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Nutrient uptake by corn and soybean, removal, and recycling with crop residue

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Background for issues that will be addressed

Phosphorus and potassium removal effects on soil-test values

The prevailing phosphorus (P) and potassium (K) management system in Iowa and the Midwest is based on soil testing, response-based fertilizer application for low-testing soils, and removal-based fertilizer application to maintain desirable soil-test P (STP) and soil-test K (STK) values. Several issues are important for an effective implementation of this management concept. These include use of appropriate soil-test methods and field calibrations to determine optimum soil-test levels and fertilization rates, knowledge of fertilization and cropping impacts on soil-test values over time, and reliable estimates of P and K removal with harvest. In Iowa, continued research during the last two decades has provided calibrations for various soil-test methods for P and K, which have been used for existing soil-test interpretations in Iowa State University (ISU) Extension publication PM 1688. This publication also suggests to use estimates of P and K removal to maintain optimum STP and STK values, assuming there is a good relationship between P and K removal and STP or STK trends over time. Research during the last two decades has shown large temporal variability of yield and both STK and STP but very large for STK. Therefore, better study of the relationship between P or K removal and STP or STK in the short term and long term should be useful to improve the effectiveness of P and K management for crop production and to maintain acceptable water quality in Iowa.

Grain yield levels, nutrient concentrations and nutrient removal

Extension publication PM 1688 also includes estimates of P and K concentrations in harvested grain and biomass for several crops, which together with yield levels should be used to decide the fertilizer rates to maintain optimum soil-test values. These estimates are based on data from the 1980s and early 1990's, and may need to be updated because yield levels, corn hybrids, and soybean varieties have changed significantly during the last decade. In fact, farmers and crop consultants have been asking questions about these changes influence the nutrient concentration in harvested grain and, consequently, removal with harvest. Research results shared in the 2009 ICM Conference by ISU researchers Drs. Antonio Mallarino and Matt Clover indicated that new corn hybrids with rootworm resistance trait have similar grain P and K concentrations than comparable hybrids without this trait, but yield more and remove more P and K from fields. Therefore, the higher yield of new hybrids should be the most important consideration when estimating P and K removal and deciding fertilizer rates to maintain optimal soil-test levels. This research was specific to corn and rootworm resistance, however, did not include soybean and did not consider a wide range of fields, management practices, and years.

Also, farmers and crop consultants have been asking questions about the concentration of micronutrients in corn and soybean grain, and how these concentrations and yield levels affect the removal of micronutrients from fields. The removal of micronutrients with harvest and its consideration to increase or maintain micronutrients levels is not a criterion used in Iowa or any other state for micronutrients fertilization for various reasons, but mainly due to lack of knowledge of how removal affects micronutrient levels in soils and needed fertilization when there is a deficiency. Therefore, knowledge about micronutrients concentrations in grain and how they relate to yield level should be part of research needed to better understand micronutrient issues and improve its management.

Phosphorus and potassium recycling with crop residues

Several reasons related to nutrient removal and recycling with crop residue may partly explain observed very large temporal variability in STK but significantly less for STP. Potassium does not form part of plant or organic compounds and is in the soluble ion form in plant tissue and crop residue. Potassium is located mainly in the cytoplasm and cell vacuoles where it activates enzymes, regulates stomata functions, and assists in transfer of compounds across membranes. In contrast, most P is incorporated into the plant organic matter and there is a small amount in solution or as soluble forms. Plant phosphorus is contained in cell membranes, nucleic acids, and is a major component of the energy compounds that drive photosynthesis and plant metabolism in general. Moreover, much more K then P is absorbed by plants, and a larger proportion of the P is found in the grain than for K. Therefore, the relative amounts of K removal and both amounts and patterns of its recycling to the soils with residue may have a larger effect on STK and its temporal variability than on STP levels and variability. No research has been conducted in Iowa, and very little has been conducted in other states, to describe K or P loss from standing plants and crop residue after grain harvest. The different functions of P and K within the plant and their different distribution among plant tissues affects accumulation in different plant parts, and may also influence losses from plant tissue and from residue to soil before and after grain harvest.

Results of recent and ongoing research

Relationship between phosphorus and potassium removal and soil-test values

Data from ongoing long-term P and K trials established in 1994 at various Iowa locations were used to study the short-term and long-term relationship between nutrient removal by corn and soybean and soil-test values. The trials were in the Northeast (NERF), North-Central (NIRF), Northwest (NWRF), Southeast (SERF), and Southwest (SWRF) ISU research farms. Treatments included tillage (chisel/disk and no-till), three P and K placement methods (broadcast, planter-band, and deep band), and several P and K rates. Yield results concerning tillage, placement, and P or K rates treatments from these trials have been summarized before in previous conferences and several publications. Some articles have been posted in the ISU Soil Fertility web page (http://www.agronext.iastate.edu/soilfertility). Results about STP and STK stratification with no-till also were summarized before, because soil was always sampled to depths of 0-3 and 3-6 inches every year from selected treatments.

Figure 1 shows the annual average P removal with grain harvest of corn and soybean and STP decrease from 1994 until 2005 for the non-fertilized plots across the five locations. There was a good general relationship between P removal and STP decreasing trends. On average removal of 37 lb P_2O_5/acre/year resulted in an average STP decrease of 0.78 ppm/year. These results imply an average removal of 47 lb P lb P_2O_5/acre/year to decrease 1 ppm STP/year. However, the relationship between P removal and STP was poor for each year.

