Nutrient Removal by Corn Grain Harvest

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ABSTRACT

Effective nutrient management requires an accurate accounting of nutrients removed from soils in the harvested portion of a crop. Because the typical crop nutrient values that have historically been used may be different under current production practices, a study was conducted to measure nutrient uptake in grain harvested in 1998 and 1999 from 23 site-years in the Mid-Atlantic region of the USA. There were 10 hybrids included in the study, but each site grew only one hybrid each year. Corn (*Zea mays* L.) production practices followed local state extension recommendations. Minimum, maximum, and mean corn grain yields were 4.9, 16.7, and 10.3 Mg ha^{-1}. Nutrient concentrations were determined on grain samples oven-dried at 70°C for 24 h. Minimum, maximum, and median nutrient concentration values were as follows: 10.2, 15.0, and 12.9 g N kg^{-1}; 2.2, 5.4, and 3.8 g P kg^{-1}; 3.1, 6.2, and 4.8 g K kg^{-1}; 0.13, 0.45, and 0.28 g Ca kg^{-1}; 0.88, 2.18, and 1.45 g Mg kg^{-1}; 0.9, 1.4, and 1.0 g S kg^{-1}; 9.0, 89.5, and 33.6 mg Fe kg^{-1}; 15.0, 34.5, and 26.8 mg Zn kg^{-1}; 1.0, 9.8, and 5.3 mg Mn kg^{-1}; 1.0, 5.8, and 3.0 mg Cu kg^{-1}; and 2.3, 10.0, and 5.5 mg B kg^{-1}. Median nutrient uptake values found in this study are similar to commonly used book values, but there was considerable variation among samples of corn grain. Concentrations of P and K in grain were positively associated with yield level, and concentrations of grain P were positively correlated with Mehlich-3 soil test P. The variability in nutrient removal values seen in this study, even for the same hybrid, raises questions about the usefulness of average values for estimating crop nutrient removal across a range of cropping conditions. Research is needed to identify or develop a means to correct for the sources of variability.

From the viewpoint of sustainable agriculture, nutrient management ideally should provide a balance between nutrient inputs and outputs over the long term (Bacon et al., 1990). In the establishment of a sustainable system, soil nutrient levels that are deficient are built up to levels that will support economic crop yields. To sustain soil fertility levels, nutrients that are removed by crop harvest or other losses from the system must be replaced annually or at least within the longer crop rotation cycle. When nutrient inputs as fertilizer, manure, or waste materials exceed crop removal over a period of years, soils become oversupplied and nutrient leaching and runoff become an environmental concern (Daniel et al., 1998; Sims et al., 1998). Accurate values for crop nutrient removal are an important component of nutrient management planning and crop production.

Although state agronomy guides and other sources often publish values for crop nutrient removal, the original studies on which those values are based are seldom cited. Also, the values that were established in the past may not be correct for current agronomic technologies such as hybrid, higher plant population, yield potential, fertilizer practice, and soil conditions. Furthermore, there is a need to re-evaluate crop nutrient removal values for corn as several states in the Mid-Atlantic USA now mandate the development of comprehensive nutrient management plans (Simpson, 1998; Sims, 1999; Pennsylvania State Conservation Commission, 1997). Nutrient removal values are a key component of nutrient management planning because manure nutrient applications are being limited to the expected level of crop nutrient removal.

The large volume of manure generated by concentrated animal-feeding operations in the Mid-Atlantic region and the environmental concerns associated with accumulation of soil P to excessive levels (Sims, 1998) have focused much attention on P in nutrient management planning. Until recently, manure application recommendations were designed to match the N requirements of the crop, often leading to manure P applications in excess of crop removal. While at present, there is emphasis on P-based nutrient management planning, other nutrients may receive greater attention in the future.

The objective of this study was to measure nutrient (N, P, K, S, Ca, Mg, Zn, Mn, Cu, B, and Fe) removal by corn grain over a range of growing conditions in the Mid-Atlantic region and to determine if nutrient concentrations in grain were related to crop yield. The study was conducted as part of a larger regional project on P fertility research. This allowed us to also examine the relationship between soil test level and crop removal of P.

