no manure, compost, or fertilizer (except N application for the fertilizer treatment only in 1999) applications were made. The experiment was conducted under sprinkler irrigation from 1997 through 1999. In all 7 yr, Pioneer brand corn hybrid 3394 was planted at a rate of 47 000 seeds ha^{-1} and a row spacing of 0.76 m. Weed control was achieved by band application of herbicide in the corn rows at planting and by cultivation. The plots were disked before planting each year. Corn was harvested from 6.1 m of the middle two rows and grain yield measured. One of these rows was cut for stover yield. Grain yields were adjusted to a water content of 155 g kg^{-1}.

Soil samples from 0- to 15- and 15- to 30-cm depths were collected from all plots each year after corn harvest. Fifteen soil cores were collected from each plot and combined. The soil samples were air-dried and analyzed for soil test P using the Bray and Kurtz no. 1 method. A decay series equation was fitted to the surface soil (0–15 cm) P data for each treatment as follows:

$$y = a\, e^{-bx}$$

Table 2. Characteristics of beef cattle feedlot manure and composted feedlot manure applied from 1992 to 1995 at Mead, NE. Nutrients, C, and ash contents are on dry-weight basis.

Year and source	Total C	Total N	Total P	Ash	Water content	NO_3–N	NH_4–N	EC†	pH†
	g kg^{-1}					mg kg^{-1}		d S m^{-1}	
1992									
Manure	78.4	7.9	2.29	844	195	30	1263	4.6	7.3
Compost	95.0	11.0	4.18	808	332	117	169	7.4	7.7
1993									
Manure	133.1	10.2	5.00	715	539	17	480	5.2	8.8
Compost	87.4	7.7	3.16	796	403	38	33	2.2	8.3
1994									
Manure	237.0	15.6	3.27	591	200	11	365	5.4	8.2
Compost	73.5	7.6	4.07	849	340	383	55	6.1	7.2
1995									
Manure	172.8	13.0	3.16	677	251	130	898	3.8	7.3
Compost	68.2	7.8	3.05	798	150	294	97	6.0	7.7

† EC and pH were determined on 2:1 water/dry manure or compost ratio.

where y is soil P level, x is time in years since termination of manure or compost application (1, 2, 3, and 4 for 1996, 1997, 1998, and 1999, respectively), and a and b are constants.

Corn Hybrids Study

This experiment was conducted near Shelton, NE, during the 1999 and 2000 growing seasons on a Hord silt loam soil (fine-silty, mixed, superactive, mesic Cumulic Haplustolls). Treatments consisted of three replications of a factorial combination of 12 corn hybrids, 2 water levels (adequate and deficit irrigation), and 2 N levels (deficit and full N, 13 and 181 kg N ha^{-1}, respectively), for a total of 48 treatment combinations. The 11 Pioneer brand hybrids (3162, 3394, 3417, 33A14, 33G27, 33H67, 33R87, 34D34, 34G82, 34K77, and 34R07) represented a combination of older and more recently developed lines. The B73 × Mo17 line represents an older standard check for comparison purposes. The B73 inbred is from Iowa State University and the Mo17 inbred is from University of Missouri. Seeding rate was approximately 79 000 seeds ha^{-1}. The hybrids were selected for their differences in relative maturity, canopy architecture (upright architecture vs. planophile orientation), drought resistance, and tolerance to various pests such as European corn borer (*Ostrinia nubilalis*) using the Bt (*Bacillus thuringiensis*) trait.

The experimental design was a randomized complete block in a split-split plot arrangement, with water as the main plot, N as the split plot, and hybrid as the split-split plot. Individual plot dimensions were 3.6 by 30 m, consisting of four rows spaced 0.9 m apart. Starter fertilizer as ammonium polyphosphate solution (10–15–0, N–P–K) was applied at a rate of 19 kg P ha^{-1} each year. A broadcast application of 20 kg P ha^{-1} (0–20–0) was made in 1999 before initiation of the experiment. Nitrogen fertilizer as anhydrous ammonia (82–0–0) was applied at growth stage of about V-5 each year. Water applied was 9.7 cm for the adequate irrigation and 1.4 cm for the deficit irrigation in 1999, while the adequate irrigation received 29.6 cm and the deficit irrigation received 9.8 cm water in 2000. Irrigation was applied with a linear drive sprinkler system. Average P level (Bray and Kurtz no. 1) in the 15-cm surface soil depth in the spring of 2000 was 14.2 mg kg^{-1} and soil pH$_{1:1}$ was 6.9.

