



Science
Societies

Understanding grain nutrient removal for 4R management of phosphorus and potassium

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This article is part of a series from
The Fertilizer Institute highlight-
ing some of the latest 4R research.



RIGHT SOURCE

Matches fertilizer type
to crop needs.



RIGHT RATE

Matches amount of
fertilizer to crop needs.



RIGHT TIME

Makes nutrients available
when crops need them.



RIGHT PLACE

Keeps nutrients where
crops can use them.

Examples of corn K deficiency across different soil test K levels (A = 76 ppm, B = 103 ppm, and C = 127 ppm). These images highlight the importance of building soil test K to critical concentrations and maintaining levels within the optimum range to reduce deficiency risk

and the likelihood of yield response to fertilization.



Understanding how much phosphorus and potassium leave the field with harvested grain is essential for maintaining soil fertility and making sound 4R nutrient management decisions. As crop yields continue to rise, nutrient removal per acre

increases, making accurate replacement strategies more important than ever. This article explains how grain nutrient removal values are developed, why they vary, and how they can be used to improve fertilizer recommendations and long-term nutrient management.

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Sustainable farming and the 4R Nutrient Stewardship Framework aim to maximize crop production and farm profitability while minimizing environmental impacts. Increasing volatility in grain prices and input costs has made the economic component of sustainability more critical than ever. As a result, farmers are placing greater emphasis on the financial resilience of their operations, alongside environmental stewardship and

agronomic performance.

A key component of nutrient management is 4R nutrient stewardship. Nutrient management directly influences crop yield, the primary driver of farm income, and also long-term soil productivity. Applying the 4Rs reduces risk of nutrient loss and enhances economic returns in a challenging farm economy.

In the Corn Belt, phosphorus (P) and potassium (K) management are generally guided by two nutrient management practices: (1) building soil test levels to an optimum range and (2) maintaining soil test levels in the optimum range by replacing nutrients removed with crop harvest. When soil test values fall below the optimum range, or the level where we expect a yield response to fertilizer (also known as the critical level), nutrient applications are needed to build soil nutrient concentrations and optimize productivity—the build component of this philosophy. In contrast, [when soil test levels are within or above the optimum range, management shifts toward maintaining levels through nutrient replacement](#) (Mallarino et al., 2023).

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The maintenance component of a “build and maintain” strategy also includes allowing crops to use readily available nutrients in the soil when soils test excessively high and draw down soil test values. ***All components require evaluating crop nutrient removal***, which is defined as the amount of nutrients removed from the field in harvested crop biomass and grain. Because these nutrients leave the system and are not returned to the soil, they must be accounted for when developing fertilization programs aimed at sustaining soil test levels over time. When all aboveground biomass is removed, such as forages, corn silage, or crop residue, total nutrient removal increases further, reinforcing the need for accurate replacement strategies.

Keeping up with nutrient replacement continues to be an important consideration for U.S. producers. Recent North American soil test summaries show that a growing share of state soil test levels for P and K have slipped to or below critical over the past two decades (TFI, 2021). In other words, more fields are drifting toward the range where low soil test levels can begin to limit yield, which underscores the value of matching fertilizer applications to crop removal. This article walks through what crop nutrient removal really means and how you can use it to fine-tune your P and K fertility program. It also looks at the main factors that determine how much P and K leave the field at harvest.

Crop nutrient removal: What it is and how it is estimated?

The importance of accounting for crop nutrient removal has grown in recent years, largely due to increasing crop yields. While nutrient removal per unit of yield (for example, per bushel) has remained relatively stable or even decreased in some cases due to nutrient dilution, total nutrient export per acre has increased with increasing crop yields (Figure 1). This relationship is well established in the literature, as increases in yield are generally associated with greater total nutrient removal (Jones et al., 2021;