The long-term trends for the annual average K removal with grain harvest of corn and soybean and STK decrease is shown in Fig. 2 for the non-fertilized plots across five locations. In this case, the data encompasses the years 1994 until 2009. There was a good general relationship between P removal and STK decreasing trends. The relationship between K removal and STK was very poor for each year, much poorer than for P. We believe that issues related to environmental impacts on short-term nutrient recycling with crop residue and reactions between different nutrient pools have a much higher impact on STK levels than STP levels. In the long-term, removal of 42 lb K_2O/acre/year resulted in an average STK decrease of 3.0 ppm/year. These results imply an average removal of 14 lb P lb K_2O/acre/year to decrease 1 ppm STK/year.

Relationships between grain yield, P and K concentrations, and P and K removal

Corn and soybean yield levels were measured in hundreds of long-term or short-term field trials conducted during the last decade to study yield responses to P and K management practices and soil-test methods calibration. In many trials we measured the concentrations of P and K in the harvested grain, and in a few dozen trials we also measured the concentrations of several micronutrients. Therefore, these data were used to study the relationship between the yield level and the grain nutrient concentration and removal with harvest. The trials were conducted in several counties, were managed with no-till or chisel-plow/disk tillage, and included several P or K fertilizer treatments.

Figure 3 shows relationships between corn and soybean grain yield and P or K concentrations in grain across all fields, years, and treatments. The graphs show that for both crops the grain P or K concentration was not related to the grain yield level. This result across fields and years is useful because the the grain P and K concentrations are used together with the yield level to decide fertilization rates needed to maintain optimum soil-test values. The results also are important because many producers and crop consultants believe that higher crop yield implies higher grain P and K concentrations. Study of relationships separately for early years and the most recent years with higher yield levels and also newer hybrids and varieties (not shown) did not change or improve the relationships, and had little or no effect on the average P or K concentrations.

The observed average soybean grain P concentration is approximately similar to the value currently suggested in the ISU Extension PM 1688 when there is no grain analysis available. However, the average grain K concentration for soybean and the concentrations of P and K for corn are lower than the values currently suggested. The values suggested in PM 1688 are 0.375 and 0.8 lb P_2O_5/bu of corn and soybean, respectively, and 0.30 and 1.5 lb K_2O/bu of corn and soybean; and are already lower than values suggested in several other states. However, the suggested average concentration values are within the upper range of observed values.

Figure 4 shows a strong linear relationship between the corn and soybean grain yield level and P or K removal with grain harvest, which is in sharp contrast to results for concentrations. Some degree of relationship should be expected between yield and nutrient removal because yield is used to calculate removal together with the grain nutrient concentration. The strength of the relationship shows, however, that in spite of apparently large variation in grain P and K concentrations across sites, years, and treatments the P or K removal with harvest tend to follow the level yield.

The relationships described lead to the conclusion that good estimates of grain yield are much more important for determining grain P and K removal than the grain nutrient concentrations, and that average concentration values can be applied to yield estimates to calculate P or K removal. Observation of variation of yield and grain P or K concentrations within a field trial or producer fields almost always show that the yield variation is much larger than the variation in grain P or K concentration at determining removal. The large variation across fields and years in the P or K concentration shown in Fig. 3 still suggest, however, a need for better understandings of factors that affect grain nutrient concentrations in order to improve removal estimates.

Micronutrients concentrations in grain and removal with harvest

The plant uptake of micronutrients is very small, usually under one percent of the P or K uptake. Therefore the concentration of micronutrients in corn or soybean grain and the removal from fields is very small. We measured several micronutrients in several fields and years, but share results for boron (B), manganese (Mn), and Zinc (Zn) because these are most often talked about in Iowa and the general results apply to the others.

Figure 5 shows relationships between corn grain yield and the concentration or removal of boron, manganese, and zinc. It is important to note that the units used are parts per million (ppm) because the concentration of all the micronutrients is very small. There was no relationship between the yield level and the concentration of any micronutrient. An interesting result for boron, which was not observed for other nutrients, was a very wide spread between low and high values at high yield levels. Although the amount of micronutrients removed tended to increase as the corn yield level increased, the trends were different than for P and K. For the micronutrients there was a slight exponential increasing trend, which is in contrast with the linear increase observed for P and K. An exponential trend indicates that the increase rate is steeper as the yield level increases. The departure from linearity was very small for manganese and zinc, however, and for boron there was very large variation at high yield levels. The figure for boron shows that that the removal at the highest yield levels ranged from a value near zero to about 0.08 lb/acre, which was the entire range of removal values observed. This result is in agreement with the spread in concentrations observed at high yield levels.

Figure 6 shows relationships between the soybean grain yield and the concentration or removal of the micronutrients. The micronutrient concentrations in soybean grain, although still very small compared with P and K, were several times higher than for corn. However, there was no relationship between the grain yield level and any micronutrient concentration. The amount of boron and manganese removed by soybean were only slightly higher than for corn, but the amount of zinc removed was two-fold higher. The micronutrients removal relationships with soybean yield do not show the exponential trend observed for corn, and relationships were linear. The variability was very large, however, much larger than for the linear relationships observed for P and K or the slightly exponential relationships observed for the micronutrients removal by corn. The concentration and removal micronutrients data for soybean suggest that management and environmental factors introduce more variation than for corn.

The amounts of micronutrients removed are insignificant compared with P and K removal and there was more variability. Also, the amount of micronutrients removed is a very small proportion of the much larger amounts in the soil that are found in many forms of different crop availability. Therefore, although a need for micronutrients may increase with higher yield levels, this does not necessarily indicate that removal should be a criterion for applying micronutrients as is done for P and K. Research is needed to learn the impact of removal on micronutrients levels in soil and plant tissue and the relationship with application rates.