Grain yield, adjusted to a water content of 155 g kg^{-1}, was determined from each plot by combine harvesting. Grain samples were analyzed for total P using the method described by Knudsen et al. (1981).

Soybean Varieties Study

The experiment was conducted near Shelton, NE, on a Hord silt loam soil planted to continuous soybean since 1991. The area received a broadcast P application of 67 kg ha^{-1} as 0–20–0 in the spring of 1997. The soil (0–15 cm) had a Bray and Kurtz no. 1 P test of 19.7 mg kg^{-1} in 1999, 14.7 mg kg^{-1} in 2000, and a pH$_{1:1}$ of 6.7 in 2000. All plots were disked once and then tilled with a field cultivator each year before planting in the spring. In both 1999 and 2000, the entire experiment was irrigated throughout the growing season as needed (9.7 cm in 1999 and 29.6 cm in 2000), using a linear drive sprinkler system. The varieties used were Pioneer 93B01, Pioneer 93B34, Pioneer 93B44, and Asgrow 3001R in 1999 and Pioneer 93B01, Pioneer 93B34, and Asgrow 3003R in 2000. All varieties were planted with a John Deere Van Brunt grain drill with disk openers spaced 18 cm apart. Seeding rates were approximately 444 600 to 494 000 seeds ha^{-1} and the seeding depth was approximately 3.8 to 5 cm. Nitrogen fertilizer treatments were applied on 8 June 1999 and 23 May 2000 as broadcast ammonium nitrate (34–0–0) at a rate of 100 kg N ha^{-1}. Nitrogen was applied to soybean to evaluate the effects of N addition on soybean yield and N uptake. The four soybean varieties used in 1999 and 2000 were Roundup-ready. Soybean plots were harvested with a plot combine on 6 Oct. 1999 and 3 Oct. 2000. Grain yield was adjusted to a water content of 130 g kg^{-1}. The grain samples from 1999 and 2000 were analyzed for total P (Knudsen et al., 1981).

Analysis of variance was used to determine differences among corn hybrids and soybean varieties using PROC MIXED of SAS (Littell et al., 1996). A probability level ≤0.05 was considered significant.

RESULTS AND DISCUSSION

Residual Manure and Compost Effects

Surface soil (0–15 cm) P levels were significantly higher for annual and biennial N-based manure and compost applications than P-based treatments or check plots in 1996 where the last applications were made in autumn 1995 (Fig. 1a). The surface soil P level decreased for all treatments, except the check and P-based manure, from 1996 through 1999 when no organic or inorganic P application was made. The rate of reduction in surface soil P level was greater when soil P was higher than when the soil P level was close to the initial soil test P level of 69 mg kg^{-1} (Table 3 and Fig. 1a). The decay series equations indicated that the time to reach the original surface soil test P level was influenced by the starting point P level (Table 3). There was a linear rela-

