

# Water Quality and Nutrient Management



**P** from **P** to  
PLANNING LACEMENT PROFIT!



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# Water Quality and Nutrient Management

Dear Agricultural Producer:

Caring for your land means caring about the environment, especially when it comes to soil and water resources. No matter where you go, from small towns to big cities, down on the farm or back at the ranch, you're always in a watershed. When considering that only two and one half percent of all the water on earth is fresh water, it is vitally important that we all work together to protect our streams, rivers and lakes for both current and future generations. Conservation and stewardship go hand-in-hand with agriculture.

Today, Ohio's waterways are facing increased water quality challenges that must be addressed to ensure a productive and prosperous future. Each and every individual plays a role in the solution to these challenges. Nutrient loading in Ohio's streams, rivers and lakes is of the utmost concern to all Ohio citizens.

In keeping with their strong global commitment to environmental stewardship, Cargill has partnered with Shelby Soil and Water Conservation District and the Shelby County Farm Bureau to bring you this "Water Quality & Nutrient Management: *from Planning to Placement to Profit!*" tool kit.

Our goal is to assist you, the American farmer who feeds the world, with making informed decisions that affect water quality, nutrient management and the success of your operation. We ask that you please take time to review the materials included in this tool kit and hope that you find them to be useful in your endeavor of being the best possible land steward and conducting a profitable farming operation.

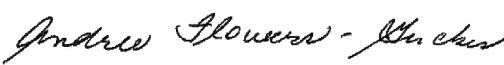
Agriculturally Yours,

  
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# Purpose

**This section contains a narrative explaining how and why nutrient management is important to the environment and the future of agriculture along with a graphic illustrating nutrient outfall in the Mississippi River Basin.**





# Water Quality and Nutrient Management: *from Planning to Placement to Profit!*

Crop production and fertilizer discussions generally center on planting dates, hybrid selections, and maximizing crop yields. However, an effective nutrient management program will focus on a much broader set of goals. Agricultural runoff and elevated nutrient levels in Ohio's lakes, streams, and rivers have been noted and will be receiving increased scrutiny in the coming years.

## Purpose

The need for a sound nutrient management plan extends beyond cropland and farm. Water quality impacts downstream will have to be addressed moving forward. A complete nutrient management plan should not only maximize crop production and profitability, but also maintain the health and quality of the soil, and maximize the use of the fertilizers and nutrients needed for crop production.

Fertilizer and nutrient application rates should be based on sound principles and applied only when needed.

Moreover; timing of applications should minimize nutrient losses, and maximize availability to the growing crops. Minimizing losses reduces the required application rates, and reduces overall production costs.

Soil health should also be considered in the nutrient management plan. Healthy soils have increased water holding capacity, are better able to absorb and retain applied nutrients, and can supply a significant amount of nitrogen to the crop during the growing season.

## Developing Nutrient Recommendations

Developing nutrient application recommendations may seem like a complicated task. However, given the proper information and some basic references, developing these recommendations is a straight forward process.

To develop nutrient application records the following information is needed:

- 1.) Current soil tests
- 2.) Planned Crop and Previous Crop
- 3.) Average Yield or Yield Goal
- 4.) Tri-State Fertilizer Guide

## Soil Tests

Soil tests serve as a gauge indicating the fertility levels of specific nutrients in your soil. Current soil tests are those that have been taken in the last 3 years. Reading soil test reports may seem complicated at first, but the gleanings of information needed to develop basic nutrient recommendations is fairly simple.





## **Soil Tests** continued

Soil samples sent to the laboratory for analysis should represent an area of 25 acres or less. Samples when testing for phosphorus and potassium should be taken to a depth of 6 to 8 inches. Soil sampling and testing should be done as consistently as possible to reduce variability in results. This should include using the same testing laboratory and pulling samples in a similar way.

Understanding and recognizing the units of the soil properties in the laboratory report is the key to properly interpreting a soil test report. Laboratories commonly post soil test results in Pounds per Acre (lb/ac) or in Parts per Million (ppm). Recommendations can be developed using either reporting unit and conversions from one to other can be done easily.

Testing methods for specific nutrients have also evolved and changed over the years. The most prominent change has been testing methods for phosphorus. Most references used to develop nutrient application recommendations refer to the Bray-Kurtz P1 values to determine phosphorus recommendations. However, many testing facilities are using a newer testing procedure called the Melich III test. When developing recommendations, differences between the two tests must be understood and accounted for in the recommendations. Please refer to the Ohio State Extension Fact Sheet **'Understanding Soil Tests for Plant-Available Phosphorus'** included in this packet.

Refer to Ohio State University Extension Fact Sheet AGF-514-12 **'Interpreting a Soil Test Report'** for more discussion on interpreting soil test reports and recommended ranges for different soil nutrients.

## **Planned Crop and Previous Crop**

Nutrient application rates are based on several variables in addition to soil nutrient levels reported in a soil test. Nutrient applications are also based on the expected yield response for the crop being planned. Plant uptake of nutrients is dependent on the crop, expected yield, soil fertility levels, and occasionally residual nutrients from the previous crop.

The previous crop will impact the recommended nitrogen applications for corn and similar crops. Legumes fix nitrogen from the atmosphere and some of the nitrogen fixed will be available during the next growing season. The result is a reduction in the recommended nitrogen application.

## **Yield Goal or Average Yield**

Harvested crops remove nutrients from the field. The higher the yield the higher the nutrient removal rates from the field. Average yields and yield goals are used to adjust the nutrient recommendations for the anticipated nutrient removal from the field.

## **Tri-State Fertilizer Guide**

The Tri-State Fertilizer Guide was developed by Michigan State University, The Ohio State University, and Purdue University, and has become the recognized guidance document for nutrient recommendations in Ohio. A copy of the Tri-State Fertilizer Guide is included in this packet.





## **Tri-State Fertilizer Guide** continued

The Ohio State Extension Factsheet AGF-515-12 '*Developing Phosphorus and Potassium Recommendations for Field Crops*' discusses the use of the Tri-State Fertilizer Guide, and how to read the tables contained within.

## **Nutrient Management and Water Quality**

Agriculture has always received some scrutiny in water quality discussions. Typically these discussions focused on livestock production and concerns over waste water runoff and manure application. However, in recent years water quality data has shown rising nutrient levels from agricultural production areas with very little livestock.

An example of this is phosphorus loads from the Maumee River draining into Lake Erie. Phosphorus loads from this basin are approaching, and sometimes exceeding loads from the 1970's. Because of this nutrient management is a growing concern for environmental groups, and an issue production agriculture will have to address.

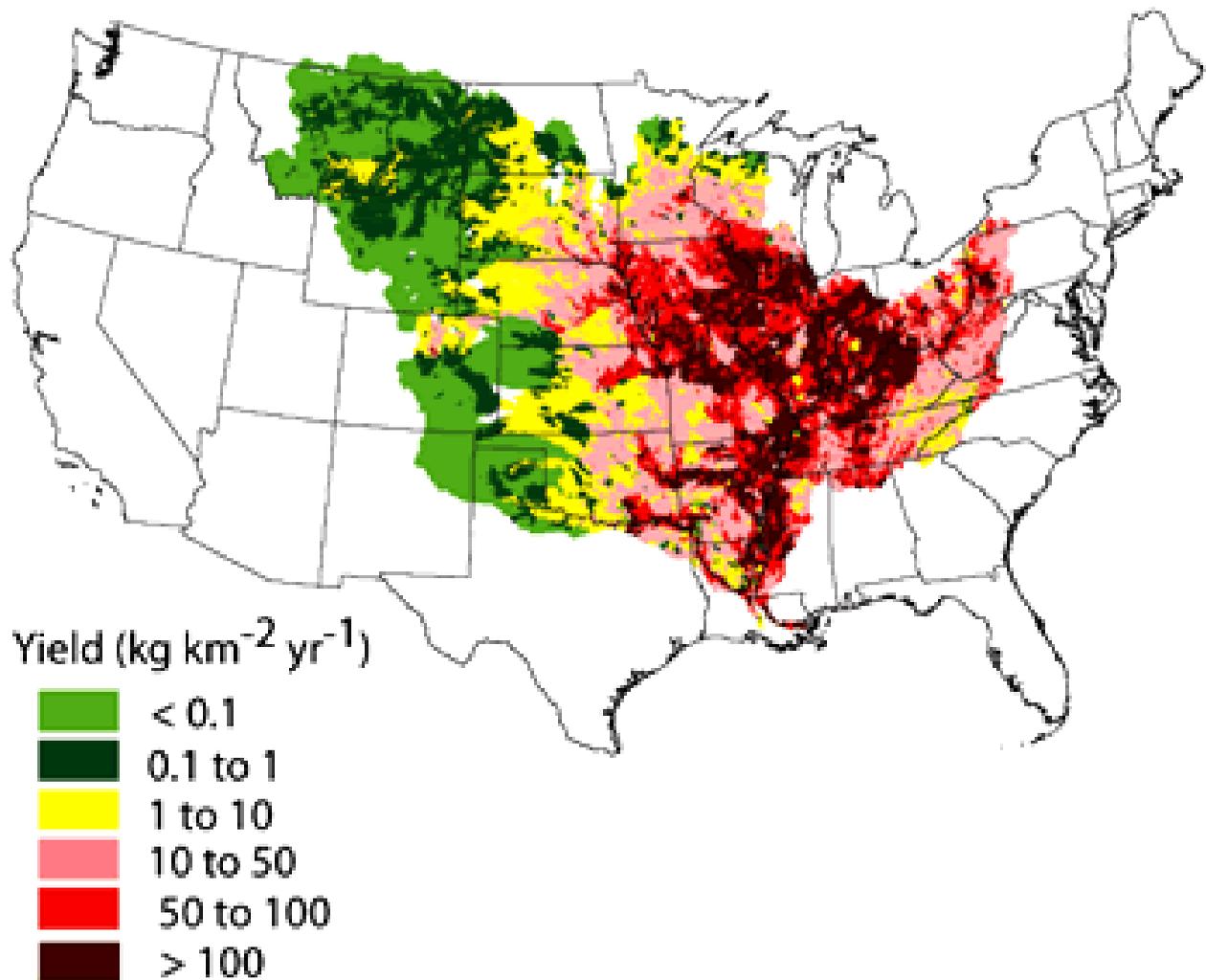


The following is a copy of a soil test report from a private laboratory. The soil test results are reported in parts per million and the Melich III test was used for phosphorus.

Sample Number	Lab Number	pH		Organic Matter %	Analysis Result* and Rating				CEC	Base Saturation		
		Soil pH	Buffer pH		Phosphorus P	Potassium K	Magnesium Mg	Calcium Ca		K %	Mg %	Ca %
21-1	E39740	7.4		4.2	77 H	324 H	651 V	3528 H	18.7	3.7	25.5	70.7
21-2	E39741	7.3		2.6	41 M	156 M	541 V	2414 H	13.4	2.5	29.7	67.8
21-3	E39742	7.4		3.6	123 H	307 G	710 V	3566 H	19.2	3.4	27.1	69.5
21-4	E39743	7.7		2.3	59 G	205 G	611 V	2548 G	14.5	3.0	30.9	66.0
21-5	E39744	7.0		2.8	78 H	232 G	603 V	2509 G	16.5	3.0	26.8	57.1

Also contained in the soil test report were nutrient application recommendations for the following three crop years with the planned crop and yield goal for each field. These recommendations are shown below.

Sample Number	Lab Number	Year	Crop	Yield Goal	Acres	Nutrient recommendations			
						CaCO <sub>3</sub> ** Lime	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O
21-1	E39740	13	Soybeans	60 bu		0	20	17	29
21-1	E39740	14	Wheat, Winter	100 bu			109	19	20
21-1	E39740	15	Corn	180 bu			230	21	30
21-2	E39741	13	Soybeans	60 bu		0	20	71	118
21-2	E39741	14	Wheat, Winter	100 bu			117	100	81
21-2	E39741	15	Corn	180 bu			246	97	152
21-3	E39742	13	Soybeans	60 bu		0	20	0	42
21-3	E39742	14	Wheat, Winter	100 bu			112	0	26
21-3	E39742	15	Corn	180 bu			236	0	43
21-4	E39743	13	Soybeans	60 bu		0	20	48	91
21-4	E39743	14	Wheat, Winter	100 bu			119	53	59
21-4	E39743	15	Corn	180 bu			249	60	103
21-5	E39744	13	Soybeans	60 bu		0	20	18	82
21-5	E39744	14	Wheat, Winter	100 bu			116	20	51
21-5	E39744	15	Corn	180 bu			244	22	85



## Phosphorus delivered to the Gulf of Mexico.

USGS Map-[http://water.usgs.gov/nawqa/sparrow/gulf\\_findings/](http://water.usgs.gov/nawqa/sparrow/gulf_findings/)



# Field Records



# Field Record

Year \_\_\_\_\_

Insert Field Sketch or Picture

## Field Information

Field ID _____		Field Size _____		Acres _____		Soil Test Date _____			
FSA Farm No. _____			FSA Tract No. _____						
Current Analysis	lb/ac ppm	Soil pH	Buffer pH	P	K	Ca	Mg	% OM	CEC
	Melich Bray								
Planned Crop		Yield Goal		Previous Crop		Nitrogen Credit			
Variety			Pop.		Planting Date				

## Tri-State Fertilizer Guide Nutrient Recommendations

N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	Lime	_____
<i>lb/acre</i>	<i>lb/acre</i>	<i>lb/acre</i>	<i>lb/acre</i>	<i>lb/acre</i>

## Planned Nutrient Applications

Product	Analysis	Rate (lb/Acre)	Planned Nutrient Application		
			N (lb/acre)	P <sub>2</sub> O <sub>5</sub> (lb/acre)	K <sub>2</sub> O (lb/acre)
Total Planned Nutrient Application					

# Field Record

Year \_\_\_\_\_

## Nutrient Application Record

Product	Analysis	Rate <i>(lb/Acre)</i>	Applied Nutrients		
			N (lb/acre)	P <sub>2</sub> O <sub>5</sub> (lb/acre)	K <sub>2</sub> O (lb/acre)
Total Nutrients Applied					

## Herbicide and Pesticide Application Record

Product	Applicator	Application Rate		Application Date	Temp °F	Wind Spd MPH
		Gal/Ac	Oz/Acre			

## Crop Yield Record

Date Harvested _____	Moisture _____	Test Weight _____
Total Harvested lb      ton      _____	Total Harvested Corrected for %M      _____	Yield Bu/Ac      Ton/Ac      _____

## Notes

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## Notes

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Total Harvested lb      ton _____	Total Harvested Corrected for %M _____	Yield Bu/Ac    Ton/Ac _____

## Notes

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# Reference Materials

This section is a compilation of various university fact sheets and bulletins in a concise order to educate agricultural producers on aspects of nutrient management. This section is ordered so that it begins with the very basics and advances into more complicated processes. This section also contains the Tri-State Fertility Guide which is considered the premiere guidance document in soil fertility recommendations at this time in Ohio.