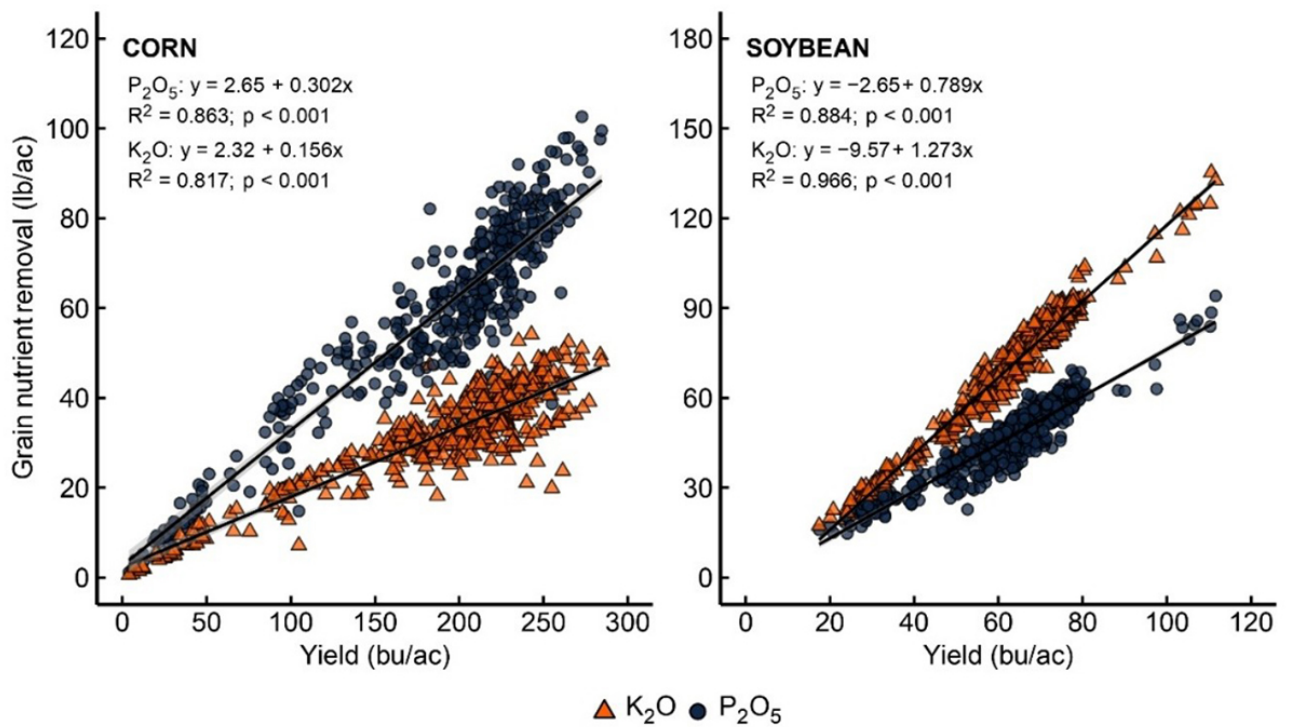


Figure 1. Grain nutrient removal (lb/ac) of P_2O_5 and K_2O as a function of yield for corn and soybean across long-term continuous P and K experiments (2013–2025).

Although increases in nutrient removal can translate into greater amounts of P and K that must be replaced, fertilizer decisions should be based on a clear understanding of how crop nutrient removal is estimated. Nutrient removal is typically calculated using coefficients derived from grain nutrient concentration and yield. In the Midwest, these values are commonly provided in state fertilizer guidelines for each crop (Villamil et al., 2019), which are developed from large datasets of grain nutrient concentrations collected across a wide range of fields and growing conditions. Values are state-dependent and commonly represent the median or 75th percentile of the supporting database. For example, the median P and K removal values for corn grown in Minnesota

are 0.28 lb P_2O_5 and 0.19 lb K_2O per bushel (Kaiser, 2024). So, for 250 bu/ac corn, the expected P removal is roughly 70 lb P_2O_5 /ac and 48 lb K_2O /ac. In Illinois, the P and K removal values for corn are 0.37 lb P_2O_5 and 0.23 lb K_2O per bushel (Kaiser, 2024). So, for 250 bu/ac corn, the expected P removal is roughly 93 lb P_2O_5 /ac and 58 lb K_2O /ac. These differences show regional patterns in removal coefficients and the effect of using median vs. 75th percentile values.

Rather than using the average value, the median value or the 75th percentile is typically selected as the book value to better account for the variability that exists among crops, environments, and management practices. However, many farmers and agronomists are increasingly interested in developing field-specific values based on their own data. While this is a valid and precise agronomic approach, it can also lead to errors if not done carefully (Figure 2).