Phosphorus and potassium uptake and loss from residue in corn and soybean

Field trials were established in 11 Iowa fields located at ISU Research Farms during 2009 and 2010. The trials locations were in the central, northeast, north, southeast, south, and southwest regions of the state. The trials included several replicated fertilization treatments, but for this plant tissue and residue sampling study we sampled treatments with non-limiting P and K fertilization rates. Aboveground plant samples were collected at physiological maturity (black layer for corn and about R 7.5 for soybean). The corn vegetative plant parts, cobs, and grain samples were collected from six plants per plot, and each plant part was analyzed separately. The soybean vegetative plant parts (including pod shells) and grain were collected from a 15-ft^2 area of each plot, and each plant part was analyzed separately. The samples were dried, weighed, and analyzed for total P and K concentrations. At grain harvest, five residue samples were collected from each plot. The corn samples included residue of ten plants and the soybean samples included residue collected from a 50-ft^2 area. The samples were placed in mesh plastic bags on top of non-tilled ground, and were removed at about 45 day intervals from harvest until spring. The plant tissue and residue samples were dried, weighed, ground, and analyzed for total P and K concentrations.

In corn, K concentrations at physiological maturity were much higher than for P except for grain (Table 1). The total accumulation within aboveground plant parts at this growth stage was nearly double for K than for P (170 lb K_2O/acre and 83.1 lb P_2O_5/acre, respectively). The difference would be much greater if the amounts were expressed in an elemental basis. With regards to relative accumulation between vegetative and cob tissue compared with grain, 76% of total P was accumulated in the grain, with only 29% of total K accounted for in grain. At grain harvest, the amount of P accumulated in grain was 56% greater than for K.

In soybean, the higher K concentration and accumulation in vegetative plant tissue and grain at physiological maturity than for P was much more different than for corn (Table 2). Total K accumulation at this stage was more than triple that of P (182 lb K_2O/acre and 47.2 lb P_2O_5/acre, respectively). With regards to the relative accumulation between vegetative tissue and grain, 65% of the total P was in the grain compared with only 32% of the total K. At the PM stage, roughly 66% of total nutrient accumulation had occurred in grain, with the remaining amount translocated between physiological maturity and grain harvest. This difference between PM and grain harvest times was not observed for corn. Perhaps the timing of our sampling time at some sites was too early, because we wanted to avoid loss of too many senescing soybean leaves.

Figure 7 shows the concentrations and amounts of K in soybean and corn tissues (except grain) from the physiological maturity growth stage until the following spring. The tissue K concentration differed between corn and soybean, but the trends over time were very similar. The amount of K in the tissues at physiological maturity was approximately similar for both crops, but both the K loss trends over time differed significantly. By the late fall, the K concentration in corn residue decreased by 31% of the concentration at physiological maturity whereas the K concentration in soybean residue decreased by 65%. Total corn K loss from physiological maturity until harvest was 41% but for soybean was significantly greater at 62%. The K loss from residue during winter was small (when soil was frozen or covered by snow), and there was increased loss in early spring. By April, 13% of the plant K at physiological maturity remained in the soybean residue and 38% in the corn residue.

Figure 8 shows the P concentrations and amounts of P in soybean and corn tissues (except grain) from physiological maturity until the following spring. Phosphorus concentration was greater in soybean than for corn, although there was a greater amount of total P in the corn plant tissues. By the late fall, P concentration in corn decreased by 27% of the concentration at physiological maturity, whereas the P concentration in soybean decreased by 65% of the concentration at physiological maturity. Total P loss by soybean harvest was 67% of that for physiological maturity, whereas for corn total P loss by harvest was only 31%. The additional P loss from residue during winter and spring was small. By April, 25% of the plant P at physiological maturity remained in the soybean residue and 53% in the corn residue.

For both corn and soybean, a greater percentage of P remained in the residue by late fall and spring. The remaining nutrient content was significantly different for P and K, however (53 and 38% for corn and 25 and 13% for soybean). This difference could be due to a larger proportion of organic P than K within the plant. The amount and distribution of rainfall, mainly from physiological maturity until late fall affected the amounts and distribution of tissue P and K loss over time. However, study of these relationships has not been completed at this time. Also, at this time we are working on nine additional trials.

The results showed that although K showed greater accumulation in plant tissue than P, the proportion of removed with grain was greater for P than for K. The P and K lost from physiological maturity to grain harvest was large and of similar relative magnitude for both nutrients, but was greater for soybean than for corn. Nutrient loss from crop residue from harvest to late fall also were significant for K but were very small for P. Additional nutrient losses from residue during winter and spring were much smaller, but were greater for K than for P. The loss trends for both nutrients were more pronounced for soybean than for corn. The results observed for K and both crops, but especially for soybean, should be considered when interpreting large temporal soil-test K variability and making decisions concerning soil sampling date.

Acknowledgements

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Tables and figures

Table 1. Phosphorus and K concentration, uptake, and removal across 11 corn site-years.

		Phosphorus	Potassium
Plant Tissue	**Units**	**Physiological Maturity**	
Concentration Veg. Tissue	% P or K	0.12	1.23
Concentration Cob		0.04	0.73
Concentration Grain		0.30	0.35
Veg. Parts Accumulation	lb/acre K_2O or P_2O_5	19.0	109.2
Cob Accumulation		1.2	12.2
Grain Accumulation		62.9	49.0
Total Accumulation		83.1	170.0
		Grain Harvest	
Concentration Harvest Grain	% P or K	0.29	0.36
Harvest Grain Yield	bu/acre	170	170
Removal with Grain	lb/ac K_2O or P_2O_5	63.3	40.7

Table 2. Phosphorus and K concentration, uptake, and removal across 11 soybean site-years.