MATERIALS AND METHODS

We grew corn in five states (Delaware, Massachusetts, Maryland, New Jersey, and Pennsylvania) in 1998 and 1999 for a total of 23 site-years (Table 1). Sites were selected to represent the wide range of soils (Alfisols and Ultisols) and P fertility levels within the Mid-Atlantic region. They included both on-farm and research station land. Local recommendations guided cultural practices. Starter fertilizer at all sites supplied 15 kg P ha^{-1} in the form of monoammonium phosphate. Spacing between rows was 0.76 m. We measured yields from a harvested area of two 6-m rows in the middle of each of four replicated plots. Harris Laboratory, Lincoln, NE, analyzed grain samples that were collected from each plot. They were oven-dried at 70°C and ground in a Wiley mill to pass

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Abbreviations: M3P, Mehlich-3 phosphorus.

Table 1. Soil types, Mehlich-3 P, corn hybrids, and grain yields at each of the experimental sites in 1998 and 1999.

Experimental site	State	Soil type	P	Hybrid brand	Grain
			mg kg^{-1}		Mg ha^{-1}
		1998			
Middletown	DE	Matapeake silt loam	235	Pioneer 3394	6.4
Seaford no. 1	DE	Evesboro loamy sand	259	Dekalb-618-Bt	9.6
Seaford no. 2	DE	Evesboro loamy sand	36	Dekalb-618-Bt	6.2
South Deerfield	MA	Merimac sandy loam	46	NKMAX21	10.7
Deerfield	MA	Hadley very fine sandy loam	51	NKMAX21	13.9
Beltsville	MD	Mattapex silt loam	326	Pioneer 3394	6.5
Adelphia	NJ	Freehold sandy loam	79	Pioneer 33Y09	15.2
Pittstown	NJ	Quakertown silt loam	45	Pioneer 33Y09	14.5
Juniata	PA	Allenwood silty clay loam	176	Unknown	7.7
Lycoming	PA	Linden sandy loam	123	Dekalb 642	9.8
Crawford	PA	Bradeville gravely loam	49	Pioneer 3752	6.7
		1999			
Georgetown no. 1	DE	Sassafrass sandy loam	44	Pioneer 3394	10.5
Georgetown no. 2	DE	Rumford loamy sand	98	Pioneer 3394	6.9
Seaford no. 2	DE	Kenansville sandy loam	69	Pioneer 3394	10.0
Middletown	DE	Matapeake silt loam	80	Dekalb 589	4.9
Deerfield Block no. 2	MA	Hadley very fine sandy loam	83	NKMAX21	14.5
S. Deerfield Plateau	MA	Merimac sandy loam	123	NKMAX21	11.2
Quantico	MD	Mattapex silt loam	418	Pioneer 33Y09	7.9
Queenstown	MD	Mattapex silt loam	319	Pioneer 3394	10.8
Centerton	NJ	Aura gravely sandy loam	144	Pioneer 33A14	14.7
Pittstown	NJ	Quakertown silt loam	138	Pioneer 33A14	16.7
Blair	PA	Hublorsburg silty clay loam	64	Doeblers 596	8.1
Lycoming	PA	Linden sandy loam	65	Dekalb 642	12.7

a 1-mm sieve. Total N in grain was determined by Kjeldahl procedure (Bremner, 1965). Concentrations of P, K, Ca, Mg, S, Zn, Mn, Cu, Fe, and B in grain were determined by inductively coupled plasma (ICP) emission spectroscopy after samples were digested with nitric acid and hydrogen peroxide (Luh Huang and Schulte, 1985). All grain nutrient concentrations are expressed on a dry weight basis. All grain yield and nutrient removal values are based on 155 g kg^{-1} moisture. Soil samples were collected in the spring from the 0- to 15-cm depth by randomly collecting 15 cores (2.25-cm diam.) from each plot. They were analyzed at the University of Delaware Soil Testing Laboratory using the Mehlich-3 method (Mehlich, 1984). Statistics calculated for nutrient concentrations in grain included the minimum, maximum, median, mean, and coefficient of variation. Regression analysis was used to examine the fit between soil test P and grain P concentration and between corn yield and grain nutrient concentration.

