New Grain P and K Concentration Values for Illinois Field Crops

María B. Villamil,* Emerson D. Nafziger, and Gevan D. Behnke

Abstract
Most fertilizer P and K rate recommendations for the North-Central US are based on a combination of critical soil-test levels and the amount of fertilizer nutrient required to maintain that level. Our goal was to update P and K removal numbers by harvest of corn (Zea mays L.), soybean [Glycine max (L.) Merr.], and wheat (Triticum aestivum L.) in Illinois. With the collaboration of farmers, grain handlers, and stakeholders, we collected, over a 3-year period, a total of 2335, 2621, and 825 samples of corn, soybean, and wheat grain, respectively, with samples from most counties in Illinois. Yields were collected during the first year of sampling; grain nutrient concentrations were found to be independent of yield. We selected the 75th percentile as the new value for grain concentrations. For corn, these values were 0.37 lb P$_2$O$_5$ and 0.23 lb K$_2$O per bushel; both are about 14% lower than the reference values. For soybean, these values were 0.75 and 1.18 lb P$_2$O$_5$ and K$_2$O, respectively, which are, respectively, 12 and 10% less than reference values. For wheat, new values are 0.46 and 0.28 lb P$_2$O$_5$ and K$_2$O, decreases of 22 and 8% for P and K, respectively, compared to reference values. While the exact origins of the reference values used in Illinois are not clear, our having found lower grain concentrations in this survey indicates that improved varieties and management practices over time have not led to increases in per-bushel nutrient removal, although increased yields will mean more removal of nutrients. But lowering, by about 12% relative to the old reference values, the per-harvested-bushel amounts of P and K fertilizer applied to replace nutrients removed should not lead to decreasing soil test values over time.

Most fertilizer P and K rate recommendations in the North-Central US are based on a combination of critical soil-test value and a mass-balance calculation of nutrient addition required to maintain that level; response-based fertilizer application for low-testing soils and removal-based fertilizer application to maintain desirable soil-test P and K values (Mallarino et al., 2011; Mallarino et al., 2013). In our current cropping systems, corn and soybean grain P and K per-bushel removal amounts are essential components of the mass-balance calculations for appropriate fertilizer use thus a high level of accuracy is needed. State agronomy guides have been questioned for using crop nutrient removal values based on yield levels, plant populations, and crop cultivars that have changed significantly over recent decades (Heckman et al., 2003; Mallarino et al., 2011; Mallarino et al., 2013).

Phosphorus and K are essential plant nutrients supplied as fertilizers from non-renewable sources, as well as from recycled through manure and sludge. The amounts of P and K required for crop

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Abbreviations: CRD, crop-reporting district; K, potassium; N, nitrogen; P, phosphorus.

Conversions: For unit conversions relevant to this article, see Table A.

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Table A. Useful conversions.

<table>
<thead>
<tr>
<th>To convert Column 1 to Column 2, multiply by</th>
<th>Column 1</th>
<th>Suggested Unit</th>
<th>Column 2</th>
<th>SI Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>62.71</td>
<td>56-lb bushel per acre, bu/acre</td>
<td>kilogram per hectare, kg/ha</td>
<td></td>
<td></td>
</tr>
<tr>
<td>67.19</td>
<td>60-lb bushel per acre, bu/acre</td>
<td>kilogram per hectare, kg/ha</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