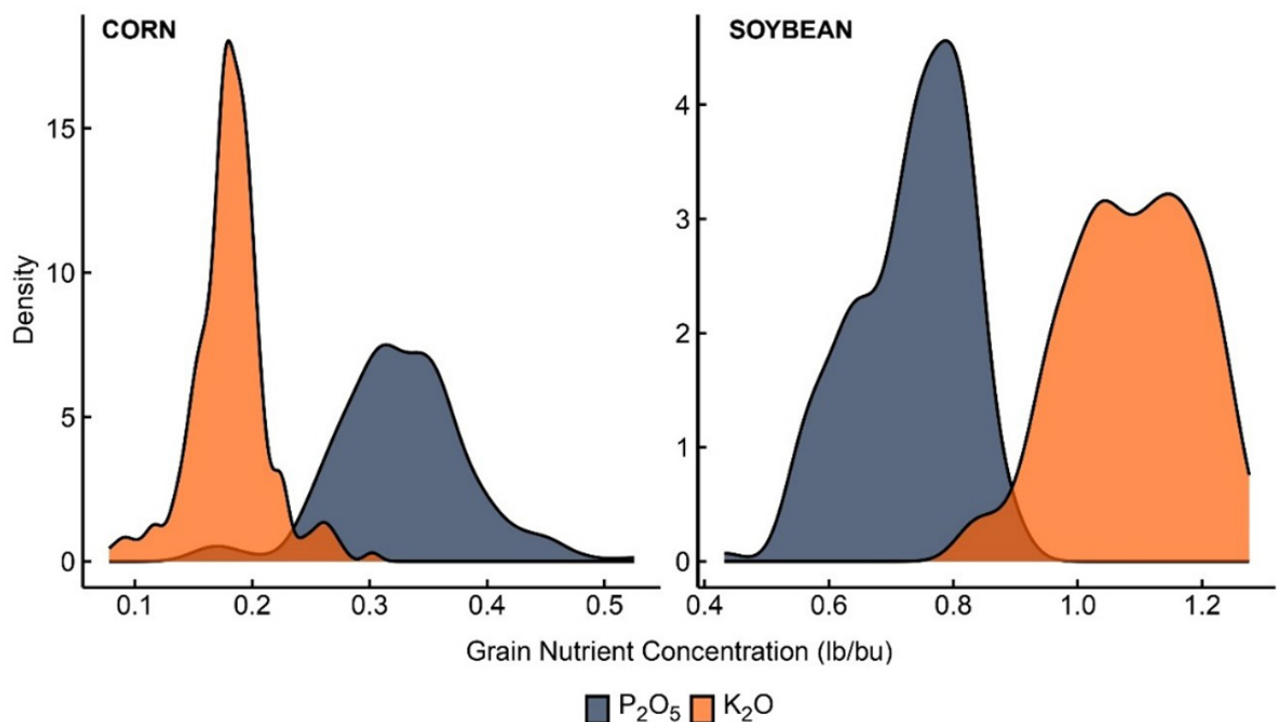


Figure 2. Frequency distribution of grain P_2O_5 and K_2O removal coefficients (lb/bu) for corn and soybean based on long-term continuous P and K experiments (2013–2025; 3,500

grain samples).

Grain nutrient removal is calculated using four main components: harvested area, weight of moist grain harvested, grain moisture content, and grain nutrient concentration (Murrell, 2008). Using these variables, nutrient removal can be estimated as:

$$\text{Nutrient Rem. (lb/ac)} = \frac{\text{wet weight (lb)} - \left(\text{wet weight (lb)} \times \frac{\text{moisture (\%)}}{100\%} \right)}{\text{area harvested (acres)}} \times \frac{\text{nutrient concentration (\%)}}{100\%}$$

While this equation captures all variables involved, most are indirectly accounted for when yield and grain nutrient concentration are known. As a result, it is not practical for routine use. In most production systems, wet grain weight, moisture, and nutrient concentration are not measured for every field. Instead, advances in yield-monitoring technology and laboratory analysis have simplified this process. Today, nutrient removal is commonly estimated using yield data from yield maps together with measured grain nutrient concentrations, resulting in a more practical and streamlined approach.

$$\text{Nut. Rem. Rate (lb/bu)} = \frac{\text{nutrient concentration (\%)}}{100\%} \times \left(\text{test weight (lb/bu)} - \left(\text{test weight (lb/bu)} \times \frac{\text{moisture (\%)}}{100\%} \right) \right)$$

$$\text{Nutrient Rem. (lb/ac)} = \frac{\text{nutrient removal rate (lb/bu)}}{\text{yield (bu/ac)}}$$

In some cases, laboratories may provide nutrient removal coefficients per bushel, which can be directly applied to yield maps, further simplifying the process for farmers. It is important to consider how grain nutrient concentration is reported. Some laboratories express P and K concentrations on a near 0% moisture basis. In those cases, values should be adjusted to standard grain moisture (e.g., 15% for corn and 13% for soybean) to avoid overestimating nutrient removal.

Finally, nutrient removal values should be expressed as P_2O_5 and K_2O when making fertilizer recommendations. If grain nutrient concentration is reported as elemental P and K, convert them to P_2O_5 and K_2O by multiplying by 2.29 and 1.20, respectively (to go the other way, divide P_2O_5 by 2.29 to calculate elemental P, and K_2O by 1.20 to calculate elemental K). Failing to apply these conversions can result in incorrect fertilizer rates. It is important to note that oxide forms of P as P_2O_5 and K as K_2O do not exist chemically in soils or plants but have nonetheless been commonplace in fertilizer terminology since the 19th century.

Factors affecting crop nutrient removal

Questions are often raised about whether factors such as soil test levels or fertilizer rates influence grain P and K removal. In general, any factor that affects yield will influence the total amount of P and K removed per acre. However, these factors typically marginally affect nutrient removal per bushel.

To illustrate this concept, a case study was analyzed using data from long-term P and K trials. These trials allowed for evaluation of nutrient removal across a range of soil test values and fertilizer rates. As shown in Figures 3 and 4, total P_2O_5 and K_2O removal significantly increases with higher soil test levels and fertilizer rates, primarily as a result of increased yields under those conditions. While soil test levels and fertilizer

rates can influence nutrient removal per acre through their effects on yield, they influenced small deviation on nutrient removal per bushel. This relative stability is one reason why statewide and regional removal values can be applied across a broad range of conditions.

In some cases, higher soil test levels do not result in additional yield response. Once soil test values reach the optimum range (e.g., In Illinois, 17 to 23 ppm P and 120 to 150 ppm K for soil in Figures 1, 3, and 4), the probability of response to additional fertilizer becomes low, and management should shift from a build-up approach to a maintenance approach (Mallarino et al., 2023; Kaiser et al., 2025). Under these conditions, fertilizer applications based on crop nutrient removal can provide a practical estimate of maintenance requirements and help sustain soil fertility over time.

In contrast, when soil test values are below the critical concentration, fertilizer needs often exceed crop removal because nutrients are required not only to replace those removed by the harvested grain, but also to gradually rebuild soil fertility. Applying nutrients beyond the optimum range can increase costs without improving yield and may increase the risk of nutrient losses from the system.