RESULTS AND DISCUSSION

Minimum and maximum grain nutrient concentrations for P and K across all sites varied by more than twofold for P and by twofold for K (Table 2). In general, micronutrients in grain exhibited more variation in concentration than macronutrients. Grain N concentrations were the least variable of any nutrient examined. The mean values that we obtained for N, P, and K removal

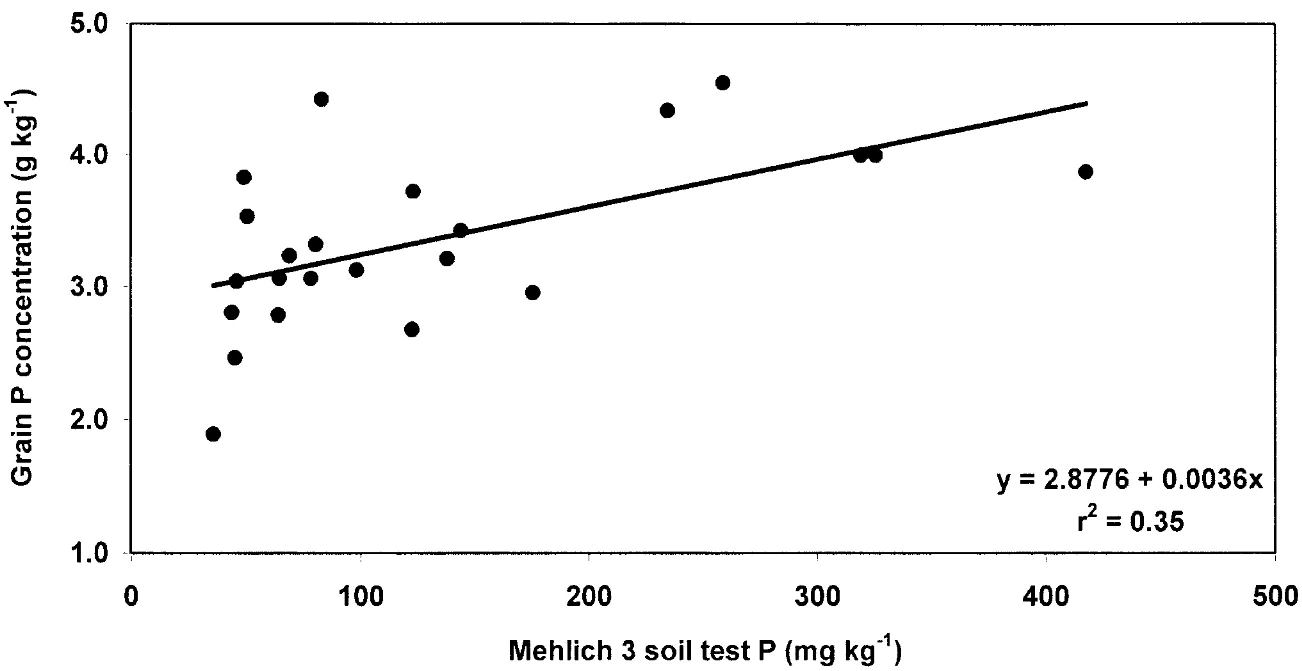

Fig. 1. Association between corn grain P concentrations and soil test P level at 23 site-years in five states.

Table 2. Variation in nutrient concentration of corn grain from 23 site-years in the Mid-Atlantic USA (Delaware, Massachusetts, Maryland, New Jersey, and Pennyslvania) in 1998 and 1999. Concentration are expressed on a dry weight basis.

Nutrient	Minimum	Maximum	Median	Mean	CV†
	g kg^{-1}				%
N	10.2	15.0	12.9	13.0	9.8
P	2.2	5.4	3.8	4.0	19.6
K	3.1	6.2	4.8	4.8	13.9
S	0.9	1.4	1.0	1.1	13.5
Mg	0.88	2.18	1.45	1.55	23.6
Ca	0.13	0.45	0.28	0.28	30.0
	mg kg^{-1}				
Fe	9.0	89.5	33.6	35.5	52.6
Zn	15.0	34.5	26.8	26.7	18.4
B	2.3	10.0	5.5	5.9	36.3
Mn	1.0	9.8	5.3	4.8	52.2
Cu	1.0	5.8	3.0	3.2	49.6

† CV, standard deviation expressed as a percentage of the mean.