production are determined by a variety of soil-extraction procedures that provide an indirect measure of plant-available P and K and relate this to crop need using calibration trials. Critical threshold values—those above which no crop response is expected—differ by state, crop, and sometime by soil region, but for corn and soybean in the Midwest region, critical values of P generally range from 20 to 45 mg P/kg (Bray-I soil extraction method), and the range for K is 88 to 300 mg K/kg (Warncke et al., 2004; Fernández and Hoeft, 2009). Soil testing summaries from 179 farm fields around Illinois indicated that soil test P levels have in many fields been built to high or very high values through fertilizer application over many years in excess of removal, whereas most K levels are in the medium category (Villamil et al., 2012). Randall et al. (1997) summarized the results of a 20-year study of annual (12-year application and 8-year residual phase) versus triennial P and K fertilization strategies at different rates in corn and soybean yields in two soils in Waseca, MN. They found that, when beginning soil test levels of P and K were relatively high, highest long-term returns were obtained with broadcast applications of 150 lb P₂O₅/ac on a triennial basis, along with monitoring of soil test P and K to take advantage of residual availability. But they also pointed out that continued drawdown of soil test levels in the absence of P and K additions will lead eventually to yield loss. Recent research in Illinois (Fernández and White, 2012; Fernández and Schaefer, 2012; Fernández et al., 2012) also reported soil test levels of P and K well in excess of levels that would likely show a yield response to additions of P and K fertilizer. Thus in many situations, profitability could be improved—and environmental risks minimized—by not applying P and K, or by applying only maintenance (removal) amounts to soils testing above the medium range.

In a number of Midwestern states including Illinois, most of the P and K response data used to relate soil test values to the need for fertilizer additions date from the 1950s to the 1970s, using cultivars that yielded less and had less tolerance to stress than do modern varieties. While there is little evidence to suggest that modern hybrids and varieties need to have higher soil test levels to assure enough P and K, the fact that they yield more has led to the observation that they likely take up more P and K per acre than did older varieties. Mallarino et al. (2011) measured crop yield and grain removal of P and K for corn and soybean in hundreds of trials around Iowa and found no support for the idea that soil test levels need to be higher to maintain yields. Mallarino et al. (2013) did, however, change the terminology to add an “optimum” category to soil test levels with some increase in threshold levels reflecting more crop removal with higher yields. With better root systems that are better able to explore the soil and intercept immobile elements like P and K, it is possible that soil test levels could be lower than those needed with older varieties. Yet research in Illinois is currently missing as to answer these questions. The Illinois Agronomy Handbook (IAH) lists removal values of 0.43 lb P₂O₅ and 0.28 lb K₂O per bushel for corn; 0.85 lb P₂O₅ and 1.30 lb K₂O per bushel for soybean; and 0.90 lb P₂O₅ and 0.30 lb K₂O per bushel for wheat in the state (Fernández and Hoeft, 2009). The value of 0.90 for wheat P removal is noted as being 1.5 times actual per-bushel removal. The source of these “book values” is not given in the IAH, and their origin remains unclear, but they are unchanged from versions of the IAH dating back into the 1970s, and so are clearly not recent.

Our goal for this project was to generate current grain concentration levels of P and K by analyzing corn, soybean, and wheat grain samples collected from producers across Illinois. Taken times yield, these values will improve the accuracy of nutrient replacement under current management of modern crop cultivars.

**Survey of Grain Samples**

We conducted a survey of field crops grain nutrient concentrations from 2014 to 2017, using samples collected throughout Illinois to update P and K removal grain concentration values for corn, soybean, and wheat. We solicited grain samples—one pound per sample per crop during harvest seasons each fall by broadcasting an appeal using the Bulletin website (http://bulletin.ipm.illinois.edu/?p=2297), through producer associations, and by radio. To ease the sampling process, we asked producers to provide only field location (county) and yield level of the field from which samples were taken. We created an email account specifically for the use of sample collectors and providers in requesting the return mailers and sample bags, which had labels requesting county of origin and (in 2014) crop yield. Our goal was to obtain samples of each crop from each crop-producing county in Illinois per year for 3 years, or a total of about 4500 samples across the three crops. Wheat was not adequately sampled in 2014, and so we extended collection for this crop to the 2017 season.

