Bulletin 974

TRI-STATE FERTILIZER RECOMMENDATIONS

for Corn, Soybean, Wheat, and Alfalfa

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Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat, and Alfalfa

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This publication draws heavily from the foundation provided by the original edition of the same title authored by Drs. M.L. Vitosh, J.W. Johnson, and D.B. Mengel.

Suggested citation: Culman, S., Fulford, A., Camberato, J., & Steinke, K. (2020). *Tri-State Fertilizer Recommendations*. Bulletin 974. College of Food, Agricultural, and Environmental Sciences. Columbus, OH: The Ohio State University.

A PDF copy of this report is available online at **extensionpubs.osu.edu.**

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FOREWORD

The *Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat and Alfalfa* (Extension Bulletin E-2567) was first published in 1995 and has served as a cornerstone in nutrient management in field crops for Indiana, Michigan, and Ohio. Field crop production practices in this region have changed over the past two and a half decades, including general reductions in tillage and crop rotations, greater plant populations and grain yields, new pests and diseases, and the emergence of precision soil sampling and fertilizer rate and placement technologies. Water and air quality issues in this region also underscore the need to manage nutrients as judiciously and profitably as possible. In short, there is ample justification for a revision of the fertilizer recommendations and this publication represents the first step to update fertilizer recommendations in this region. The focus of this document is on managing mineral fertilizer sources in field crop systems. Animal manures and biosolids are important sources of nutrients in this region and management guidelines are provided wherever appropriate, however, proper management of these nutrient sources requires additional consideration that can lie outside the scope of this document.

ACKNOWLEDGMENTS

This publication represents a tremendous collective effort by many committed agricultural professionals with the ultimate goal of providing objective and scientifically vetted nutrient management information to farmers in this region. The authors would like to thank the following individuals for their contributions in helping generate data:

Eric Anderson
Mark Badertscher
John Barker
Amanda Bennett
Bob Battel
Chris Bruynis
Florian Chirra
Chris Clark
Bruce Clevenger
Sam Custer
Matt Davis
Joe Davlin
Carl DeBruin
John DeLong
Jacob Dennis
Nick Farquhar
Jason Greve
Paul Gross
Lee Havens
Andrew Hofner
Don Jackson
Carri Jagger
Phil Kaatz
Rory Lewandowski
John Linder
John Mackson
Clifton Martin
Jeff McCutcheon
Dave McKinniss
Jared McLaughlin
Martin Nagelkirk
Phillip Neal
Joe and Clint Nester
Les Ober
Tom Puch
Dustin Ramsier
Jeff Rice
Laura Ringler
George Silva
Van Slack
Jacci Smith
Jeff Stachler
Mike Sword
Marilyn Thelen
Luke VanTilburg
Myron Wehr
Martha Winters
Ted Wiseman
Chris Zoller

We sincerely appreciate all the analytical service provided by Bill Urbanowicz and Spectrum Analytic, as well as the support from A&L Great Lakes Laboratories.

We also would like to thank the following individuals who provided valuable feedback on the draft:

Tom Bruulsema
Jamie Bultemeier
Craig Houin
Matthew Lane
Robert Mullen
Will Osterholz
John Spargo
Mark Sulc
Randall Warden
Ron Wyss

The work was made possible through the committed financial support of the Ohio Soybean Council, Ohio Corn Checkoff Program, Ohio Small Grains Checkoff Program, and the USDA National Institute for Food and Agriculture.

OHIO SOYBEAN COUNCIL

Ohio Corn&Wheat

USDA

United States Department of Agriculture
National Institute of Food and Agriculture

Additional support was provided by the Corn Marketing Program of Michigan, the Michigan Wheat Program, Michigan State University Project GREEEN, Michigan AgBioResearch, the Michigan State University's College of Agriculture and Natural Resources, and the School of Environment and Natural Resources at The Ohio State University.

EXECUTIVE SUMMARY

The *Tri-State Field Crop Fertilizer Recommendations for Indiana, Michigan, and Ohio* have been revised and updated. Extensive research station and on-farm trials have been conducted over the past decade to validate and refine the guidelines. In general, the fertilizer recommendations originally published in 1995 provide a solid framework for managing fertilizers and soil fertility. Some changes, however, have been made to the recommendations. Here are the important points:

- Soil sampling remains a critical component of effective nutrient management.
  - Soil sample in a consistent way every 3 to 4 years at no more than 25-acre samples.
  - Adapt nutrient management based on trends over time.
- Soil pH remains one of the most important aspects of supplying adequate nutrition to crops.
  - Soil pH should be kept between 6.0 and 6.8 for field crops.
- Optimizing nitrogen management is challenging and requires careful consideration of many factors.
  - Nitrogen rate recommendations for corn are based on an economic model designed to maximize farmer profitability (maximum return to N (MRTN)) available at **cnrc.agron.iastate.edu.**
  - Nitrogen recommendations for wheat have been updated and are similar to the original recommendations.
- Soil test levels determine phosphorus and potassium fertilizer application rates and timing.

Soil Test Levels Classify Soils into One of Three Phases

Assessment	Rate to Apply	When to Apply
Deficient	Crop removal + fertilizer to build soil test levels	Immediately, before next crop
Optimal	Approximate crop removal	Sometime within the rotation
Sufficient	Do not fertilize	Do not fertilize

- Mehlich-3 is now the default soil extractant that has replaced Bray P1 for phosphorus and ammonium acetate for base cations. Mehlich-3 P returns approximately 35% higher soil test phosphorous (STP) values than Bray P1. Mehlich-3 K returns approximately 14% higher soil test potassium (STK) than ammonium acetate.
- **Optimal soil test levels for all crops are largely consistent with the original recommendations, except for revising the values to reflect Mehlich-3 as the soil extractant.**

New Mehlich-3 P and K Optimal Levels for Field Crops in the Tri-State Region

Crop	Phosphorus (Mehlich-3 P)	Potassium (Mehlich-3 K)	
		Sandy soils (CEC <5 meq/ 100g)	Loam and clay soils (CEC >5 meq/ 100g)
Corn, Soybean	20–40 ppm	100–130 ppm	120–170 ppm
Wheat, Alfalfa	30–50 ppm	100–130 ppm	120–170 ppm

- Crop removal rates were updated with current analyses of grain P and K concentrations.
- Nutrient removal rates per bushel of grain have decreased, especially with potassium.

Nutrients Removed in Harvested Grain		
Crop	Grain Nutrient Removal Rate	
	lb P_2O_5/ bushel	lb K_2O/ bushel
Corn	0.35	0.20
Soybean	0.80	1.15
Wheat	0.50	0.25

Crop	Forage Nutrient Removal Rate	
	lb P_2O_5/ ton	lb K_2O/ ton
Wheat Straw	3.7	29
Corn silage	3.1	7.3
Alfalfa	12.0	49

Source: International Plant Nutrition Institute (2014), dry matter basis: 100% for wheat straw and alfalfa; 35% for corn silage (0% moisture for wheat straw, 65% moisture for corn silage).

- Updated P and K fertilizer rates are based on expected yield goals when soil test P and K are in the maintenance range (optimal):

Crop	Yield	Recommended Fertilizer Rate		
		IN, MI, OH	IN & OH	MI
	bushe/acre	lb P_2O_5	lb K_2O/ acre	lb K_2O/ acre
Corn	150	55	50	30
	200	70	60	40
	250	90	70	50
	300	105	80	60
Soybean	30	25	55	35
	50	40	80	60
	70	55	100	80
	90	70	125	105
Wheat	60	30	35	15
	90	45	45	25
	120	60	50	30
	150	75	60	40

- Soils in the tri-state region typically supply adequate Ca, Mg, S and micronutrients for crop production.
- Sulfur deficiencies remain infrequent but are increasing.
- The judicious use and placement of fertilizer remains a key factor in running a profitable farming operation.
- The concept of soil fertility should be extended beyond fertilizer management to include sound agronomic practices that promote soil biology and physical structure in field crop systems.

Quick Reference Guide to Tri-State Fertilizer Recommendation Changes

What has changed?	Why the change?	Details
Soil Sampling		
Sample every 3 to 4 years in a consistent way as the foundation for an adaptive nutrient management program.	No changes	Page 11
Soil pH and Lime Recommendations		
Michigan and Indiana liming recommendations are consistent, Ohio recommendations are different.	States label and regulate liming materials differently.	Page 13
Nitrogen Fertilizer Recommendations		
Corn N recommendations are now based on economic model to maximize profitability.	Fluctuating grain and fertilizer prices necessitate a focus on economics in addition to yield.	Page 20
Wheat N recommendations have been updated.	They are calibrated with recent field trials with modern varieties.	Page 22
Phosphorus and Potassium Recommendations		
Management framework drops drawdown range, makes build-up recommended but not required.	Recommendations are simplified to provide farmers with greater flexibility to manage nutrients profitably.	Page 24
Default soil test P and K levels now based on Mehlich-3.	Make recommendations consistent with current soil laboratory practices.	Page 31
P critical level 20 ppm for corn and soybean, 30 ppm for wheat and alfalfa (Mehlich-3 P).	This update is based on extensive field trials over past decade.	Page 27
K critical levels are 100 ppm for sandy soils, 120 ppm silt and clay soils (Mehlich-3 K, all crops)	This update is based on extensive field trials over past decade.	Page 27
Grain nutrient removal rates per bushel of yield have decreased.	Crops are yielding more but grain nutrient concentrations have decreased.	Page 31
Calcium, magnesium, sulfur recommendations		
Liming supplies sufficient Ca & Mg; S deficiencies remain infrequent but are increasing.	No changes	Page 40
Micronutrients		
Most soils supply sufficient micronutrients; diagnostic tools are limited.	No changes	Page 42

SOIL SAMPLING AND TESTING

KEY CONCEPTS

- Soil sampling remains a critical component of effective nutrient management.
- Soil sample in a consistent way every 3 to 4 years at no more than 25-acre samples.
- Adapt nutrient management based on trends over time.

The accuracy of a fertilizer recommendation depends on the quality of the soil sample collected and analyzed to produce a soil test value. Taking the time to collect a quality soil sample is the first and perhaps most important step in developing a sound nutrient management plan. Consider that a typical 1-inch diameter soil probe represents ~0.6 square inches while an acre is more than 6 million square inches. If a farmer submits a single soil sample made up of 10 soil cores from an acre to a lab for analysis, this sample represents only 1 millionth of an acre. Soil samples are a very small fraction of the field they represent, so the importance of taking the time to collect a quality and representative sample cannot be overstated. In general, a quality soil sample should represent no more than 25 acres and be from a composite of no less than 10 soil cores. Sampling smaller areas (2.5 acres) with more soil cores (~15) provide more reliable information with greater confidence.

Farmers in the tri-state region enjoy a robust infrastructure for soil testing. Numerous high-quality, professional soil testing laboratories analyze soils rapidly and inexpensively. Nearly all these laboratories enroll in voluntary quality control programs that ensure the values leaving their laboratories are both accurate and precise. Soil testing is a small investment in managing nutrients and is a necessary tool to run a profitable farm operation, especially when considering the potential costs of over- or under-applying lime and fertilizer.

There are many resources on soil testing including:

- Ohio State University Soil Fertility Resources: **agcrops.osu.edu/fertilityresources**
- Purdue Extension Soil Sampling Guidelines: **extension.purdue.edu/extmedia/AY/AY-368-w.pdf**
- Michigan State University Soil Fertility and Plant Nutrition Resources: **soil.msu.edu** and **canr.msu.edu/spnl**

Soil Sampling Strategies

Four factors are generally considered when taking soil samples: 1) the spatial variability of soil within a field, 2) the depth of sampling, 3) the time of year when samples are taken, and 4) how often an area is sampled. Proper consideration of these factors will help ensure the soil sample accurately reflects the area sampled.

Spatial Variability

The degree of spatial variability determines how many soil samples are needed for a field. All fields have some degree of natural horizontal and vertical soil variability, so the density of soil sampling should increase as field variability increases. Deciding on a soil sample strategy is always a trade-off between the collection and analysis cost and the level of detail of the information gathered. The goal is for soil analyses to reasonably reflect field variability and accurately reflect field conditions that impact nutrient needs in crop production.

There are many soil sampling approaches farmers take to deal with spatial variability, but each approach can be classified into one of these three categories:

1. *Whole field sampling: One representative soil sample per field*
2. *Zone sampling: Field sub-divided into geo-referenced zones based on soil texture, landscape position, previous history, production potential, etc.*
3. *Grid sampling: Field sub-divided systematically in a grid pattern*

Zone and grid sampling approaches provide more information than whole field sampling and are the typically recommended approaches. Soil samples should represent no more than 25 acres and be from a composite of no less than 10 soil cores. A common practice is a 2.5-acre grids (1 soil sample to represent 2.5 acres), and many growers are moving to higher density samplings such as 1-acre grids. These higher density approaches require a larger investment in soil testing but can provide more precise information to manage nutrients profitably. Few growers regret or second-guess these investments once they realize the valuable information they return.

Sampling Depth

Soil samples used for nutrient recommendations should be taken to the same depth each sampling to ensure changes in soil test levels can be reliably tracked over time. The recommendations here are based on a 0 to 8-inch soil sample, following the original tri-state recommendations. However, many agricultural practitioners sample at different depths than 0–8" inches (e.g., 0–4", 0–5", 0–6"). Soil samples based on shallower sampling depths typically do not align perfectly with the recommendations presented here, as shallower soil samples often return higher soil test values relative to 0–8" samples due to nutrient stratification of pH and nutrients. No attempt has been made at this time to generate recommendations at differing depths, as nutrient stratification of pH and nutrients is highly dependent on tillage practices, soil texture, initial soil test levels, and lime and fertilizer placement strategies. Grove, Ward, and Weil (2007) provide an excellent practical reference on the implications of nutrient stratification in no-till systems (**go.osu.edu/stratification**).

Time of Year to Sample

Soil sampling after harvest in the fall or before planting in the spring is recommended. Fall sampling is preferred if lime applications are anticipated. Soil samples taken in the spring can produce different results than fall samples due to the effect of moisture on soil pH and nutrient levels, particularly K. For the purpose of tracking trends in soil nutrient levels, sample soil at the same time of the year the field was last sampled. Sampling during the growing season may give erroneous results due to the effect of crop uptake and other processes. (See **Murdock and Call 2006** for an example.)

Intervals Between Sampling

Most fields should be sampled every 3 to 4 years. Phosphorus, potassium, and pH are highly buffered in this region, so changes in soil test values from one year to the next are typically modest. Shorter sampling intervals (1 to 2 years) are recommended on low cation exchange capacity soils (CEC <5 meq/ 100 g) where rapid changes in fertility can occur, when high value crops are often in the crop rotation, or where soils are below or near critical levels.

Although not essential, another recommended practice is to sample at the same time within a crop rotation. For example, in a corn-soybean rotation, soil could be sampled every 4 years after the 2nd soybean harvest (corn => soybean => corn => soybean => ***soil sample***). Likewise, in a corn-soybean-small grain rotation, sampling could occur every 3 years (corn => soybean => ***soil sample*** => wheat, or corn => soybean => wheat => ***soil sample***).