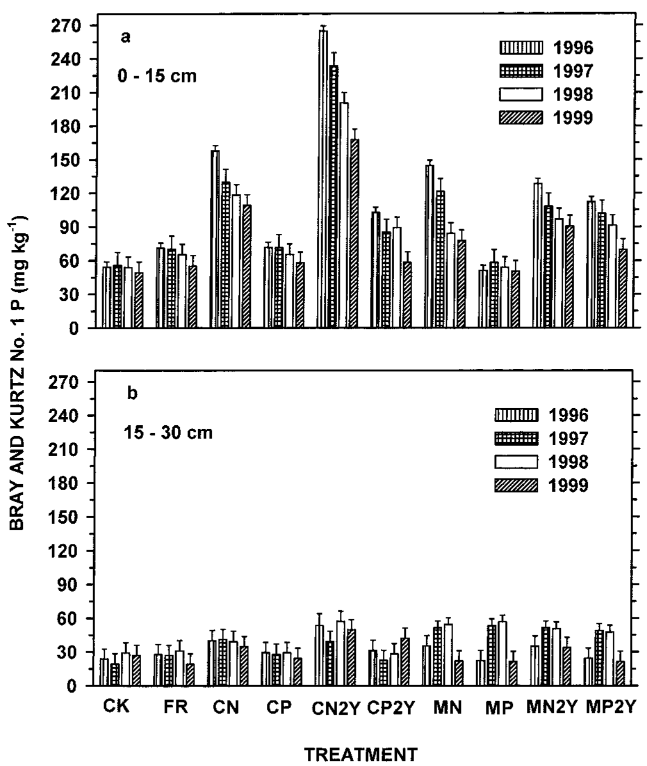

Fig. 1. Soil P levels in the 0- to 15- and 15- to 30-cm depths for 10 treatments during 4 yr of corn production without P application in eastern Nebraska. The vertical bars are standard errors, CN is compost for N, CP is compost for P, MN is manure for N, MP is manure for P, FR is inorganic fertilizer, CK is check, and 2Y indicates biennial application.

Table 3. Phosphorus levels in 1996 and parameters for the equation $y = a\,e^{-bx}$ relating soil Bray and Kurtz no. 1 P level (y) as a function of years (x: 1, 2, 3, and 4 for 1996, 1997, 1998, and 1999, respectively) of corn grain P removal for 10 treatments.

Variables	P level in 1996	a	b	R^2	Year†
	mg kg^{-1}				
Manure for N‡	144.6	183.0	0.2280	0.96	4.3
Manure for P	51.19	54.9	0.01169	0.06	–
Manure for N/2y	128.4	141.9	0.1202	0.96	6.0
Manure for P/2y	112.2	132.5	0.1435	0.94	4.5
Compost for N	157.8	174.7	0.1260	0.95	7.4
Compost for P	71.7	79.0	0.0691	0.86	2.0
Compost for N/2y	264.5	309.9	0.1488	0.99	10.1
Compost for P/2y	102.6	120.0	0.1491	0.77	3.7
Fertilizer	71.0	79.2	0.07796	0.83	1.8
Check	54.3	57.7	0.03169	0.60	–

† Projected years to reach the original soil P level of 69 mg kg^{-1} before manure and compost applications in 1992; manure and compost were applied from 1992 to 1995.
‡ Nitrogen and P indicate applications to meet N or P needs of corn, respectively, and 2y indicates biennial application.

tionship between the surface soil P level and the years to reach the original P level of 69 mg kg^{-1} (yr = $-0.626 + 0.04256$ Soil P, $R^2 = 0.90$). This indicated that if the soil had a P level of 265 mg kg^{-1}, then it would require 10 yr of corn grain P removal to reach the original P level of 69 mg kg^{-1}. Reducing the 265 mg kg^{-1} P level to 150 mg kg^{-1}, which is used as a critical level by some states (Sharpley et al., 1996), would require only 5 yr of corn production (Table 3). However, the time required to reduce the soil P level depends on soil P adsorption characteristics, crop grown, and the soil P level to be reached. Other factors influencing P removal from surface soil include wind and water erosion and P leaching. Erosion was probably not a significant factor at this site since average slope was about 1%.

Across 4 yr, soil P level in the 15- to 30-cm soil depth did not significantly change for the check, fertilizer, and compost treatments (Fig. 1b). For the manure treatments, there were increases in the 15- to 30-cm soil P levels in 1997 and 1998 as compared with those in 1996 (Fig. 1b), indicating movement of P to this soil depth from manure-applied P. By 1999, however, the soil P level in the 15- to 30-cm soil was similar to the 1996 level for all treatments. It appears that P uptake from this soil depth by corn was not significant enough to reduce the P level in years without P addition. Most of the P in plants appears to have come from the surface soil.