Soil Sampling to Develop Nutrient Recommendations AGF-513-12

Interpreting Soil Test Reports AGF-514-12

Understanding Soil Tests for *Plant-Available* Phosphorus

Developing Phosphorus and Potassium Recommendations for  
Field Crops AGF-515-12

lbs per A Tri-State Supplemental

PPM Tri-State Supplemental

Soil Acidity and Liming for Agronomic Production AGF-505-07

Best Management Practices for Mitigating Phosphorus Loss  
from Soil AGF-509-09

Tri-State Fertility Guide E-2567

How to Sample Manure for Nutrient Analysis PM 1558





AGF-513-12

# Soil Sampling to Develop Nutrient Recommendations

**Greg LaBarge**  
Field Specialist  
Agronomic Systems

**Laura Lindsey**  
Assistant Professor  
Soybean and Small Grain Production

The goal of a comprehensive soil fertility program is to maximize economic return while minimizing potential off-site environmental impacts. A soil fertility program starts with a representative soil sample that is used to develop nutrient recommendations. Crops have basic nutritional requirements, which need to be met with the available soil nutrients. An inadequate nutrient supply will lead to yield losses. Nutrients in excess of crop demand are subject to loss at the edge of the field via surface runoff, tile drainage, or erosion under certain conditions. The nutrients lost at the edge of the field are an economic loss to the farmer and can have environmental costs such as excessive algae growth in streams and lakes.

To generate an accurate nutrient recommendation, there are several factors that should be considered in soil sampling. Make sure that . . .

1. the sample area is divided into representative areas based on yield potential and/or plant response to nutrients.
2. samples are taken and handled properly.
3. a reputable laboratory is selected to do the analysis.
4. the soil test results are understood.
5. nutrient recommendations are generated from studies calibrated to the same test that was used for the soil analysis.

Additionally, consideration should be given to the nutrient source, placement, and application timing. All nutrient sources applied—whether applied as commercial fertilizer or organic fertilizer (manure, compost,

biosolids, etc.) or applied with different timings (starter or broadcast)—should be credited in a comprehensive soil fertility program.

## Taking a Representative Soil Test

The reliability of soil testing depends on the farmer, the agricultural retailer, the certified crop advisor, or the Extension professional who examines the field history. Factors to consider include cropping patterns, use of organic nutrients, application methods of commercial fertilizers, drainage, crop yield response, and topography (Figure 1). These factors all affect the inherent fertility of the landscape.

Field history and topography can be used to divide the landscape into areas with similar crop response. Soil sampling is an averaging process, and soil cores should be taken so that the properties of all cores making up a composite sample are as similar as possible. Even after

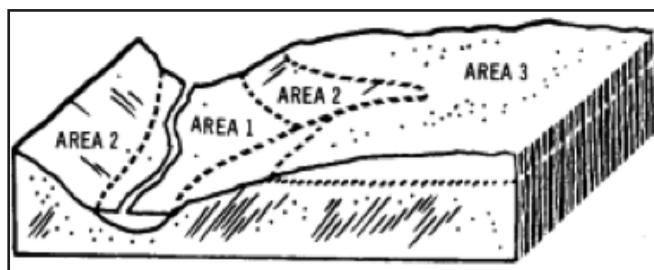


Figure 1. Area 1 is bottom land. Area 2 is slope. Area 3 is level upland. Sample each area separately.

careful consideration to the field landscape and variability, no individual sample zone should represent more than 25 acres.

Over time, crop yield can have a large impact on soil fertility. When the same fertilizer application rate is used for an entire field, the highest fertility levels will generally occur in the lowest yielding areas of the field. Table 1 provides an example field where crop removal rates of nutrients were applied based on a whole-field corn grain yield average of 160 bushels per acre (bu/A). The field has two zones: a low-yielding (130 bu/A) and a high-yielding area (195 bu/A). With a uniform application rate over the entire field, changes in soil test levels in two areas over a 10-year period are shown.

<b>Table 1. Example of predicted phosphorus and potassium change over a 10-year period when fertilizer is applied annually at a uniform application rate.</b>						
	Whole field		Low-yielding area		High-yielding area	
Corn Yield (bu/A)	160		130		195	
	P <sub>2</sub> O <sub>5</sub> (lbs/A)	K <sub>2</sub> O (lbs/A)	P <sub>2</sub> O <sub>5</sub> (lbs/A)	K <sub>2</sub> O (lbs/A)	P <sub>2</sub> O <sub>5</sub> (lbs/A)	K <sub>2</sub> O (lbs/A)
Crop removal <sup>1</sup>	-59	-43	-48	-35	-72	-52
Fertilizer applied to whole field based on crop removal rates	59	43	59	43	59	43
Annual over (+) or under (-) application	0	0	+11	+8	-13	-9
Pounds to change soil test 1 ppm	20	8 <sup>2</sup>	20	8 <sup>2</sup>	20	8 <sup>2</sup>
Expected ppm change in soil test over 10 years <sup>3</sup>	0	0	+5	+10	-6	-11
<sup>1</sup> Crop removal is based on 0.37 lb P <sub>2</sub> O <sub>5</sub> and 0.27 lb K <sub>2</sub> O per bushel of corn grain. Removal rates are from <i>Tri-state Fertilizer Recommendations for Corn, Soybeans, Wheat, and Alfalfa</i> .						
<sup>2</sup> For K <sub>2</sub> O range of pounds to change soil test 1 ppm is 6–10 depending on cation exchange capacity.						
<sup>3</sup> Example calculation: Expected change in ppm soil test = ((Crop Removal + Fertilization) × 10 years) ÷ Pounds to change soil test 1 ppm. Phosphorous calculation for low-yielding area +5 = ((-48+59) × 10) ÷ 20.						

## Soil Sampling with Precision Agriculture

The use of Global Positioning System (GPS) technology, yield maps, digitized soil maps, and other data give spatial information to help divide the landscape for soil sampling. Systematic grid sampling and zone management are the two primary methods of dividing field areas for soil sampling using precision applications (Table 2). Systematic grid sampling defines sample points across a field at predetermined intervals. Zone management utilizes field yield maps, farmer knowledge of management history, and other data to divide the landscape into regions for soil sampling.

### Systematic Grid Sampling

Systematic grid sampling involves taking point samples at regular intervals across a field. Grid sizes that match up to spreader equipment widths have been used. A 360 × 360 foot grid results in a systematic sampling pattern for each 2.5 acres in a field. Soil samples are collected at each sample point within a 10-foot diameter circle, with two cores pulled from each quadrant, for a total of eight cores.

Results from the field sampling with a systematic grid soil test can then be used in geographic information software (GIS), which interpolates the results of soil samples across the landscape. This technique estimates the fertility areas in unsampled areas of the field through the use of geostatistical methods. Studies have concluded that the initial selection of sample number is more important in successfully reflecting actual fertility levels across the landscape than the statistical model used.

Grid sampling may be useful in fields where variability is expected but the field history is not well known, topography is uniform but differences in soil type occur, varied management patterns have been used in the past, or manure applications have occurred.

### Zone Management

Numerous other data layers added to the farmer's knowledge of the field can be used to define field zones with similar characteristics, thus reducing the total number of samples taken. Management zones are a better choice than grids when the operator has a long history of working with the field, topography varies, yield map data over time has defined high- and low-yielding areas, the soil type map represents yield zones, or other remote sensing data is available to overlay with operator experience to define yield patterns in a field.

Sample points should be taken randomly with 10–15 cores per sample area of up to 25 acres. Georeferenced sample points may give a better opportunity to compare

sample trends over time by returning to near the same point in future years. This can be beneficial to tracking soil fertility recommendation program effects on soil test levels over time.

<b>Systematic Grid Sampling</b>	<b>Zone Management Sampling</b>
<p><i>Strengths</i></p> <ul style="list-style-type: none"> <li>• Non-mobile nutrients P, K and pH</li> <li>• Soil test levels range from high to low</li> <li>• History of manure use</li> <li>• Small fields merged into large</li> <li>• Field history unknown</li> <li>• Identify hot spot/trouble spots</li> </ul>	<p><i>Strengths</i></p> <ul style="list-style-type: none"> <li>• Measure of mobile nutrients is primary concern</li> <li>• Relatively low rates of fertilizer used in recent years</li> <li>• Reduces number of samples taken and cost</li> <li>• No history of manure</li> <li>• Field history and additional information is known</li> </ul>
<p><i>Weaknesses</i></p> <ul style="list-style-type: none"> <li>• Grid size may need to vary based on degree of variability</li> <li>• Grid arbitrarily placed in field</li> <li>• Ignores field characteristics and soil properties</li> <li>• Fertility zone may not represent yield results</li> <li>• Higher number of samples taken</li> </ul>	<p><i>Weaknesses</i></p> <ul style="list-style-type: none"> <li>• Greater setup time in developing zones</li> <li>• More computer analysis</li> <li>• Knowledge of field is needed</li> </ul>

### Taking the Soil Cores

The accuracy of soil test results is greatly influenced by the soil sample collected. Preplanning soil sample collection procedures and care in sample collection can improve the reliability of a soil test. Here are some recommendations for collecting soil samples:

1. For a standard soil sample, take at least 15 sample cores from each field area of 25 acres or less into one composite sample. Follow a zigzag pattern over the sample area when zone sampling (Figure 2). If the field has a history of banded fertilizer applications, increase the number of samples to 20–25 cores.
2. Take all sample cores at the same depth. This has an influence on sample accuracy due to the volume of soil collected, and placement of nutrients in the soil profile. Most soil tests are calibrated using an 8-inch sampling depth, which corresponds to the plow depth. Management in no-till systems may benefit from a 0–2 inch sample for pH, especially

where pH-sensitive herbicides are used. Consult your local Extension professional for ridge till sampling suggestions, as they require a different strategy. An example of the effect of sampling depth on soil test results is shown in Table 3. Nutrient concentration tends to be lower at deeper soil depths due to a variety of factors. Sampling deeper in the soil profile would result in lower nutrient measurements while shallower sampling increases nutrient measurements.

3. Remove crop debris or residue off the soil surface prior to sampling.
4. Do not include cores from dead furrows, turn rows, old fence rows, fertilizer spill, lime stockpile, or other unusual areas.
5. Individual cores should be mixed thoroughly to form a composite sample. Moist cores should be crushed into aggregates approximately 1/8–1/4 inch in diameter for optimum mixing.
6. If the mixed sample is to be dried, drying should be done at temperatures no greater than 120°F (50°C).
7. Most laboratories provide sample containers. If sample bags are not available, use clean paper containers or bags. Identify samples through all stages of the sampling process.

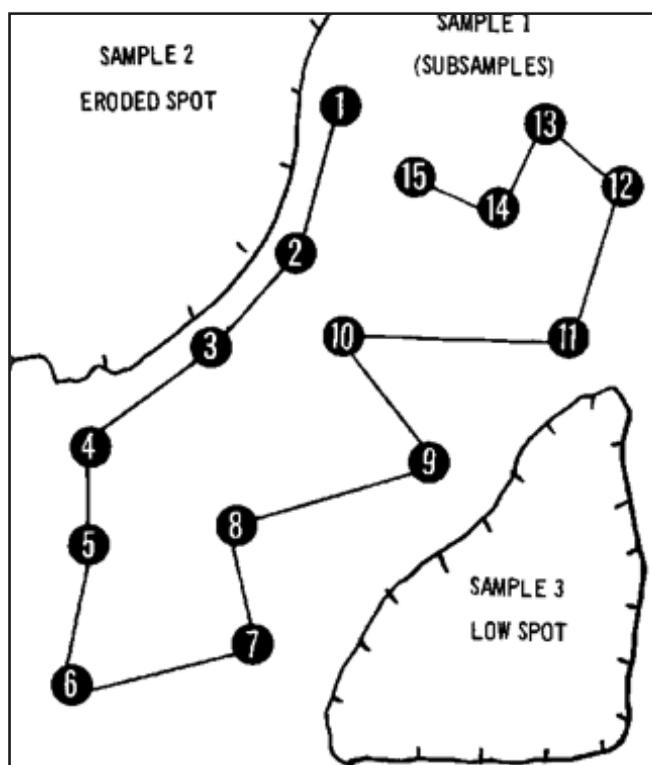


Figure 2. Zigzag pattern of taking soil samples in an area.

**Table 3. Effect of sampling depth on soil test results from 15 year no-till fields in Northwest Ohio.**

Depth	pH	P (ppm)	K (ppm)
Field 1			
0-8	6.7	59	169
0-4	6.5	66	201
4-8	6.9	47	130
8-12	7.2	17	113
Field 2			
0-8	6.8	15	112
0-4	6.8	16	136
4-8	6.6	10	86
8-12	6.9	4	77

### Sending the Sample to the Testing Lab

Standards for laboratory procedure and extraction solutions have been established by land-grant universities in the publication *Recommended Chemical Soil Test Procedures for the North Central Region*. It is a good practice to ask if the laboratory utilizes these procedures in their analysis process.

Quality control is an important method in testing the accuracy of sample results. Many laboratories participate in testing programs that provide blind samples for use in evaluating accuracy. One such program administered by the Soil Science Society of America is the North American Proficiency Testing Program (NAPT). A listing of participating labs can be found at <http://www.naptprogram.org/> (website verified on August 24, 2012). In addition to external programs, many labs have extensive internal checks they use to assure process quality.

Most laboratories provide very good testing services. In 2009, The Ohio State University conducted a blind sample survey of 13 soil testing laboratories that provide soil testing services to Ohio farmers. A standard soil sample was obtained from a total of 10 fields. Each laboratory was sent 3–5 subsamples from these 10 sites. Of the 13 laboratories, 12 laboratories reported sample results that were within an acceptable range.

Other factors to consider when choosing a laboratory are highlighted in the Ohio State fact sheet *Guidelines for Choosing a Soil-Testing Laboratory*, HYG-1133-99. Also, *Plant Nutrient Testing Laboratory Listing* provides a list of laboratory contacts for Ohio farmers.