Adaptive Nutrient Management

Soil testing provides the foundation of an adaptive nutrient management strategy when sample depth, time of year samples are collected, and intervals between sampling are all kept consistent. Maintaining consistency over many years enables a grower to monitor soil test trends and evaluate how management practices and nutrient management regimes are performing. This can be critical information to further refine a fertility program, control input costs, maximize farm profitability, and meet management goals. Most soil testing laboratories keep excellent electronic records and are happy to provide customers with soil test results from previously submitted samples upon request.

With increased adoption of grid sampling, many growers have questioned the validity of taking high density grid samples (1 acre) less frequently (every 5 or 8 years). An effective adaptive nutrient management framework requires accurate information on ***both*** a spatial and temporal scale. As the time between soil samplings increase, the ability to observe timely trends in soil test values is diminished, thus exposing a grower to increased risk of compromised nutrient management. Extremely high-density grids cannot serve as a substitute for trends over time. Hybrid approaches can be considered. For example, a grower can sample 2.5 acre grids every 3-4 years with every third soil sampling at 1-acre grids to get more precise information on spatial variability.

Sample Submission to a Soil Testing Laboratory

After soil samples have been collected, care should be taken to mix the sampled cores well and send them to a soil testing laboratory without delay. Sample contamination with dirty soil samplers, excessive heat, or prolonged storage in a bag can all compromise soil test results. Soil testing laboratories provide instructions, optional sample bags, and sample submission forms when submitting soils.

Soil Testing Procedures

The specific procedures used to test soils in Indiana, Michigan, and Ohio are described in NCR Publication 221, *Recommended Chemical Soil Test Procedures for the North Central Region,* written by the North Central Regional Committee on Soil Testing and Plant Analysis (NCERA-13), a team of soil fertility Land Grant University experts and available at **https://extension.missouri.edu/publications/sb1001.**

All soil nutrient test data in this publication are reported as parts per million (ppm) rather than pounds per acre (lb/acre). Preference is given to ppm since it represents what is actually measured in the laboratory. Soil test values are an index of availability and not the total amount of available nutrients in soil (a common misconception when reporting in lb/acre). To convert soil test data from lb/acre to ppm, divide the lb/acre value by 2.

SOIL pH AND LIME RECOMMENDATIONS

KEY CONCEPTS

- Soil pH remains one of the most important aspects of supplying adequate nutrition to crops.
- Soil pH should be kept between 6.0 and 6.8 for field crops.

Soil pH is one of the most important properties in determining the cycling and availability of soil nutrients. Soil testing regularly and applying lime to maintain recommended pH levels should be the first step growers take to assure crops have sufficient availability of nutrients. Soil pH should generally range from 6.0 to 6.8 in mineral soils, but different field crops require different soil pH levels for optimum performance (Table 1). The pH of organic soils (more than 20 percent organic matter) is generally maintained at much lower levels than the pH in mineral soils (less than 20 percent organic matter) to minimize the risk of micronutrient deficiencies. The topsoil in fields with acid subsoils should be maintained at higher pHs than those fields with neutral or alkaline subsoils to minimize chances for nutrient deficiencies associated with acid soil conditions.

Table 1. Recommended Soil pH Levels for Field Crops in the Tri-State Region

Crop	Mineral soils		Organic soils
	Subsoil pH < 6.0	Subsoil pH > 6.0	
	---------------------------------- Target pH	----------------------------------	
Grain crops (corn, soybean, small grains)	6.5	6.0	5.3
Alfalfa	6.8	6.5	5.3
Other forage legumes	6.8	6.0	5.3

Lime recommendations are dependent on the ability of the lime material to neutralize soil acidity. Liming materials vary, as do their ability to raise soil pH. Factors such as chemistry and purity of the material, fineness of grind, and moisture all influence how effective lime is at neutralizing acid. Indiana, Michigan, and Ohio each use different metrics to rate the neutralizing ability of lime; Indiana uses Relative Neutralizing Value (RNV), Michigan uses Neutralizing Value (NV), and Ohio uses Effective Neutralizing Power (ENP). As a result, Ohio liming recommendations differ from Indiana and Michigan recommendations. Liming recommendations also differ between mineral and organic soils.

Recommended Liming Rates

Table 2. Indiana and Michigan Liming Rates for Mineral Soils

Tons of material (assuming a neutralizing value of 90% for Michigan and a relative neutralizing value of 65 for Indiana) needed to raise the soil pH. Equations for this recommendation and those for liming to higher pH are in the footnote of this table.

Buffer pH[4]	Desired Soil pH		
	6.0[1]	6.5[2]	6.8[3]
	Tons of lime/ acre		
6.9	0.4	0.6	0.8
6.8	1.2	1.6	1.8
6.7	1.9	2.5	2.9
6.6	2.7	3.5	3.9
6.5	3.5	4.4	4.9
6.4	4.3	5.3	5.9
6.3	5.1	6.3	6.9
6.2	5.8	7.2	8.0
6.1	6.6	8.2	9.0
6.0	7.4	9.2	10.0

[1] For target pH of 6.0: lime recommendation = 54.2 – (0 .78 x LI)
[2] For target pH of 6.5: lime recommendation = 65.5 – (0 .94 x LI)
[3] For target pH of 6.8: lime reccommendation = 71.2 – (1 .02 x LI)
[4] To compute lime index (LI), multiply buffer pH by 10.

Table 3. Indiana and Michigan Liming Rates for Organic Soils

Tons of liming material (assuming a neutralizing value of 90% for Michigan and a relative neutralizing value of 65 for Indiana) needed to raise the soil pH to pH 5.3. Equations for this recommendation and those for liming to higher target pH are in the footnote of this table.

Soil pH	5.3
5.2	0.7
5.1	1.4
5.0	2.1
4.9	2.8
4.8	3.5
4.7	4.2
4.6	5.0
4.5	5.6
4.4	6.3
4.3	7.1

When the Target pH is 5.3 and the soil pH is < 5.3, then the LR = 37.6–(7.1 x soil pH).

When the Target pH is greater than 5.3 and the soil pH is < 5.3, then the LR = [37.6 x (7.1 x soil pH)] + [(target pH–5.3) x 5.0].

When the Target pH is greater than 5.3 and the soil pH is > 5.3, then the LR = [(target pH–soil pH) x 5.0].

Table 4. Tons of Liming Material (ENP of 2000 lbs/ton) Needed to Raise Soil pH to Desired Level for Ohio Mineral Soils

	Desired Soil pH		
	6.0[1]	6.5[2]	6.8[3]
Buffer pH[4]	Tons of lime/ acre		
6.8	0.7	0.8	0.9
6.7	1.1	1.4	1.5
6.6	1.6	1.9	2.2
6.5	2.0	2.5	2.9
6.4	2.5	3.1	3.6
6.3	3.0	3.6	4.3
6.2	3.4	4.2	4.9
6.1	3.9	4.7	5.6
6.0	4.3	5.3	6.3

[1]For desired pH of 6.0: lime recommendation = -4.5721*buffer pH + 31.7602
[2]For desired pH of 6.5: lime recommendation = -5.6399*buffer pH + 39.1496
[3]For desired pH of 6.8: lime recommendation = -6.7553*buffer pH + 46.8098
[4]To compute lime test index (LTI), multiply buffer pH by 10.

Table 5. Tons of Liming Material (ENP of 2000 lbs/ton) Needed to Raise the Soil pH to the Target Level of 5.3 for Ohio Organic Soils

Soil pH	Target pH of 5.3
5.2	0.1
5.1	0.5
5	0.8
4.9	1.3
4.8	1.7
4.7	2.1
4.6	2.5
4.5	2.9
4.4	3.3

More information on Ohio liming rates can be found in *Soil Acidity and Liming for Agronomic Production* (AGF-505) at **go.osu.edu/lime**.

Soil pH should be corrected by liming when the pH in the zone of sampling falls 0.2 to 0.3 pH units below the recommended level. Liming rate recommendations target the desired pH level, but the exact pH is not always achieved. Applications of less than 1 ton/acre often may not be practical. When the lime recommendation exceeds 4 tons/acre, applications should occur over multiple seasons, or at the least in split applications. Large applications of lime without thorough soil mixing may cause localized zones of high alkalinity, reducing the availability of some essential nutrients. A sound approach when the recommendation exceeds 4 tons/acre would be to apply 3-4 tons of lime with incorporation and then resample soil after 2 years to determine a second rate of application.

Surface applications of urea forms of N fertilizer are not recommended on fields where lime has been applied recently. The potential N loss by ammonia volatilization is high when urea reacts with unincorporated lime. Urea forms of N should not be surface applied within 4 months of the lime application. Injected or banded applications of N are preferred when lime is not incorporated.

Weakly Buffered Soils

Because sandy soils (<5 meq/100 g soil) are often weakly buffered, there is concern that SMP or Sikora buffer tests may underestimate lime requirements. These soils may have a pH below the desired range for optimum crop growth, but the buffer pH does not indicate a need for lime. This occurs because weakly buffered soils do not have sufficient capacity to lower the pH of the buffer solution. When this situation occurs, growers may want to consider using 1 ton of lime/acre when the soil pH is more than 0.3 to 0.5 pH units below the desired soil pH and 2 tons/acre when the soil pH is more than 0.6 pH units below the desired soil pH. Lime applications of more than 2 tons/acre are not recommended on sandy soils. More frequent applications of lime (annual or biennial) in sandy soils is typically recommended relative to heavier soils with greater buffering capacity.

NITROGEN

KEY CONCEPTS

- Optimizing nitrogen management is challenging and requires careful consideration of many factors.
- Nitrogen rate recommendations for corn are based on an economic model designed to maximize farmer profitability (maximum return to N (MRTN)) available at **cnrc.agron.iastate.edu.**
- Nitrogen recommendations for wheat have been updated and are similar to the original recommendations

The profitability of crop production is highly dependent on proper nitrogen (N) management, as N fertilizer represents a large fraction of the total cost of production. Unfortunately, N is the one of the most challenging nutrients to manage in field crops for a number of reasons: 1) many crops require large amounts of N for growth and development, 2) soil N availability is primarily governed by soil organic matter decomposition dynamics and 3) there are many pathways for N loss to the environment. Nitrogen availability and losses are strongly driven by temperature and rainfall and therefore, weather variability adds a large amount of uncertainty to N management.

A primary challenge for farmers is to provide a sufficient quantity of plant available nitrogen (nitrate and/or ammonium) to crops, while minimizing N loss to the environment. Nitrogen is a very dynamic nutrient and large amounts of available N can be lost to the atmosphere (gaseous losses via denitrification or volatilization) or with water draining out of the soil profile (leaching). Typically, the longer the time that soluble quantities of available N exist in the soil, the larger the risk of loss and reduced return on investment. Farmers have some control of N loss through best management practices of N fertilizer and soil, but uncontrollable factors of rainfall and temperature also drive N loss. Farmers can retain N in soil through best management practices, but uncontrollable factors of rainfall and temperature also drive N loss.

Nitrogen Best Management Practices

Best N fertilizer management strategies have been studied for decades and there is a great deal of valuable information available. Here we attempt to summarize some main points on when to apply (timing), how to apply (placement), what to apply (source), and how much to apply (rate).

Nitrogen Timing

There are inherent tradeoffs and risks with timing of N fertilizer application. Nitrogen should be applied to coincide with crop demand and uptake to the extent possible. Application of N fertilizer before planting simplifies management but poses a greater risk of N loss to the environment. Application of N fertilizer during the growing season minimizes N loss, but adds a new risk of not being able to apply N if soil conditions remain wet for too long. Growers need to balance these tradeoffs and adjust N management based on time, equipment constraints, soil texture, and weather patterns.

Fall applications of N are generally not recommended for corn as potential for N loss is high. If N fertilizer is applied in the fall for corn, the recommendation is to use anhydrous ammonia (AA), and delay application until the soil temperature is below 50 °F and continuing to decline. Addition of a nitrification inhibitor with AA reduces the risk of N loss from fall applications. Fall N application can be beneficial for fall-planted small grains to foster plant establishment and encourage tillering. A low rate (20-30 lb N/acre) at or before planting can be made with a commonly available N fertilizer source or using the ammonium present in phosphorus fertilizers.

Spring applications of N should strive to minimize the time between N application and N uptake. Fertilizers that do not initially contain nitrate, such as anhydrous ammonia, are preferred for earliest applications for corn. Small grains should receive urea ammonium nitrate (UAN) or urea before the first node visible (Feekes Growth Stage 6 or "jointing," typically mid- to late April), as this begins the period of rapid N uptake. Fertilizing N at Feekes Growth Stage 5 "Leaf Sheaths Strongly Erect," typically early to mid-April is recommended. Research has found little benefit to applying N fertilizers in the spring before this stage. Benefits from properly timed N applications are most likely to be realized with warmer temperatures that favor conversion of ammonium to nitrate or with greater rainfall to drive N losses.

For loam and clay soils, yield differences between preplant and side-dress applications to corn can vary depending on the year, soil texture and weather. Side-dress applications on sandy soils are usually more effective at reducing N loss and maintaining yield than preplant treatments containing a nitrification inhibitor. Multiple applications of N fertilizer during the growing season can be an effective method of reducing N losses on sandy soils with high potential for N loss through leaching. Irrigation systems equipped for fertigation are often used to apply N efficiently in irrigated crops.

Nitrogen Placement

The appropriate placement of N fertilizer depends on the type and timing of fertilizer applied. Anhydrous ammonia (AA) must be placed into the soil to capture ammonia. Urea containing fertilizers should be incorporated into the soil when temperatures are warm but can be left on the soil surface when cold. Banding urea-containing fertilizers and AA slows their conversion to nitrate which can reduce N loss. More details related to placement are discussed below for different N sources.

Nitrogen Sources

Nitrogen fertilizer source trials have consistently shown that numerous N fertilizer forms are effective in providing N nutrition to crops. Nitrogen fertilizers commonly used to supply the majority of the crop N requirement are shown in Table 6. The choice of fertilizer source should be based on application timing and placement, cost, availability, equipment considerations, and farmer preference.

Table 6. Common N Fertilizers Found in the Tri-State Region

Source	Advantages	Disadvantages
Anhydrous ammonia (82% N)	Most concentrated and often cheapest form of N, losses to enviroment can be low, preferred source for fall and early-spring applications	Hazardous to handle, needs to be injected properly and in right conditions or volatilization losses can be high
UAN (28 to 32% N)	Safe and easy to handle, can be mixed with other liquid fertilizers or herbicides	Surface applications can result in high volatilization losses, nitrate can be lost to leaching or denitrification
Urea (46% N)	Concentrated N form, safe and easy to handle	Surface applications can result in high volatilization losses

Anhydrous Ammonia. Sealing the application slot is critical to capturing ammonia (NH_3) during application. Sealing may be incomplete in soils that are excessively wet or dry and significant amounts of NH_3 can be lost to the air during application. In excessively dry soil even when the slot is sealed, NH_3 may diffuse through the soil to the air and be lost. In moist soils, NH_3 reacts with water to form ammonium (NH_4^+) which is retained by negative charges on organic matter and clay prior to conversion to nitrate.