		Phosphorus	Potassium
Plant Tissue	**Units**	**Physiological Maturity**	
Concentration Veg. Tissue	% P or K	0.13	1.80
Concentration Grain		0.57	1.84
Veg. Parts Accumulation	lb/acre K_2O or P_2O_5	16.7	124
Grain Accumulation		30.5	57.7
Total Accumulation		47.2	182
		Grain Harvest	
Concentration Harvest Grain	% P or K	0.58	1.97
Harvest Grain Yield	bu/acre	57.1	57.1
Removal with Grain	lb/ac K_2O or P_2O_5	45.0	81.3

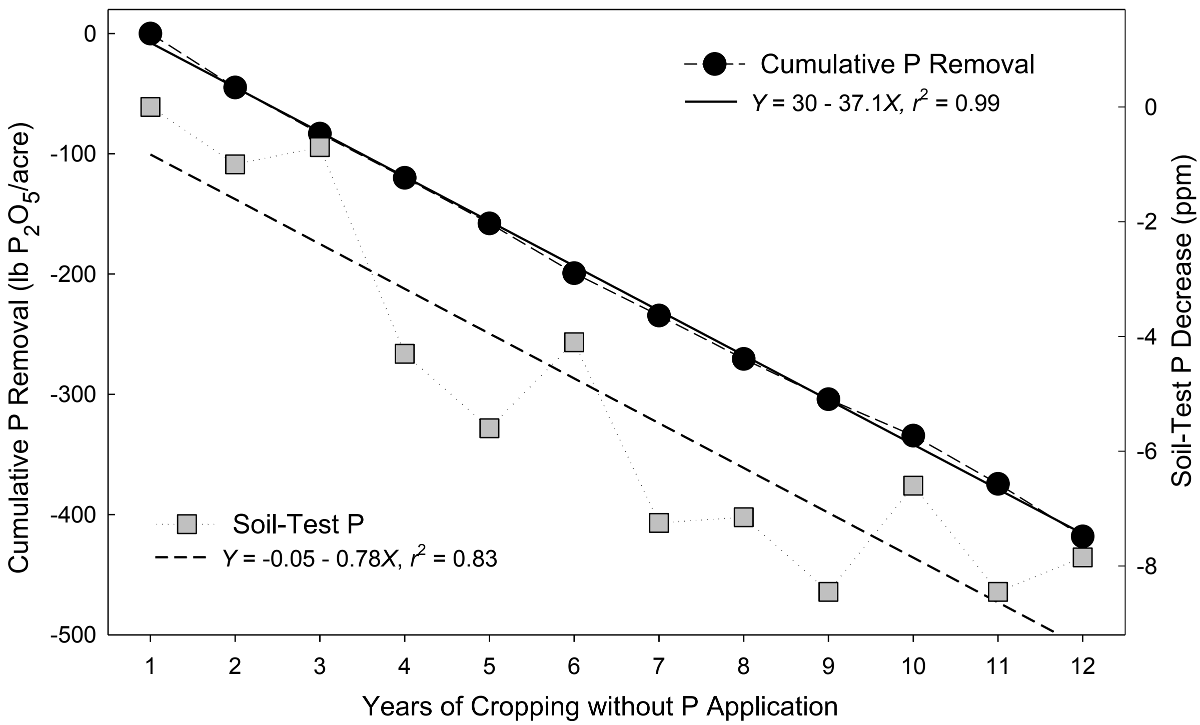

Figure 1. Phosphorus removal with grain harvest and soil-test P trends over time for corn-soybean rotations across five sites for soils that were not fertilized with P.