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# Interpreting a Soil Test Report

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Soil test reports vary from laboratory to laboratory; however, they all report key results of pH, lime test index (LTI) or buffer pH, phosphorous, and potassium. These results are used to develop fertilizer recommendations. Other useful measures on the report, such as cation exchange capacity (CEC), organic matter, and base saturation, further define soil factors related to nutrient availability and holding capacity that should be considered as nutrient plans are developed. Desirable ranges to maximize crop production for each of the tests performed in a standard soil test are listed in Table 1. This table should serve as a general guideline to help determine if your soil is within the desirable range for each of the parameters tested. Thorough guidelines are given in *Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat, and Alfalfa*.

## Soil pH and Buffer pH

The level of active soil acidity is measured using soil pH. A pH value above 7.0 is alkaline; a value below 7.0 is acidic. A pH value of 7.0 is neutral. LTI or buffer pH is an indicator of the reserve (potential) acidity in the soil and is used to determine the quantity of lime needed to correct the pH of an acidic soil. In Ohio, subsoil pH varies based on soil parent material. Limestone parent materials found in western and northwestern Ohio may have a subsoil pH that is greater than 7.0 and contain as much as 50% calcium carbonate or its equivalent. Eastern and southeastern Ohio soils, developed mainly from sandstones and shale and subsoil, may have pH values as low as 5.0. The Ohio State University Extension fact sheet *Soil Acidity and Liming for Agronomic Production*, AGF-505-07, provides a detailed explanation of pH, buffer pH, and liming considerations in Ohio.

**Table 1. Common soil test result parameters with desirable ranges for corn and soybean production.**

Test Item	Desirable Ranges		Use of Measure
pH	6.3–7.0		Water pH (Neutral pH = 7.0)
Buffer pH -or- Lime Test Index	6.8–7.0 68–70		Used to determine lime requirement.
	When reported as pound per acre	When reported as part per million	
Phosphorous (P)	30–60	15–30	Used to make phosphorous recommendation.
Potassium (K)			Used to make potassium recommendation. CEC is used in determining desirable range.
CEC= 5 meq/100g	176–236	88–118	
CEC=10 meq/100g	200–260	100–130	
CEC=20 meq/100g	250–310	125–155	
CEC=30 meq/100g	300–360	150–180	
Calcium (Ca)	800–16,000	400–8,000	Levels less than 200 ppm are a concern. Ca deficiencies are rare in Ohio.
Magnesium (Mg)	150–2,000	75–1,000	Levels less than 20 ppm are a concern. Dolomitic limestone is a major source of Mg.

## Phosphorus, Potassium, Calcium, and Magnesium

Soil test values may be reported in parts per million (ppm) or pounds per acre (lb/ac). To convert from ppm to lb/ac, multiply ppm by two. Phosphorus, potassium, calcium, and magnesium soil test values are indicators of the relative available nutrient levels in the soil and not equal to the total amounts of these nutrients available in the soil for plant uptake. Phosphorus and potassium soil test values are correlated with crop yield response and fertilizer needs (i.e., as the soil test value increases, the need for supplemental fertilizer decreases).

Soil Test Variable	Typical Ranges
Organic Matter	1–6%
Cation Exchange Capacity (CEC)	meq/100g
Coarse Texture Soil (sand)	1–5
Medium Texture Soil (silt)	6–20
Fine Texture Soil (clay)	21–30 or more
Base Saturation	
% Ca	40–80
% Mg	10–40
% K	1–5

Soil organic matter, CEC, and base saturation are other variables that are shown on the soil test report to quantify soil characteristics and help understand other qualitative factors associated with the area represented by the sample. Typical ranges for organic matter, CEC, and base saturation are shown in Table 2.

### Organic Matter

Tillage, parent material, crop productivity, and other management factors influence soil organic matter. Organic matter is important in nutrient holding capacity.

### Cation Exchange Capacity (CEC)

CEC measures the capacity of the soil to hold exchangeable cations (positively charged ions) and is reported as meq/100g of soil (meq = milliequivalents). Reports may also be reported as cmolc/kg of soil (cmolc = centimoles of charge).

One cmolc/kg is equal to one meq/100 g. Exchangeable cations include aluminum, hydrogen, calcium, magnesium, and potassium. The CEC depends largely on the amount and type of clay and the organic matter content. The higher the CEC value, the more cations the soil is able to hold, reducing the likelihood of leaching. It is not practical to attempt to increase the CEC of a soil by adding clay or organic matter. Liming an acid soil will slightly increase the effective CEC.

### Base Saturation: % Calcium, % Magnesium, and % Potassium

Base saturation is the extent to which the adsorption complex of a soil is saturated with exchangeable cations other than hydrogen or aluminum. It is expressed as a percentage of the total CEC. The calcium to magnesium ratio is calculated on the basis of percentage saturation of the soil CEC by both elements. This ratio should be considered when lime is added to the soil. If the Ca:Mg ratio is 1:1 or less (less Ca than Mg), a lower percentage magnesium limestone should be used. Agronomic crops grow over a wide range of ratios with the ideal ratio being about 6:1 to 10:1.

The magnesium to potassium ratio should be greater than 2:1. In other words, the percent base saturation of Mg should be at least two times the percent base saturation of K. High K frequently results in reduced uptake of Mg by plants. Therefore, to help prevent plant nutrient imbalance, additional Mg may be required to maintain an Mg:K ratio of at least 2:1. The greatest concern with this ratio is for grass hay production where forage produced on a field with less than 2:1 Mg:K ratio can result in grass tetany conditions.

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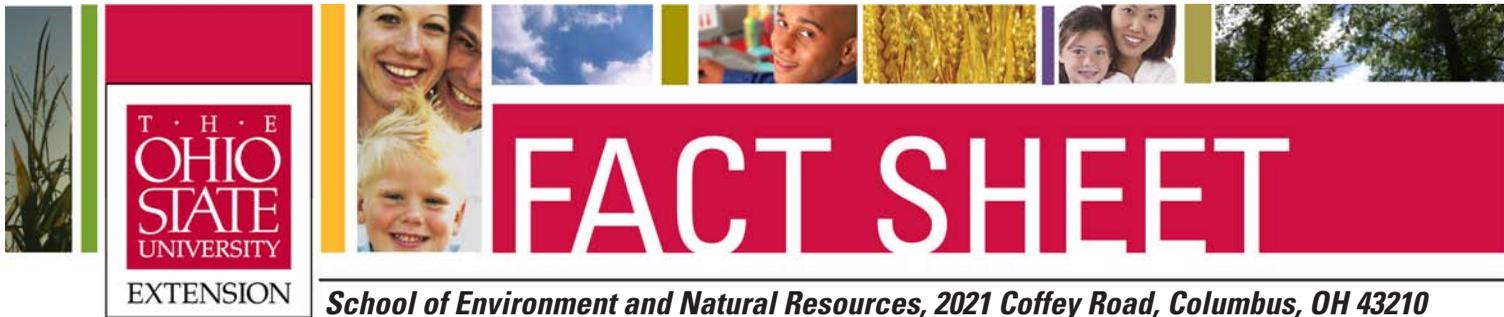
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# Understanding Soil Tests for *Plant-Available* Phosphorus

Maurice Watson (Emeritus Associate Professor) and Robert Mullen (Assistant Professor)

## Introduction

Phosphorus (P) is an essential element for all plants. Plants will grow slowly with low levels of P in the soil; however, for agricultural production purposes, the soil should provide a sufficient concentration of P for optimum plant growth. While this goal is easily stated, it is difficult to determine whether or not soil P is sufficient for optimum plant production. Consequently, much effort has been dedicated to the development of soil tests that determine the concentration of *plant-available* P, and whether or not that concentration is sufficient for optimum crop growth.

Soil testing has been practiced in one form or another for nearly 150 years. Modern soil testing was developed in the 1940s, and improvements in, and the use of, soil testing have increased in contemporary times. The soil P tests that are used today provide an indication of the level of soil P that is available to the plant. The tests do not determine the total concentration of P in the soil or even the actual concentration of available P, but provide an index measurement of the P that can be taken up by the plant. Many years of research are required to develop a valid soil P test. Soil P test methods for Ohio soils are described in the publication “Recommended Chemical Soil Test Procedures for the North Central Region” (1).

The purpose of this fact sheet is to discuss soil testing for *plant-available* P and the different soil tests used to determine soil test P. The majority of private laboratories in Ohio are using a soil test (Mehlich III) different from the one used to establish soil critical values (Bray-Kurtz

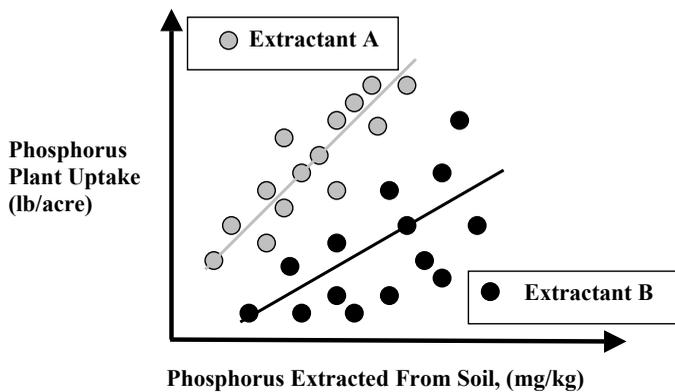
P1). To ensure that historical recommendations are still valid an adjustment will be presented to determine Bray-Kurtz P1 values from Mehlich III measurements.

## Development of a Soil Phosphorus Test

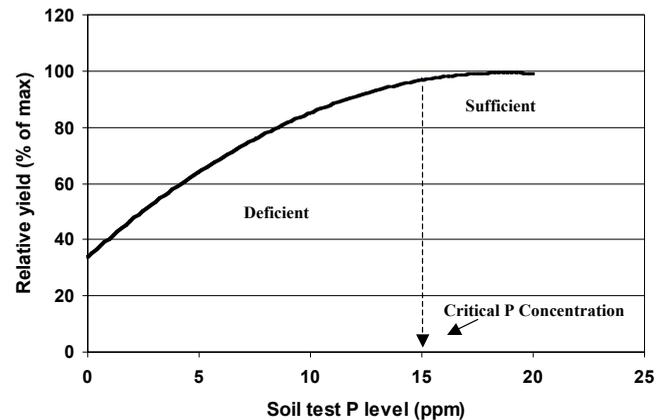
**Correlation**—A useful soil P test requires that the testing be accomplished in a timely and accurate manner. Consequently, specific chemical solutions, known as extractants, are used to extract P from the soil. Development of the tests requires two phases of research—a correlation phase and a calibration phase. Since a determination of the *total* amount of P in the soil is not meaningful to a growing plant, a correlation between the amount of P extracted by the chemical extractant and the amount of P taken up by the plant in question is necessary. This quantity of P is known as the *plant-available* P, and the better the correlation, the better the test. In the development of soil P tests, correlations between P extracted and P uptake by the plant (for numerous extractants) have been evaluated. The extractant showing the highest correlation is usually the one selected for the test. Ideally, many different soils will have been used in determining the best extractant.

Figure 1 shows the correlation of the amount of P taken up by a test plant with the amount of P extracted from the soil by two chemical extractants.

In this example correlation, Extractant A shows a better correlation with plant uptake of P than does Extractant B. Consequently, Extractant A would be the extractant that would be chosen for the soil P test. Although this



**Figure 1.** Correlation of two different extractions with plant P uptake.



**Figure 2.** Relationship between soil test P level and relative yield. This correlation is used to identify the critical soil P concentration.

example shows only two extractants, in the development of the soil P test many different extractants would have been evaluated.

Once the extractant (chemical solution) has been selected, it is essential to relate soil test level to relative crop yield so that a critical level can be identified (the soil test level where P is no longer limiting). Thus, soils can be categorized as deficient or sufficient in plant-available P depending on how the crop response relates to the concentration of P in the soil test extract. To do this, soil test P level is correlated with relative crop yield (expressed as a percent of maximum yield) to determine the ability of the extractant to relate the nutrient concentration to crop productivity. The data in Figure 2 indicate that the critical level is 15 ppm for this particular crop and soil test. Generally speaking, the nutrient in question is not considered limiting if the relative yield is 95% of maximum yield. The relationship will also allow an estimation of crop response relative to soils very low in plant-available P to those soils that are high in plant-available P. For example, the data in Figure 2 reveals that a soil test level of 5 ppm P would result in 63% of the maximum yield if P were not limiting putting this level in the deficient category. Thus, if the soil is in the P deficient category, the calibration will provide information on how much increase in crop yield might be expected with increases in the concentration of plant-available P upon the addition of P to the soil.

**Calibration and Interpretation**—In order to determine the relationship among soil P test results, phospho-

rus fertilizer application rate, and plant response<sup>1</sup>, research is carried out over many years and for many different soils for crops of interest. Recommended fertilizer P rates based on the soil tests can also be identified by conducting field work with a range of P fertilizer rates applied at various soil test levels. For example, Figures 3a and 3b show the fertilizer rate response to P at two different soil test levels (5 and 10 ppm respectively). This calibration would be repeated over as wide a range of soil test levels and conditions as possible. Thus, both the interpretation of the soil P test and the fertilizer P recommendation are established with the calibration. Notice that in Figure 3b (compared to Figure 3a) the response to fertilizer P is much less dramatic because the soil test level is closer to the established critical concentration.

## Recommended Soil Phosphorus Tests

**Bray-Kurtz P1 Test**—The Bray-Kurtz P1 test (often referred to as the Bray-P1 test) was developed in 1945 at the University of Illinois by Dr. Bray and Dr. Kurtz (2). The test's extractant is a dilute hydrochloric acid and ammonium fluoride solution. It is recommended for neutral and acid soils ( $\text{pH} \leq 7.0$ ), but not for alkaline soils ( $\text{pH} > 7.0$ ). The correlation between P uptake by the plant and the P concentration in the extractant ranges from 0.74 to 0.94 for soils of the North Central Region of the United States (3). The detection limit of this test is 1.0 part per million (dry soil basis) with a reproducibility of 10%. This test has

<sup>1</sup>This relationship is often termed the "calibration relationship."

been approved by the USDA's North Central Regional Soil Testing Research Committee for the acid/neutral soils of the North Central Region of the United States (1). Phosphorus fertilizer recommendations for crops grown on Ohio soils are based on this test.