Table 4. Variation in nutrient concentration in corn grain from a single hybrid (Pioneer Hybrid Brand 3394) grown at six different site-years in 1998 and 1999. Concentrations are expressed on a dry weight basis.

Nurtient	Minimum	Maximum	Median	Mean	CV†
	g kg^{-1}				%
N	12.3	14.6	12.9	13.1	4.5
P	2.2	4.0	3.6	3.4	18.6
K	3.1	5.0	4.4	4.2	15
S	0.9	1.4	1.1	1.1	16
Mg	0.88	1.45	1.34	1.27	16
Ca	0.15	0.35	0.29	0.27	25.6
	mg kg^{-1}				
Fe	9.0	61.5	35.1	34.2	41
Zn	15.0	30.0	24.5	23.9	24.2
B	4.5	7.8	6.4	6.2	20.9
Mn	3.0	7.0	4.5	4.7	31
Cu	1.0	5.8	3.3	3.5	49.2

† CV, standard deviation expressed as a percentage of the mean.

agree fairly well with those found in existing nutrient removal tables (Table 3).

Corn grain samples used in this study represented different hybrids grown on a variety of soils under different weather conditions (Table 1). Although it is not possible to completely isolate the effect of hybrid, the same hybrid was also grown at multiple sites. This one hybrid grown at six sites (Table 4) exhibited approximately the same variation in nutrient concentrations as the 10 hybrids grown across all 23 site-years (Table 2). Thus, grain nutrient concentrations can be highly variable even for a given corn hybrid grown in different environments.

Some of the variability in grain P concentration appeared to be associated with soil test P (Fig. 1). The Mehlich-3 P (M3P) soil test ranged from 36 to 418 mg kg^{-1} across the 23 site-years, with a mean of 133 mg kg^{-1}. Because the agronomic optimum range is about 30 to 50 mg kg^{-1}, most of these soils were high in P. Soil test P correlated positively with grain P concentration ($r^2 = 0.35$; $p < 0.003$). However, for any given soil test level, there was still considerable variability in grain P concentration. Because the application of N, K, Ca, Mg, S, B, Mn, Cu, and Zn varied from site to site, we could not evaluate whether a similar relationship existed between soil test level and concentrations of these nutrients in grain.

Grain yields ranged from 4.9 to 16.7 Mg ha^{-1} among the 23 sites (Table 1). Nutrient concentrations were positively associated with yield for P, K, Zn, and Fe (Fig. 2). Because yields reflect the favorability of the growing environment, it is possible that sites with more favorable conditions for corn growth also had better conditions for the diffusion of nutrients from the soil to the roots. The correlation coefficients between grain P, K, Zn, and Fe concentration and yield ($r^2 = 0.14$, 0.13, 0.12, and 0.16, respectively), though statistically significant at $P < 0.10$, were not strong.

Much of the variability in grain P concentration was not explained even by a combination of the associations with soil test P and yield. Grain P concentration could be expressed as a function of both yield and M3P as follows: $P = 2.901 + 0.05909(Y) + 0.003209(\text{M3P})$, $r^2 = 0.40$, where P = grain P (g kg^{-1} dry matter basis), Y = grain yield (Mg ha^{-1} at 155 g kg^{-1} moisture), and M3P = M3P in soil (mg kg^{-1}). Within this two-variable equation, statistical significance for the Y coefficient was only at the 16% level of probability while that for M3P was at the 1% level. Our observations do not support interpretation of this equation as proof of a cause-and-effect relationship. Rather, the equation describes the mean grain P concentration as a function of weak trends with soil test P and yield observed within

Table 3. Corn grain nutrient removal values in the present study compared with published reference values. Nutrient concentrations are based on grain at 155 g kg^{-1} moisture.