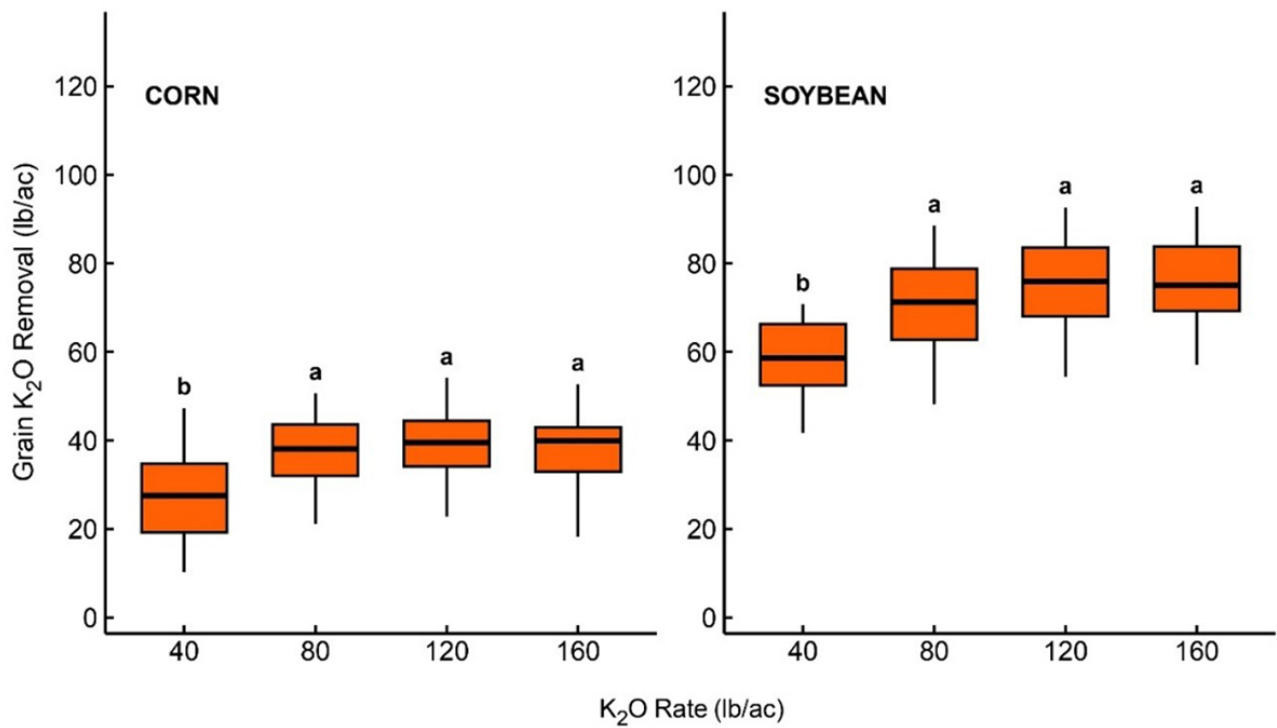
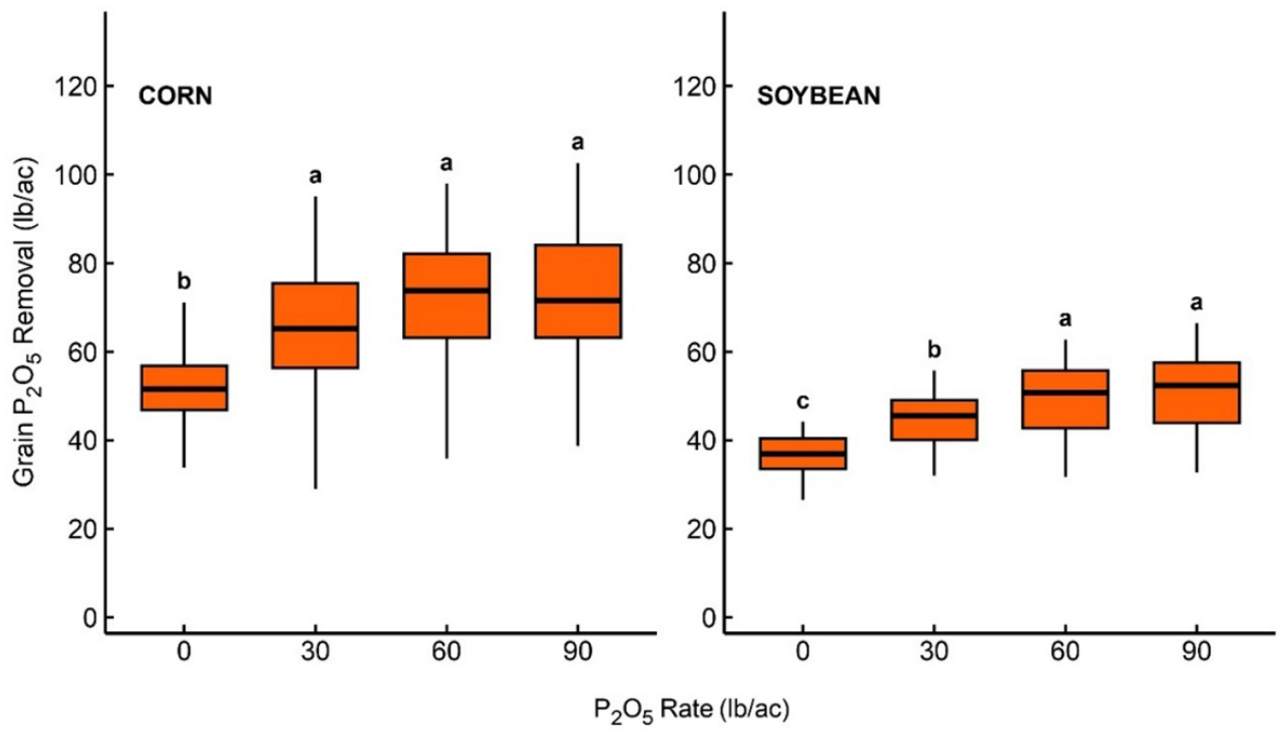