Moisture and soil texture influence the size of the initial zone of ammonia retention, commonly referred to as the injection zone. The sandier and drier the soil the larger the injection zone. In the injection zone, AA results initially in an extremely high pH, and high concentrations of NH_3, nitrite, and salt. All these factors often cause a reduction in soil organisms that convert ammonium to nitrate (nitrification). The delay in nitrate formation is why AA is preferred for fall and early spring N applications. Over time, conditions in the injection zone equilibrate and soil organisms recolonize from the periphery and nitrate conversion resumes.

Under some circumstances if AA is placed too close to the seed row, the harsh conditions in the injection zone can inhibit seed germination and damage seedlings. Plant growth may be reduced by AA even if seedlings become established. If the location of the AA band and planted row cannot be controlled then deep placement, delayed planting, and diagonal application of AA are tactics used to avoid damaging the crop. Placement of AA no shallower than 7 inches deep is recommended. Although delay between AA application and planting reduces the risk of damage, even fall AA applications have been known to damage corn planted in the spring. Application of AA diagonal to the planted row avoids planting directly over the AA band so that the number of plants affected are limited to the intersection of the planted row and the AA application. Using real-time kinematic (RTK) positioning to keep AA bands at least 5–7 inches offset from the planted row generally avoids negative effects.

Urea and Urea-Containing Fertilizers. Urea is a 46% nitrogen (N) fertilizer that may be added to soils alone or in combination with other N fertilizers. The most common example is the liquid nitrogen fertilizer urea-ammonium nitrate (UAN) which is approximately half urea and half ammonium nitrate and ranges from 28% to 32% N by weight. Surface-applied urea fertilizers can result in some nitrogen being lost to the air as ammonia. Losses are more likely and greater in magnitude in no-till cropping systems and when temperatures are warm. Incorporate urea fertilizers into the soil whenever possible to reduce nitrogen losses. If surface applications must be made, band rather than broadcast the fertilizer to encourage movement into the soil and reduce ammonia loss. Using a strong urease inhibitor with broadcast applications of urea fertilizers and avoiding early-spring applications are strategies that slow N losses to the environment.

Secondary Nitrogen Sources. The most commonly utilized phosphorus (P) sources monoammonium and diammonium phosphate (MAP and DAP) are primarily used to supply P, but also contain N. MAP and DAP applications providing 100 pounds of P_2O_5 per acre supply approximately 21 and 39 pounds of N per acre, respectively. Ammonium sulfate (AS) is commonly used to supply sulfur (S) to crops, but also contains N. An application rate of 100 pounds of AS per acre provides 21 pounds of N per acre and 24 pounds of S per acre.

The N in MAP, DAP, or AS is utilized efficiently when applied to small grains in the fall. Despite all the N being in the ammonium form in these fertilizers, fall applications of MAP, DAP, and AS likely result in considerable N loss after conversion to nitrate, thus contributing little N to a spring-planted corn crop. When left on the soil surface under most conditions MAP, DAP, and AS do not result in ammonia loss to the air. MAP, DAP, and AS generate approximately twice the acidity as AA or urea-containing fertilizers. Therefore, liming requirements would increase substantially if these sources were used to supply the majority of the crop N requirement.

Nitrogen Rates for Corn

Indiana, Michigan, and Ohio corn N rate recommendations (and those of Iowa, Illinois, Minnesota, and Wisconsin) are based on extensive N response trials conducted over several years in each state. These trials have determined the N rate at which the last pound of added nitrogen fertilizer returns a yield increase large enough to pay for the cost of the additional fertilizer. This approach, called the maximum return to nitrogen (MRTN), is favored over trying to maximize corn yields because of the economic volatility in both corn grain and nitrogen fertilizer prices. The past 10 years (2010-2020) provides ample evidence of these price fluctuations.

Calculating the MRTN requires 4 inputs: 1) location, 2) the previous crop grown (corn; soybean or small grain), 3) price of nitrogen fertilizer, and 4) price expected per bushel of corn. When corn prices are low and/or fertilizer prices are high, nitrogen rates are reduced; when corn prices rise or N fertilizer prices fall, recommended nitrogen rates increase. The corn N rate recommendations do not account for N fertilizer application timing, but rather assumes best management practices are used. Therefore, the recommended N fertilizer rate represents the total N to be applied over the growing season, regardless of timing of N application. Application timing and placement practices that result in N loss will often require higher N rate applications to maximize profit. Soybean or crop rotation credits are based on field trials in each state and are already built into the recommendations.

The corn N rate calculator at **cnrc.agron.iastate.edu** provides both a single recommended N rate and also a *Profitable N Rate Range*, that is, a range of N fertilizer rates predicted to produce a profitable return. The simplicity of this tool helps to facilitate the ease of use across each state, but farmers are encouraged to use other available information such as weather, soil type, pre-sidedress N tests, management history and previous performance to help refine a localized N rate for any given field. Emerging technologies such as crop sensors and weather-driven soil-crop models may also be considered as information to guide N management decisions.

When N is supplied through manure or biosolid applications, the recommended economic N rate needs some additional consideration. Nitrogen from manure or biosolids is considered by some to be a “zero cost” nutrient that inflates the recommended N rate produced by the model. This is a misrepresentation of the tool which has been parameterized with mineral N fertilizers. Applying manure at a rate to meet the full N requirement for a crop typically supplies P_2O_5 that significantly exceeds crop requirements. If manure can be applied in excess of crop P_2O_5 needs, a more appropriate nutrient management approach would be to estimate first year available N with a manure analysis and then apply at a rate using current market prices for commercial fertilizer.

Nitrogen rate recommendations for corn in the tri-state region are based on each individual state and the N rate trials conducted in that state. The N rate calculator is housed on an Iowa State University website (**cnrc.agron.iastate.edu**) that collects data from each respective state on a yearly basis and is updated annually. The rationale of this approach and more information can be found at **extension.iastate.edu/Publications/PM2015.pdf**.

Indiana Corn N Rates

Economically optimal N rate recommendations for corn following soybean differ by region in Indiana. In addition to the calculator website given above, specific recommendations and additional guidelines for Indiana are at **agry.purdue.edu/ext/corn/news/timeless/nitrogenmgmt.pdf**.

Optimal rates for corn following corn are expected to be 40 to 50 pounds per acre greater than rates recommended for corn following soybean based on paired trials conducted for several years. For either crop rotation, N rate recommendations were based on efficient application timing and placement, usually side-dress UAN. If choosing inefficient practices, such as fall or early-spring applied N, optimal rates will be higher than those given.

Michigan Corn N Rates

Michigan corn N rate model provides an N rate and profitable range adjustable by growers based upon crop rotation, soil productivity potential, current price of N fertilizer and corn grain, and field history. It is important to remember that the MRTN model is a pre-season general N recommendation model that provides corn N response data that have proven profitable over many years and accounts for both optimal and sub-optimal growing seasons. The model does not account for individual site variability or variable in-season weather events (e.g., large individual rainfall events or excessive rainfall following early N application) which may affect corn N response and require adjustments to in-season N applications. Corn N rates listed near the 0.05 price ratio will be near maximum production levels but N rates for greater price ratios may result in a greater economic return to the grower.

Table 7. Suggested N Rates for Corn Grain Grown in Michigan

Please see **soil.msu.edu** for recent updates on suggested N rates as data are updated biennially.

Soil Productivity Potential[1]	Previous Crop	N: Corn Price Ratio			
		0.05	0.10	0.15	0.20
		Suggested N Rate (lb N/acre)			
High/Very High	Corn	195 180–210[2]	170 160–185	155 145–170	145 135–160
	Soybeans[3] and small grains[4]	170 155–185	145 135–160	130 120–145	120 110–135
Medium/Low	Corn	165 150–180	145 135–160	135 125–150	120 110–135
	Soybeans[3] and small grains[4]	140 125–155	120 110–135	110 100–125	100 90–115
Loamy Sands and Sands (CEC < 8.0)	Irrigated—all crops	215 200–230	195 180–210	180 165–195	170 155–185

[1] **Low**: average yield = < 135 bu/A; **Medium**: average yield = 136 to 165 bu/A; **High**: average yield = 166 to 195 bu/A; **Very High** = more than 196 bu/A; (average yield is the five-year running average disregarding unusual highs and lows).
[2] Range approximates + $1 of the maximum return to N (MRTN) rate.
[3] When the previous crop is soybean, the nitrogen credit is built into the recommendation. Do not take any additional nitrogen credit. Nitrogen credits for previously applied manure need to be subtracted from the N recommendations.
[4] Refers to small grains interseeded with leguminous cover crop species. Small grains not interseeded with leguminous cover crop species should default to previous crop corn.

Ohio Corn N Rates

Ohio corn N rates are based on 281 total trials (228 trials after soybean, 53 after corn). The recommended nitrogen rates can be found in Table 8-9.

Table 8. Ohio Recommended Nitrogen Rates (lb nitrogen/acre) for Corn Following Soybean Based on Price of Corn Grain and Nitrogen Fertilizer

	Price of Nitrogen Fertilizer ($/ lb)				
Price/ bushel corn	$0.30	$0.35	$0.40	$0.45	$0.50
$3.25	185	176	168	162	155
$3.50	187	180	173	166	160
$3.75	191	184	176	170	164
$4.00	195	186	180	174	168
$4.25	199	190	184	177	171
$4.50	200	193	185	180	175

Table 9. Ohio Recommended Nitrogen Rates (lb nitrogen/acre) for Corn Following Corn Based on Price of Corn Grain and Nitrogen Fertilizer

	Price of Nitrogen Fertilizer ($/ lb)				
Price/ bushel corn	$0.30	$0.35	$0.40	$0.45	$0.50
$3.25	193	185	177	170	164
$3.50	197	189	182	175	168
$3.75	201	193	185	179	172
$4.00	205	196	189	182	176
$4.25	208	200	192	186	180
$4.50	211	203	195	189	183

Nitrogen Rates for Soft Winter Wheat

When developing an optimal N fertilizer rate for soft winter wheat, soil texture, organic matter, residual manure or fertilizer contributions, crop rotation, planting date, and yield goal should all be considered. **The nitrogen recommendations provided here for wheat should be considered a starting point with adjustments made based on these factors and in-season growth observations.**

Sandier soil may require greater N rates than loamy or clayey soils due to lower water-holding capacity and lower organic matter levels. Drainage impacts wheat growth as soils can be waterlogged in the spring during critical periods of growth and development, thus reducing yield goals. Soils with insufficient infiltration rates or inadequate tile drainage may lose a significant portion of applied N due to denitrification. Crop rotation may impact yield potential through C:N ratios of crop residues and soil residual N following the previous crop. Perhaps most importantly, a timely planted winter wheat crop will enable sufficient development and tillering in the autumn, potentially allowing for reduced N rates than those recommended.

The following N rate recommendation for soft winter wheat (Table 10) assume that the crop is planted during the optimum planting period on mineral soils with 1 to 5 percent organic matter and either good natural or improved drainage, and that proper cultural practices are utilized. Soils with lower organic matter, such as sands, may require more N. To prevent lodging on organic soils (greater than 20% organic matter) reduce the N rate by 30 to 50 lb N per acre. Consider a yield goal that is achievable 50% of the time. Over application of N from unrealistically high yield goals will promote lodging and disease development and increase the risk of surface and groundwater contamination. No N credits are given for the previous crop. The N rate recommended in Table 10 is a total rate, so spring-applied N rates should account for what was already applied in the fall.

Table 10. Total (Fall + Spring) Nitrogen Recommendations for Soft Winter Wheat

Wheat Yield Goal (bushel/acre)				
60	70	80	90	100
lb N/acre				
70	80	90	110	120

Recommendations based on the following equation: N Rate (lb N/acre) = (1.33 x Yield Potential)–13.

Timing of N Applications. Applying starter N up to 25 lbs N/acre can promote autumn growth and tillering with timely planted winter wheat. However, excessive autumn growth can lead to prolific tillering and biomass, resulting in disease and lodging issues. Pre-plant soil-NO_3 values less than 5 ppm have demonstrated the greatest benefit to autumn-applied starter fertilizer. Spring N fertilizer should be applied between green-up (Feekes 3-4) and the beginning of stem elongation or jointing (Feekes 5-6). Nitrogen applications prior to Feekes 4-5 may assist with some spring tiller development but often result in greater risks for N loss. Research has not shown any clear advantage to spring split-applied N on winter wheat. Above normal April-May rainfall may favor split-applied spring N due to leaching and denitrification N losses, but below normal April-May rainfall often creates difficulties with getting the spring split-applied N into the plant. Nitrogen fertilization for grain protein is not common practice in this region but may change in the future. Nitrogen applied to increase grain protein is required later in wheat growth and development than N utilized for grain yield, which may affect N application timings.

Nitrogen Source and Stabilizers. Urea and urea-ammonium nitrate (UAN) are the most common N sources used for wheat. Other N sources include ammonium sulfate, ammonium thiosulfate, diammonium phosphate, monoammoniun phosphate, ESN, and manure. Generally, for agronomic production, it does not matter which source is used. Often, the source selected is based on cost, product availability and application equipment. However, early applications and wet years, the source with the least potential for N loss may be the better choice. Generally, UAN has the greatest potential for N loss; ammonium sulfate the least, and urea intermediate potential. The source of N is less critical as wheat approaches Feekes 6.

Wheat generally does not benefit from a nitrification inhibitor since temperatures are relatively cool at application time and the application is made to a growing crop. This is especially true as the crop approaches Feekes 6. However, urea-base products may benefit from a urease inhibitor if conditions for volatilization exist for several days after application, including an extended dry period with warm drying temperatures (above 70°F) and evaporating winds. Urea-based fertilizers need at least a half inch rain within 48 hours after application to minimize volatilization losses unless temperatures remain relatively cool. The urease inhibitor will prevent volatilization for 10 to 14 days with the anticipation of a significant rainfall event during this time.

PHOSPHORUS AND POTASSIUM

KEY CONCEPTS

- The framework for P and K fertilizer management remains a build and maintain approach. Minor tweaks to the original framework have been made.
- Soil test levels determine phosphorus and potassium fertilizer application rates and timing.
- Mehlich-3 (M3) is now the default soil extractant, replacing Bray P1 for phosphorus and ammonium acetate for base cations.
- Critical levels are largely consistent with the original recommendations, but now in Mehlich-3.
- Crop removal rates were updated with current grain P and K concentrations.
- A typical corn-soybean rotation yielding 180 bushel per acre corn and 60 bushel per acre soybean removes 100–120 pounds per acre of both P_2O_5 and K_2O. This is equivalent to 210 pounds MAP (11-52-0)/acre, 240 pounds DAP (18-46-0)/acre, 180 pounds potash (0-0-60)/acre.

Build-up and Maintenance Framework

The tri-state fertilizer recommendations for P and K are based on a build-up and maintenance approach. This framework strives to build soil test levels up to and beyond a critical level, then maintain these levels over time. The critical level is a key component to this framework. Soil test levels above the critical level are "optimal," unlikely to be responsive to fertilizer application. Soil test levels below the critical level are "deficient," more likely to have a yield response to fertilizer application. The critical level has been determined empirically from the results of hundreds of field trials across the tri-state region.