**Mehlich-3 Test**—The Mehlich-3 test was developed by Adolph Mehlich in 1984 (4). It was a modification of previous Mehlich tests for the acid soils of North Carolina. The colorimetric version of the test has been approved by the USDA's North Central Regional Soil Testing Research Committee number 13 (NCR-13) for the acid/neutral soils of the North Central Region of the United States (1). It has not been approved by the NCR-13 committee for alkaline soils. The Mehlich-3 extracting solution consists of multiple chemical solutions: acetic acid, ammonium nitrate, ammonium fluoride, nitric acid and the chelate, EDTA. The detection limit of this test is 1.0 part per million (dry soil basis) with a reproducibility of 10%. The correlation between the amount of P extracted and plant uptake of P ranges from 0.83 to 0.99 for North Central U.S. soils. With the development of Inductively Coupled Plasma Spectroscopy (ICP) instrumentation, it was found that not only the concentrations of plant-available P in the Mehlich-3 extracting solution could be determined, but also the concentration of plant-available potassium (K) and other nutrients could possibly be measured at the same time.

**Olsen Test**—The Olsen test (often referred to as the bicarbonate test) was developed for the alkaline soils of Colorado by Drs. Olsen, Cole, Watanabe, and Dean in 1954 (5). The extracting solution is a solution of weak

sodium bicarbonate. The correlation between the amount of P extracted from the soil with the P taken up by the plant ranges from 0.73 to 0.96 for alkaline soil conditions (3). It is approved by the NCR-13 committee for alkaline soils (1).

### Comparison between the Bray-Kurtz P1 and Mehlich-3 Tests

Because of the economy and versatility of an ICP instrument, many soil testing laboratories have adopted the Mehlich-3 extractant for simultaneously determining the concentrations of plant-available soil P and K. However, Mallarino and others have shown that greater P concentrations are obtained from soils with the Mehlich-3-ICP method compared to the Bray-Kurtz P1-colorimeter method or the Mehlich-3-colorimeter method (6,7,8,9). Studies by Mallarino on Iowa soils showed that the Bray-Kurtz P1-colorimetric and the Mehlich-3-colorimetric soil P tests compared favorably in measuring plant-available P (6). The average P concentration of 59 Iowa soils was 17 parts per million (ppm) for the Bray-Kurtz P1 test and 19 ppm for the Mehlich-3 colorimetric test. However, Mallarino's work showed an average P concentration of 31 ppm with the Mehlich-3-ICP for the same soils. His studies showed that the absolute or relative differences between the Mehlich-3-ICP and the Bray-Kurtz P1-colorimeter methods were not highly correlated with the soil P level. Field calibration work on Iowa soils have shown that the Mehlich-3-ICP test has a similar capacity to the Mehlich-3 and Bray-Kurtz P1 colorimetric tests to predict

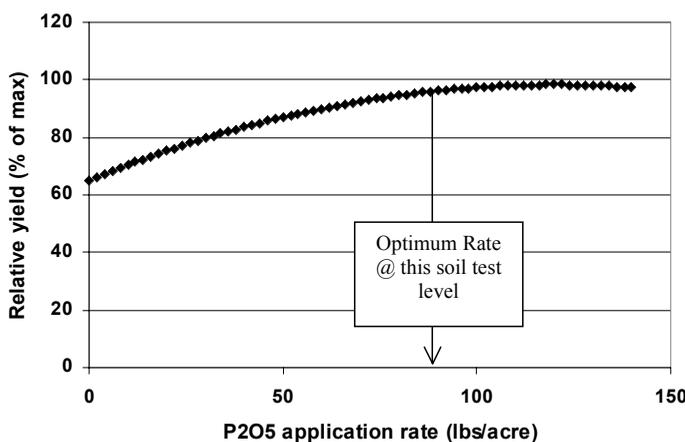


Figure 3a. Crop response (measured as relative yield) to applied P fertilizer for a soil with a soil test level of 5 ppm.

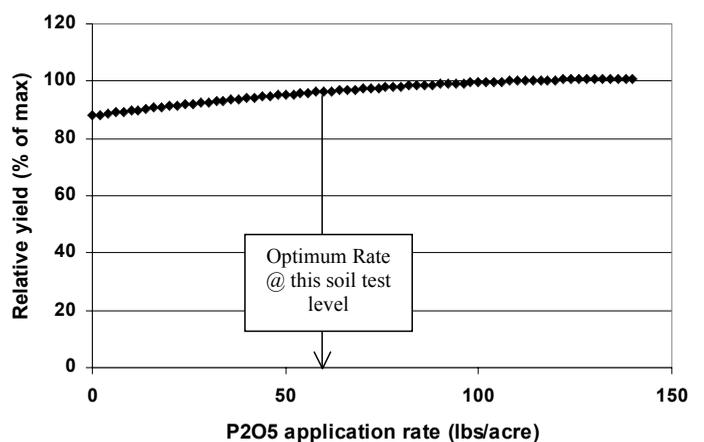


Figure 3b. Crop response (measured as relative yield) to applied P fertilizer for a soil with a soil test level of 10 ppm.

crop response to P. However, the critical P concentrations defined by Mehlich-3-ICP test was greater than that for the Mehlich-3 and Bray-Kurtz P1 colorimetric tests. In Mallarino's study the critical P concentration ranged from 20 to 32 ppm for the Mehlich 3-ICP compared to 16 to 21 ppm for the Mehlich-3 colorimetric test and 13 to 20 ppm for the Bray-Kurtz P1 colorimetric test (6).

Because of high research expense, field calibration with the Mehlich-3-ICP method for Ohio soils has not been performed to date. Since the fertilizer recommendations for crops grown in Ohio soils are based on the Bray-Kurtz P1-colorimetric method and many soil testing laboratories are using the Mehlich-3-ICP method, the question is how can Mehlich-3-ICP test results be used for making P fertilizer recommendations for Ohio soils?

Laboratory research was conducted by Eckert and Watson to investigate the relationship between the Mehlich-3-ICP and the Bray-Kurtz P1-colorimetric methods on Crosby and Hoytville soils of Ohio (7). These soils are extensive and used mainly for corn and soybean production. The comparison of the data for the two methods revealed a linear correlation of 0.90 with the Mehlich-3-ICP P concentration being greater than that determined with the Bray-Kurtz P1-colorimetric method. The average P concentration of the combine Crosby and Hoytville soils was 30 ppm for the Mehlich-3-ICP method and 17 ppm for the Bray-Kurtz P1-colorimetric method. In order to utilize the P fertilization recommendations, which are based on the Bray-Kurtz P1-colorimetric method, the Mehlich-3-ICP values should be adjusted to Bray-Kurtz P1-colorimetric values as determined by the linear regression between the two methods.

The adjustment is:

$$\text{Bray-Kurtz P1-colorimetric value} = -8.08 + 0.832(\text{Mehlich-3-ICP value})$$

Work by Pittman, Zhang, and Schroder obtained a similar relationship for a comparison between Mehlich-

3-ICP and Mehlich-3-colorimeter methods where a field calibration involving crop response for Oklahoma soils was unavailable (9).

Thus, in lieu of field calibration information, the adjustment equation is practical in order to make appropriate P fertilizer recommendations for Ohio soils.

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# Developing Phosphorus and Potassium Recommendations for Field Crops

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Recommendations from soil test results are based on soil calibration studies that correlate soil test levels to crop yield response. In Ohio, this response curve data was used to develop *Extension Bulletin E-2567: Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat, and Alfalfa*, which was a coordinated effort of Michigan State University, The Ohio State University, and Purdue University. This fact sheet describes how to use a soil test result and tables in *Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat, and Alfalfa* to develop phosphorus and potassium nutrient recommendations. The nutrient recommendations are then developed into a fertilizer recommendation. This fact sheet does not provide the steps to determine a lime recommendation, but soil pH should be considered first in developing a nutrient plan since availability of many nutrients is pH-dependent. Soil pH and lime recommendation development are thoroughly covered in the Ohio State University Extension fact sheet *Soil Acidity and Liming for Agronomic Production*.

According to *Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat, and Alfalfa*, “Tri-state recommendations are designed to provide adequate nutrition

for the crop, and to create or maintain a soil capable of providing sufficient nutrients without fertilizer addition for one or more years.” The tri-state fertilizer recommendation philosophy for phosphorus and potassium follows a buildup and maintenance approach as opposed to a sufficiency approach. If a nutrient is below the critical soil test level, fertilizer is annually applied until the soil is capable of supplying the nutrient required by the crop (buildup stage). Once soil test values reach the critical soil test level, a maintenance approach is used, where nutrients removed with annual crop production are replaced through fertilizer applications. When soil test levels are above the maintenance limit, low or no fertilizer is recommended to drawdown the soil test level. It is important to note that fertilizer recommendations developed by soil test laboratories or agricultural retailers may or may not be based on *Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat, and Alfalfa* since there is no requirement to use this criterion. Check with the recommendation provider for the standard used in developing fertilizer recommendations they provide.

## Steps to Develop Phosphorus and Potassium Fertilizer Recommendations

In this example, a one-year fertilizer recommendation for grain corn will be developed using soil test results shown in Table 1 and the desirable nutrient ranges shown in Table 2; Tables 13 and 18 from *Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat, and Alfalfa* will also be used. Appendix A contains a blank template for future fertilizer calculations.

Follow these steps to develop a phosphorus and potassium fertilizer recommendation:

1. Determine the crop yield potential by averaging the yield of the last five years, not including the highest and lowest yield. In this example, the corn grain yield potential is 140 bushels/acre.
2. Use soil test results from representative soil sampling (Table 1) to compare with the desirable range for phosphorus and potassium shown in Table 2. Write the soil test results in the table column named "Soil Test Value" as shown in the Table 2 example. Compare soil test values to the desirable range.

Phosphorous is reported as 23 ppm and is in the middle of the range with the critical level of 15 ppm and maintenance limit of 30 ppm. In addition to the potassium soil test result, cation exchange capacity (CEC) is also used to develop the potassium recommendation. For this example, the CEC is 10 and the soil test is 72 ppm. For a soil with a CEC of 10 ppm, the critical level is 100 ppm and the maintenance limit is 130 ppm.

**Table 1. Example soil test results.**

Field	OM (%)	P (ppm)	K (ppm)	MG (ppm)	Ca (ppm)	Soil pH	Buffer pH	CEC (meq/100g)
Example 1	3.8	23	72	295	1550	6.8	7.0	10

**Table 2. Example nutrient and fertilizer recommendation worksheet with desirable pH and nutrient ranges.**

Test Item	Desirable Ranges		Soil Test Value	Lime Recommendation
pH	6.3–7.0		6.8	---
Buffer pH -or- Lime Test Index	6.8–7.0  68–70		7.0	<i>No lime needed</i>
Nutrient	Reported as pound per acre	Reported as part per million (ppm)	Reported as ppm	Nutrient recommendation (lb/acre)
Phosphorous (P)	30–60	15–30	23	50 P <sub>2</sub> O <sub>5</sub>
Potassium (K)				
CEC= 5 meq/100g	176–236	88–118	---	---
<b>CEC=10 meq/100g</b>	<b>200–260</b>	<b>100–130</b>	72	95 K <sub>2</sub> O
CEC=20 meq/100g	250–310	125–155	---	---
CEC=30 meq/100g	300–360	150–180	---	---
Calcium (Ca)	800–16,000	400–8,000	1,550	---
Magnesium (Mg)	150–2,000	75–1,000	295	---

To develop the phosphorus recommendation, use Table 13 from *Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat, and Alfalfa*. Locate the yield potential on the top of the chart and the soil test result on the left-hand side of the chart. In this example, yield potential is 140 bushels/acre and soil test phosphorus is 23 ppm, which falls in the 15–30 ppm range. The resulting phosphorus recommendation is 50 pounds  $P_2O_5$ /acre.

Table 13.  
**PHOSPHATE ( $P_2O_5$ ) RECOMMENDATIONS FOR CORN.**

Soil test	Yield potential — bu per acre				
	100	120	140	160	180
ppm (lb/acre)	— lb $P_2O_5$ per acre —				
5 (10) <sup>1</sup>	85	95	100	110	115
10 (20)	60	70	75	85	90
15-30 (30-60) <sup>2</sup>	35	45	50	60	65
35 (70)	20	20	25	30	35
40 (80)	0	0	0	0	0

<sup>1</sup> Values in parentheses are lb/acre.  
<sup>2</sup> Maintenance recommendations are given for this soil test range.

The phosphorus recommendation in this example is based on the “maintenance equation” given in *Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat, and Alfalfa*. Here is the maintenance equation for phosphorus:

$$\text{lb } P_2O_5/\text{acre to apply} = YP \times CR$$

YP is the yield potential in bushels per acre for corn grain and CR is the crop removal in pounds of  $P_2O_5$  per bushel. Corn grain removal for phosphorus is 0.37 pound  $P_2O_5$  per bushel. The equations for buildup, maintenance, and drawdown recommendations are provided in *Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat, and Alfalfa*.

To develop the potassium recommendation, use Table 18 of *Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat, and Alfalfa*. Locate the yield potential on the top of the chart and the soil test on the left-hand side of the chart. In this example, yield potential was 140 bushels/acre and soil test potassium was 72 ppm, which is below the maintenance range. The CEC of this soil is 10 meq/100g (shown in Table 1). The potassium recommendation is 95 pounds of  $K_2O$  per acre, which is based on crop removal plus additional potassium to build potassium soil test levels.

Table 18.  
**POTASH ( $K_2O$ ) RECOMMENDATIONS FOR CORN AT VARIOUS YIELD POTENTIALS, CATION EXCHANGE CAPACITIES (CEC's) AND SOIL TEST LEVELS.**

Yield potential	bu/acre	100	120	140	160	180
Soil test K	— lb $K_2O$ per acre —					
ppm (lb/acre)	CEC	— 5 meq/100g —				
25 (50) <sup>1</sup>		125	130	135	140	145
50 (100)		95	100	105	110	115
75 (150)		65	70	75	80	85
88-118 (175-235) <sup>2</sup>		45	50	60	65	70
130 (260)		20	20	20	25	25
140 (280)		0	0	0	0	0
	CEC	— 10 meq/100g —				
25 (50)		160	165	170	175	180
50 (100)		120	125	135	140	145
75 (150)		85	90	95	100	105
100-130 (200-260) <sup>2</sup>		45	50	60	65	70
140 (280)		25	25	30	30	35
150 (300)		0	0	0	0	0

The potassium recommendation in this example is based on the “buildup equation” given in *Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat, and Alfalfa*. Here is the buildup equation for potassium:

$$\text{lb } K_2O/\text{acre to apply} = [(CL - STL) \times (1 + (0.05 \times CEC))] + (YP \times CR) + 20$$

CL is the critical level (100 ppm at a CEC of 10), STL is the soil test level in ppm, CEC is the cation exchange capacity in meq/100g, YP is the yield potential in bushels per acre for corn grain, and CR is the crop removal in pounds of  $K_2O$  per bushel. Crop removal is 0.27 pound of  $K_2O$  per bushel of grain corn. The equations for buildup, maintenance, and drawdown recommendations are provided in *Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat, and Alfalfa*.