Grain P concentrations were different among treatments in 1996, 1998, and 1999, but the differences were not consistent across years (Table 4). The check plots had lower grain P concentrations than other treatments in 1996 when the experiment was under rainfed condition. In the following years when the plots were irrigated (1997–1999), grain P concentrations of the check plots were similar to the other treatments (Table 4), indicating that adequate water improved P absorption by the roots. Phosphorus removal in grain was the lowest for the check plots in all 4 yr (Table 4), reflecting the lower grain yield in the check plots.

There was no significant difference among the residual effects of N and P based manure or compost treatments for corn grain P removal (Table 4), even though the surface soil P levels were different among treatments (Table 3 and Fig. 1a). The surface soil P level, with values >51 mg kg^{-1}, was adequate for corn production for all treatments. In 1999 when only the fertilizer treatment received N (others received no N), corn grain P removal was the highest for the fertilizer treatment pointing to the importance of adequate N for removing P from the soil.

The correlation between corn grain P concentration and surface soil P test level was significant only in 1999 ($r = 0.33$, $P = 0.03$) in the residual study, indicating that higher soil P level did not necessarily result in greater P concentration in grain. However, the correla-

Table 4. Residual effects of beef cattle manure or composted manure application on corn (Pioneer brand 3394) grain P concentration and removal in 4 yr in eastern Nebraska.

Treatment	Grain P conc.				Grain P removal				
	1996	1997	1998	1999	1996	1997	1998	1999	Total
	mg kg^{-1}				kg ha^{-1}				
Manure for N†	2610	2600	2920	3860	19.9	25.4	24.9	30.9	101.1
Manure for P	2430	2450	2580	3740	21.0	23.0	20.5	29.3	93.8
Manure for N/2y	2530	2620	2860	3680	21.5	25.6	25.1	30.9	103.1
Manure for P/2y	2550	2350	3190	3890	19.3	24.4	28.3	31.1	103.1
Compost for N	2630	2450	2760	4020	22.4	24.0	22.4	31.5	100.3
Compost for P	2830	2420	2580	3830	24.8	24.8	22.4	29.3	101.3
Compost for N/2y	2660	2540	2730	4120	19.2	24.9	24.0	32.6	100.7
Compost for P/2y	2830	2460	2700	3660	26.4	22.7	21.4	32.3	102.8
Fertilizer	3010	2460	2730	3770	22.3	25.4	23.2	35.9	106.8
Check	1860	2350	2680	3970	11.4	16.8	20.0	30.6	78.8
Avg.	2590	2470	2770	3850	20.8	23.7	23.2	31.5	99.2
LSD (0.05)	390	NS‡	460	320	5.3	6.1	5.9	6.2	–

† Nitrogen and P indicate applications to meet N or P needs of corn, respectively, and 2y indicates biennial application. Manure and compost were applied from 1992 to 1995.
‡ NS indicates nonsignificant.

tion coefficients between grain P concentrations and soil P levels increased with year of residual measurements as follows: 0.10 for 1996, 0.14 for 1997, 0.24 for 1998, and 0.33 for 1999. When corn is grown under insufficient N, P concentration in the grain is higher.

The amount of P removed integrates both the P concentration in the grain and the amount of grain produced. Using the soil bulk density (1.27 Mg m^{-3}) determined for this soil in 1996 (Eghball, 2002), the quantity of plant-available P in the top 15-cm soil can be determined. The decreases in plant-available soil P (Bray and Kurtz no. 1) from 1996 to 1999 were 9.8 kg ha^{-1} for the check, 30.3 for fertilizer, 92.8 for compost applied to meet corn N needs, 26.1 for compost applied to meet corn P needs, 184.6 for compost applied to meet N needs for 2 yr, and 84.6 for compost for P for 2 yr. Additionally, available P decreased 127.7 kg ha^{-1} for manure for N, 1.5 for manure for P, 71.7 for manure for N for 2 yr, and 80.9 for manure for P for 2 yr treatment from 1996 to 1999. Phosphorus removed in the grain accounted for the reduction in soil P for all treatments except compost applied for N for 2 yr. Phosphorus adsorption by the soil seemed to reduce the soil P for this treatment. Some of the P was also in the corn stover when soil samples were collected. The stover P would be mineralized in the following years after incorporation.