Figure 3. Grain P_2O_5 and K_2O removal (lb/ac) for corn and soybean across fertilizer rates. Different letters indicate significant differences among treatments (P value ≤ 0.05).

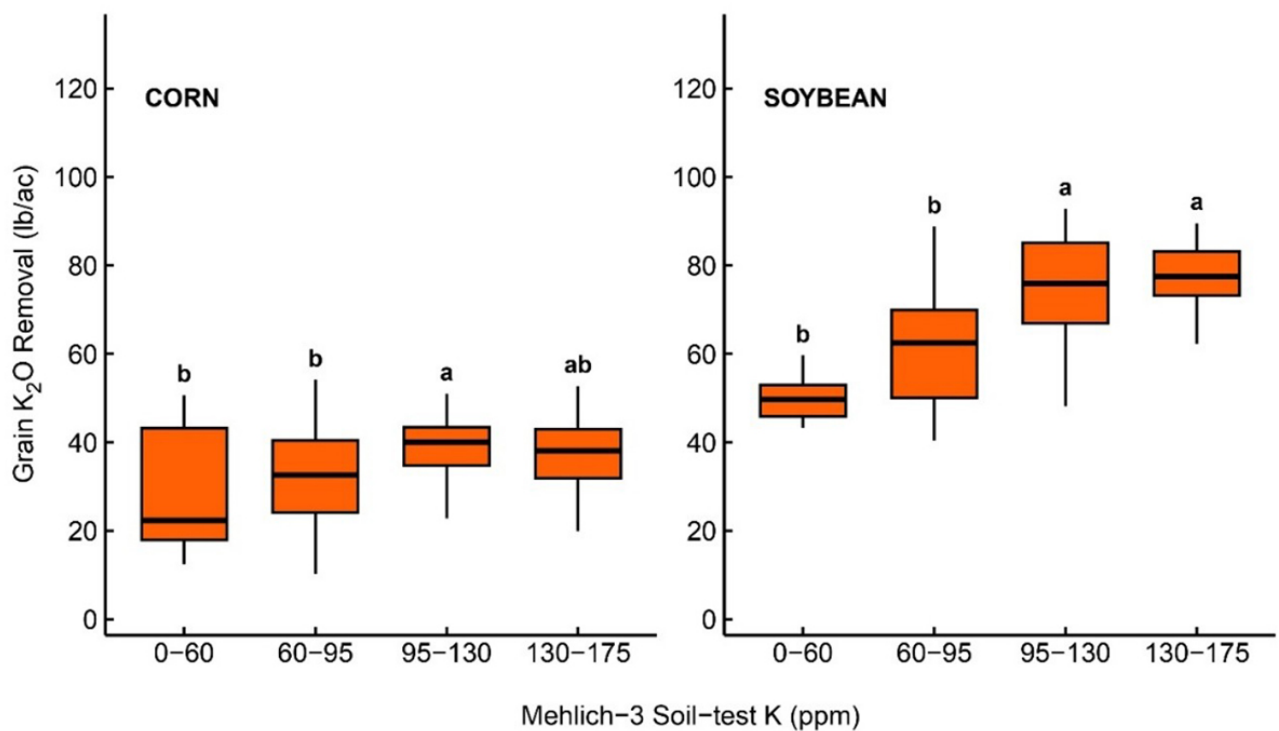
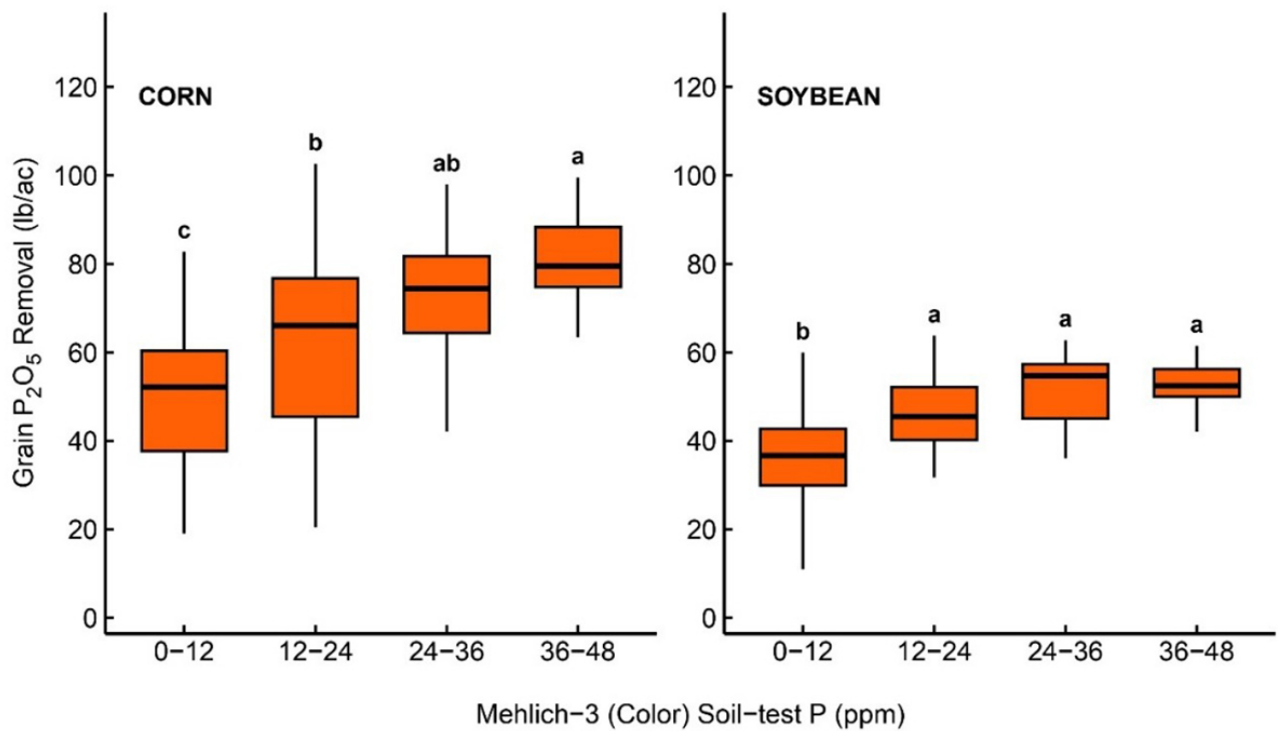