The original tri-state recommendations had three distinct recommendations based on soil test values: 1) build-up, 2) maintenance and 3) drawdown (Figure 1). Overall, as soil test levels increase, recommended fertilizer rates decrease. At low soil test levels (below the critical level) the recommendations are in the build-up phase, where fertilizer rates include crop removal plus additional fertilizer to build soil test levels to the critical level within 4 years. When soil test levels are between the critical level and the maintenance limit, recommendations are designed to keep soil test levels in the maintenance range. Here fertilizer rates approximate crop removal, that is, nutrients removed in the harvested grain or forage. As soil test levels extend above the maintenance limit, the recommendations are in the drawdown phase. In the drawdown phase, fertilizer rates are less than crop removal so that soil test levels decrease over time to the maintenance limit. The drawdown phase provided an additional buffer beyond the maintenance range, which is already, as the original tri-state recommendations stated, a "safeguard against sampling or analytical variation." No fertilizer is recommended when soil test levels are above the drawdown phase.

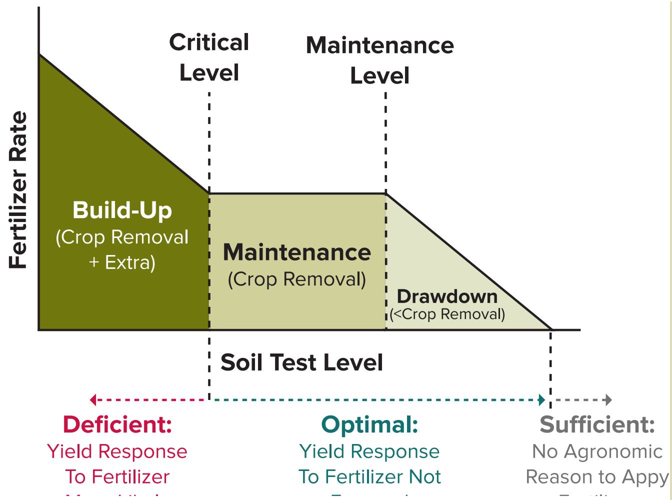

Figure 1. The Original Tri-State Fertilizer Recommendation Framework

The new tri-state fertilizer recommendations use a similar but simplified framework (Figure 2). The major changes to the new framework include 1) providing the option where the build-up phase is recommended but not required and 2) eliminating the drawdown phase. These changes are intended to simplify recommendations and provide farmers with greater flexibility in managing nutrients.

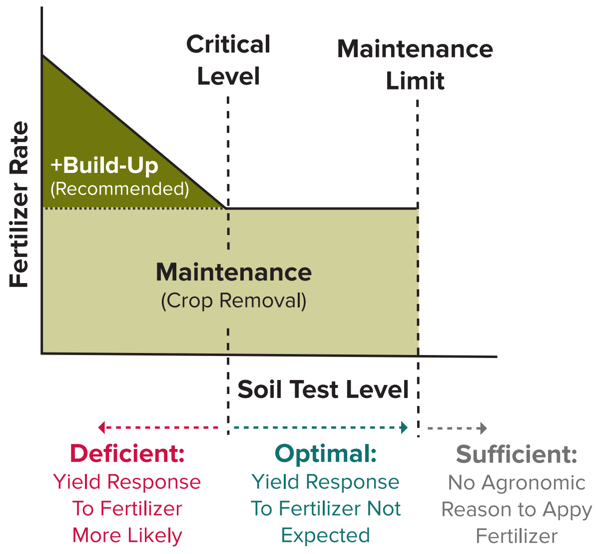

Figure 2. The New Tri-State Fertilizer Recommendation Framework

Making the build-up rate recommended, but not required, acknowledges the fact that the build-up rate may not be the most economical rate for a single season. A significant percentage of cropped acres in the tri-state region is rented under various land contracts often on a year to year basis. The uncertainty of future rental agreements, along with fluctuations in fertilizer and grain prices complicate decisions regarding when and to what degree to invest in building soil fertility. Providing farmers with the option of either investing in building soil test levels or waiting until future years gives them additional tools to run their farming operation as a profitable business.

However, farmers should recognize that as soil test levels decline below the critical level, the likelihood of reduced yield increases, and the amount of fertilizer needed to optimize profit also increases. A recent soybean trial in Indiana demonstrates how simply applying crop removal at low soil test K levels is insufficient to optimize profit. Fertilizing K_2O at removal rates in this field with very low soil test K levels (20-25 ppm, cation exchange capacity (CEC) <6 meq/100g) resulted in a 15 bushel/acre reduction in yield and a $100/acre decrease in profit, relative to following the tri-state build-up equation.

In low testing soils, P and K fixation can increase dramatically, necessitating a higher rate of fertilizer to increase soil test levels. For example, Thom and Dollaride (2002) fertilized 16 soils in Kentucky with different initial soil test P levels. They found that soils with lower STP levels required much more P_2O_5 fertilizer to raise STP levels, compared to high STP soils which took little fertilizer to raise STP levels (Figure 3). This demonstrates that P fixation rates can be high in low testing soils and therefore fertilizer application rates that only match crop removal and do not attempt to build soil test levels, pose an additional risk of yield loss.

Rates of P and K fixation vary by soil texture, environment, and management history, so farmers should recognize the potential tradeoffs of not attempting to build up soil test levels. Note that this modification should also not be misconstrued as a greenlight to neglect soil fertility levels in rented fields, failing to apply sufficient fertilizer and allowing soil test levels to drop to extremely low levels. Building-up and maintaining soil test levels in the long-term remains an unchanged recommendation in this update.

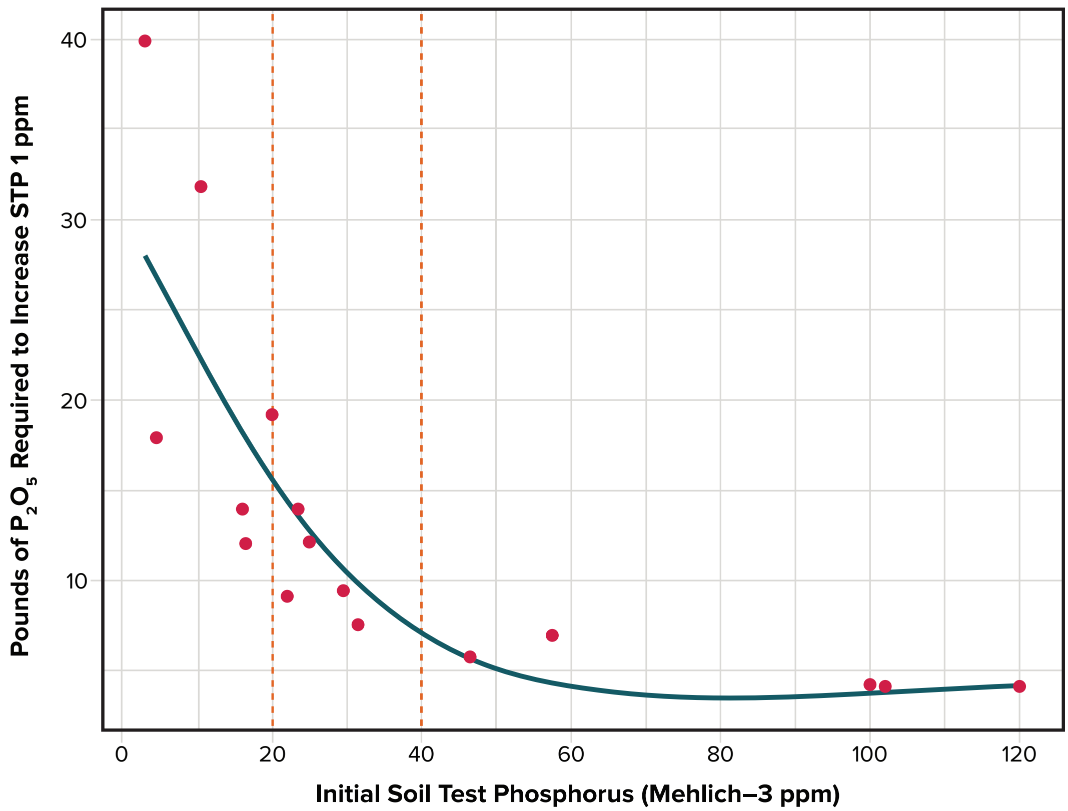

Figure 3. Pounds of P_2O_5 fertilizer required to increase soil test phosphorus levels by 1 part per million in 16 Kentucky soils (Adapted from Thom and Dollarhide, 2002). Red vertical, dashed lines indicate the tri-state maintenance range for corn and soybean.

The second change to the framework is to eliminate the drawdown phase. The uncertainty of soil test levels has generally decreased over the past several decades because 1) more fields are being tested on a regular basis than ever before, 2) soil sampling densities within fields have increased over time as more farmers move to grid and zone sampling and variable rate technologies, 3) commercial soil testing laboratories in the region generally do an outstanding job of generating precise and accurate soil test numbers, and 4) most farmers are applying fertilizer more frequently than every 4 years. The original 1995 drawdown phase has often been misinterpreted to mean that some fertilizer (lower than crop removal) is needed if soil test levels are anywhere above the maintenance limit. Eliminating the drawdown phase for the 2020 update simplifies the recommendations and provides greater clarity, while still maintaining the safeguard against yield reductions from insufficient crop nutrition.

New fertilizer rate and timing specifics are summarized in Table 11.

Table 11. Overview of Build-up and Maintenance Phases and Associated Fertilizer Recommendations

Assessment	Phase	Rate to Apply	When to Apply
Deficient	Build-Up (below critical level)	Crop removal + additional fertilizer to build soil test levels	Immediately, before next crop
Optimal	Maintenance (above critical level, below maintenance limit)	Approximate crop removal	Sometime within the rotation
Sufficient	Above maintenance	Do not fertilize	Do not fertilize

Under the new framework, the default recommendation remains as build-up (crop removal plus additional fertilizer to build soil test levels) **if soils test below the critical level or are "deficient**." The recommendations are designed to supply additional nutrients and to raise the soil test to the critical level over a four-year period. For deficient soils, recommended rates of fertilizer should be applied annually. Placement and timing techniques to enhance nutrient availability, such as sub-surface banding, or spring application may also be beneficial on nutrient-deficient soils. Applying 25 to 50 percent of the recommended fertilizer in a band to enhance early growth should be considered.

When soils are in the maintenance range (above the critical level, less than the maintenance limit) they are "optimal," that is, capable of supplying nutrients required by the crop. No response to fertilizer is expected. Fertilizer should be applied at some point within the rotation to replace the nutrients removed in the harvested crop each year. Fertilizer applications can be made annually or every other year. In some cases, fertilizer may be applied every 3 or 4 years. Soil testing should be used to assess soil test levels and fertilizer requirements no less than every 4 years. **Soils above the maintenance limit are "sufficient."** There is no agronomic reason to apply fertilizer when soil tests are in this range.

Phosphorus and Potassium Fertilizer Recommendation Overview

P and K Critical Levels

One of the most important components of P and K management is knowing when a crop will need P or K fertilizer. The critical soil test level provides this information. Over the past 6 years, more than 200 on-farm P and K trials have been conducted in corn, soybean and wheat in the tri-state region. These trials were all randomized and replicated and were typically in large strips. In addition, several long-term P and K trials have been conducted on university farms. Soil test levels were measured and related to crop yields to answer the basic question of "Did P or K fertilizer increase grain yield at this given soil test level?" **Collectively, our results demonstrate that when soil test levels are above the critical level and therefore in the maintenance range or above, the chance of a yield response to P or K fertilizer is highly unlikely.**

Our results provide no evidence the original tri-state fertilizer recommendations critical levels are too low or need to be modified. This work confirms that despite new genetics, tillage regimes, plant populations, and other advancements in agronomy, the stated critical levels still serve as a guideline for productive and profitable field crop production in this region. Critical levels for soil test P and K are provided in Table 12.

New critical levels are now reported using Mehlich-3 as the default extractant for soil test P and K (see below for more information).

Table 12. Recommended Mehlich-3 Soil Test Phosphorus and Potassium Levels (Critical Level and Maintenance Limit) for Field Crops in the Tri-State Region

Crop	Mehlich-3 Phosphorus Maintenance Range	Mehlich-3 Potassium Maintenance Range	
		Sandy soils (CEC <5 meq/ 100g)	Loam and clay soils (CEC >5 meq/ 100g)
Corn (grain or forage), Soybean	20–40 ppm	100–130 ppm	120–170 ppm
Wheat, Alfalfa	30–50 ppm	100–130 ppm	120–170 ppm

The critical levels for soil test phosphorus have been modified to use Mehlich-3P but are largely consistent with the original tri-state recommendations. Note that wheat and alfalfa have historically had higher soil testing levels than corn and soybean. Recent evaluations have confirmed the need for higher STP levels with wheat. (Alfalfa was not evaluated but is assumed to be consistent with wheat.) For fields with corn and soybean only (continuously or in rotation), the recommended critical level is 20 ppm Mehlich-3 P. For fields that include a small grain and/or alfalfa in the rotation with corn and soybean, the recommendation is to either 1) increase the critical level to 30 ppm Mehlich-3 P, or 2) to keep the critical level at 20 ppm and apply an annual maintenance rate of P_2O_5 when the soil test level is below 30 ppm Mehlich-3 P. In other words, apply P fertilizer in the fall before planting a small grain, or apply P fertilizer annually with alfalfa if soil test levels are below 30 ppm Mehlich-3 P.

Potassium critical levels have been modified more substantially, primarily simplified. The original tri-state potassium recommendations were based on cation exchange capacity (CEC) levels of the soil. As CEC increased, so did the recommended critical level and the K fertilizer rate in build-up range. Tables in the original recommendations identified four CEC levels (5, 10, 20, 30 meq/ 100 g) and potassium recommendations increased with each level. The results of both our on-farm and on-station trials provide no evidence to justify a successive increase in potassium critical level based on CEC to this level of detail. Furthermore, no other states in the Corn Belt have potassium recommendations scaled continuously by CEC. It is well-established, however, that low CEC sandy soils (<5 meq/100 g) are not capable of supporting the same Mehlich-3 K levels as a silt loam or clay soil. As a result, and consistent with the original tri-state recommendations, the maintenance range (critical level and maintenance limit) is lower for sandy soils than loam and clay soils (Table 12). The new recommendations classify all loam and clay soils together (CEC >5 meq/100 g) into a consistent and simplified recommendation.

Simply stated, the fertilizer recommendations are designed to keep soils in the maintenance range (above the critical level, but below the maintenance limit). When soil test levels are in the maintenance range, farmers can use the fertilizer rates in Tables 13 and 14. More details on equations are provided in Table 17.

Table 13. Recommended Fertilizer Rate Based on Expected Grain Yields When Soil Test P and K Are in the Maintenance Range

Potassium recommendations differ by state.