Nutrient	Present study		A+L†	Zublena (1991)	PPI‡	Beegle (2002)	Reid (1998)	Lander et al. (1998)
	g kg^{-1}	lb bu^{-1}						
N	11.0	0.615	0.75	0.9	0.75	0.7	0.65–1.0	0.80
P	3.34	0.187						0.15
P_2O_5	7.64	0.428	0.44	0.35	0.44	0.4	0.36–0.44	0.344
K	4.06	0.228						0.17
K_2O	4.88	0.273	0.29	0.27	0.29	0.3	0.26–0.29	0.204
S	0.90	0.0506	0.07	0.067			0.07	
Mg	1.31	0.0733	0.09	0.053			0.087	
Ca	0.237	0.0132	0.02	0.013			0.0066	
Fe	0.0300	0.00168						
Zn	0.0226	0.00126		0.001				
B	0.0050	0.00028						
Mn	0.0041	0.00023		0.0006				
Cu	0.0027	0.00015		0.0004				

† Ankerman and Large (2001).
‡ Potash and Phosphate Institute (2001).

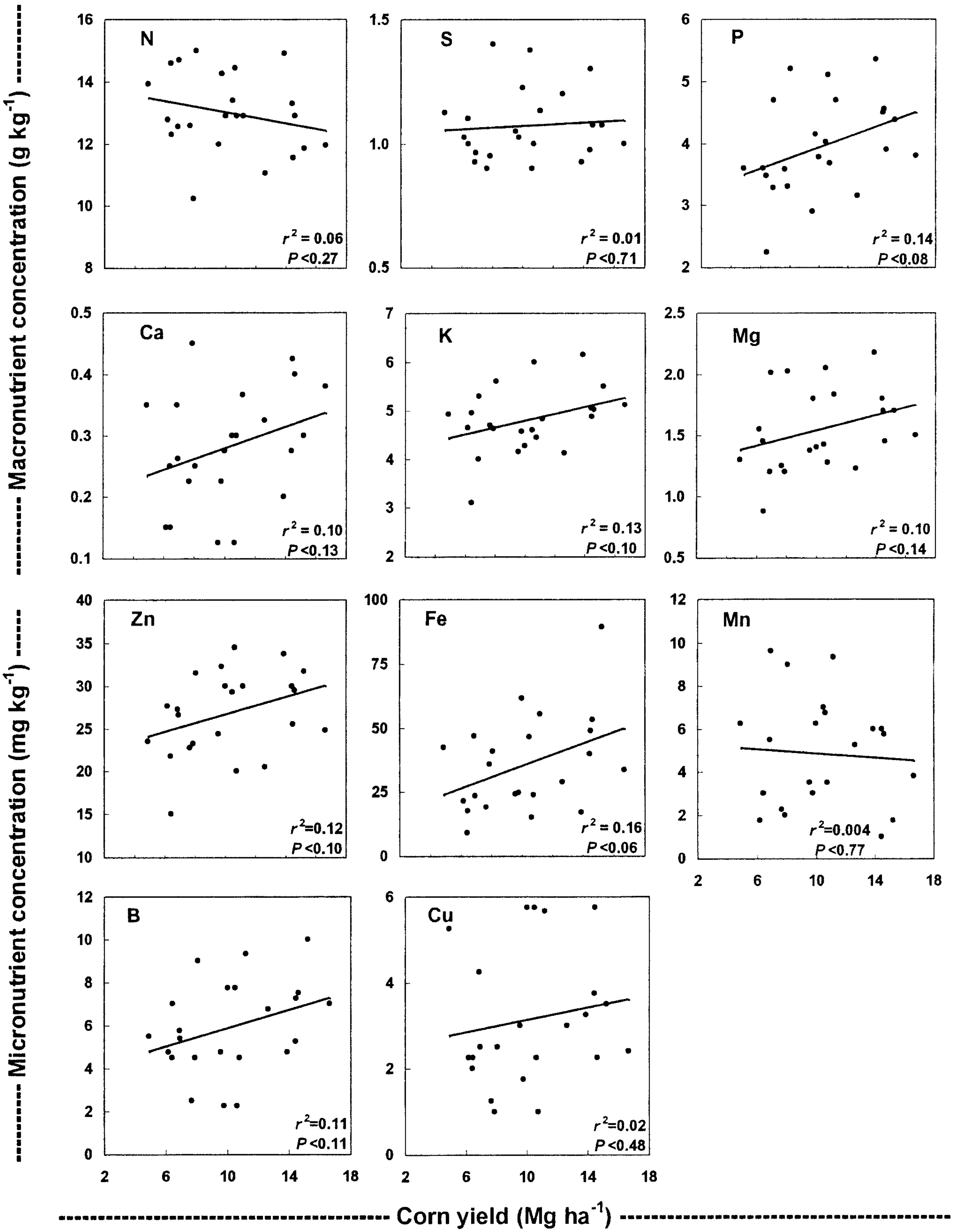

Fig. 2. Relationship between nutrient concentrations in corn grain and crop yield level.

the five states. The r^2 value of 0.40 indicates that it explained less than half of the variability observed. In other words, this equation does not estimate nutrient removal much better than the mean value of 3.34 g kg^{-1}. Neither the mean value nor the regression should be extrapolated to soil test and yield levels beyond the range encountered in our sites, nor should they be used in other regions without verification by local data.

Some of the remaining variability in grain P concentrations may have been related to the soils at each of the sites. Specific effects of soil characteristics could not be separated from the differences in weather conditions encountered at each site.

Variability in nutrient concentration implies that some farmers may need to obtain an analysis of their harvested crop to accurately assess nutrient removal. Nutrient management planners may consider taking into account increased crop removal of P at higher soil test levels and at higher yield levels. Livestock producers should also consider the implications of nutrient variability of grain on ration balancing for the mineral nutrition of their animals.

In the Mid-Atlantic region, manure production is generally high relative to crop nutrient removal; consequently, a low percentage (<22% on average for the five states represented in this study) of soils in the region test medium or below in P (Fixen, 2002). In a long-term study conducted in North Carolina, Kamprath (1999) found that grain harvest may remove P from high-testing Coastal Plain soils for 13 yr or longer before a response to P fertilization is exhibited.