Eghball et al. (1990) showed that the Sharpsburg soil has a high P adsorption capacity, which reduced longevity of applied fertilizer P remaining as plant-available in the soil as compared with two other soils. The P adsorption maximum for the Sharpsburg soil was 237 μg cm^{-3} (Eghball et al., 1990). In soils that have low P adsorption capacity, i.e., sandy soils, crop removal would be the primary mechanism for reducing soil P level. Phosphorus saturation index can also influence residual P in the soil. Sharpley (1996) found that the rate of P release to iron-oxide–impregnated strips decreased more rapidly as P adsorption saturation increased in soils with a history of beef cattle, swine, and poultry manure applications. Bicarbonate inorganic P accounted for 46% of the P released to the strips.

Corn Hybrids

Adequate irrigation reduced grain P concentration in 1999 but increased grain P removal in both years as compared with deficit irrigation (Table 5). Adequate N application had no effect on grain P concentration but significantly increased P removal by grain reflecting the effect of N addition on increasing corn grain yield (Table 5). Averaged across water and N treatments, P removal ranged from 24.3 to 35.0 kg ha^{-1} in 1999 and from 16.6 to 25.7 kg ha^{-1} in 2000 for various hybrids (Table 5). Averaged across N rates, corn grain yields for the hybrids ranged from 6.84 to 9.68 Mg ha^{-1} for the deficit irrigation and from 8.08 to 10.41 Mg ha^{-1} for the adequate irrigation in 1999. In 2000, corn grain yields ranged from 5.00 to 7.54 Mg ha^{-1} for the deficit irrigation and from 7.89 to 9.62 Mg ha^{-1} for the adequate irrigation (averaged across N rates). No significant correlation was observed ($r = 0.06$, $n = 288$) between corn grain yields and grain P concentrations across 2 yr. Grain P concentrations and P removals were significantly influenced by corn hybrids (Table 5). The differences among corn hybrids for grain P concentration points to the opportunity for selecting hybrids with either high or low grain P concentrations. Low P concentration corn can be used to reduce P in ethanol production by-product or in animal rations and subsequently in manure.

Averaged across 2 yr, the grain P removal with adequate levels of water and N was different among various hybrids (Table 6). The P removal by 34K77 hybrid points to the potential of this hybrid to remove greater quantities of P from the soil. The Pioneer brand hybrid 3394 that was used in both the manure–compost and the corn hybrid studies removed only 26.7 kg P ha^{-1}

Table 5. Effects of water and N treatments on grain P concentration and removal by corn hybrids in 2 yr in central Nebraska.

Variables	df	Grain P conc. 1999	Grain P conc. 2000	Grain P removal 1999	Grain P removal 2000
		mg kg^{-1}		kg ha^{-1}	
Water					
Deficit irrigation		3050	2710	28.2	17.1
Adequate irrigation		2920	2760	34.1	24.6
N, kg ha^{-1}					
13		3010	2740	27.4	13.0
181		2960	2730	34.9	28.7
Hybrids					
3162		3160	2960	33.2	20.2
3394		2640	2410	24.3	18.8
33A14		2910	2390	31.5	19.2
33G27		3290	3010	35.0	20.3
33H67		2980	2880	32.7	21.7
33R87		3110	3180	32.3	23.6
3417		2750	2300	30.1	19.8
34D34		3190	3240	32.9	25.4
34G82		3180	2720	28.9	19.4
34K77		3140	3110	32.1	25.7
34R07		2910	2470	33.3	19.7
B73 × Mo17		2570	2120	27.4	16.6
LSD (0.05)		270	270	4.9	2.6
Analysis of variance†	df	*PR* > *F*			
Water	1	0.02	0.63	0.03	0.01
N	1	0.32	0.92	0.02	0.01
Water × N	1	0.41	0.19	0.24	0.01
Hybrid	11	0.01	0.01	0.01	0.01
Water × Hybrid	11	0.07	0.75	0.09	0.13
N × Hybrid	11	0.82	0.25	0.62	0.01
Water × N × Hybrid	11	0.18	0.88	0.86	0.29

† In this analysis, replication and other error terms were considered random effects.