A spreadsheet to calculate phosphorous, potassium, and lime recommendations for multiple field and up to a three year crop rotation can be downloaded at <http://agcrops.osu.edu/specialists/fertility/fertility-fact-sheets-and-bulletins>.

To calculate fertilizer application rates, first consult the guaranteed analysis of the commercial fertilizer being used. Commercial fertilizer sources are required by law to give the guaranteed analysis of the fertilizer. The three values given on fertilizer bags are nitrogen, phosphorus, and potassium (N-P-K). Additional nutrients such as sulfur or micronutrients may also be given after these three initial values.

Nitrogen is given in pounds of N per 100 pounds of product, phosphorus is given in pounds of P<sub>2</sub>O<sub>5</sub> per 100 pounds of product, and potassium is given in pounds of K<sub>2</sub>O per 100 pounds of product. For this example, 11-52-0 is the fertilizer source to meet the phosphorus requirement and 0-0-60 is the fertilizer source to meet the potassium requirement.

From the guaranteed analysis, the actual amount of fertilizer product to apply needs to be calculated. Additional nutrients that will be applied need to be calculated (i.e., the fertilizer 11-52-0 used to meet phosphorus requirements also contains nitrogen). Pounds of fertilizer to apply per acre and additional nutrient application calculations are shown in Table 3.

## References

LaBarge, Greg and Laura Lindsey. 2012. *Interpreting a Soil Test Report, AGF-514-12*. Ohio State University Extension. Available at [http://ohioline.osu.edu/agffact/pdf/Interpreting\\_a\\_Soil\\_Test\\_Report\\_AGF-514-12.pdf](http://ohioline.osu.edu/agffact/pdf/Interpreting_a_Soil_Test_Report_AGF-514-12.pdf). (verified 29 Oct. 2012).

Mullen, Robert, Edwin Lentz, and Maurice Watson. 2007. *Soil Acidity and Liming for Agronomic Production, AGF-505-07*. Ohio State University Extension. Available at <http://agcrops.osu.edu/specialists/fertility/fertility-fact-sheets-and-bulletins/AGF505.pdf>. (verified 29 Aug. 2012).

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**Table 3. Pounds of fertilizer to apply per acre to meet phosphorus and potassium requirements and additional nutrient application calculation.**

Nutrient	Nutrient Recommendation (lb/acre)	Fertilizer Source	Amount of fertilizer to apply (lb/acre) <sup>1</sup>	Other nutrients added <sup>2</sup>
P <sub>2</sub> O <sub>5</sub>	50	11-52-0	96	11 lb N/acre
K <sub>2</sub> O	95	0-0-60	158	---

<sup>1</sup>Amount of fertilizer to apply = (nutrient recommendation) ÷ (fertilizer analysis/100). For phosphorus in this example, 50 ÷ 0.52 = 96, which means 96 lb of 11-52-0 needs to be applied to meet the phosphorus requirement of 50 lb P<sub>2</sub>O<sub>5</sub>/acre.

<sup>2</sup>Other nutrients added = (pounds of fertilizer/acre) x (fertilizer analysis/100). When 11-52-0 is applied, nitrogen is also applied. When 96 lb/acre of 11-52-0 is applied, 11 lb N/acre is applied accordingly (i.e., 96 x 0.11 = 11).

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## Appendix A. Nutrient and Fertilizer Recommendation Worksheet

Test Item	Desirable Ranges		My Soil Test Value	Nutrient Recommendation
pH	6.3–7.0			
Buffer pH -or- Lime Test Index	6.8–7.0  68–70			
Nutrient	Reported as pound per acre	Reported as part per million (ppm)	Reported as _____	Recommendation (lb/acre)
Phosphorous (P)	30–60	15–30		
Potassium (K)				
<i>CEC= 5 meq/100g</i>	<i>176–236</i>	<i>88–118</i>		
<i>CEC=10 meq/100g</i>	<i>200–260</i>	<i>100–130</i>		
<i>CEC=20 meq/100g</i>	<i>250–310</i>	<i>125–155</i>		
<i>CEC=30 meq/100g</i>	<i>300–360</i>	<i>150–180</i>		
Calcium (Ca)	800–16,000	400–8,000		
Magnesium (Mg)	150–2,000	75–1,000		

Nutrient	Nutrient Recommendation (lb/acre)	Fertilizer Source	Amount of fertilizer to apply (lb/acre) <sup>1</sup>	Other nutrients added <sup>2</sup>

<sup>1</sup>Pounds of fertilizer per acre = (nutrient recommendation) ÷ (fertilizer analysis/100).

<sup>2</sup>Other nutrients added = (pounds of fertilizer/acre) x (fertilizer analysis/100).

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## Phosphorous Fertility Recommendations for Soil Testing Reported in pounds per acre (lbs/A)

### *Fertilizer rate recommendations based on Tri-state Fertilizer Recommendations*

The purpose for a soil sample should be to generate a fertilizer recommendation. The Tri-State Fertilizer recommendations were generated using calibration studies with a Bray P1 soil test result. The tables can be used for levels reported from both a Bray P1 or Mehlich III-IPC equivalent result. Farmers need to look on the soil test report to check the laboratory method reported in association with the Phosphorus soil test level. If the method used to report is unclear then a call to the laboratory can clear up any confusion. For a complete discussion of the comparison of phosphorus testing see [http://agcrops.osu.edu/specialists/fertility/fertility-fact-sheets-and-bulletins/Soil\\_Tests.pdf](http://agcrops.osu.edu/specialists/fertility/fertility-fact-sheets-and-bulletins/Soil_Tests.pdf)

Fertilizer recommendation tables on Tables 13 through 17 of the original publication have been updated. The tables shown below can be substituted in the original publication. The tables are updated to reflect the higher productivity of today's production systems utilizing the equations (page 11) from the Tri State Fertilizer Recommendations publication can be found at: <http://ohioline.osu.edu/e2567/index.html>. The philosophy of these recommendations can be found in the original publication on pages 10-12.

**Table 13. Fertilizer (P<sub>2</sub>O<sub>5</sub>) Recommendations for Corn. (adapted from Tri-state Fertilizer Recommendations for Corn, Soybeans, Wheat and Alfalfa)**

Soil Test Level and Method		Realistic Yield Goal (bu/acre)					
		120	145	170	200	225	250
Bray P1 Colorometric	Mehlich III-ICP	lbs P <sub>2</sub> O <sub>5</sub> /acre recommended					
lbs/A	lbs/A						
10	32	95	105	115	125	135	145
20	44	70	80	90	100	110	120
30-60	56-92	45	55	65	75	85	95
70	104	20	25	30	40	45	50
80	116	0	0	0	0	0	0

**Table 14. Fertilizer (P<sub>2</sub>O<sub>5</sub>) Recommendations for Corn Silage. (adapted from Tri-state Fertilizer Recommendations for Corn, Soybeans, Wheat and Alfalfa)**

Soil Test Level and Method		Realistic Yield Goal (Tons/acre)					
		20	22	24	26	28	30
Bray P1 Colorometric	Mehlich III-ICP	lbs P <sub>2</sub> O <sub>5</sub> /acre recommended					
lbs/A	lbs/A						
10	32	115	125	130	135	140	150
20	44	90	100	105	110	115	125
30-60	56-92	65	75	80	85	90	100
70	104	35	40	40	45	45	50
80	116	0	0	0	0	0	0

**Table 15. Fertilizer (P<sub>2</sub>O<sub>5</sub>) Recommendations for Soybean. (adapted from Tri-state Fertilizer Recommendations for Corn, Soybeans, Wheat and Alfalfa)**

Soil Test Level and Method		Realistic Yield Goal (bu/acre)					
		30	40	50	60	70	80
Bray P1 Colorometric	Mehlich III-ICP	lbs P <sub>2</sub> O <sub>5</sub> /acre recommended					
lbs/A	lbs/A						
10	32	75	80	90	100	105	115
20	44	50	55	65	75	80	90
30-60	56-92	25	30	40	50	55	65
70	104	10	15	25	25	30	35
80	116	0	0	0	0	0	0

**Table 16. Fertilizer (P<sub>2</sub>O<sub>5</sub>) Recommendations for Wheat (Grain only).  
(adapted from Tri-state Fertilizer Recommendations for Corn, Soybeans,  
Wheat and Alfalfa)**

Soil Test Level and Method		Realistic Yield Goal (bu/acre)					
		50	65	80	95	110	125
Bray P1 Colorometric	Mehlich III-ICP	lbs P <sub>2</sub> O <sub>5</sub> /acre recommended					
lbs/A	lbs/A						
30	56	80	90	100	110	120	130
40	68	55	65	75	85	95	105
50-80	80-116	30	40	50	60	70	80
90	128	15	20	25	30	35	40
100	158	0	0	0	0	0	0

**Table 17. Fertilizer (P<sub>2</sub>O<sub>5</sub>) Recommendations for Alfalfa (adapted from  
Tri-state Fertilizer Recommendations for Corn, Soybeans, Wheat and  
Alfalfa)**

Soil Test Level and Method		Realistic Yield Goal (Tons/acre)					
		5	6	7	8	9	10
Bray P1 Colorometric	Mehlich III-ICP	lbs P <sub>2</sub> O <sub>5</sub> /acre recommended					
lbs/A	lbs/A						
30	56	115	130	140	155	165	180
40	68	90	105	115	130	140	155
50-80	80-116	65	80	90	105	115	130
90	128	35	40	45	50	60	65
100	158	0	0	0	0	0	0

For computer generated recommendations the following equations were used to generate the fertilizer recommendations in the tables.

**BUILDUP EQUATION**

for P:  $\text{lb P}_2\text{O}_5/\text{A to apply} = [(\text{CL} - \text{STL}) \times 5] (\text{YP} \times \text{CR})$   
for K:  $\text{lb K}_2\text{O}/\text{A to apply} = [(\text{CL} - \text{STL}) \times (1 + (0.05 \times \text{CEC}))] + (\text{YP} \times \text{CR}) + 20$

**MAINTENANCE EQUATION**

for P:  $\text{lb P}_2\text{O}_5/\text{A to apply} = \text{YP} \times \text{CR}$   
for K:  $\text{lb K}_2\text{O}/\text{A to apply} = (\text{YP} \times \text{CR}) + 20$  (for non-forage crops)

**DRAWDOWN EQUATION**

for P:  $\text{lb P}_2\text{O}_5/\text{A to apply} = (\text{YP} \times \text{CR}) - [(\text{YP} \times \text{CR}) \times (\text{STL} - \text{CL} - 15)]/10]$   
for K:  $\text{lb K}_2\text{O}/\text{A to apply} = (\text{YP} \times \text{CR}) + 20 - [((\text{YP} \times \text{CR}) + 20) \times (\text{STL} - (\text{CL} + 30))]/20]$  (for non-forage crops)

**Note:** The K maintenance and drawdown equation for forages, including corn silage, is

$$\text{lb K}_2\text{O}/\text{A to apply} = [(\text{YP} \times \text{CR}) + 20] - [((\text{YP} \times \text{CR}) + 20) \times (\text{STL} - \text{CL})/50]$$

where:

CL = critical soil test level (ppm)

STL = existing soil test level (ppm)

YP = crop yield potential (bu per acre for grains, tons per acre for forages)

CR = nutrient removed per unit yield (lb/unit)

CEC = soil cation exchange capacity (meq/100g)

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## Phosphorous Fertility Recommendations for Soil Testing Reported in parts per million (PPM) or mg/kg

### *Fertilizer rate recommendations based on Tri-state Fertilizer Recommendations*

The purpose for a soil sample should be to generate a fertilizer recommendation. The Tri-State Fertilizer recommendations were generated using calibration studies with a Bray P1 soil test result. The tables can be used for levels reported from both a Bray P1 or Mehlich III-IPC equivalent result. Farmers need to look on the soil test report to check the laboratory method reported in association with the Phosphorus soil test level. If the method used to report is unclear then a call to the laboratory can clear up any confusion. Reporting in PPM or kg/mg are equivalent unit measures. For a complete discussion of the comparison of phosphorus testing see [http://agcrops.osu.edu/specialists/fertility/fertility-fact-sheets-and-bulletins/Soil\\_Tests.pdf](http://agcrops.osu.edu/specialists/fertility/fertility-fact-sheets-and-bulletins/Soil_Tests.pdf)

Fertilizer recommendation tables on Tables 13 through 17 of the original publication have been updated. The tables shown below can be substituted in the original publication. The tables are updated to reflect the higher productivity of today's production systems utilizing the equations (page 11) from the Tri State Fertilizer Recommendations publication can be found at: <http://ohioline.osu.edu/e2567/index.html>. The philosophy of these recommendations can be found in the original publication on pages 10-12.