Crop	Yield (bushel/acre)	Recommended Fertilizer Rate		
		IN, MI, OH	IN & OH	MI
		lb P_2O_5/ acre	lb K_2O/ acre	lb K_2O/ acre
Corn	150	55	50	30
	200	70	60	40
	250	90	70	50
	300	105	80	60
Soybean	30	25	55	35
	50	40	80	60
	70	55	100	80
	90	70	125	105
Wheat	60	30	35	15
	90	45	45	25
	120	60	50	30
	150	75	60	40

Table 14. Recommended Fertilizer Rate Based on Expected Forage Biomass Yields When Soil Test P and K Are in the Maintenance Range

Crop	Yield (tons/acre)	Recommended Fertilizer Rate	
		lb P_2O_5/ acre	lb K_2O/ acre
Corn Silage	20	60	165
	24	75	195
	28	85	225
	32	100	255
Alfalfa	2	25	120
	4	50	215
	6	70	300
	8	95	300

Phosphorus and Potassium Fertilizer Recommendation Details

Fertilizer recommendations often encompass all aspects of the 4R framework, including fertilizer rate, fertilizer source, and timing and placement of fertilizer applications. The focus of the tri-state P and K fertilizer recommendations is on fertilizer rate and assumes a typical broadcast application. Fertilizer timing is also important and guided by soil test levels (Table 11).

Different combinations of 4R practices may enable farmers to further refine and lower rates of fertilizer in their operation. Banding fertilizer, conservation tillage, increasing crop diversity through cash or cover crops, using manure or organic amendments, and improving soil health are all ways to potentially lower fertilizer requirements and input costs.

Fertilizer sources and placement options are important considerations but can vary by farming operation and be dictated by fertilizer availability and application equipment. Specific considerations on source and placement options with starter fertilizer are discussed below.

P and K Fertilizer Sources

There are many suitable P and K fertilizer sources that are effective at providing available nutrients to growing crops. Commercial granular and liquid fertilizers have different attributes than manure or organic amendments, but both serve as important sources for crop nutrition. The recommendations provided here can be applied to either commercial fertilizers or manures. If using manures as the primary source of fertilizers, manure analyses are recommended to guide application rates. More information can be found at **go.osu.edu/manure-info.**

Starter P and K Fertilizer

When crops are establishing, soil test levels low, soil surface residues high, and soil temperatures cold, starter fertilizers become very important for optimum plant growth. In many instances, applying some or all the fertilizer needed with the planter improves fertilizer efficiency. If starter fertilizer is used, apply 20 to 40 lb of N, P_2O_5 and/or K_2O per acre in a band 2 inches to the side and 2 inches below the seed. The total amount of salts (N + K_2O) should not exceed 100 lb per acre for corn or 70 lb per acre for 30-inch-row soybeans. Nitrogen and P are the most important major nutrients for early plant growth, particularly in no-till production systems. It is not necessary to include K in the starter fertilizer unless the soil test K levels are very low (less than 70 ppm K).

The general practice of applying fertilizer in contact with seed is typically not recommended. Band placement to the side and below the seed is usually superior to any other placement. If placing fertilizer in-furrow with the seed, caution should be used to prevent seed or seedling injury from fertilizer salts. For corn, do not place more than 8 lb N + K_2O per acre in contact with the seed on heavier soils and decrease rates in soils with lower CECs. No more than 5 lb N + K_2O per acre should be applied with corn seed on sandy soils (<5 meq/100 g). Soybean seed is very sensitive to salt injury. Consequently, all fertilizer for drilled soybeans should be broadcast before planting. Starter fertilizer used with soybean should be a low-salt product. For small grain seedings, do not drill more than 100 lb of plant nutrients (N + P_2O_5 + K_2O) per acre in contact with the seed. Do not apply more than 10 lb N per acre as urea in contact with small grain seed. Young germinating seeds and seedlings are very sensitive to salt. Dry soil conditions will increase the likelihood of seed injury.

When seeding forage legumes, do not place more than 100 lb P_2O_5 and 50 lb K_2O per acre in contact with the seed. If the fertilizer is placed 1 to 1.5 inches below the seed, the seeding time fertilizer may include all the P and up to 150 lb K_2O per acre. Broadcast and incorporate any additional fertilizer requirements before seeding. For established legumes, all fertilizer requirements should be top-dressed in the late summer or early fall before plants go dormant or after the first cutting in the spring.

Phosphorus Placement to Minimize Losses

Subsurface placement of phosphorus fertilizer is recommended wherever possible, to minimize risk of dissolved phosphorus losses through water. Since 1995, conservation tillage systems have increased across the tri-state region, minimizing soil disturbance and leaving more residue on the soil surface. These practices are good from a soil conservation perspective, but considerable scientific evidence shows that phosphorus fertilizer or manure applied to the surface of fields and not incorporated poses a more substantial risk of dissolved phosphorus loss. Depending on the tillage system, light incorporation, strip tillage, or banding are preferred methods of phosphorus placement relative to broadcast and unincorporated. Developing and optimizing economical P fertilizer placement technologies remains an active area of research in the region.

Soil Test Extractants: Mehlich-3 as the New Default Extractant

Phosphorus (P) and potassium (K) recommendations are based on soil test levels for P and K. The original tri-state fertilizer recommendations were based on the Bray-P1 extractant for P and the ammonium acetate extractant for K, Ca, and Mg. This required two different extractions to be independently analyzed to estimate plant-available P, K, Ca, and Mg. Today, however, nearly all commercial soil testing labs in this region use Mehlich-3 as the primary soil test extractant. In response, one major revision in this update is to move to the Mehlich-3 soil test extractant as the new default for P and K.

For these revised recommendations, Mehlich-3 P and K recommendations are presented in the main tables, with equivalent Bray P1 and ammonium acetate recommendations presented in the Appendix. **Mehlich-3 P values are considered 35% higher than Bray P values, and Mehlich-3 K values are considered 14% higher than ammonium acetate values.** Moving to Mehlich-3 as the default extractant is ultimately intended to reduce confusion about soil test extractants and lead to more unified recommendations.

The change to Mehlich-3 can have implications for cation exchange capacity (CEC) values returned on soil tests. Soil testing labs in the region commonly calculate CEC values by summing the base cations (Ca, Mg, K) and exchangeable acidity. Some labs in the region currently calculate CEC based on ammonium acetate values converted from a Mehlich-3 extractant. Since Mehlich-3 extracts proportionally more Ca, Mg and K than ammonium acetate, switching extractants may increase CEC values on soil tests by 15% or more. Any changes observed on soil test reports will depend on how individual soil test laboratories adopt to and modify their calculations. More detail on switching to Mehlich-3 can be found in the fact sheet *Converting Between Mehlich-3, Bray P, and Ammonium Acetate Soil Test Values* at **go.osu.edu/mehlich** and in the article *Calibration of Mehlich-3 with Bray P1 and Ammonium Acetate in the Tri-State Region of Ohio, Indiana, and Michigan* (**Culman et al., 2020**).

P and K Crop Nutrient Removal Rates

When soils are above the critical level, fertilizer recommendations approximate crop nutrient removal rates. Therefore, knowing the nutrient concentration in grain is a key piece to developing fertilizer recommendations. Over the past six years, thousands of corn, soybean, and wheat grain samples have been analyzed for nutrient content. Grain nutrient concentrations were multiplied by grain yield to get total nutrient removal rates. Table 15 shows updated grain nutrient removal rates. Nutrient removal rates of forage crops (corn silage and alfalfa) have not been comprehensively measured as part of this update, but contemporary reference values are being used here (Table 16).

Table 15. Nutrients Removed in Harvested Grain

Crop	Grain Nutrient Removal Rate	
	lb P_2O_5/ bushel	lb K_2O/ bushel
Corn	0.35	0.20
Soybean	0.80	1.15
Wheat	0.50	0.25

Table 16. Nutrients Removed in Harvested Forage Biomass

Crop	Forage Nutrient Removal Rate	
	lb P_2O_5/ ton	lb K_2O/ ton
Wheat Straw	3.7	29
Corn silage	3.1	7.3
Alfalfa	12.0	49

Source: International Plant Nutrition Institute (2014), dry matter basis: 100% for wheat straw and alfalfa; 35% for corn silage (0% moisture for wheat straw, 65% moisture for corn silage).

New nutrient removal rates were compared to previously published rates from the original tri-state fertilizer recommendations to look at basic trends in grain nutrients over the past several decades. The new data show that plant breeding over the past several decades have resulted in more efficient crops. Corn, soybean and wheat now yield more grain with less nutrient removed per bushel of grain relative to 20 or 30 years ago. For phosphorus, there was a 5%, 1% and 22 % reduction in pounds of P_2O_5 per bushel of corn, soybean and wheat grain, respectively. For potassium, there was a 26%, 19%, and 35% reduction in pounds of K_2O per bushel of corn, soybean and wheat grain, respectively. Reduced grain nutrient concentrations have also been recently reported in other states (Mallarino et al., 2013; Villamil et al., 2019). Reduced nutrient removal rates per bushel of grain ultimately translate into lower rates of fertilizer needed to replace the nutrients exported in each bushel. This provides an important opportunity for farmers to save on fertilizer input costs per bushel harvested. More detail on grain nutrient removal rates can be found in the fact sheet, *Nutrients Removed with Harvested Corn, Soybean, and Wheat Grain in Ohio* (**go.osu.edu/grain**). Note that soybean and wheat values reported in Table 15 have been rounded up 0.01 lb/bushel in some cases to make more memorable and are the final values used to calculate fertilizer recommendations here.

P and K Soil Test Trends

Three long-term corn-soybean trials in Ohio have shown soil test level trends over time. The soils were fertilized at three different rates: 1) not-fertilized (0), 2) fertilized at grain nutrient removal rates (1x) and 3) fertilized at two to three times the grain nutrient removal rates (2-3x). Soil test P levels over time generally drop without fertilization, are maintained when fertilized at removal rates, and build with 2 to 3x fertilization (Figure 4).

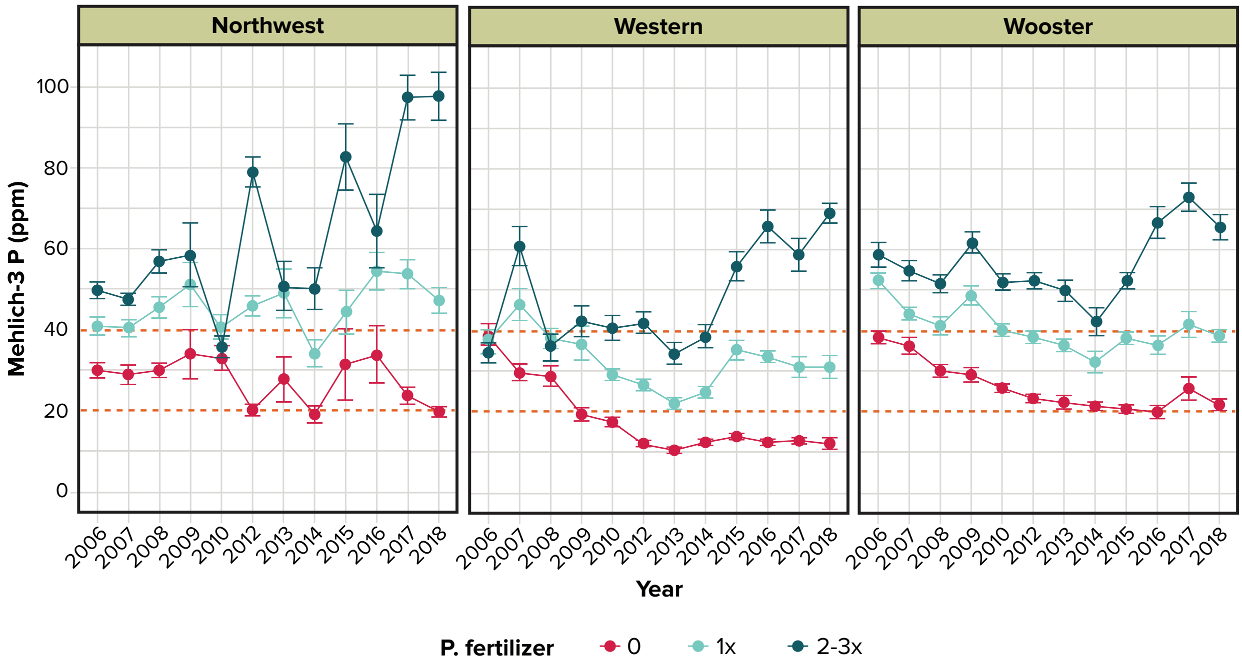

Figure 4. Soil test phosphorus trends over years of a corn-soybean rotation in three Ohio farms with three fertilizer rates: not-fertilized (0), fertilized at grain nutrient removal rates (1x), and fertilized at twice to three times the grain nutrient removal rates (2-3x). The first 9 years was fertilized at twice the removal rate (2x) and starting in 2016 this rate was increased to 3x.

Similar to phosphorus, soil test potassium levels show clear differences based on fertilizer treatments (Figure 5). However, unlike P, soil test K levels when fertilized at the nutrient removal rate (1x) failed to maintain soil test levels. Likewise, fertilization at twice to three times the removal rate (2-3x) failed to substantially build soil test levels. The original tri-state recommendations recognized that soil K fixation rates were higher than soil P fixation, as maintenance recommendations for P are simply crop removal, while K are crop removal plus an additional 20 lbs of K_2O fertilizer per acre. Based on these results, it appears the additional 20 lbs of K_2O fertilizer per acre is likely insufficient to maintain soil test levels.

Many crop consultants and agricultural industry professionals have corroborated the difficulty in maintaining soil test K levels on certain soil types. This is an area where more research is needed to fully understand these dynamics. Some of the uncertainty in K soil test levels has been acknowledged by widening the revised maintenance ranges for K to provide producers with more flexibility in managing K (Table 12). Practitioners are encouraged to soil test regularly to monitor soil test K levels and modify recommendations on a per field basis to maintain soil test K levels over time. More detail on soil test trends can be found in Fulford and Culman, 2018.