Table 6. Grain P removal in corn grown under adequate water and N levels averaged across 2 yr (1999 and 2000) in central Nebraska.

Hybrids†	Grain P removal
	kg ha^{-1}
34K77	40.6
33H67	38.6
33G27	38.1
33R87	38.1
34D34	37.1
3162	35.9
34G82	31.0
34R07	30.4
3417	29.6
33A14	27.7
3394	26.7
B73 × Mo17	26.4
LSD (0.05)	6.0

† All pioneer brand hybrids except B73 × Mo17.

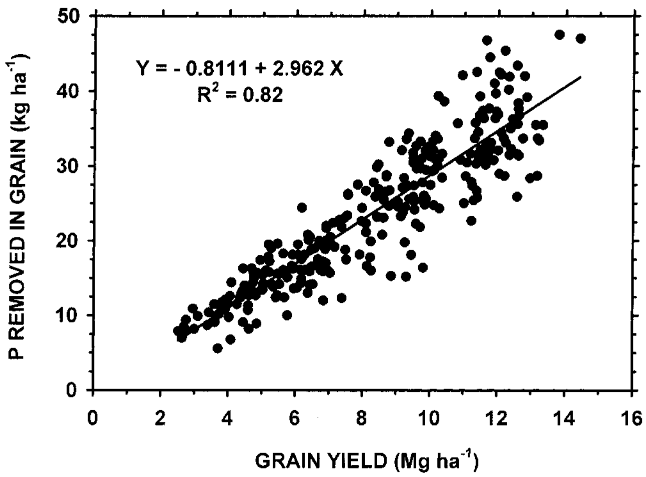

Fig. 2. Phosphorus removal in corn grain as influenced by grain yield level in 1999 and 2000 in the corn hybrids study in central Nebraska.

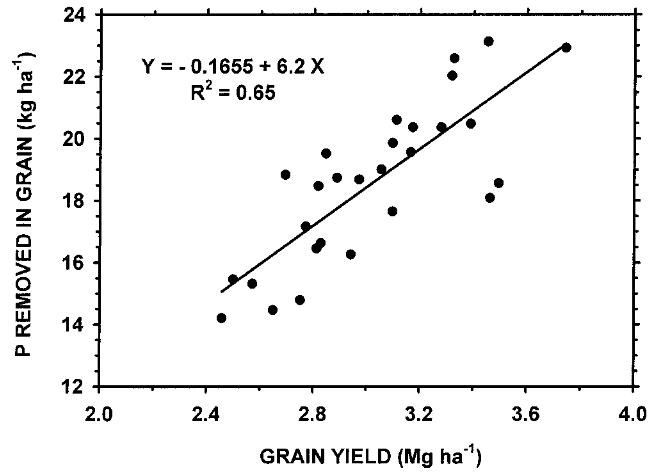

Fig. 3. Phosphorus removal in irrigated soybean grain as influenced by grain yield level in the soybean varieties study in central Nebraska.

yr^{-1} in grain, 34% less than the 34K77 hybrid. Pioneer 3394 removed 24.2 kg P ha^{-1} yr^{-1} in grain in the manure–compost study (Table 4). Even with hybrid 3394, the soil P level was reduced significantly with corn P removal and time (Fig. 1a). Substituting hybrid 34K77 for 3394 would have removed an estimated 66 kg ha^{-1} additional P in the 4 yr of the residual study. Eakin (1976) reported corn grain P removal of 25.8 kg ha^{-1} at a yield level of 9.4 Mg ha^{-1}. Based on the linear equation in Fig. 2, a corn yield level of 9.4 Mg ha^{-1} resulted in grain P removal of 27.0 kg ha^{-1}. There was only 5% difference between the P removal reported by Eakin (1976) and this study, even though the hybrids used in the Eakin's report were more than 25 yr old.