After the results showed no association between crop yield and nutrient concentration, we removed the requirement of yield reporting for sample submission in subsequent years; this enabled sample collection at sites such as elevators where those delivering grain did not know yield levels. In collaboration with the Illinois Soybean Association, the Illinois Corn Growers Association, University of Illinois Extension, University of Illinois Variety Testing Program,
and a number of grain elevators in Illinois, we surpassed our goal. Over the growing seasons, we collected 2336, 2621, and 825 samples of corn, soybean, and wheat, respectively, with every county and crop reporting district represented. Crop reporting districts (CRDs) are assigned by the United States Department of Agriculture National Agricultural Statistics Service (USDA NASS, 2018); these are shown in Fig. 1.

**Lab Determinations and Statistical Analyses of Grain Samples**

Samples were sent to a commercial laboratory (Brookside laboratories, Inc., New Bremen, OH) for the determination of N, P, and K in grain samples using standard methodology recommended for the North-Central Region (Gavlak et al., 2003). Laboratory results were expressed as elemental percentages on a dry weight basis, and grain nutrient concentrations were calculated following Murrell (2008); elemental concentrations were converted to oxides, and grain moisture converted to 15, 13, and 13.5% for corn, soybean, and wheat, respectively. Descriptive statistics (mean, standard errors, and quantiles) were obtained within the R environment for statistical computing (R Core Team, 2018), and figures were created using the packages lattice (Deepayan, 2008), and ggplot2 (Wickham, 2009). Likewise, we used linear models in R to explore the relationship between grain nutrient concentrations and grain yield of field crops, the different regions of the state represented by CRDs, and the years of data collection. Variance component analyses were used to investigate what percentage of the variability in nutrient concentration data was explained by our 3 years of collection across CRDs (grouped by latitude) in the state (the interaction CRDs × Year).

**Grain Survey Results and Implications for Management**

Fig. 2 A, B, and C show scatterplots of the grain nutrient concentration and their relationship with the yield of field crops.

Regression analyses of nutrient concentration against yield shows that the concentration of each nutrient measured was significantly associated with corn grain yield level (Table 1). For corn, however, while all three nutrients contributed significantly to the model (with positive coefficients), the \( R^2 \) for the model was only 0.06; that is, only 6% of the variability in crop yields was explained by concentration of nutrients in the grain. For soybean, \( P_2O_5 \), and \( K_2O \) but not N, were statistically significant in their relation with crop yields; with a negative coefficient for \( P_2O_5 \) and a positive one for \( K_2O \). Yet, as we found with corn, the \( R^2 \) of the multiple regression model indicates that only 6% of the variability in soybean yield was explained by the level of nutrients in the grain. Only N grain levels were statistically significant in the model of wheat yields, yet the multiple regression model explained 12% of the yield variability, reflecting a weak linear association between wheat yield and nutrient concentrations.

Table 2 shows the average values of nutrient removal for each field crop along with the measured standard errors, and the lower (25th) and upper (75th) quantiles.

The actual distribution of nutrient concentration in grain samples is shown in Fig. 3 for grain P (top) and K (bottom plot) concentration levels (as oxides) based on 2335, 2621,
and 825 samples for corn, soybean, and wheat, respectively. While we expected some variability among samples, this variability produces uncertainty about nutrient concentrations in a given sample of grain; they could be below, at, or above the average values we found in the survey.

In addition, results from our linear models indicated the statistical significance of the interaction effect between year and CRDs \( (p < 0.0001) \) for each nutrient and crop, meaning that the removal levels for each crop and nutrients, varied among the CRDs with no consistent pattern each year of collection (data not shown). The high level of precision that we achieved with the high number of samples lead us to find differences among CRDs and years in some cases only at the third decimal place. We thus decided to investigate what was the percentage of the variability in nutrient removal that was explained by the interaction effect of CRD × year using a variance component analyses. We found that for corn, the temporal and spatial variation in our samples explained only about 8% of the P and 16% of the K concentration variability measured in the grain. For soybean, the interaction CRD × year explained about 14 and 18%, of the P and K concentrations respectively, whereas for wheat-with about a third of the number of samples of corn and soybean-CRD × year was