Figure 4. Grain P_2O_5 and K_2O removal (lb/ac) for corn and soybean across soil test categories. Different letters indicate significant differences among treatments (P value ≤ 0.05).

For these reasons, fertilizer guidelines that integrate soil test values with crop nutrient removal are essential. Crop removal values provide a useful benchmark for estimating nutrient replacement, but soil test information remains necessary to determine whether fertilizer applications should focus on building, maintaining, or drawing down soil nutrient levels (Figure 5).

As a general guide for rebuilding, data from the University of Minnesota indicate that roughly 16 to 18 lb P_2O_5 per acre is needed to raise soil test P by 1 ppm, and roughly 7–10 lb K_2O are required to increase ammonium acetate K tests by 1 ppm (Kaiser, 2024).

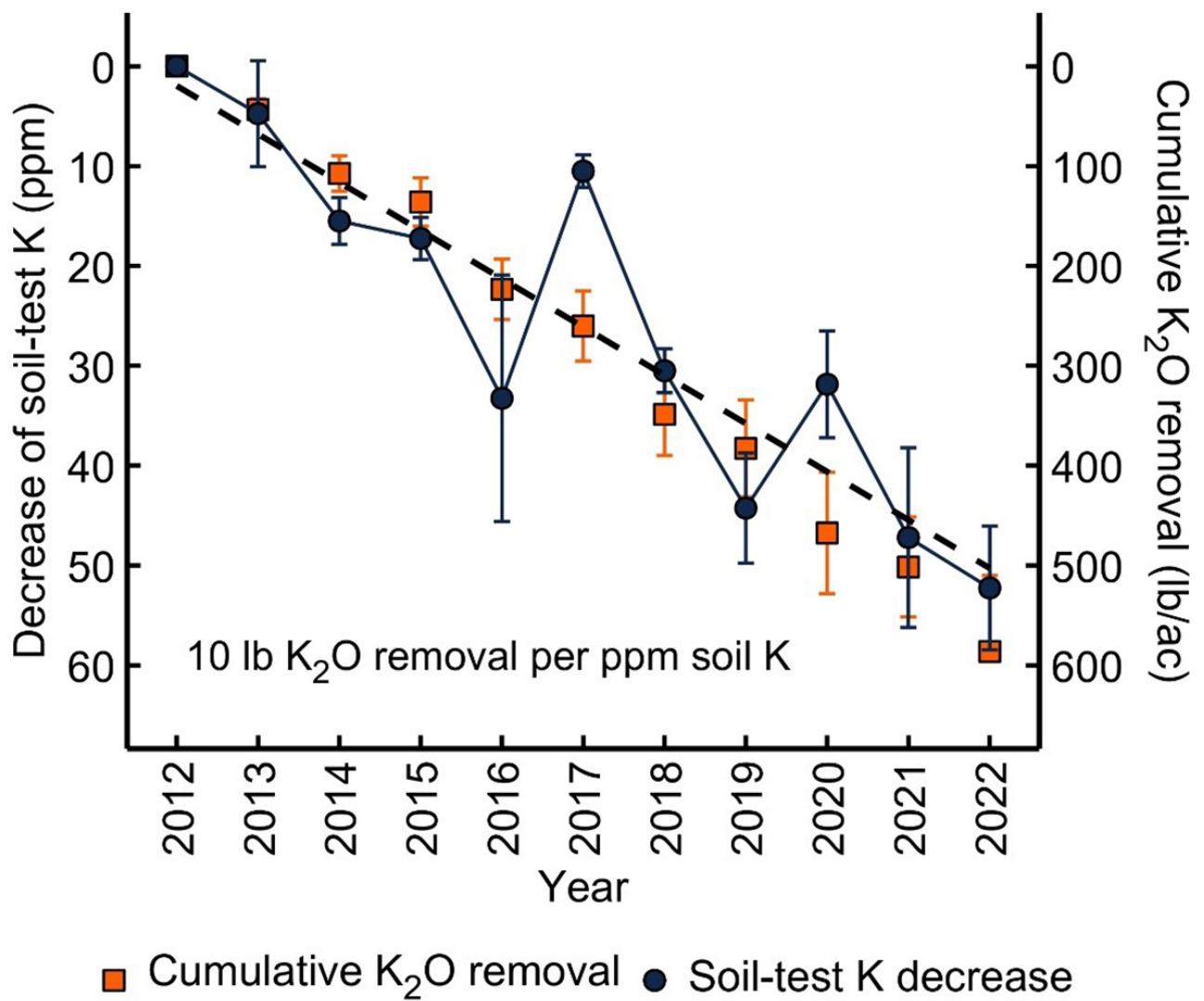


Figure 5. Soil test K drawdown associated with cumulative crop K removal from a corn-soybean rotation. The decline in soil test K illustrates the need for nutrient replacement to maintain soil fertility and avoid reaching critical soil test levels where yield response to K fertilization becomes more likely.

Optimizing P and K management in a challenging market

When margins tighten, P and K are often among the first inputs growers consider cutting. Unlike nitrogen, P and K that are not removed largely stay in the soil, so soil test levels act as a nutrient bank that can be managed across years rather than fully replenished every season. The goal in a high-cost year is to use soil test values and

crop removal together to decide where each fertilizer dollar is most likely to pay. In most cases, a tight year is not the time to build soil test levels above the optimum range; [the better mindset is maintenance, letting crop removal, rather than a goal of raising soil test levels, guide how much P and K to apply](#). In the language of the 4Rs, this sharpens the right rate and right time, directing P and K to the fields and zones where soil tests and removal show they will pay and easing off where they will not.