**Table 13. Fertilizer (P<sub>2</sub>O<sub>5</sub>) Recommendations for Corn. (adapted from Tri-state Fertilizer Recommendations for Corn, Soybeans, Wheat and Alfalfa)**

Soil Test Level (expressed as P) and Method		Realistic Yield Goal (bu/acre)					
		120	145	170	200	225	250
Bray P1 Colorometric	Mehlich III-ICP	lbs P <sub>2</sub> O <sub>5</sub> /acre recommended					
PPM	PPM						
5	16	95	105	115	125	135	145
10	22	70	80	90	100	110	120
15-30	28-46	45	55	65	75	85	95
35	52	20	25	30	40	40	45
40	58	0	0	0	0	0	0

**Table 14. Fertilizer (P<sub>2</sub>O<sub>5</sub>) Recommendations for Corn Silage. (adapted from Tri-state Fertilizer Recommendations for Corn, Soybeans, Wheat and Alfalfa)**

Soil Test Level (expressed as P) and Method		Realistic Yield Goal (Ton/acre)					
		20	22	24	26	28	30
Bray P1 Colorometric	Mehlich III-ICP	lbs P <sub>2</sub> O <sub>5</sub> /acre recommended					
PPM	PPM						
5	16	115	125	130	135	140	150
10	22	90	100	105	110	115	125
15-30	28-46	65	75	80	85	90	100
35	52	35	40	40	45	45	50
40	58	0	0	0	0	0	0

**Table 15. Fertilizer (P<sub>2</sub>O<sub>5</sub>) Recommendations for Soybean. (adapted from Tri-state Fertilizer Recommendations for Corn, Soybeans, Wheat and Alfalfa)**

Soil Test Level (expressed as P) and Method		Realistic Yield Goal (bu/acre)					
		30	40	50	60	70	80
Bray P1 Colorometric	Mehlich III-ICP	lbs P <sub>2</sub> O <sub>5</sub> /acre recommended					
PPM	PPM						
5	16	75	80	90	100	105	115
10	22	50	55	65	75	80	90
15-30	28-46	25	30	40	50	55	65
35	52	10	15	20	25	30	35
40	58	0	0	0	0	0	0

**Table 16. Fertilizer (P<sub>2</sub>O<sub>5</sub>) Recommendations for Wheat (Grain only).  
(adapted from Tri-state Fertilizer Recommendations for Corn, Soybeans,  
Wheat and Alfalfa)**

Soil Test Level (expressed as P) and Method		Realistic Yield Goal (Ton/acre)					
		50	65	80	95	110	125
Bray P1 Colorometric	Mehlich III-ICP	lbs P <sub>2</sub> O <sub>5</sub> /acre recommended					
PPM	PPM						
15	28	80	90	100	110	120	130
20	34	55	65	75	85	95	105
25-40	40-58	30	40	50	60	70	80
45	64	15	20	25	30	35	40
50	79	0	0	0	0	0	0

**Table 17. Fertilizer (P<sub>2</sub>O<sub>5</sub>) Recommendations for Alfalfa (adapted from Tri-  
state Fertilizer Recommendations for Corn, Soybeans, Wheat and Alfalfa)**

Soil Test Level (expressed as P) and Method		Realistic Yield Goal (bu/acre)					
		5	6	7	8	9	10
Bray P1 Colorometric	Mehlich III-ICP	lbs P <sub>2</sub> O <sub>5</sub> /acre recommended					
PPM	PPM						
15	28	115	130	140	155	165	180
20	34	90	105	115	130	140	155
25-40	40-58	65	80	90	105	115	130
45	64	35	40	45	50	60	65
50	79	0	0	0	0	0	0

For computer generated recommendations the following equations were used to generate the fertilizer recommendations in the tables.

#### **BUILDUP EQUATION**

for P: lb P<sub>2</sub>O<sub>5</sub>/A to apply = [(CL - STL) x 5] (YP x CR)  
for K: lb K<sub>2</sub>O/A to apply = [(CL - STL) x (1 + (0.05 x CEC))] + (YP x CR) + 20

#### **MAINTENANCE EQUATION**

for P: lb P<sub>2</sub>O<sub>5</sub>/A to apply = YP x CR  
for K: lb K<sub>2</sub>O/A to apply = (YP x CR) + 20 (for non-forage crops)

#### **DRAWDOWN EQUATION**

for P: lb P<sub>2</sub>O<sub>5</sub>/A to apply = (YP x CR) - [(YP x CR) x (STL - CL - 15)]/10  
for K: lb K<sub>2</sub>O/A to apply = (YP x CR) + 20 - [(YP x CR) + 20] x (STL - (CL + 30))/20] (for non-forage crops)

**Note:** The K maintenance and drawdown equation for forages, including corn silage, is

lb K<sub>2</sub>O/A to apply [(YP x CR) + 20] - [(YP x CR) + 20] x (STL-CL)/50]

where:

CL = critical soil test level (ppm)  
STL = existing soil test level (ppm)  
YP = crop yield potential (bu per acre for grains, tons per acre for forages)  
CR = nutrient removed per unit yield (lb/unit)  
CEC = soil cation exchange capacity (meq/100g)

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# Extension FactSheet

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## Soil Acidity and Liming for Agronomic Production

Robert Mullen, Edwin Lentz, and Maurice Watson

Soil pH is an important consideration when producing any crop, and soil pH should be the first soil consideration when attempting to grow a plant. Soil pH affects soil microbial activity and populations, many soil chemical reactions, and nutrient availability; thus it is an important soil property to consider for maximum productivity.

pH is a measure of the hydrogen ( $H^+$ ) ion concentration in solution. Due to the way pH is calculated, the higher the hydrogen concentration, the lower pH becomes. A pH value below 7.0 is considered acid and, depending upon the soil pH and the crop being grown, may require neutralization to raise the soil pH. High concentrations of hydrogen in soil solution (low soil pH) may cause the release of soluble aluminum from soil minerals. Aluminum in soil solution binds with phosphorus (decreasing phosphorus availability

to plants) and inhibits root growth and development (limiting nutrient uptake). Low soil pH also limits the release of some nutrients from soil organic matter and reduces nitrogen fixation by legumes. However, soil does not have to be neutral (pH 7.0) to maximize nutrient uptake or crop production. For example, legumes require pH levels of 6.2 or higher, but corn can be productive in soils with pH levels as low as 6.0. Additional information on soil pH may be found in the *Ohio Agronomy Guide*.

### Causes of Soil Acidity

Soil parent material and the climate under which a soil was formed are important determinants of soil acidity. Soils that developed from parent materials low in carbonate minerals (calcium/magnesium carbonates) are usually acidic. Soils in eastern Ohio are derived mostly from sandstone and shale parent material that are low in carbonate minerals and are likely to be acidic. Soils of western Ohio are mainly derived from glacial deposits rich in calcitic (calcium carbonate) and dolomitic (calcium-magnesium carbonate) minerals and are less likely to be acidic (Ohio History Central, 2005). Soils that form under high rainfall (conditions like those in Ohio) are subject to extensive chemical weathering and leaching of basic cations that are replaced with  $H^+$  and other acidic cations ( $Al^{3+}$  and iron [ $Fe^{3+}$ ]). These basic cations include calcium ( $Ca^{2+}$ ), magnesium ( $Mg^{2+}$ ), potassium ( $K^+$ ), and sodium ( $Na^+$ ). Over time, this continuous removal of basic cations is faster than is their replacement from weathering minerals, resulting in acid soil conditions.



Figure 1. Photograph of typical aglime.

High yielding crops, applications of certain forms of nitrogen, and other agricultural practices also contribute to soil acidity. Roots of high-yielding grain and forage crops remove basic cations from the soil and release hydrogen into soil solution to maintain an ionic charge balance within the tissue. Ammonium-based fertilizers release hydrogen when oxidized to form nitrate, contributing to soil acidity. The amount of lime required to neutralize the acidity created by various nitrogen fertilizer materials is given in Table 1.

**Table 1.** Pounds of calcium carbonate equivalent lime needed to neutralize acidity produced by application of various nitrogen fertilizers (nitrogen rate of 100 lb N/A) (adapted from Havlin et al., 1999).

Fertilizer source	Fertilizer source application rate (lb/A)	Equivalent lbs of lime/A
Anhydrous ammonia (82-0-0)	122	180
Ammonium nitrate (34-0-0)	294	180
Ammonium sulfate (21-0-0)	476	540
Urea (46-0-0)	217	180
Monoammonium phosphate (MAP)	821	540
Diammonium phosphate (DAP)	476	360

## Soil Sampling and Testing to Determine Soil pH and Lime Requirement

Soil pH measurement is a routine analysis conducted on almost any soil sample submitted to a soil testing laboratory. For tilled soils, soil samples should be collected to a depth of 8 inches, and for no-till soils samples should be collected to a depth of 4 inches. Soil water content and resulting salt concentration at the time of soil sampling can affect pH measurements. Avoid collecting soil samples when the soil is excessively dry or wet. Soils sampled during a dry period may result in lower pH values, and conversely, soil samples collected during an excessively wet period may result in higher pH values. Because soil pH levels change slowly in a natural setting, soil analysis does not need to be conducted every year. Soil testing performed every two to four years should be adequate.

Soil pH measurement reveals the amount of active acidity (free hydrogen ions) in the soil solution and

whether or not lime should be applied. If the soil pH level is below the optimum for the desired crop, liming may be necessary (Table 2). In order to accurately determine the amount of lime necessary to neutralize soil acidity to the desired level, the buffering capacity of the soil must be measured. Buffer pH measurement reveals how much potential acidity needs to be neutralized by the lime. Potential acidity refers to the hydrogen and aluminum cations that are held by soil exchange sites. As buffer pH decreases, the amount of lime required to neutralize both active and potential acidity increases. Soils with an abundance of exchange sites (high buffering capacities) have a greater supply of  $H^+$  and  $Al^{3+}$  than soils with fewer exchange sites (low buffering capacities). Fine textured soils (clay) typically require higher rates of lime than coarse textured soils (sands). Soils that have high buffering capacities also require less frequent application of lime than soils with low buffering capacities (i.e. coarse textured soils are likely to require lime more frequently). Coarse textured soils should also be sampled more frequently than fine textured soils to determine lime need.

Actual buffer pH is a measurement often reported by soil testing laboratories, but another term has also been used—lime test index (LTI). Lime test index is simply buffer pH multiplied by 10.

**Table 2.** Recommended topsoil pH (to a depth of 8 inches for tilled soils and to a depth of 4 inches for no-till soils) for various crops on mineral and organic soils (adapted from Tri-State Fertilizer Recommendations, 1996).

Crop	Mineral soils with subsoil pH		Organic soils
	pH > 6	pH < 6	
Alfalfa	6.5	6.8	5.3
Other legume forages	6.0	6.8 <sup>1</sup>	5.3
Corn	6.0	6.5	5.3
Soybeans	6.0	6.5	5.3
Small grains	6.0	6.5	5.3
Other crops	6.0	6.5	5.3

<sup>1</sup>Birdsfoot trefoil soils should be limed to pH 6.0.

## How Lime Works

Even though liming materials are not the same, they all follow the same process to neutralize soil acidity. Lime supplies a surplus of the basic cations  $Ca^{2+}$  and/or  $Mg^{2+}$  in a carbonated, hydroxide, or oxide form ( $CaCO_3$ ,

MgCO<sub>3</sub>, CaOH, MgOH, CaO). As the compounds dissolve in soil solution, the carbonate (CO<sub>3</sub><sup>2-</sup>), hydroxyl (OH<sup>-</sup>), or oxide (O<sup>2-</sup>) react with active acidity (H<sup>+</sup>) to form carbonic acid (H<sub>2</sub>CO<sub>3</sub>) or water (H<sub>2</sub>O). Also, because H<sup>+</sup> is being removed from soil solution, free Al<sup>3+</sup> reacts with OH<sup>-</sup> to form an insoluble compound. Hydrogen held by soil-clay (potential acidity) is released into soil solution to maintain chemical equilibrium as active acidity is neutralized, and Al<sup>3+</sup> is released from the soil to form insoluble compounds. The H<sup>+</sup> released into the soil solution is then neutralized until the CO<sub>3</sub><sup>2-</sup>, OH<sup>-</sup>, and O<sup>2-</sup> are exhausted. Ultimately, most of the carbonic acid will dissociate to form water and carbon dioxide. Thus, excess H<sup>+</sup> is converted into water, and free Ca<sup>2+</sup> and/or Mg<sup>2+</sup> replace the released H<sup>+</sup> and Al<sup>3+</sup> on the soil exchange sites (Figure 2).

Any legitimate liming material (based on Ohio Department of Agriculture standards (2005) works the

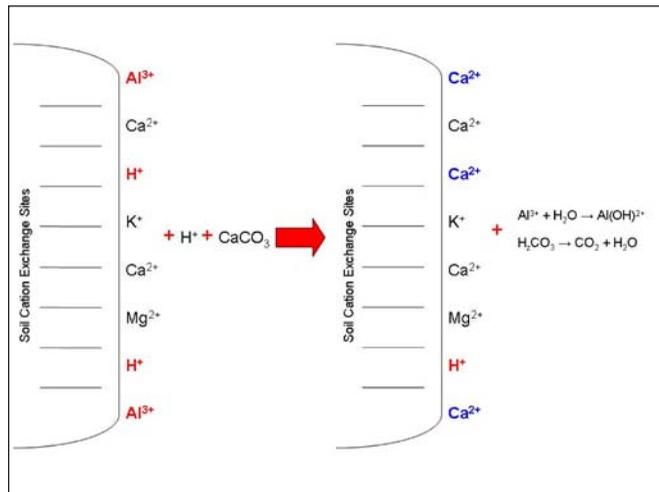


Figure 2. Generalized reaction of typical aglime with soil.

same way. However, quality and cost do differ among lime sources.

**ENP**

In Ohio, liming materials are labeled based on their effective neutralizing power (ENP), which is reported in lbs/ton (Table 3). The ENP considers the total neutralizing power (TNP), fineness of grind, and percent moisture of a liming material (Ohio Aglime Council, 2003), and may be calculated by Equation 1.

**Equation 1:**

ENP (lbs/ton) = TNP/100 \* FI/100 \* %DW/100 \* 2000 lbs/ton

**TNP**

Total Neutralizing Power (TNP) is a measure of the ability of a liming material to raise the pH. The percentage of calcium, percentage of magnesium, and impurities, such as silt and clay, determine TNP. Pure calcium carbonate has a neutralizing power of 100: other liming materials are compared on a percentage basis with it (Table 3). The two major liming materials are dolomitic and calcitic limestone. Both are sources of calcium and magnesium, but the percentage of each varies and thus the TNP varies.

Dolomitic limestone contains approximately 20 to 22% calcium and 11 to 13% magnesium. Because of molecular weight differences, magnesium carbonate—on a pound for pound basis—is 16% more effective in raising the pH than calcium carbonate. Therefore the TNP will normally range from 100 to 110 for dolomitic limestone. Calcitic or hi-cal lime contains approximately 32 to 35% calcium, 2 to 5% magnesium, and has a TNP of 90 to 99.

Table 3. Total neutralizing power (TNP), fineness, water content, and ENP of common liming materials.

Grade	TNP (%)	Fineness				Water (%)	ENP (lbs/ton)
		% passing mesh size					
		8	20	60	FI		
Aglime superfine	100	100	100	100	100	0	2000
Dolomitic hydrated aglime	140	100	99	76	90	0	2520
Calcitic aglime	99	99	60	37	59	0	1168
Dolomitic aglime	105	97	95	90	93	0	1953
Waste water lime	102	100	100	100	100	74	530
Pelletized lime	93	100	100	100	100	0	1860

These are liming materials available in the state of Ohio. Depending upon source, lime characteristics will vary.