Soybean Varieties

Soybean varieties had similar grain P concentrations but had significantly different grain P removal (Table 7). Soybean grain P concentration was twice that of corn grain (Tables 5 and 7). However, because of the greater grain yield of corn, average soybean P removal was about half that of corn (Tables 6 and 7), pointing out the advantage of corn over soybean for soil P removal. More than 60% of the corn roots are in the top 30 cm soil (Eghball and Maranville, 1993) and that can significantly reduce the surface soil test P level. Root dry matter in the top 30 cm soil ranged from 46 to 68% of total root dry matter for three corn hybrids and one inbred line (Eghball and Maranville, 1993). This indicates that corn hybrids can be selected to have the maximum amounts of roots in the topsoil to remove P from this P-rich soil layer. Even though a great portion of corn roots are in the top 30 cm soil, the soil P level did not change from 1996 to 1999 in the 15- to 30-cm soil depth for any of the treatments (Fig. 1b). This indicated that most of the P absorbed by the corn roots was in the 0- to 15-cm soil depth. Soybean taproot probably removes P from deeper in the soil profile than corn. McVickar and Walker (1978) reported a soybean grain P removal of 19.6 kg ha^{-1} at the yield level of 2.7 Mg ha^{-1}. Based on the linear equation in Fig. 3, a soybean yield level of 2.7 Mg ha^{-1} would remove 16.6 kg P ha^{-1} in the grain.

Table 7. Grain P concentration and removal by four soybean varieties in 1999 and three varieties in 2000 in central Nebraska.

Varieties	Grain P		Grain P removal	
	1999	2000	1999	2000
	—— mg kg^{-1} ——		—— kg ha^{-1} ——	
Pioneer93B01	6380	6080	21.4	22.2
Pioneer93B34	6560	5990	21.9	18.7
Pioneer93B44	6120	–	18.8	–
Asgrow3001R	6440	–	18.7	–
Asgrow3003R	–	5750	–	17.3
LSD (0.05)	NS†	NS†	2.7	2.7

† NS indicates nonsignificant.

The amount of P removed in grain depends mainly on the grain yield amount. Across hybrids, water, and N treatments, P removal by corn was linearly related to the amount of grain yield (Fig. 2). A similar, but less well defined, relationship was observed for soybean (Fig. 3). Thus, to increase P removal in grain, management variables should be optimized so that maximum grain yield is produced.

CONCLUSIONS

Crop P removal can be an effective method of reducing high soil test P. Based on the amount of P removed by grain, corn would be more effective than soybean in reducing soil test P. When soil test P was increased to 265 mg kg^{-1} by biennial composted manure application, it was projected to take 10 yr of corn P removal to reduce the soil P level to the original level of 69 mg kg^{-1} before compost application. Lowering the 265 mg kg^{-1} P level to 150 mg kg^{-1}, which is used as the critical level by some states, would require only 5 yr of corn P removal without additional P application. Most of the P in the plants was absorbed from the 0- to 15-cm soil depth since no significant reduction in soil P level was observed from 1996 to 1999 in the 15- to 30-cm soil depth. No difference was observed among the residual manure, compost, and fertilizer treatments for corn grain P removal since the soil P level was adequate for corn production for all treatments. There were significant differences among corn hybrids and soybean varieties for grain P removal. There was as much as 54% difference among corn hybrids for grain P removal when corn was grown under adequate water and N. The maximum difference among soybean varieties for grain P removal was 28%. Grain P concentrations were different among corn hybrids but not among soybean varieties, indicating the potential for selecting corn hybrids with high P concentrations in remediation efforts. If low P concentration corn is desired in the animal ration to reduce P excretion in manure or in ethanol production by-product, low P corn hybrids can also be selected.

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