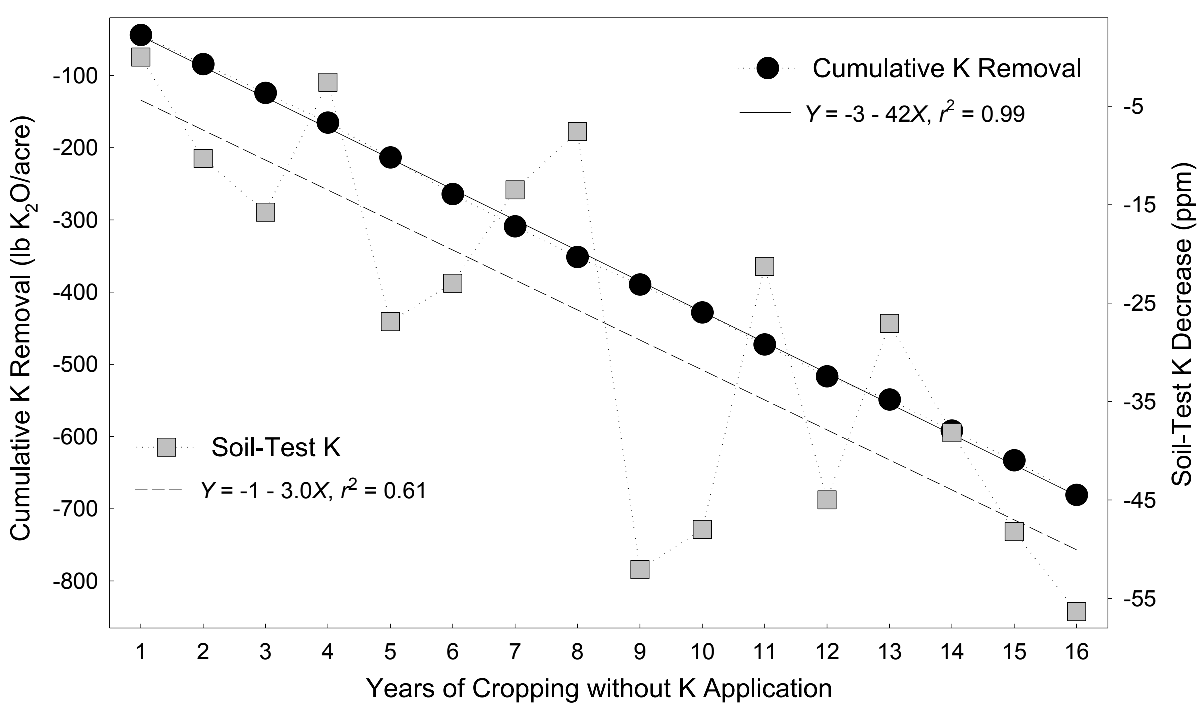

Figure 2. Potassium removal with grain harvest and soil-test K trends over time for corn-soybean rotations across five sites for soils that were not fertilized with K.

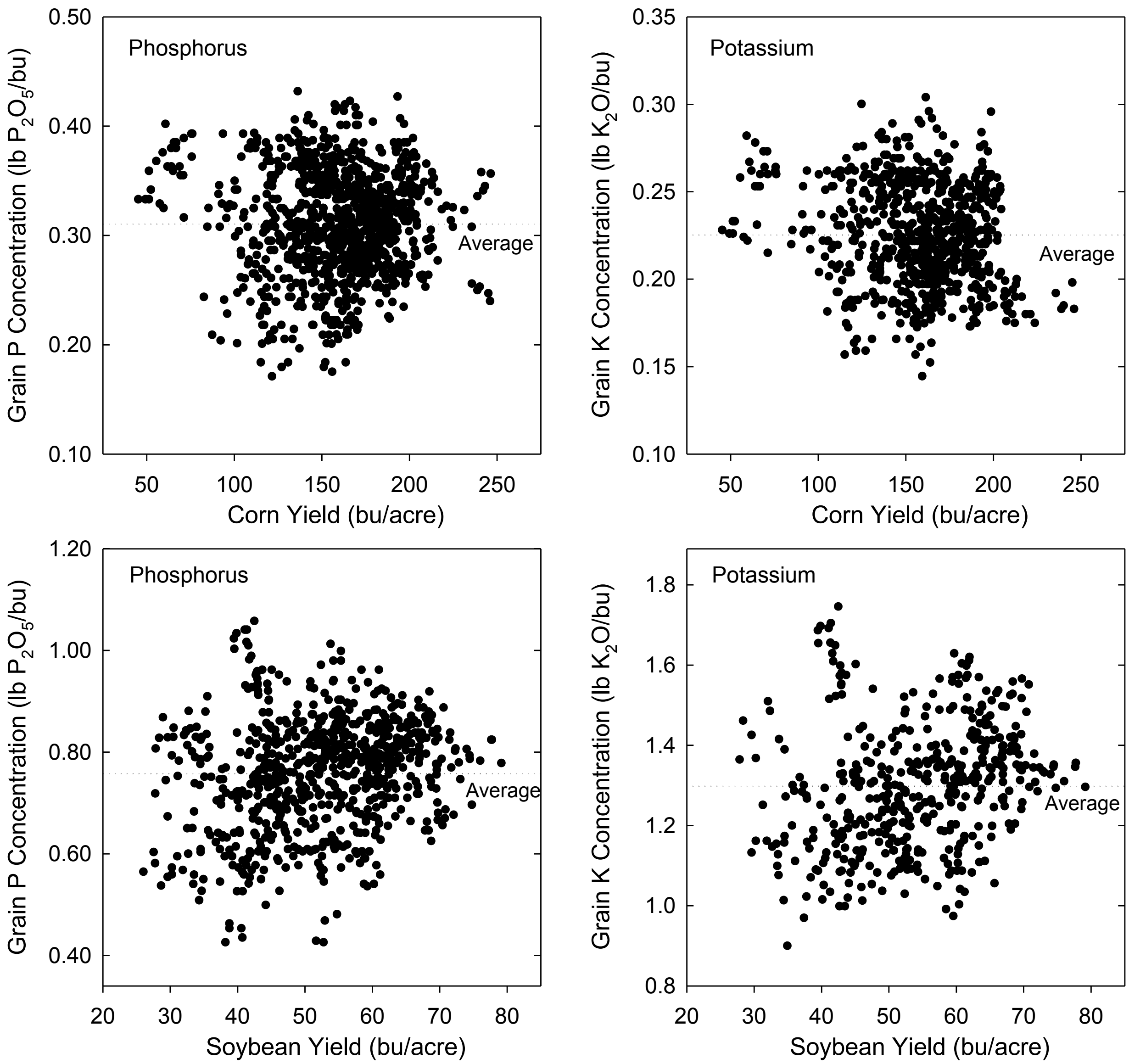

Figure 3. Relationships between corn and soybean grain yield and P or K concentrations across sites, years, and treatments (averages of 3 to 4 replications by site).