## Fineness of Grind

Fineness of grind is also considered when determining the ENP of a liming material. Because the neutralization of soil acidity is based upon the dissolution of the lime material in soil solution, the finer the grind, the more effective the material is in neutralizing soil acidity quickly. Fineness of aglime in Ohio is determined by passing a lime material through three different sized screens. The percentage of materials that pass 8, 20, and 60 mesh screens is used to compute a fineness index (FI) (the higher the mesh number, the smaller the lime particle). Liming materials that contain smaller particles neutralize soil acidity faster and more effectively than materials with larger particles when applied at equivalent rates. The fineness index of a liming material is calculated using Equation 2.

### Equation 2:

$$FI = (0.2 * (\% \text{ pass } 8 - \% \text{ pass } 20)) + (0.6 * (\% \text{ pass } 20 - \% \text{ pass } 60)) + (1 * \% \text{ pass } 60)$$

## Water Content

Water content is also important when determining ENP. Water does not contribute to the neutralization of soil acidity; thus, its presence in liming material only adds to the weight of the material (which is important because liming materials are sold and transported based on weight). Water content may be an issue with

by-product limes, such as municipal water treatment sludges, because it may be high if the material is not properly dried and stored before distribution. Based on the water content, a percent dry weight (%DW) can be computed using Equation 3.

### Equation 3:

$$\%DW = (100 - \% \text{ water})$$

Even though ENP is the only value needed for selecting lime material, the TNP, fineness of grind, water content, and the percent calcium and magnesium may also be found on the lime analysis sheet for a given material.

## Lime Recommendations

Once it has been determined that liming is necessary by soil pH and the buffer pH measurement, a lime recommendation can be made (Table 4). Reported lime rates assume an effective neutralizing power (ENP) of 2000 lb/ton and an incorporation depth of 8 inches. To compute the application rate of a lime source with an ENP different from 2000 lb/ton use Equation 4.

If depth of incorporation is different than 8 inches, divide the lime recommendation by 8 and multiply by the new depth. For example, assume the lime rate needed is 1.6 t/A from Table 4. The lime will be incorporated

**Table 4.** Tons of liming material (ENP of 2000 lbs/ton) needed to raise the soil pH to the desired pH level based on the SMP (Shoemaker-McLean-Pratt) buffer and an incorporation depth of 8 inches (adapted from Tri-State Fertilizer Recommendations, 1996).

Buffer pH <sup>1</sup>	Desired pH levels				
	Mineral soils			Organic soils	
	6.8 <sup>2</sup>	6.5 <sup>3</sup>	6.0 <sup>4</sup>	Soil pH	5.3
	tons agricultural limestone/acre				tons/acre
6.8	0.9	0.8	0.7	5.2	0.0
6.7	1.6	1.4	1.1	5.1	0.5
6.6	2.2	2.0	1.6	5.0	0.8
6.5	2.9	2.5	2.0	4.9	1.3
6.4	3.6	3.1	2.5	4.8	1.7
6.3	4.2	3.6	3.0	4.7	2.1
6.2	4.9	4.2	3.4	4.6	2.5
6.1	5.6	4.7	3.9	4.5	2.9
6.0	6.2	5.3	4.4	4.4	3.3

<sup>1</sup>To compute LTI multiply buffer pH by 10.

<sup>2</sup>For desired pH of 6.8: lime recommendation =  $-6.8 * \text{buffer pH} + 46.8$

<sup>3</sup>For desired pH of 6.5: lime recommendation =  $-5.6 * \text{buffer pH} + 39.1$

<sup>4</sup>For desired pH of 6.0: lime recommendation =  $-4.6 * \text{buffer pH} + 31.8$

into the top 6 inches, so the new rate of lime is 1.2 t/A, (i.e.,  $1.6/8 \times 6 = 1.2$ ). For no-till fields, assume 4-inch incorporation depths, so rates should be one-half the recommendation given in Table 4.

## Lime Selection

Selecting the correct liming material may seem daunting due to the number of products available, but remember that all liming materials react with the soil the same way to neutralize soil acidity. Base your selection of lime material on three things: soil magnesium levels, ENP, and cost of material.

If soil magnesium is low, dolomitic lime sources should be considered. Dolomitic lime contains magnesium and calcium and is considerably less expensive per pound of magnesium than alternative sources of magnesium. Soil test magnesium is considered adequate if soil test levels are greater than 50 ppm (100 lb). Hi-cal (calcitic) lime should be used if the percentage of base saturation of calcium on the soil test is equal to or lower than the percentage of base saturation of magnesium (a Ca:Mg ratio of 1:1 or less), otherwise, economics should guide the selection.

All liming materials sold commercially in Ohio are evaluated by the Department of Agriculture to guarantee their analysis. Every retail outlet that sells a liming material is required by law to have an analysis of the material available (if the lime is bulk, the data sheet should be present on the premises; if the lime is bagged, the bag should have the analysis printed on it). If the analysis is not readily available at the outlet, the retailer should be able to find the analysis online through the Ohio Department of Agriculture web site (<http://www.ohioagriculture.gov/pubs/divs/plnt/curr/ff/plnt-ff-limeanalysis-2003.pdf>).

The only value needed from the lime analysis sheet is ENP, given as pounds per ton (be careful not to use %ENP, which may also be on a lime analysis report). ENP will allow a producer to determine the amount needed and the cost of each source. To determine the amount of liming material needed, utilize Equation 4.

### Equation 4:

$$\text{Tons of material / A} = LR \times \left( \frac{2000}{ENP} \right)$$

Where LR (ton/A) is the lime requirement based on the Tri-State Fertilizer and lime recommendation. This calculation determines the amount of a specific lime

source needed to neutralize acidity to the appropriate pH level.

To determine the cost of a liming material (\$/A) use Equation 5. This equation allows for a comparison of liming materials based on cost.

### Equation 5:

$$\text{Cost} \left( \frac{\$}{A} \right) = \frac{LR}{ENP / 2000} \times \frac{\$}{\text{ton}}$$

### Example

Let's assume two liming materials are available. Lime source A has an ENP of 900 lb/ton and costs \$14/ton; lime source B has an ENP of 1500 lb/ton and costs \$20/ton. If the lime requirement is 2.2 ton/A (based on Tri-State recommendations), 4.8 ton/A of lime source A would have to be applied at a cost of \$68.44/A. Lime source B would have to be applied at a 2.9 ton/A rate at a cost of \$58.60/A. Obviously lime source B is the cheaper of the sources (\$9.84/A cheaper), even though lime source A is cheaper on a per ton basis.

If the liming material is purchased directly from a quarry, the cost of hauling must be considered. Let's assume the material is being shipped from a quarry at a cost of \$0.50/mile over 100 miles. To factor this cost into the price per acre (\$/A), divide the cost of hauling, in this case \$50 (\$0.50/per mile \* 100 miles), by the number of acres to be covered. So if 60 acres are to be covered it costs an additional \$0.83/A (\$50 hauling charge/60 acres).

## Summary

In summary, make sure you obtain a soil test, determine if lime is needed for your crop situation, determine if magnesium is needed, and then use the ENP and magnesium content to select the most cost-effective lime material. Soil testing every three to four years can determine the continuing lime requirements for your fields.

Available online is an Excel spreadsheet to help you determine lime material rates and to compare different lime sources based on ENP and cost. The Excel file can be found and downloaded at: <http://agcrops.osu.edu/fertility/>

**REMEMBER:** All liming materials react with the soil the same way to neutralize soil acidity. Make your selection based on soil Mg<sup>2+</sup> level, ENP, and cost.

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# Best Management Practices for Mitigating Phosphorus Loss from Agricultural Soils

Robert Mullen, Keith Diedrick, and David Henry

Monitoring of watersheds that discharge into Lake Erie has revealed that dissolved reactive phosphorus (DRP) levels have increased over the last decade (Baker, 2007). Many of these watersheds have a large agricultural base, suggesting that a portion of the increased DRP is likely attributable to agricultural activities. The objective of this fact sheet is to discuss management practices that can be implemented by producers to minimize the risk of phosphorus loss. Implementation of these practices not only has environmental benefits but economic benefits as well. Producers today are facing higher input costs (including fertilizer), and the more efficiently inputs are managed, the greater the economic return. Any nutrient transported off-farm represents a loss on an investment.

## Soil Testing

The most cost effective and environmentally sound practice a producer can implement is the use of soil analysis. Soil testing allows one to assess a soil's current nutrient status and decide on appropriate fertilizer rates to maximize crop production. The Ohio State University recommends that a single composite soil sample (consisting of a minimum of 15 individual cores at an 8-inch depth) represent no more than 20 contiguous, uniform acres. Once soil samples have been collected, they should be thoroughly mixed and submitted to a reputable lab for analysis. After analysis has been completed, one will receive a soil test report that should reveal the soil's current phosphorus level.

The first step in making a phosphorus fertilizer decision is determining whether additional phosphorus is necessary. Ohio State has established critical levels for phosphorus based upon a Bray-Kurtz P1 extraction (Table 1). If a Mehlich III extractant is used for phosphorus determination, refer to the fact sheet titled "Understanding Soil Tests for *Plant-Available* Phosphorus" (search <http://ohioline.osu.edu>) to make the conversion from Mehlich III to Bray-Kurtz P1. Soil test levels near or below the established critical levels indicate a risk of phosphorus deficiency, and warrant an application of

phosphorus to ensure that it is not limiting crop productivity. Phosphorus fertilizer rates have also been calibrated to soil test levels (Table 2). Utilization of Ohio State phosphorus fertilizer recommendations should minimize the risk of phosphorus deficiency and ensure that soil test levels are maintained at or reasonably above the established critical level.

Notice that for soil test levels above the established critical level, Ohio State recommendations are designed to reduce soil test phosphorus levels (Table 2). A producer can grow crops with little risk of phosphorus deficiency for many years on these soils. Remember, the soil is well buffered against changes in soil test phosphorus. This means that phosphorus added or removed from the soil should not dramatically change soil test levels. An illustration of this concept can be made with fluid dynamics. Figure 1 shows two reservoirs of varying width. The left side (narrow reservoir) represents what we measure with soil testing, and the right side (wide reservoir) represents the soil's capacity to buffer against change in the soil test level (from phosphorus that is adsorbed to soil particles or precipitated from solution). If we desire to increase the level in the narrow reservoir by 1 unit, can we just add 1 unit to the right side? No, we have to add considerably more to the right side due to the width of the reservoir. Similarly, to lower the level in the narrow reservoir, we have to remove considerably more from the wide reservoir to observe a change. This relationship is how phosphorus behaves in soils, where the extent of buffering is a function of soil texture, phosphorus saturation, and soil pH. As a rule of thumb, for every 15–20 lbs of phosphorus in fertilizer ( $P_2O_5$ ) added or removed, the available phosphorus level will change by 1 ppm. (Some soils may be more buffered/some less). Thus, soils that test high in available phosphorus are unlikely to receive any agronomic benefit from additional phosphorus fertilizer (at least in the short term).

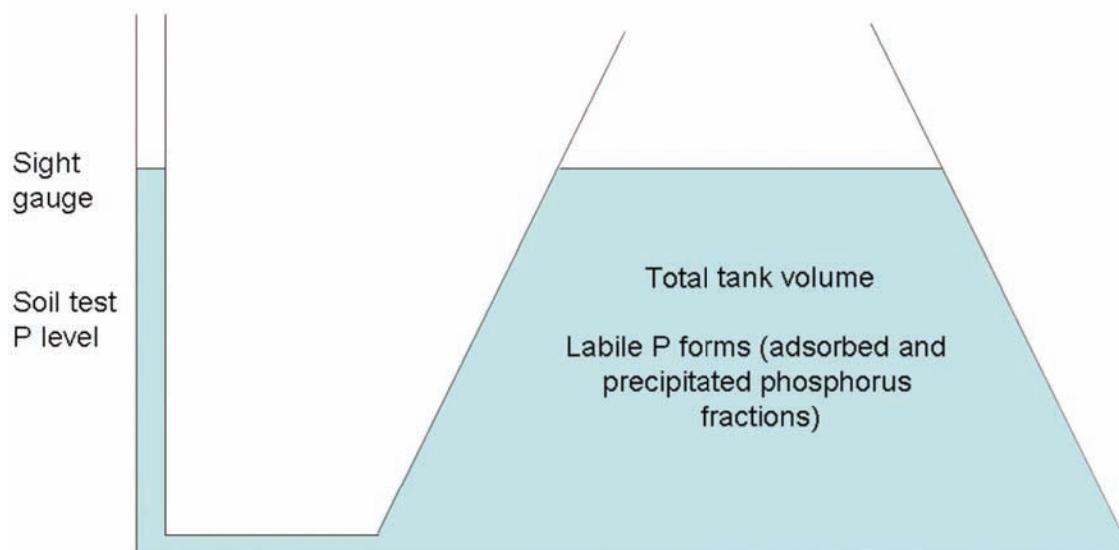
**Table 1. Critical Soil Test Phosphorus Levels**  
(adapted from *Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat, & Alfalfa*)

Crop	Critical soil test phosphorus levels, ppm (lb/acre)
Corn	15 (30)
Soybeans	15 (30)
Wheat	25 (50)
Alfalfa	25 (50)

**Table 2. Fertilizer Phosphorus ( $P_2O_5$ ) Rate Recommendations for Corn**  
(adapted from *Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat, & Alfalfa*)

	Realistic yield goal, bu/acre				
Soil test level	100	120	140	160	180
ppm (lb/acre)	lb $P_2O_5$ /acre				
5 (10)	85	95	100	110	115
10 (20)	60	70	75	85	90
15–30 (30–60)	35	45	50	60	65
35 (70)	20	20	25	30	35
40 (80)	0	0	0	0	0

Figure 1. Illustration of the Soil Test Phosphorus Buffer Concept



### Timing and Method of Application

Once a fertilizer rate has been determined, the next considerations are when and how the application should occur. While there is no “best” time for applying phosphorus (comparing spring to fall), there *are* times when applications should be avoided for potential loss reasons. Avoid applications of phosphorus fertilizer to frozen/snow-covered ground, especially on soils that have any appreciable slope. Fertilizer applied under these conditions is subject to movement in runoff and potential loss from the field. Phosphorus fertilizers can bind to soil particles easily, but if a phosphorus prill never enters the soil as it sits on frozen or snow-covered surfaces, it may be carried off the surface by runoff. Not only does this loss have potential negative environmental implications, it also represents a significant economic loss given the price of phosphorus fertilizers.

How phosphorus is supplied also affects loss potential. Surface-applied phosphorus is at more risk for loss than fertilizer phosphorus that has been incorporated with tillage. A minimum amount of tillage following the application decreases the risk of dissolved reactive phosphorus transport and potential loss. Thus, to minimize the risk of phosphorus transport, some tillage (even if minimally invasive) is beneficial (Kleinman et al., 2002). It should be noted here that in a no-till system, while plant residue left on the soil surface can reduce runoff volume, it does not reduce the concentration of phosphorus in runoff (Nicolaisen et al., 2007).