Phosphorus is not the only nutrient that may accumulate in soil from regular applications of manure. Mineral supplementation of livestock feeds often enriches manures and soils to which they are applied with Cu and Zn (Mikkelsen, 2000). Nutrient removal values for Cu and Zn are relatively low compared with amounts of these nutrients that may be applied in a typical manure application. To use broiler litter as an illustration, a single application at the rate of 11.2 Mg ha^{-1} could potentially add the following nutrient amounts: N, 403; P, 193; K, 212; S, 84; Mg, 45; Ca, 230; Fe, 7.3; Zn, 3.5; B, 0.3; Mn, 3.8; and Cu, 2.5 kg ha^{-1}. A corn grain harvest of 11.0 Mg ha^{-1} would remove on average the following nutrient amounts: N, 120.8; P, 36.7; K, 44.7; S, 9.9; Mg, 14.4; Ca, 2.6; Fe, 0.33; Zn, 0.25; B, 0.055; Mn, 0.045; and Cu, 0.03 kg ha^{-1}. It would take an estimated 3.3 harvest years of corn grain to remove all of the manure-applied N, 5.3 for P, 4.7 for K, 8.4 for S, 3.1 for Mg, 88 for Ca, 22 for Fe, 14 for Zn, 5 for B, 84 for Mn, and 84 for Cu. In general, removing the micronutrients from the applied broiler litter would take longer than the macronutrients.

Even though average values of corn grain nutrient removal in this study are similar to existing reference values, the variability seen in this study raises questions about the usefulness of average values for estimating crop nutrient removal across a range of conditions. Future research on nutrient removal should focus on identifying the sources of variation in nutrient concentration in corn grain to enable better monitoring of crop nutrient removal. Alternatively, grain harvest equipment may be designed in the future to measure and map crop nutrient removal from a field as well monitor yields. This information could be used in conjunction with nutrient management planning and variable-rate nutrient application equipment to take precision agriculture to the next level of development.

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