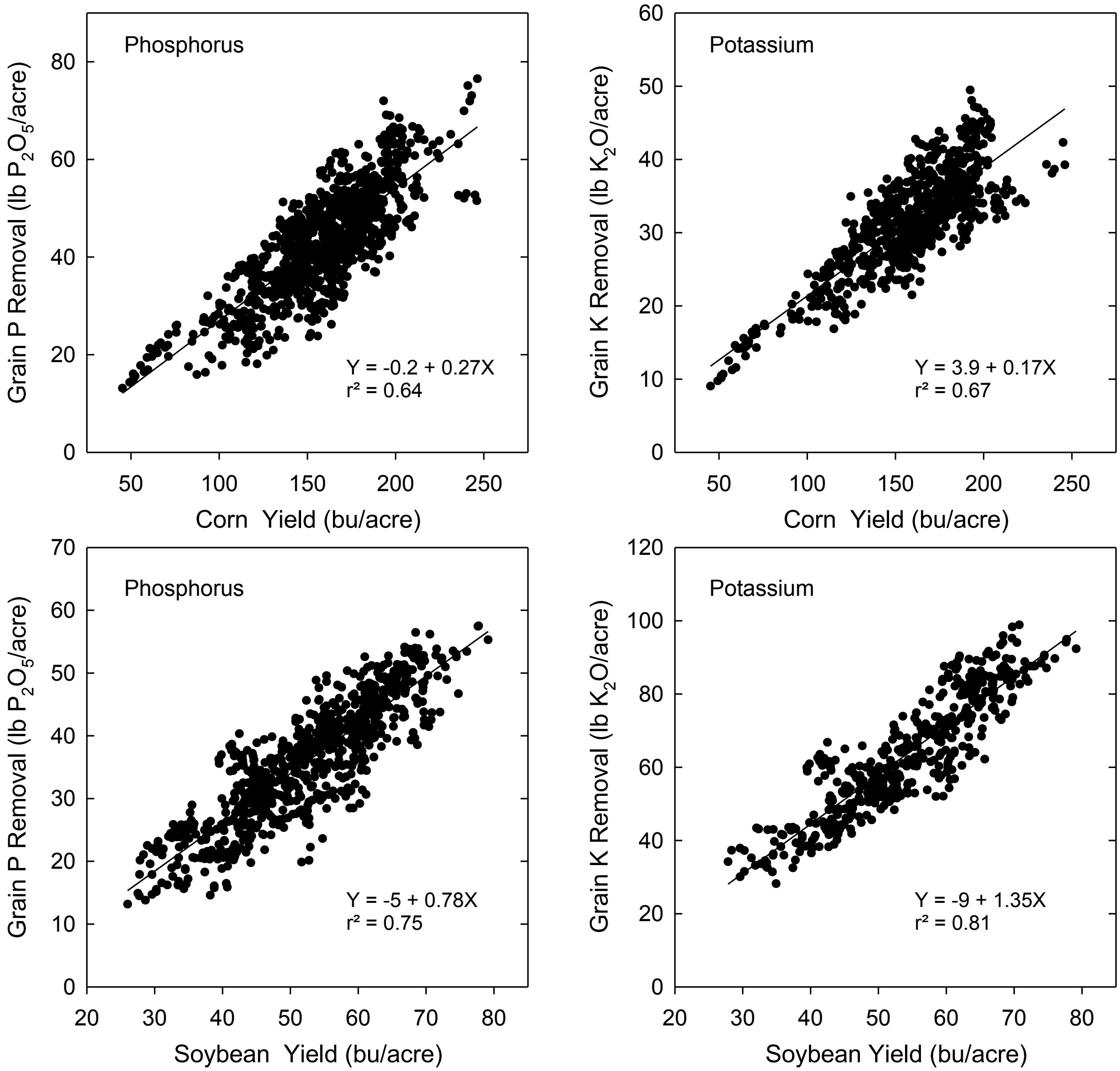

Figure 4. Relationships between corn and soybean grain yield and P or K removal with harvest across sites, years, and treatments (averages of 3 to 4 replications by site).