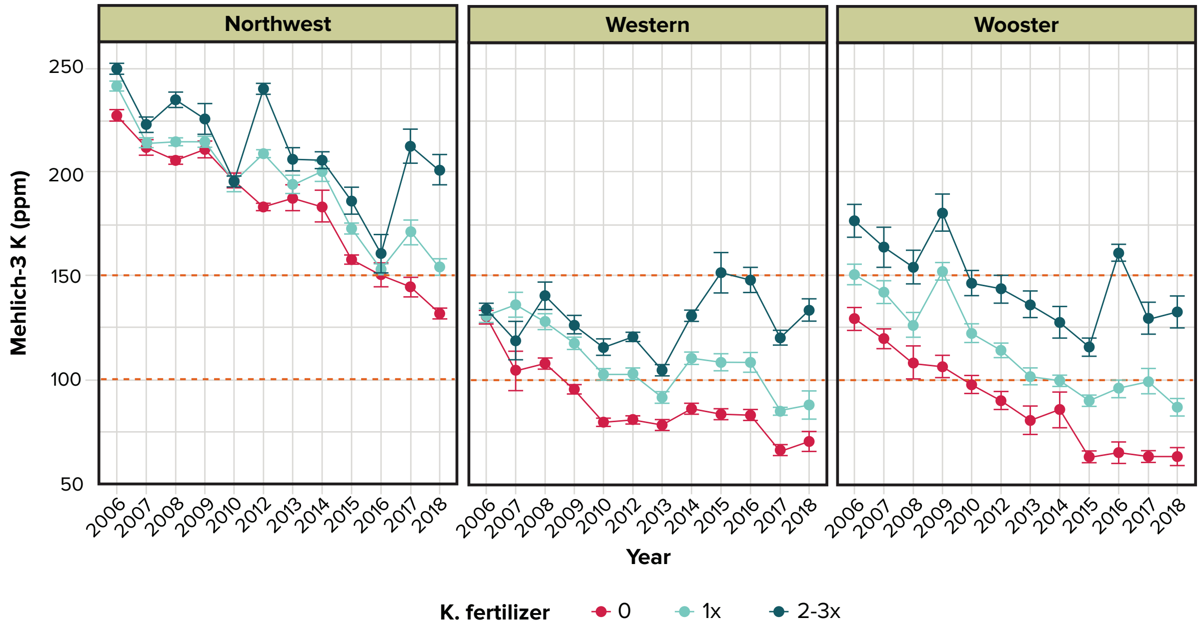

Figure 5. Soil test potassium trends over years of a corn-soybean rotation in three Ohio farms with three fertilizer rates: not-fertilized (0), fertilized at grain nutrient removal rates (1x) and fertilized at twice to three times the grain nutrient removal rates (2-3x). The first 9 years was fertilized at twice the removal rate (2x) and starting in 2016 this rate was increased to 3x.

P and K Fertilizer Rate Calculations

The revised tri-state fertilizer recommendations are calculated based on the equations in Table 17. The equations require the user to provide the soil test level and the expected yield potential of the crop. The equations for soils in the build-up range differ from those than in the maintenance range. These equations remain unchanged from the original recommendations, with the exception that Michigan does not recommend the 20 lbs added to the total nutrient removal for K recommendations. Note that build-up equations have not been recently validated and should be considered a priority for future research.

Table 17. Equations Used for Calculating New Fertilizer Recommendations

Michigan potassium equations are identical to Indiana and Ohio with the exception there is not an additional 20 lbs of K_2O added to crop nutrient removal.

Phosphorus (lb P_2O_5/ acre to apply)	
Maintenance range	Yield x Nutrient Removal
Build-up range	(Yield x Nutrient Removal) + [(CL–STP) x 5]

Potassium for Indiana and Ohio (lb K_2O/ acre to apply)	
Maintenance range (grain crops)	(Yield x Nutrient Removal) + 20
Maintenance range (forage crops)	[(Yield × Nutrient Removal) + 20] - [((Yield × Nutrient Removal) + 20) x (STK–CL)/50]
Build-up range	[(Yield × Nutrient Removal) + 20] + [(CL–STK) × (1 + (0.05 x CEC))]
Potassium for Michigan (lb K_2O/ acre to apply)	
Maintenance range (grain crops)	Yield × Nutrient Removal
Maintenance range (forage crops)	(Yield × Nutrient Removal) - [(Yield × Nutrient Removal) x (STK–CL)/50]
Build-up range	(Yield × Nutrient Removal) + [(CL–STK) × (1 + (0.05 x CEC))]

Yield = Yield potential in bushels/ acre or ton/acre
Nutrient Removal = Nutrient removal rates from Tables 15 and 16 (lbs/bushel or lbs/ton)
CL = Critical level from Table 12 (ppm)
STP = Soil test phosphorus (Mehlich-3ICP ppm), quantified by inductively coupled plasma emission spectroscopy (ICP)
STK = Soil test potassium (Mehlich-3 ICP ppm), quantified by ICPCEC = cation exchange capacity (meq/100g)

Quick reference tables, rounded to the nearest 5 pounds are provided for corn, soybean, wheat, corn silage, and alfalfa for phosphorus (Tables 18-22) and potassium (Tables 23-27). Potassium recommendations differ for sandy soil (CEC <5 meq/100g) and loam and clay soils (CEC >5 meq/ 100g) and the tables use CECs of 5 meq/100g for sandy soils and 15 meq/100g for loam and clay soils. Consistent with the original recommendations, these forage crop K recommendations differ from grain crops when soils are above the critical level.

Note the equations and quick tables provide recommendations for pounds of P_2O_5 or K_2O per acre, not pounds of fertilizer per acre. Final fertilizer recommended rates in pounds of fertilizer per acre can be calculated by dividing the provided nutrient recommendation by the percent concentration of that nutrient in the fertilizer. For example, potash fertilizer (potassium chloride) is often 0-0-60, or 60% K_2O. A recommendation of 60 lbs of K_2O per acre would equate to 100 lbs of KCl per acre, calculation below:

$$\textit{Fertilizer rate (lb fertilizer/acre)} = \frac{\text{Recommended nutrient rate (lb / acre)}}{\textit{Fertilizer nutrient content (lb / lb)}}$$

$$\textit{Fertilizer rate} = \frac{60 \text{ lb } K_2O\text{/acre}}{0.60 \text{ lb } K_2O\text{/lb KCl}} = 100 \text{ lb KCl / acre}$$

Phosphorus Fertilizer Recommendations

Table 18. Corn Phosphorus Recommendations

	Corn Yield Potential (bushels per acre)			
Mehlich-3 P	150	200	250	300
(ppm)	---------------- lb P_2O_5/ acre ----------------			
10	105	120	140	155
15	80	95	115	130
20-40	55	70	90	105
>40	0	0	0	0

Table 19. Soybean Phosphorus Recommendations

	Soybean Yield Potential (bushels per acre)			
Mehlich-3 P	30	50	70	90
(ppm)	---------------- lb P_2O_5/ acre ----------------			
10	75	90	105	120
15	50	65	80	95
20-40	25	40	55	70
>40	0	0	0	0

Table 20. Wheat Phosphorus Recommendations

Mehlich-3 P (ppm)	Wheat Yield Potential (bushels per acre)			
	60	90	120	150
	---------------- lb P_2O_5/ acre ----------------			
10	130	145	160	175
20	80	95	110	125
30-50	30	45	60	75
>50	0	0	0	0

Table 21. Corn Silage Phosphorus Recommendations

Mehlich-3 P (ppm)	Corn Silage Yield Potential (tons per acre)*			
	20	24	28	32
	---------------- lb P_2O_5/ acre ----------------			
10	110	125	135	150
15	85	100	110	125
20-40	60	75	85	100
>40	0	0	0	0
*35% dry matter				

Table 22. Alfalfa Phosphorus Recommendations

Mehlich-3 P (ppm)	Alfalfa Yield Potential (tons per acre)*			
	2	4	6	8
	---------------- lb P_2O_5/ acre ----------------			
10	125	150	170	195
20	75	100	120	145
30-50	25	50	70	95
>50	0	0	0	0
*100% dry matter				

Potassium Fertilizer Recommendations

Indiana and Ohio potassium fertilizer recommendations are shown in Tables 23-27. For Michigan, subtract 20 lb K_2O/ acre from the values listed in these tables.

Table 23. Corn Potassium Recommendations for Ohio and Indiana

For Michigan recommendations, subtract 20 lb K_2O/acre from these values.

Soil CEC	Mehlich-3 K (ppm)	Corn Yield Potential (bushels per acre) 150	200	250	300
		---------------- lb K_2O/ acre ----------------			
Sands (<5 meq/ 100 g)	50	115	125	135	145
	75	80	90	100	110
	100-130	50	60	70	80
	>130	0	0	0	0
Loams and Clays (>5 meq/ 100 g)	50	175	185	195	205
	75	130	140	150	160
	100	85	95	105	115
	120-170	50	60	70	80
	>170	0	0	0	0

When soils are below the maintenance range, recommendations will depend on CEC. Table uses CEC of 5 meq/100g for sandy soil and 15 meq/100g for loam and clay soils

Table 24. Soybean Potassium Recommendations for Ohio and Indiana

For Michigan recommendations, subtract 20 lb K_2O/acre from these values.

Soil CEC	Mehlich-3 K (ppm)	Soybean Yield Potential (bushels per acre) 30	50	70	90
		---------------- lb K_2O/ acre ----------------			
Sands (<5 meq/ 100 g)	50	115	140	165	185
	75	85	110	130	155
	100-130	55	80	100	125
	>130	0	0	0	0
Loams and Clays (>5 meq/ 100 g)	50	175	200	225	245
	75	135	155	180	200
	100	90	115	135	160
	120-170	55	80	100	125
	>170	0	0	0	0

When soils are below the maintenance range, recommendations will depend on CEC. Table uses CEC of 5 meq/100g for sandy soil and 15 meq/100g for loam and clay soils.

Table 25. Wheat potassium recommendations for Ohio and Indiana

For Michigan recommendations, subtract 20 lb K_2O/acre from these values.

Soil CEC	Mehlich-3 K (ppm)	Wheat Yield Potential (bushels per acre)			
		60	90	120	150
		---------------- lb K_2O/ acre ----------------			
Sands (<5 meq/ 100 g)	50	100	105	115	120
	75	65	75	80	90
	100-130	35	45	50	60
	>130	0	0	0	0
Loams and Clays (>5 meq/ 100 g)	50	160	165	175	180
	75	115	120	130	135
	100	70	80	85	95
	120-170	35	45	59	60
	>170	0	0	0	0

When soils are below the maintenance range, recommendations will depend on CEC. Table uses CEC of 5 meq/100g for sandy soil and 15 meq/100g for loam and clay soils.

Table 26. Corn Silage Potassium Recommendations for Ohio and Indiana

For Michigan recommendations, subtract 20 lb K_2O/acre from these values.

Soil CEC	Mehlich-3 K (ppm)	Corn Silage Yield Potential (tons per acre)*			
		20	24	28	32
		---------------- lb K_2O/ acre ----------------			
Sands (<5 meq/ 100 g)	50	230	260	285	300
	75	195	225	255	285
	100	165	195	225	255
	125	85	100	110	125
	>130	0	0	0	0
Loams and Clays (>5 meq/ 100 g)	50	290	300	300	300
	75	245	275	300	300
	100	200	230	260	290
	120	165	195	225	255
	150	65	80	90	100
	>170	0	0	0	0

*35% dry matter

When soils are below the maintenance range, recommendations will depend on CEC. Table uses CEC of 5 meq/100g for sandy soil and 15 meq/100g for loam and clay soils. Recommendations capped at 300 lb K_2O/acre.

Table 27. Alfalfa Potassium Recommendations for Ohio and Indiana

For Michigan recommendations, subtract 20 lb K_2O/acre from these values.

Soil CEC	Mehlich-3 K (ppm)	Alfalfa Yield Potential (tons per acre)* 2	4	6	8
		---------------- lb K_2O/ acre ----------------			
Sands (<5 meq/ 100 g)	50	180	280	300	300
	75	150	245	300	300
	100	120	215	300	300
	125	60	110	155	205
	>130	0	0	0	0
Loams and Clays (>5 meq/ 100 g)	50	240	300	300	300
	75	195	295	300	300
	100	155	250	300	300
	120	120	215	300	300
	150	45	85	125	165
	>170	0	0	0	0

*100% dry matter

When soils are below the maintenance range, recommendations will depend on CEC. Table uses CEC of 5 meq/100g for sandy soil and 15 meq/100g for loam and clay soils. Recommendations capped at 300 lb K_2O/acre.

CALCIUM, MAGNESIUM, AND SULFUR

KEY CONCEPTS

- Soils in the tri-state region typically supply adequate Ca, Mg, S and micronutrients for crop production.
- Sulfur deficiencies remain infrequent but are increasing.

Calcium (Ca), magnesium (Mg), and sulfur (S) are the three secondary nutrients required by plants, but less likely to be added as fertilizer as N, P or K. Most soils in Indiana, Michigan, and Ohio adequately supply these nutrients for plant growth. A standard soil test measures the relative availability of Ca and Mg in soils. There is no accurate soil test for S at this time. A plant analysis is the best diagnostic tool for confirming S availability.

If the exchangeable Ca level is in excess of 200 ppm, no response to Ca is expected. If the soil pH is maintained in the proper range, then the added Ca from lime maintains an adequate level for crop production (Table 28). The required soil exchangeable Mg level is 50 ppm or greater on loam and clay soils (CEC >5 meq/ 100 g) and 35 ppm or greater on sandy soils (CEC <5 meq/ 100 g). Low levels of Mg are commonly found in eastern Ohio and southern Indiana and on acid sandy soils in southwestern and western Michigan. Large applications of calcium amendments, such as gypsum, and high levels of exchangeable K can both reduce the uptake of Mg. If the ratio of Mg to K, as a percent of the exchangeable bases, is less than 2 to 1, then Mg is recommended for forage crops. Most Mg deficiencies can be corrected by maintaining proper soil pH using dolomitic lime that is high in Mg. The ratio of Ca to Mg should be considered when lime is added to a soil. If the ratio, as a percent of the exchangeable bases, is 1 to 1 or less (less Ca than Mg), a high calcium/low magnesium limestone should be used. Most plants grow well over a wide range of Ca to Mg soil ratios.

Table 28. Recommended Mehlich-3 Soil Test Critical Levels Calcium, Magnesium, and Sulfur for Field Crops in the Tri-State Region

Soil Type	Calcium	Magnesium	Sulfur
Sands (CEC <5 meq/ 100 g)	200 ppm	35 ppm	Not established
Loams and Clays (CEC >5 meq/ 100 g)	200 ppm	50 ppm	Not established

Excessive use of K fertilizers can greatly reduce the uptake of Ca and Mg. Forage with high K or low Mg concentrations can cause grass tetany, milk fever, hypocalcemia, and other health problems for ruminant animals. For these reasons, the tri-state K recommendations for alfalfa and corn silage do not follow the maintenance concept above the critical K soil test level. Potassium recommendations above the critical level are less than crop removal so as to discourage excessive uptake (i.e., luxury consumption) of K and improve Mg uptake. This can sometimes result in fields rotating out of alfalfa to have depleted soil test K levels.

Sulfur is taken up as sulfate by plants. Sulfate sulfur is primarily supplied by microbial decomposition of soil organic matter. Sulfate is a negative ion and can leach in soils. Historically, most soils in Indiana, Michigan, and Ohio supplied adequate S for plant growth, but crop responses to S fertilization are becoming more common. Sandy soils low in organic matter that are subject to excessive leaching may not supply adequate S. Small grains and alfalfa that grow rapidly at cool temperatures when mineralization of S is low are most likely to be S deficient. If elemental sulfur is used, it should be applied at least 2 months before the crop is planted. This would allow time for a portion of the S to be converted to the plant-available sulfate form by the soil bacteria. Sometimes the oxidation of elemental S to sulfate is insufficient to satisfy crop needs within a single season. Sulfur should be added in the sulfate form (ammonium sulfate, thiosulfate) when S deficiencies are expected or previously observed. Sulfur removal rates are listed in Table 29. A typical corn and soybean rotation removes approximately 20 lbs of S/acre (9 lbs of S/acre with 180 bushel/acre corn; 11 lbs of S/acre with 60 bu/acre soybean). Recent field trials in the tri-state region have shown infrequent crop response to S fertilization. If S deficiency is expected, applying 10-20 lbs S/acre every year typically supplies sufficient nutrition for grain crops.