Table 1. Results of the multiple regression analyses of the concentration of N, P\(_2\)O\(_5\), and K\(_2\)O (expressed as lb per bushel) with the yields of corn, soybean, and wheat.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Yield predictor(s)</th>
<th>Units</th>
<th>Adjusted ( R^2 ) †</th>
<th>B Estimate ‡</th>
<th>B Std. Error §</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn  ((n = 644))</td>
<td>Constant</td>
<td>–</td>
<td>0.06</td>
<td>236.6</td>
<td>16.0</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td></td>
<td>N ( \text{lb N per bu} )</td>
<td>43.8</td>
<td>14.5</td>
<td>0.00027</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>P(<em>2)O(<em>5) ( \text{lb P}</em>{2}O</em>{5} \text{ per bu} )</td>
<td>144.0</td>
<td>43.6</td>
<td>0.0010</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K(<em>2)O ( \text{lb K}</em>{2}O \text{ per bu} )</td>
<td>–429.8</td>
<td>74.0</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybean ((n = 390))</td>
<td>Constant</td>
<td>–</td>
<td>0.06</td>
<td>87.0</td>
<td>12.1</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td></td>
<td>N ( \text{lb N per bu} )</td>
<td>–4.2</td>
<td>3.2</td>
<td>0.1901</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>P(<em>2)O(<em>5) ( \text{lb P}</em>{2}O</em>{5} \text{ per bu} )</td>
<td>–42.0</td>
<td>8.9</td>
<td>&lt;.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K(<em>2)O ( \text{lb K}</em>{2}O \text{ per bu} )</td>
<td>14.2</td>
<td>7.2</td>
<td>0.048</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat ((n = 101))</td>
<td>Constant</td>
<td>–</td>
<td>0.12</td>
<td>50.8</td>
<td>14.0</td>
<td>0.0004</td>
</tr>
<tr>
<td></td>
<td>N ( \text{lb N per bu} )</td>
<td>26.3</td>
<td>14.1</td>
<td>0.0659</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>P(<em>2)O(<em>5) ( \text{lb P}</em>{2}O</em>{5} \text{ per bu} )</td>
<td>55.4</td>
<td>45.0</td>
<td>0.2212</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K(<em>2)O ( \text{lb K}</em>{2}O \text{ per bu} )</td>
<td>–84.1</td>
<td>85.1</td>
<td>0.3256</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

† Adjusted \( R^2 \): R-squared that has been adjusted for the number of predictors in the model.
‡ Beta estimates; regression coefficients, slope, or degree by which the crop yield will change as a result of one unit change in the nutrient concentration if the other two nutrient concentrations remain constant.
§ Beta standard error: standard error of the regression coefficients.
responsible for about 18 and 35% of the P and K concentration variability measured in grains, respectively.

To set values more likely to overestimate than to underestimate crop removal, we chose the 75th percentile–the point at which three-quarters of the values are below and one-quarter are above–as the new value to use for per-bushel nutrient removal in Illinois. Mallarino et al. (2013) used the same approach in revising grain concentration numbers in Iowa. Linear model analyses on these third quartiles values showed that there was no CRD x year effect present in nutrient concentration in any of the field crops. Instead, as we show in Table 3, a main effect of year of collection is evident for P removal in soybean and wheat crops; and for K removal for all crops (Table 3). Likewise, a main effect of CRDs was statistically significant for soybean P removal levels specifically between CRD 8–9 and the rest, with southern districts showing the highest removal levels. Table 3 shows the 75th quantiles for the nutrient removal levels for the different CRDs and years of collection for each of the three field crops.

To get some perspective of how these old and new numbers compare, we collected information in Table 4 that shows the nutrient removal numbers currently in use for Illinois (IHA), and those suggested by the International Plant Nutrition Institute (IPNI), the extension services of Michigan (MI), specifically between CRD 8–9 and the rest, with southern districts showing the highest removal levels. Table 3 shows the 75th quantiles for the nutrient removal levels for the different CRDs and years of collection for each of the three field crops.