On fields or zones already testing above the optimum range, the probability of a yield response to additional P or K is low (Mallarino et al., 2023; Kaiser et al., 2025). These acres are good candidates for reducing P and K and letting crop removal draw soil test levels down toward the optimum range (Figure 5). This is a recommended 4R practice to reduce overapplication and loss of nutrient to environment; it captures the value of nutrients already in the soil and frees cash without sacrificing yield, as long as levels are not allowed to fall below the critical concentration.

Below-critical fields are the opposite case. There, skipping P and K risks a yield loss that usually costs more than the fertilizer saved, and rebuilding later is expensive. Minnesota guidelines suggest 16 to 18 lb P_2O_5 /ac is needed to raise soil test P by 1 ppm and roughly 7 to 10 lb K_2O is needed to raise ammonium acetate soil test K by 1 ppm (Kaiser, 2024), though it is important to remember these values can vary from 10 to 35 lb P_2O_5 per ppm for P and 6 to 20 lb K_2O per ppm for K (Mallarino et al., 2023). In fact, research in Illinois shows how build coefficients are relative to the initial starting soil test values as shown in Figure 6 (Bardeggia & Jones, 2026). When the budget forces cuts, protect the responsive, low-testing acres first and take the reductions on high-testing ground, rather than making a 20% cut across all ground.

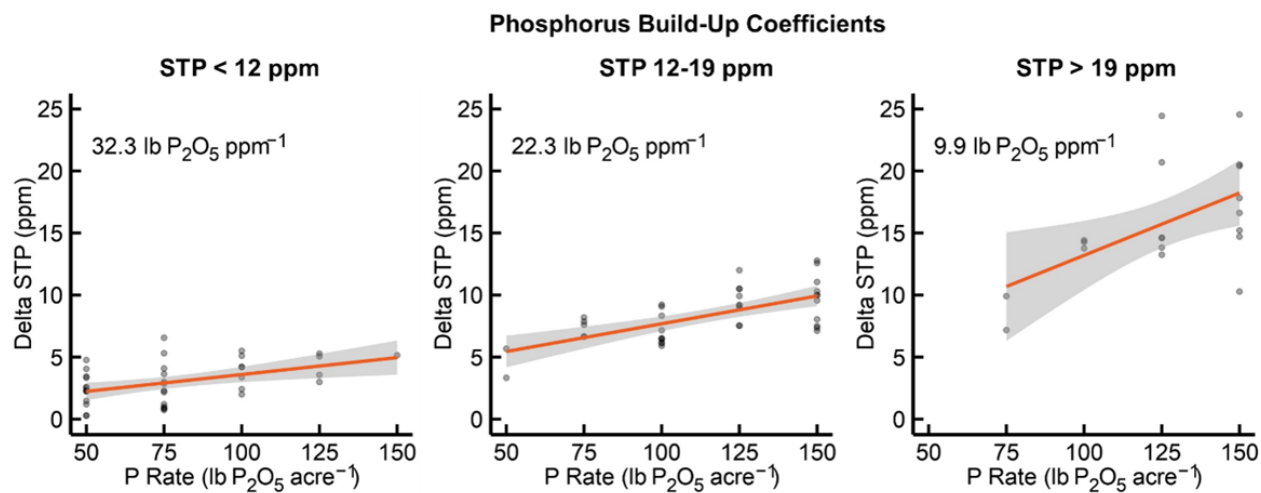


Figure 6. Relationship between phosphorus fertilizer rate and the change in Mehlich-3 colorimetric soil test phosphorus (Delta STP) for soils with different initial soil test phosphorus values. For each situation, the estimated P build-up coefficients are expressed as the amount of P₂O₅ required to increase soil test phosphorus by 1 ppm of Mehlich-3 colorimetric P.