Table 29. Sulfur Removal Rates in Field Crops

Grain Crop	Grain S removal rates (lb of S/bushel grain)	Total S removed at harvest (lb of S/acre)
Corn	0.05	9 lb S @ 180 bu/acre
Soybean	0.18	11 lb S @ 60 bu/acre
Wheat	0.07	6 lb S @ 80 bu/acre
Forage Crop	**Forage S removal rates (lb of S/ton forage)**	**Total S removed at harvest (lb of S/acre)**
Corn Silage	1.1	27 lb S @ 24 ton/acre
Alfalfa	5.4	32 lb S @ 6 tons/acre

MICRONUTRIENTS

Micronutrients are essential plant nutrients that are found in trace amounts in tissue but play a vital role in plant growth and development. Of the 17 elements essential for plant growth, eight are micronutrients: boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), zinc (Zn) and nickel (Ni). Other nutrients such as cobalt (Co), sodium (Na), silicon (Si), selenium (Se) and vanadium (V) can also benefit crop function, although are generally not considered essential to all plants. Most soils in the tri-state region contain adequate quantities of micronutrients. This is particularly true for fields that regularly receive livestock manure. Field crop deficiencies of Cl, Mo and Fe have rarely been observed in this region of the United States. Some soils, however, may be deficient in B, Cu, Mn, and Zn, which can cause plant abnormalities, reduced growth, and yield loss. When called for, micronutrient fertilizers should be used judiciously and with care. Some micronutrient fertilizers can be toxic if added to sensitive crops or applied in excessive amounts. Table 30 lists the soil and crop conditions under which micronutrient deficiencies are most likely to occur.

Table 30. Crop and Soil Conditions Under Which Micronutrient Deficiencies May Occur

Micronutrient	Soil	Crop
Boron (B)	Sandy soils or highly weathered soils low in organic matter	Alfalfa and clover
Copper (Cu)	Acid peats or mucks with pH < 5.3 and black sands	Wheat, oats, corn
Manganese (Mn)	Peats and mucks with pH > 5.8, black sands and lakebed/ depressional soils with pH > 6.2	Soybean, wheat, oats, sugar beets, corn
Molybdenum (Mo)	Acid prairie soils	Soybean
Zinc (Zn)	Peats, mucks and mineral soils with pH > 6.5	Corn and Soybean

Diagnosing Micronutrient Deficiencies

Both soil testing and plant analysis are useful in diagnosing micronutrient deficiencies. Relative to soil pH, micronutrient soil tests are not as reliable and so plant analysis can play an important role to complement a soil test. Combining plant analysis with soil tests provides more accurate assessment of the micronutrient status of crops and soils. The original tri-state recommendations called for using different extractants depending on the micronutrient of interest: 0.1 N HCl for Mn and Zn and 1.0 N HCl for Cu. In the tri-state region, however, soil testing labs most often use the Mehlich-3 extractant to estimate micronutrient availability. But how effective the "universal" Mehlich-3 extraction is at characterizing soil micronutrient availability is not well understood, as recommended micronutrient concentration ranges based on the Mehlich-3 extraction have not been developed for the tri-state region. Recently, extensive efforts were made to field calibrate Mehlich-3 and DTPA extractants to micronutrient yield response in soybeans and determine which extractant was better able to predict micronutrient deficiency in the Midwest (Mallarino et al., 2017). The results were inconclusive because very few grain yield responses to micronutrient fertilization were observed. The lack of yield responses in micronutrient fertilization trials is a major limitation to developing soil test extractants that can predict micronutrient deficiencies. Despite the uncertainties that exist, Mehlich-3 extractable micronutrients likely relate meaningful information about availability of each nutrient and can be useful information to have.

Summary of Micronutrient Trials

A recent effort to summarize micronutrient trials in Ohio found a total of 194 trials (17 alfalfa, 33 corn and 144 soybean trials) that tested a micronutrient fertilized treatment (or set of treatments) relative to an unfertilized control treatment. Overall, yield responses to micronutrient fertilization were rare, with the only responses observed when Mn was applied to soybean (9 out of 144 trials). Table 31 reports tissue concentrations from a recent study in Ohio (corn and soybean at 3 sites over 2 years) that did not respond to micronutrient fertilization (foliar and soil applied) and had no previous history of visual symptoms of micronutrient deficiency. These concentrations can be considered adequate for crop nutrition. For more information see **go.osu.edu/micronutrients.**

Table 31. Corn and Soybean Tissue Ranges at Three Development Stages Across Three Sites Over Two Years

These crops were not responsive to micronutrient (B, Cu, Fe, Mn and Zn), so these ranges can be considered adequate for micronutrient needs.

Crop	Plant part (Stage)	Boron	Copper	Iron	Manganese	Zinc
		--------------------- part per million (ppm) ---------------------				
Corn	Whole young plant (V5)	16–32	3–17	109–800	15–111	20–63
	Ear leaf at silking (R1)	10–44	6–19	87–448	16–86	14–45
	Harvested grain (R6)	3–10	1–4	9–49	3–8	10–36
Soybean	Whole young plant (V5)	37–74	3–37	238–2800	24–170	17–80
	Upper trifoliate at flowering (R1-R2)	45–100	6–18	83–384	22–124	18–76
	Harvested grain (R8)	25–52	11–24	49–107	18–42	26–50

Source: Culman, 2015 & 2016. Soil Amendment and Foliar Application Trials, extension.agron.iastate.edu/compendium/index.aspx

In addition, the original tri-state recommendations provided a sufficiency table for micronutrient concentrations in field crop components (Table 32). These values remain unchanged in this update.

Table 32. Micronutrient Plant Tissue Sufficiency Ranges for Corn, Soybean, Alfalfa, and Wheat

Element	Corn Ear leaf sampled at initial silking	Soybean Uppermost fully developed trifoliate sampled prior to initial flowering	Alfalfa Top 6 inches sampled prior to initial flowering	Wheat Upper leaves sampled prior to initial bloom
	---------------------------------- parts per million (ppm) ----------------------------------			
Manganese (Mn)	20–150	21–100	31–100	16–200
Iron (Fe)	21–250	51–350	31–250	11–300
Boron (B)	4–25	21–55	31–80	6–40
Copper (Cu)	6–20	10–30	11–30	6–50
Zinc (Zn)	20–70	21–50	21–70	21–70
Molybdenum (Mo)	–	1.0–5.0	1.0–5.0	–

Micronutrient Recommendations

Table 33 gives recommended rates of soil-applied inorganic sources of micronutrients for manganese, zinc, and copper based on soil type, soil test, and pH. These rates are recommended only for the responsive crops listed in Table 30. The micronutrient soil tests recommended for use in Michigan, Ohio, and Indiana are 0.1 N HCl for Mn and Zn, and 1.0 N HCl for Cu using a 1 to 10 soil-to-extractant ratio. Note most micronutrient soil test recommendations are based on Mehlich-3 extractable levels which have not been systematically calibrated to crop response in the tri-state region.

Table 33. Micronutrient Recommendations Based on 1.0 and 0.1 N HCl Extractants

Micronutrient	Soil Type	Recommendation
Manganese	Mineral	Pounds Mn/acre = (6.2 x soil pH) - (0.35 x 0.1N HCl extractable Mn in ppm) - 36
	Organic	Pounds Mn/acre = (8.38 x soil pH) - (0.31 x 0.1N HCl extractable Mn in ppm) - 46
Zinc	Mineral and Organic	Pounds Zn/acre = (5.0 x soil pH) - (0.4 x 0.1 N HCl extractable Zn in ppm) - 32
Copper	Organic	Pounds Cu/acre = 6.3 - (0.3 x 1.0 N HCl extractable Cu in ppm)

Micronutrient availability in both mineral and organic soils is highly regulated by soil pH. The higher the soil pH and the lower the soil test, the more micronutrient fertilizer is needed to correct a deficiency. Copper deficiency in Michigan, Ohio, and Indiana has been observed only on black sands and organic soils. Because of the extreme Mn and Cu deficiency problems and often excess N mineralization in organic soils, wheat and oat plantings are not recommended on these soils.

Boron recommendations for Michigan, Ohio, and Indiana are not based on any soil test; they are based on soil type and responsiveness of the crop. Boron is recommended annually at a rate of 1 to 2 pounds per acre broadcast applied on established alfalfa and clover grown on sandy soils.

Molybdenum deficiency of soybeans has been found on certain acid soils in Indiana and Ohio. Most molybdenum deficiencies can be corrected by liming soils to the proper soil pH range. The recommended molybdenum fertilization procedure is to use ½ ounce of sodium molybdate per bushel of seed as a planter box treatment or 2 ounces of sodium molybdate per acre in 30 gallons of water as a foliar spray. Extreme care should be used when applying molybdenum because 10 ppm of Mo in forage may be toxic to ruminant animals.

Micronutrient Placement and Availability

Micronutrient fertilizers can be soil or foliar applied. Micronutrients banded with starter fertilizers at planting time are usually more effective over a longer period of growth than foliar applied micronutrients. Micronutrient placement is particularly important in organic soils. Most soil applied micronutrients, with the exception of boron for alfalfa and clover, should be banded with the starter fertilizer for efficient uptake. Boron applications for alfalfa and clover should be broadcast with other fertilizers or sprayed on the soil surface. Broadcast applications of 5 to 10 lb Zn per acre may be used to alleviate plant deficiencies and build up Zn-deficient soils. Broadcast applications of Mn, however, are not recommended because of high soil fixation and limited residual effect, thus foliar Mn fertilizers are usually recommended (Brouder et al., 2003). Foliar applications of other micronutrients are more frequently used when deficiency symptoms are present or suspected and when banded soil applications are not practical.

Soil acidification to improve micronutrient uptake is usually not practical over a large field. Some starter fertilizers are acid-forming and may improve the uptake of both applied and native soil forms of micronutrients when deficiencies are slight. When micronutrient deficiencies are moderate or severe, starter fertilizers alone will not overcome the deficiency.

There are many micronutrient fertilizers formulations currently sold in the tri-state region. These exist as straight grade nutrients, combinations or blends, and granular or foliar formulations. All reputable fertilizers should be labeled for rate, spray volume, placement, and important precautions. Growers are encouraged to follow the manufacturers labels closely to minimize any risks of crop damage.

ADDITIONAL RESOURCES

Original 1995 Tri-State Fertilizer Recommendations

Vitosh, M.L., J.W. Johnson, and D.B. Mengel. 1995. Tri-State Fertilizer Recommendations for Corn, Soybean, Wheat, and Alfalfa. Extension Bulletin E-2567. **agcrops.osu.edu/publications/tri-state-fertility-guide-corn-soybean-wheat-and-alfalfa**

Soil Sampling

Ohio State University Soil Fertility Resources, **agcrops.osu.edu/FertilityResources**

Ackerson, Jason. Soil Sampling Guidelines, Purdue Extension, **extension.purdue.edu/extmedia/AY/AY-368-w.pdf**

Warncke, Darryl, Jon Dahl, and Lee Jacobs. 2009. Nutrient Recommendations for Field Crops in Michigan, Michigan State University Extension. **soils.msu.edu/wp-content/uploads/2014/06/MSU-Nutrient-recomdns-field-crops-E-2904.pdf**

Michigan State University Soil and Plant Nutrient Lab, **canr.msu.edu/spnl**

Grove, John, Raymond Ward, and Raymond Weil. 2007. "Nutrient Stratification in No-till Soils." Leading Edge, The Journal of No-Till Agriculture. **go.osu.edu/stratification**

Soil Testing

North Central Regional Committee on Soil Testing and Plant Analysis (NCERA-13). 2015. Recommended Chemical Soil Test Procedures for the North Central Region. NCR Publication 221. **ehttps://extension.missouri.edu/publications/sb1001**

Murdock, Lloyd and Dottie Call. 2006. "Managing Seasonal Fluctuations aof Soil Tests." AGR-189. University of Kentucky Cooperative Extension Service. **www2.ca.uky.edu/agcomm/pubs/agr/agr189/agr189.pdf**

Soil pH

Warncke, Darryl, Laura Bast, and Don Christenson. "Lime for Michigan Soils." Michigan State University Extension. **soils.msu.edu/wp-content/uploads/2014/06/Lime-for-MI-soils-E-471.pdf**

Warncke, Darryl, Jon Dahl, and Lee Jacons. 2009. Nutrient Recommendations for Field Crops in Michigan, Michigan State University Extension. **soils.msu.edu/wp-content/uploads/2014/06/MSU-Nutrient-recomdns-field-crops-E-2904.pdf**

Mullen, Robert, Edwin Lentz, and Maurice Watson. 2016. "Soil Acidity and Liming for Agronomic Production." AGF-505. Ohio State University Extension. **ohioline.osu.edu/factsheet/AGF-505-07**

Nitrogen

Corn Nitrogen Rate Calculator, **cnrc.agron.iastate.edu**

Rationale for an economic model to corn N rate recommendations: **extension.iastate.edu/Publications/PM2015.pdf**

Sawyer, John, Emerson Nafziger, Gyles Randall, Larry Bundy, George Rehm, and Brad Joern. 2006. Concepts and Rationale for Regional Nitrogen Rate Guidelines for Corn. Iowa State University Extension. **extension.iastate.edu/Publications/PM2015.pdf**

Camberato, James, and Robert Nielsen. Nitrogen Management Guidelines for Corn. Purdue University. **agry.purdue.edu/ext/corn/news/timeless/nitrogenmgmt.pdf**

Phosphorus and Potassium/ Mehlich-3 extraction

Culman, Steve, Meredith Mann, Stuti Sharma, Muhammad Tariq Saeed, Anthony Fulford, Laura Lindsay, Aaron Booker, Libby Dayton, Branly Eugene, Randall Warden, Kurt Steinke, Jim Camberato, and Brad Joern. 2019. "Converting between Mehlich-3, Bray P, and Ammonium Acetate Soil Test Values." ANR-75. Ohio State University Extension. **ohioline.osu.edu/factsheet/anr-75**

Culman, Steve, Meredith Mann, Stuti Sharma, Muhammad Tariq Saeed, Anthony Fulford, Laura Lindsay, Aaron Brooker, Elizabeth Dayton, Randall, and Brad Joern. 2020. "Calibration of Mehlich-3 with Bray P1 and Ammonium Acetate in the Tri-State Region of Ohio, Indiana, and Michigan." Communications in Soil Science and Plant Analysis 51: 86–97. **doi: 10.1080/00103624.2019.1695825**

Thom, William and James Dollarhide. 2002. "Phosphorus Soil Test Change Following the Addition of Phosphorus Fertilizer to 16 Kentucky Soils. UKnowledge Agronomy Notes 11. **uknowledge.uky.edu/pss_notes/11**

Phosphorus and Potassium/ Critical levels and crop response

Culman, Steve, Muhammad Tariq Saeed, and Anthony Fulford. 2017. "Ohio Data that Shaped the Tri-State Fertilizer Recommendations." AGF-518. Ohio State University Extension. **ohioline.osu.edu/factsheet/agf-518**

Fulford, Anthony and Steve Culman. 2018. Over-Fertilization Does Not Build Soil Test Phosphorus and Potassium in Ohio. Agronomy Journal 111:56-65.