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Table 4. Per–bushel nutrient removal numbers currently in use for Illinois (IAH), and those suggested by the International Plant Nutrition Institute (IPNI), the Extension services of Michigan (MI), Missouri (MO), and Iowa (IA), and our proposed new values for Illinois. †

<table>
<thead>
<tr>
<th>Source</th>
<th>Grain P removal (lb P₂O₅/bu)</th>
<th>Grain K removal (lb K₂O/bu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAH</td>
<td>Corn 0.43 Soybean 0.85 Wheat 0.90</td>
<td>Corn 0.28 Soybean 1.30 Wheat 0.30</td>
</tr>
<tr>
<td>IPNI</td>
<td>Corn 0.38 Soybean 0.84 Wheat 0.60</td>
<td>Corn 0.27 Soybean 1.30 Wheat 0.34</td>
</tr>
<tr>
<td>MI</td>
<td>Corn 0.37 Soybean 0.80 Wheat 0.63</td>
<td>Corn 0.27 Soybean 1.40 Wheat 0.37</td>
</tr>
<tr>
<td>MO</td>
<td>Corn 0.32 Soybean 0.80 Wheat 0.50</td>
<td>Corn 0.25 Soybean 1.30 Wheat 0.30</td>
</tr>
<tr>
<td>IA</td>
<td>Corn 0.32 Soybean 0.72 Wheat 0.55</td>
<td>Corn 0.22 Soybean 1.20 Wheat 0.27</td>
</tr>
<tr>
<td>IL new values</td>
<td>Corn 0.37 Soybean 0.75 Wheat 0.46</td>
<td>Corn 0.23 Soybean 1.15 Wheat 0.24</td>
</tr>
</tbody>
</table>


Missouri (MO), and Iowa (IA), and our proposed new values for Illinois. The location of these information sources are listed below the table.

For corn, the new grain removal numbers of 0.37 lb P₂O₅ and 0.23 lb K₂O per bushel are both about 15% lower than the book values currently in the Illinois Agronomy Handbook. For soybeans, the new numbers of 0.75 lb P₂O₅ and 1.15 lb K₂O per bushel are 12 and 10% lower than the book values, respectively. The book value for wheat P in the Illinois Agronomy Handbook is 50% higher than actual removal, and after adjusting that number (from 0.90 to 0.60 lb P₂O₅ per bushel) the new removal numbers are 22 and 8% less than the book values for P and K, respectively. Because we used the 75th percentile values as the removal numbers, these values are 4 to 8% higher than the average or median values; in other words, they’re a little higher than actual removal for a field with average grain nutrient concentration.

The new numbers we found are close to those reported by Iowa State University after conducting a survey and also using the 75th percentile values (Mallarino et al., 2013). The other sources listed in Table 4 used mean nutrient concentration values. One possible explanation for the new numbers being lower than the older values is that nutrient levels have decreased and yield levels have increased with newer corn hybrids (Woli et al., 2018). In addition, it is possible that older numbers were not based on many samples, or that, to make sure that these numbers would never underestimate actual removal; they were set at the high end of ranges of values found. It is clear that newer cultivars and the high yields they produce have not led to increases in per-bushel nutrient removal.

How much difference will using the new numbers make? Over two seasons, one with 200-bushel corn and the next with 60-bushel soybean, P removal using the Illinois Agronomy Handbook book values totaled 137 lb P₂O₅ per acre; the new values reported here calculate removal at 119 lb P₂O₅ per acre, or 13% less P removed. For potassium, the old values calculate to 134 lb K₂O per acre while the new ones calculate to 118 lb K₂O per acre, or 12% less. These are not large changes, but using these replacement numbers instead of the old numbers might mean that using replacement amounts may mean less, or no, increase in soil test nutrient levels over the years.

Acknowledgments

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References