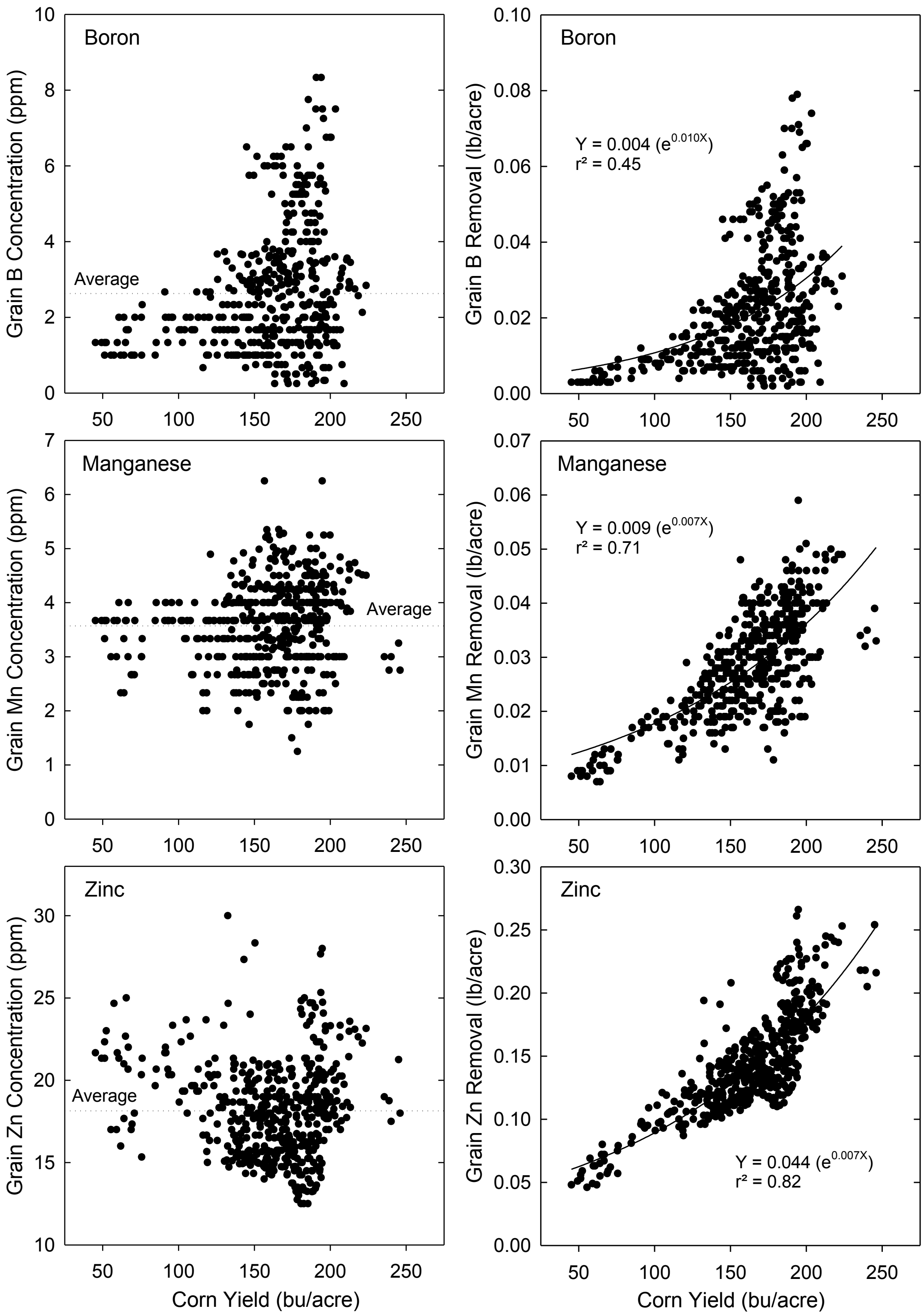

Figure 5. Relationships between corn grain yield and the concentration and removal of three micronutrients across sites, years, and treatments (averages of 3 to 4 replications by site).

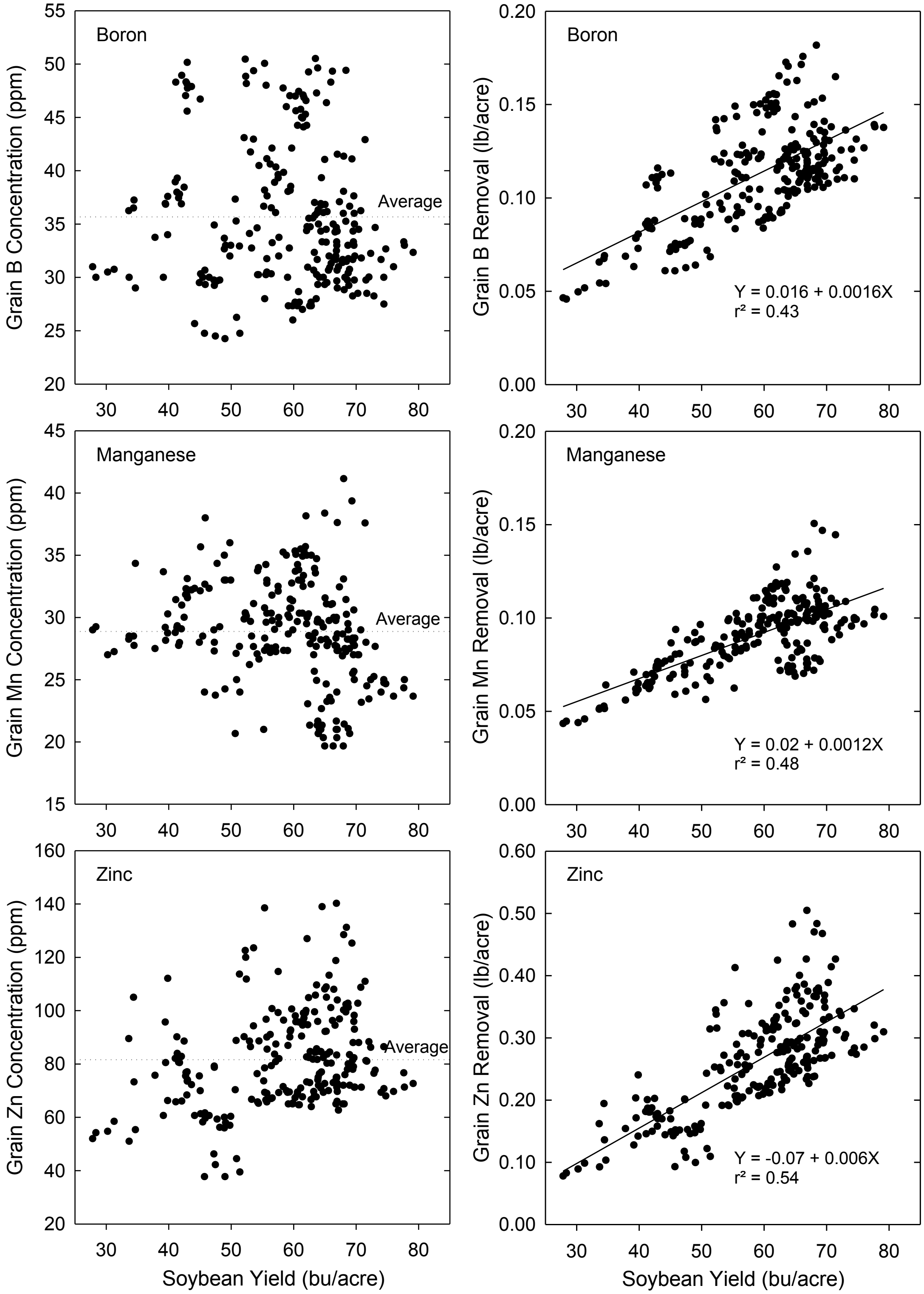

Figure 6. Relationships between soybean grain yield and the concentration and removal of three micronutrients across sites, years, and treatments (averages of 3 to 4 replications by site).