Grain Nutrient Removal Rates

Culman, Steve, Phoo P. Zone, Nakian Kim, Anthony Fulford, Laura Lindsey, Peter Thomison, Anne Dorrance, Rich Minyo, Eric Richer, Ed Lentz, Ryan Haden, Harold Watters, and Greg LaBarge. 2019. "Nutrients Removed with Harvested Corn, Soybean and Wheat Grain in Ohio." ANR-74. **ohioline.osu.edu/factsheet/anr-74**

Villamil, Maria, Emerson Nafziger, and Gevan Behnke. 2019. "New Grain P and K Concentration Values for Illinois Field Crops." Crop, Forage & Turfgrass Management 5: 1-7. **doi.org/10.2134/cftm2018.11.0090**

Mallarino, Antonio, John Sawyer, and Steve Barnhart. 2013. A General Guide for Crop Nutrient and Limestone Recommendations in Iowa. Iowa State University Extension and Outreach. **store.extension.iastate.edu/product/5232**

Micronutrients

Mallarino, Antonio, Daniel Kaiser, Dorivar Ruiz-Diaz, Carrie Laboski, James Camberato, and Tony Vyn. 2017. Micronutrients for Soybean Production in the North Central Region. Iowa State University Extension and Outreach. **store.extension.iastate.edu/product/15259**

Sharma, Stuti, Steve Culman, Anthony Fulford, Laura Lindsey, Douglas Alt, and Grace Looker. 2018. "Corn, Soybean, and Alfalfa Yield Responses to Micronutrient Fertilization in Ohio." AGF-519. Ohio State University Extension. **go.osu.edu/micronutrients**

Brouder, Sylvie, Andrea Bongen, Kenneth Eck, and Stephen Hawkins. 2003. "Manganese Deficiencies in Indiana Soils." AY-276-W. Purdue University Cooperative Extension Service. **agry.purdue.edu/ext/pubs/AY-276-W.pdf**

APPENDIX 1:
Comparisons of 1995 v. 2020 Recommendations

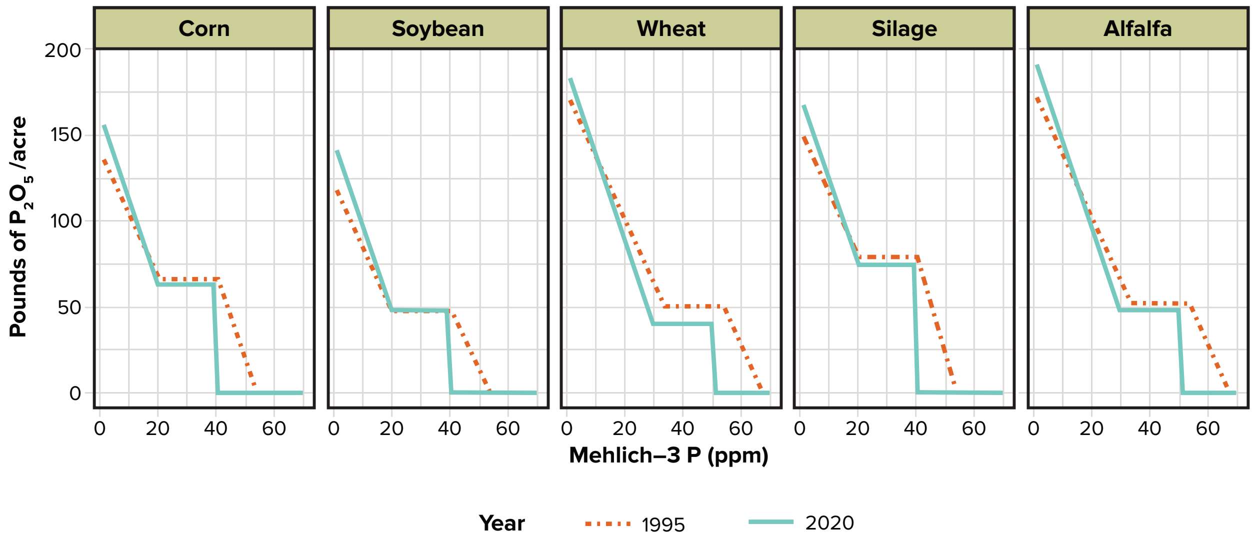

Figure A1. Comparison of Phosphorus Recommendations in 1995 v. 2020 for Each Crop (Corn at 180 bu/ acre, Soybean at 60 bu/acre, Wheat at 80 bu/acre, Corn Silage at 24 tons/acre, Alfalfa at 4 tons/acre).

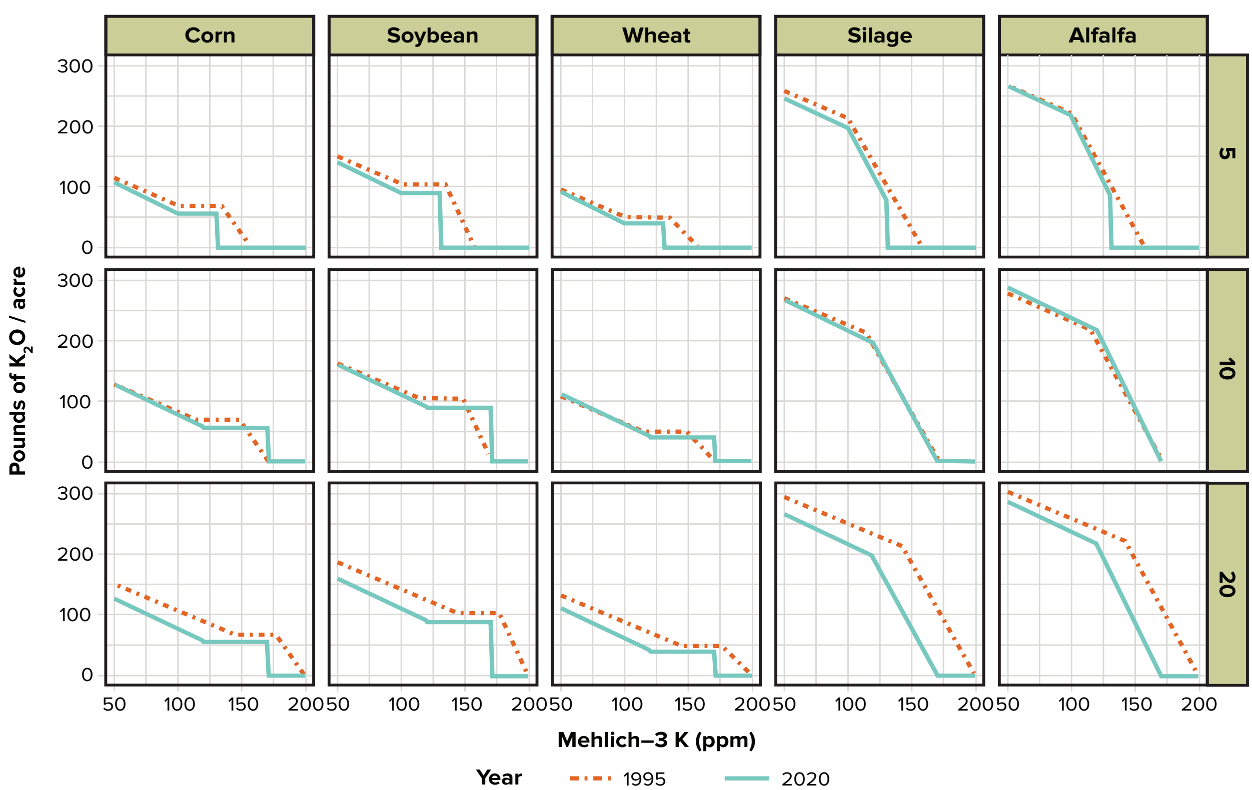

Figure A2. Comparison of Potassium Recommendations in 1995 v. 2020 by Cation Exchange Capacity (CEC) Class and Each Crop (Corn at 180 bu/ acre, Soybean at 60 bu/acre, Wheat at 80 bu/acre, Corn Silage at 24 tons/acre, Alfalfa at 4 tons/acre).

APPENDIX 2:
Phosphorus Recommendations using Bray P1

Phosphorus Fertilizer Recommendations

Table A1. Corn Phosphorus Recommendations Based on Bray P1 quantified colorimetrically

	Corn Yield Potential (bushels per acre)			
Bray P1	150	200	250	300
(ppm)	----------------------- lb P_2O_5/ acre -----------------------			
5	105	120	140	155
10	80	95	115	130
15-30	55	70	90	105
>30	0	0	0	0

Table A2. Soybean Phosphorus Recommendations Based on Bray P1 quantified colorimetrically

	Soybean Yield Potential (bushels per acre)			
Bray P1	30	50	70	90
(ppm)	----------------------- lb P_2O_5/ acre -----------------------			
5	75	90	105	120
10	50	65	80	95
15-30	25	40	55	70
>30	0	0	0	0

Table A3. Wheat Phosphorus Recommendations Based on Bray P1 quantified colorimetrically

	Wheat Yield Potential (bushels per acre)			
Bray P1	60	90	120	150
(ppm)	----------------------- lb P_2O_5/ acre -----------------------			
10	105	120	135	150
20	55	70	85	100
25-40	30	45	60	75
>40	0	0	0	0

Table A4. Corn Silage Phosphorus Recommendations Based on Bray P1 quantified colorimetrically

	Corn Silage Yield Potential (tons per acre)*			
Bray P1	20	24	28	32
(ppm)	------------------------ lb P_2O_5/ acre ------------------------			
5	110	125	135	150
10	85	100	110	125
15–30	60	75	85	100
>30	0	0	0	0

*35% dry matter

Table A5. Alfalfa Phosphorus Recommendations Based on Bray P1 quantified colorimetrically

	Alfalfa Yield Potential (tons per acre)*			
Bray P1	2	4	6	8
(ppm)	------------------------ lb P_2O_5/ acre ------------------------			
10	100	125	145	170
20	50	75	95	120
30–50	25	50	70	95
>50	0	0	0	0

*100% dry matter

APPENDIX 3:
Potassium Recommendations using Ammonium Acetate

Table A6. Corn Potassium Recommendations for Ohio and Indiana Based on Ammonium Acetate

For Michigan recommendations, subtract 20 lb K_2O/acre from these values.

		Corn Yield Potential (bushels per acre)			
Soil CEC	AA K	150	200	250	300
	(ppm)	--------------------- lb K_2O/ acre ---------------------			
Sands (<5 meq/ 100 g)	50	100	110	120	130
	75	65	75	85	95
	88–115	50	60	70	80
	>115	0	0	0	0
Loams and Clays (>5 meq/ 100 g)	50	145	155	165	175
	75	105	115	125	135
	100	60	70	80	90
	105–150	50	60	70	80
	>150	0	0	0	0

When soils are below the maintenance range, recommendations will depend on CEC. Table uses CEC of 5 meq/100g for sandy soil and 15 meq/100g for loam and clay soils.

Table A7. Soybean Potassium Recommendations for Ohio and Indiana Based on Ammonium Acetate

For Michigan recommendations, subtract 20 lb K_2O/acre from these values.

		Soybean Yield Potential (bushels per acre)			
Soil CEC	AA K	30	50	70	90
	(ppm)	-------------------- lb K_2O/ acre --------------------			
Sands (<5 meq/ 100 g)	50	100	125	150	170
	75	70	95	115	140
	88–115	55	80	100	125
	>115	0	0	0	0
Loams and Clays (>5 meq/ 100 g)	50	150	175	195	220
	75	105	130	155	175
	100	65	85	110	130
	105–150	55	80	100	125
	>150	0	0	0	0

When soils are below the maintenance range, recommendations will depend on CEC. Table uses CEC of 5 meq/100g for sandy soil and 15 meq/100g for loam and clay soils.

Table A8. Wheat Potassium Recommendations for Ohio and Indiana Based on Ammonium Acetate

For Michigan recommendations, subtract 20 lb K_2O/acre from these values.

		Wheat Yield Potential (bushels per acre)			
Soil CEC	AA K	60	90	120	150
	(ppm)	------------------- lb K_2O/ acre -------------------			
Sands (<5 meq/ 100 g)	50	85	90	100	105
	75	50	60	65	75
	88-115	35	45	50	60
	>115	0	0	0	0
Loams and Clays (>5 meq/ 100 g)	50	130	140	145	155
	75	90	95	105	110
	100	45	50	60	65
	105-150	35	45	50	60
	>150	0	0	0	0

When soils are below the maintenance range, recommendations will depend on CEC. Table uses CEC of 5 meq/100g for sandy soil and 15 meq/100g for loam and clay soils.

Table A9. Corn Silage Potassium Recommendations for Ohio and Indiana Based on Ammonium Acetate

For Michigan recommendations, subtract 20 lb K_2O/acre from these values.

		Corn Silage Yield Potential (tons per acre)*			
Soil CEC	AA K	20	24	28	32
	(ppm)	------------------- lb K_2O/ acre -------------------			
Sands (<5 meq/ 100 g)	50	215	245	270	300
	75	180	210	240	270
	88	165	195	225	255
	115	75	90	105	115
	>115	0	0	0	0
Loams and Clays (>5 meq/ 100 g)	50	260	290	300	300
	75	220	250	275	300
	100	175	205	235	260
	105	165	195	225	255
	>150	0	0	0	0

*35% dry matter

When soils are below the maintenance range, recommendations will depend on CEC. Table uses CEC of 5 meq/100g for sandy soil and 15 meq/100g for loam and clay soils. Recommendations capped at 300 lb K_2O/acre.

Table A10. Alfalfa Potassium Recommendations for Ohio and Indiana Based on Ammonium Acetate

For Michigan recommendations, subtract 20 lb K_2O/acre from these values.

		Alfalfa Yield Potential (tons per acre)*			
Soil CEC	AA K	2	4	6	8
	(ppm)	------------------- lb K_2O/ acre -------------------			
Sands (<5 meq/ 100 g)	50	165	265	300	300
	75	135	230	300	300
	88	120	215	300	300
	115	55	100	145	190
	>115	0	0	0	0
Loams and Clays (>5 meq/ 100 g)	50	215	300	300	300
	75	170	270	300	300
	100	125	225	300	300
	105	120	215	300	300
	150	10	20	30	40
	>150	0	0	0	0

*100% dry matter

When soils are below the maintenance range, recommendations will depend on CEC. Table uses CEC of 5 meq/100g for sandy soil and 15 meq/100g for loam and clay soils. Recommendations capped at 300 lb K_2O/acre.

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974–NOV20–1M–UNI–Q46281