Similar to build-up tactics, drawdown is not a permanent program. Regular soil testing is essential to track how fast levels are falling and to flag fields approaching the critical range, where removal-based maintenance should resume. Applying at crop removal holds soil test levels steady, applying below removal draws them down, and once prices ease, applying above removal rebuilds the reserve for the next tight year. Matched field by field, these decisions to build, maintain, or draw down are the 4R framework in practice, putting the right source and rate of P and K in the right place at the right time to protect both yield and cash flow when input costs are high.

Key takeaways: Practical implications for fertilizer management of crop removal

Evaluating crop nutrient removal provides a practical framework for linking yield, soil test values, and fertilizer management decisions. While removal values are useful for estimating nutrient replacement, effective fertilizer programs must also consider soil

test levels to determine whether management should focus on building, maintaining, or drawing down soil nutrient reserves. The main practical implications can be summarized as follows:

- Grain nutrient removal per acre increases with yield, whereas nutrient removal per bushel remains relatively stable and varies by environment.
- Soil test values **below optimum ranges** often require fertilizer applications beyond crop removal to rebuild soil nutrient levels.
- Maintenance fertilization is most appropriate when soil test values are **within the optimum range**.

On fields already testing **above the optimum range**, reducing P and K to draw soil test levels down toward the optimum captures the value of nutrients already in the soil and frees cash without sacrificing yield.

- Long-term nutrient removal without replacement can lead to soil test drawdown and increased risk of yield response to fertilization, requiring greater costs to rebuild levels.
- In a high-cost year, let crop removal, rather than a goal of raising soil test levels, guide how much P and K to apply; soil test levels act as a nutrient bank that can be managed across years rather than fully replenished every season.
- When budgets force cuts, protect the responsive, low-testing acres first and take reductions on high-testing ground rather than making an across-the-board cut.

- Periodic updates to removal coefficients help keep fertilizer recommendations aligned with modern crop productivity.

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1. As defined in the article, crop nutrient removal is the amount of nutrients

- a. applied as fertilizer each season.
- b. exported from the field in harvested crop biomass and grain.
- c. lost through leaching and runoff.

d. held in reserve in the soil.

2. As crop yields increase, which of the following is true regarding grain nutrient removal?

- a. Removal per acre remains relatively constant because nutrient concentrations decline as yields increase.
- b. Removal per acre increases, while removal per bushel remains relatively stable.
- c. Removal per bushel increases, while removal per acre remains stable.
- d. Both removal per acre and per bushel decrease because of nutrient dilution.

3. When soil test values fall below the critical level, fertilizer applications should generally

- a. match crop removal exactly.
- b. be skipped until fertilizer prices improve.
- c. exceed crop removal to gradually rebuild soil fertility.
- d. be reduced below crop removal.

4. To account for variability among crops, environments, and management, which value is typically selected as the “book value” for a

removal coefficient?

- a. The minimum observed value.
- b. The average (mean) value.
- c. The median or 75th percentile value.
- d. The maximum observed value.

5. To convert grain nutrient concentrations reported as elemental P and K to P_2O_5 and K_2O , multiply by

- a. 2.29 and 1.20, respectively.
- b. 1.20 and 2.29, respectively.
- c. 0.44 and 0.83, respectively.
- d. 2.29 and 2.29, respectively.

6. Once soil test values reach the optimum range, management should shift from a build-up approach to

- a. a drawdown-only approach.
- b. a maintenance approach based on crop removal.
- c. a drawdown approach that reduces soil testing.
- d. increasing fertilizer rates.

7. The article describes soil test levels as a “nutrient bank” for P and K because

- a. nutrients must be fully replenished every season, as with nitrogen.
- b. P and K that are not removed largely stay in the soil and can be managed across years.
- c. soil test levels fluctuate too rapidly to be managed across multiple years.
- d. applied P and K leach from the soil as readily as nitrogen.

8. In a high-cost year, when budgets force cuts, the article recommends that growers

- a. make an equal, across-the-board cut on all acres.
- b. cut the most on responsive, low-testing acres.
- c. build all fields above the optimum range.
- d. protect responsive, low-testing acres and take reductions on high-testing ground.

9. According to University of Minnesota data cited in the article, roughly how much P_2O_5 is needed to raise soil test P by 1 ppm?

- a. 1 to 2 lb/ac.
- b. 7 to 10 lb/ac.

c. 16 to 18 lb/ac.

d. 50 to 56 lb/ac.

10. In the article, drawdown of soil test levels is best described as

a. a permanent fertilization program.

b. a short-term tactic that requires regular soil testing to track how fast levels fall.

c. A practice used only on below-critical fields.

d. A way to build soil test levels above the optimum range.

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