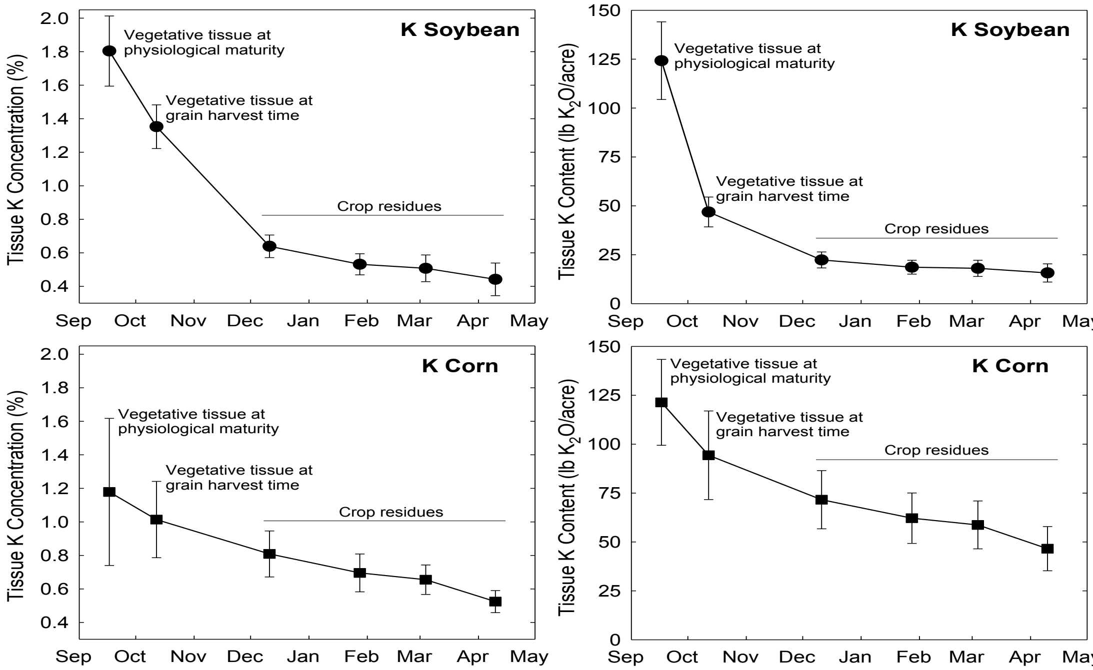

Figure 7. Potassium concentration and amounts in corn and soybean plant tissue or residue as a function of time. Vertical lines indicate standard errors of the means.

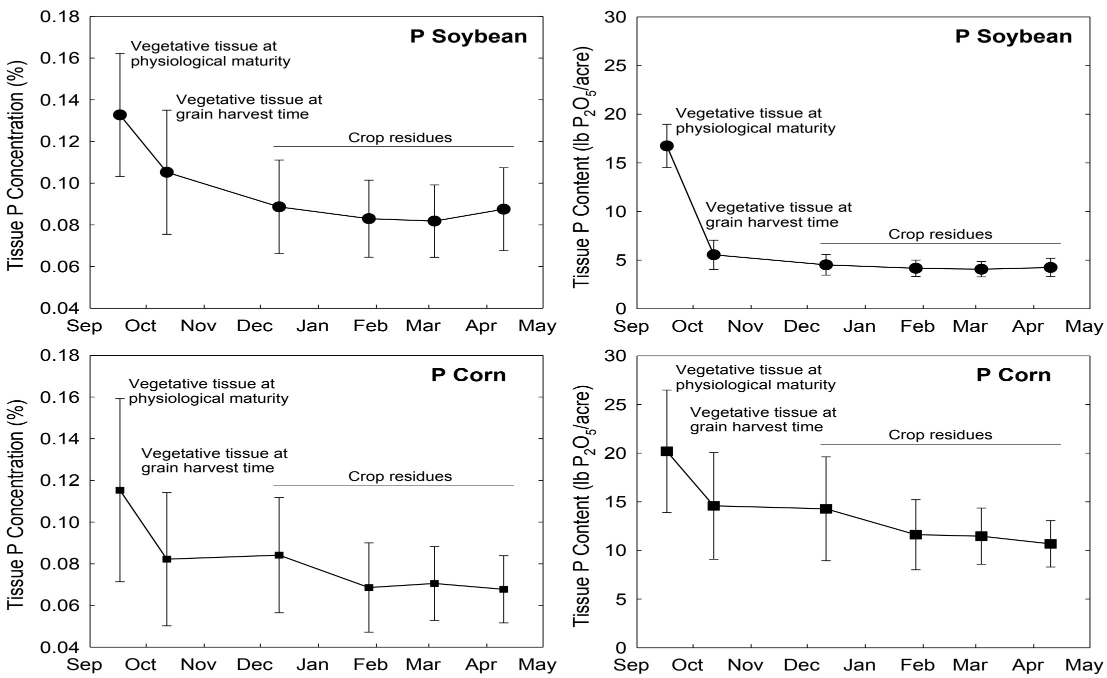

Figure 8. Phosphorus concentration and amounts in corn and soybean plant tissue or residue as a function of time. Vertical lines indicate standard errors of the means.