### Alternatives to Broadcast Applications

Instead of making a broadcast application of phosphorus, one may consider supplementing phosphorus in a starter blend applied with a planter. If soil test levels are near the critical level, phosphorus can be included in a starter to ensure that it is not limiting. Starter phosphorus responses have also been noted on soils with adequate phosphorus that are in a no-till production system. Phosphorus supplied

as a starter is much less susceptible to loss due to the fact that it is placed below the soil surface. The unfortunate trade-off is that liquid forms of phosphorus supplied as a starter are typically much more expensive than broadcast applications on a price-per-pound of phosphorus basis.

### Manure Issues

Much of the focus to this point has been on commercial fertilizer applications, but similar rules apply for manure applications. Avoid applications to frozen/snow-covered ground due to the risk of surface transport. Target applications to soils likely to benefit from phosphorus supplementation and avoid applications to soils with fertility well above established critical levels. Incorporation, with tillage or injection, is preferred to surface applications.

Remembering and utilizing these simple rules for phosphorus application will dramatically reduce the risk of phosphorus transport from agricultural soils. Considering the prices of these fertilizer materials, the economic implications for poor management are much more severe today than they have been historically. Any nutrient that remains in the soil is an economic and environmental benefit.

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**TRI-STATE**

**FERTILIZER RECOMMENDATIONS**

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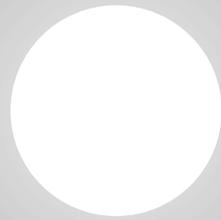
**CORN,**

**SOYBEANS,**

**WHEAT**

**&**

**ALFALFA**



Michigan State University  
The Ohio State University  
Purdue University

# Tri-state Fertilizer Recommendations for Corn, Soybeans, Wheat and Alfalfa

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*Co-editors*

## FOREWORD

When fertilizer first became readily available in the 1930s, university researchers began to conduct field studies, develop soil tests and make fertilizer recommendations. One of the early publications in the tri-state region was "How to Fertilize Corn Effectively in Indiana" by G.D. Scarseth, H.L. Cook, B.A. Krantz and A.J. Ohlrogge, Bulletin 482, 1944, Purdue University, Agricultural Experiment Station. Since that time, many soil fertility scientists have made significant contributions to our understanding of plant nutrition and the development of fertilizer recommendations. We have learned a great deal from this legacy and are very grateful for their contributions.

In the past, universities have developed fertilizer recommendations independently without much regard for differences that might have existed between states. We have reached a

time in our history when different recommendations at the state boundary line are being questioned. It is time to break with tradition and develop common fertilizer recommendations that will serve more than one state. In this publication, we have developed common fertilizer recommendations for the major crops in the tri-state region. The task has not been easy. We found that some changes and compromises were necessary. This is our first attempt at developing tri-state fertilizer recommendations for corn, soybeans, wheat and alfalfa. More work is needed on other crops and has already begun. We look forward to the continued development of these recommendations and are confident that they will be of great value to many farmers, consultants and agribusiness associates in the tri-state region.

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# SAMPLING, HANDLING AND TESTING SOILS

The accuracy of a fertilizer recommendation depends on how well the soil sample on which the recommendation was based represents the area on which the recommendation will be used. The physical and chemical characteristics of soil in an area can vary considerably from place to place because of natural factors and the management to which the area has been subjected. Natural variation arises from soil-forming processes (such as mineral weathering and erosion) that lead to accumulations or losses of nutrients at different sites. Management factors might include tillage and fertilization practices, crop selection and irrigation. It may be necessary to take many samples from a given area (at random or in a systematic manner) to assess its fertility accurately.

## SAMPLING STRATEGIES

Four variables are generally considered when taking soil samples:

1. The spatial distribution of samples across the landscape.
2. The depth of sampling.
3. The time of year when samples are taken.
4. How often an area is sampled.

Proper consideration of these variables ensures that the sample accurately reflects the fertility of the area in question and allows for the best possible fertilizer recommendations.

## Sample Distribution

Sample distribution usually depends on the degree of variability in a given area. In relatively uniform areas smaller than 25 acres, a composite sample of 20 to 30 cores taken in a random or zigzag manner is usually sufficient. Larger areas are usually subdivided into smaller ones. Non-uniform areas should be subdivided on the basis of obvious differences such as slope position or soil type.

Banding fertilizer creates zones of very high fertility in soils because the fertilizer is mixed with only a small portion of the soil. Samples taken in the band can greatly overestimate the overall fertility of a site. Because the position of fertilizer bands is rarely known with certainty, one should take more random samples than usual in fields with fertilizer bands and vary sampling position with respect to row location to ensure that the bands do not bias test results.

For non-uniform sites, a systematic sampling approach is best. Sampling in a grid pattern can give an idea of variability in a field and fertilizer application can be adjusted according to the distribution of soil test results within the grid. The grid spacing can vary from as little as 30 feet to several hundred feet. Often the grid spacing is some multiple of fertilizer applicator width. Grid geometry can be adjusted to account for characteristics of the site in question. For example, a rectangular grid may be more useful than a square grid when fertilizer applications have been primarily in one direction. Eight to 10 cores are usually taken and combined for analysis at each sampling point in the grid.

## Sampling Depth

Soil samples used for nutrient recommendations should be taken at the same depth that is used in the research generating the recommendations, normally 0 to 8 inches. A major exception involves sampling sites subjected to little or no inversion tillage, including those in established forages, no-till and ridges. In such cases, *additional* samples should be taken at a shallower depth (0 to 4 inches) to assess acidification of the soil surface and make appropriate lime recommendations. Surface soil pH may greatly affect herbicide activity and/or carry-over problems. Occasionally sampling the soil profile in 4-inch increments also may be useful for assessing the degree of nutrient stratification in fields managed with conservation tillage, but no recommendations are being made at this time based on the results of such samples.

## Time of Year to Sample

Sampling after harvest in the fall or before planting in the spring is recommended. Fall sampling is preferred if lime applications are anticipated. Sampling during the growing season may give erroneous results due to effects of crop uptake and other processes. In-season sampling should be used only to test soils for nitrate as a guide to sidedressing additional N. Recommendations for sampling soils for nitrate are not consistent across Indiana, Michigan and Ohio, so those interested in such tests should use in-state recommendations.

Sampling should occur at the same time of the year each time a particular field is sampled. This allows better



tracking of trends in soil test values over time, which may be as important as the test values themselves.

## Intervals Between Sampling

Most sites should be sampled every three to four years. On sites where rapid changes in fertility (particularly decreases) are expected or when high-value crops are involved, shorter sampling intervals (1 to 2 years) are recommended. Regardless of the sampling interval, records of changes in soil test values over time should be kept for each site tested.

## SAMPLE HANDLING

After the sample has been collected, contamination must be avoided. Common sources of contamination include dirty sampling tools, storage vessels and surfaces on which soils are spread to dry. Ashes from tobacco products can cause considerable contamination of soil samples. Soils should be shipped to the testing laboratory only in containers approved by the lab.

Individual cores should be mixed thoroughly to form a composite sample. Moist cores should be crushed into aggregates approximately 1/8 to 1/4 inch across for optimum mixing. If the mixed sample is to be dried, the drying should be done at temperatures no greater than 120 degrees F (50 degrees C). After drying, a subsample of appropriate size should be taken from the composite mixture and sent to the testing laboratory for analysis.

## SOIL TESTING PROCEDURES

Several tests are available to measure the availability of individual nutrients in the soil. The recommendations made here are based on research conducted using very specific tests, which are identified for each nutrient. Producers and consultants should always be certain their fertilizer recommendations are based on research using the same procedures used to generate their soil test results.

The specific procedures used to test soils in Indiana, Michigan and Ohio are

described in NCR Publication 221, 1988, Recommended Chemical Soil Test Procedures for the North Central Region, written by the USDA-sanctioned North Central Regional Committee on Soil Testing and Plant Analysis (NCR-13) and published by the North Dakota Agricultural Experiment Station. Other procedures may yield results incompatible with the recommendations given here.

All soil test data in this publication are reported as parts per million (ppm) rather than pounds per acre (lb/acre). The change to ppm is being made because it more truly represents what is measured in the soil. Soil test values are an index of availability and do not reflect the total amount of available nutrients in soil. The use of lb/acre in the past has also led to some confusion about soil testing and the resulting fertilizer recommendations. Most commercial soil test laboratories are currently reporting soil test values in terms of ppm. To convert ppm to lb/acre, multiply ppm by 2.



## SOIL pH AND LIME RECOMMENDATIONS

Different crops require different soil pH levels for optimum performance; when pH falls below these levels, performance may suffer (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 chances of micronutrient deficiencies. The topsoil in fields with acid subsoils (most common in eastern Ohio) 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.

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. The rates of application given in Table 2 are based on the lime test index obtained using the SMP-buffer lime requirement test and are applicable to an 8-inch depth. For no-till and established forages, lime recommendations are based on a 0- to 4-inch depth, so the rates of application should be one-half the values given in Table 2. These rates are for agricultural ground

Table 2.  
**TONS OF AGRICULTURAL LIMESTONE NEEDED TO RAISE THE SOIL pH TO THE DESIRED pH LEVEL BASED ON THE SMP LIME TEST INDEX AND AN INCORPORATION DEPTH OF 8 INCHES.**

Lime test index <sup>1</sup>	Desired pH levels				
	Mineral soils			Organic soils	
	6.8	6.5	6.0	Soil pH	5.3
	tons agricultural limestone/acre <sup>2</sup>			tons/acre	
68	1.4	1.2	1.0	5.2	0.0
67	2.4	2.1	1.7	5.1	0.7
66	3.4	3.0	2.4	5.0	1.3
65	4.5	3.8	3.1	4.9	2.0
64	5.5	4.7	3.9	4.8	2.6
63	6.5	5.6	4.6	4.7	3.2
62	7.5	6.5	5.3	4.6	3.9
61	8.6	7.3	6.0	4.5	4.5
60	9.6	8.2	6.7	4.4	5.1

<sup>1</sup>Lime test index is the SMP buffer pH x 10.

<sup>2</sup>These values are based on agricultural limestone with a neutralizing value of 90 percent (Indiana RNV = 65, Ohio TNP = 90+). Adjustments in the application rate should be made for liming materials with different particle sizes, neutralizing values and depths of incorporation.

limestone with a neutralizing value of 90 percent. They should be adjusted if other types of liming material are used. To adjust for a liming material with a different neutralizing value (nv), multiply the lime recommendation given in the table by 0.90 and divide by the new neutralizing value.

other depths, divide by 8 and multiply by the new incorporation depth.

*Example:* Lime recommendation = [(tons per acre / 8) x 10] if incorporation depth is 10 inches.

Lime recommendations (LR) are calculated from the lime test index (LTI) for mineral soils and the soil pH for organic soils using the following formulas and rounding to the nearest tenth of a ton:

### Mineral soils

to pH 6.8: LR = 71.4 - 1.03 x LTI

to pH 6.5: LR = 60.4 - 0.87 x LTI

to pH 6.0: LR = 49.3 - 0.71 x LTI

### Organic soils

to pH 5.3: LR = 32.9 - 6.31 x soil pH

These rates should raise soil pH to the desired pH level, but the exact pH is not always achieved. Applications of less

Table 1.  
**SOIL pH RECOMMENDED FOR VARIOUS CROPS ON VARIOUS SOILS.**

Crop	Mineral soils with subsoil pH		Organic soils
	> pH 6	< pH 6	
	pH		
Alfalfa	6.5	6.8	5.3
Other forage legumes	6.0	6.8 <sup>1</sup>	5.3
Corn	6.0	6.5	5.3
Soybeans	6.0	6.5	5.3
Small grains	6.0	6.5	5.3
Other crops	6.0	6.5	5.3

<sup>1</sup> Birdsfoot trefoil should be limed to pH 6.0.

*Example:* Lime recommendation = [(tons per acre x 0.90) / 0.80] if nv is 80 percent.

The relative availability of the liming material is also affected by the lime particle size. For information on adjusting lime recommendations because of differences in lime particle size, see in-state publications.

Lime rates also should be adjusted for other depths of incorporation. To adjust for

than 1 ton/acre often may not be practical and will not appear in computer-generated recommendations. When the recommendation is for 2 tons/acre or less, the application can be made any time in a cropping sequence. When the lime recommendation exceeds 4 tons per acre, apply the lime in a split application — i.e., half before plowing and half after plowing. Do not apply more than 8 tons of lime in one season. Large applications of lime without thorough mixing may cause localized zones of high alkalinity, reducing the availability of some essential nutrients. If the soil test indicates more than 8 tons per acre are required, retest two years after the application to see if more lime is needed.

Surface applications of urea forms of N fertilizer are not recommended on fields where lime has been surface 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 one year of the lime application. Surface applications of ammonium nitrate, ammonium sulfate, or injected 28 percent N or anhydrous ammonia are preferred when lime is not incorporated.

## WEAKLY BUFFERED SOILS

Because sandy soils are often weakly buffered, there is concern about lime

requirements determined by the SMP lime test. These soils may have a soil water pH below the desired pH range for optimum crop growth but the lime index test does not indicate a need for lime. This occurs because weakly buffered soils do not have sufficient capacity to lower the pH of the SMP buffer solution. When this situation occurs, growers may want to consider using 1 ton of lime per acre when the soil water pH is more than 0.3 pH units below the desired soil pH and 2 tons per acre when the soil water pH is more than 0.6 pH units below the desired soil pH.

**P**rofitability, concern for groundwater quality and conservation of energy are good reasons to improve nitrogen use efficiency. Placement of fertilizer nitrogen and timing of application affect nitrogen use efficiency. Placement and timing of nitrogen application are management decisions within a producer's production system. Soil characteristics, rainfall and temperature, tillage system and fertilizer source affect the efficacy of application. Because of our inability to predict the occurrence and amounts of rainfall for a specific year, nitrogen placement and timing should be based on conditions that most frequently occur. Most of the fertilizer nitrogen applied in the eastern Corn Belt is used on corn, so most of the discussion here is on nitrogen management practices for corn.

## NITROGEN PLACEMENT

Tillage system and fertilizer source affect proper placement of fertilizer nitrogen. The most satisfactory way to apply anhydrous ammonia is by injection in a band. Knife spacing provides an application option for anhydrous ammonia. Injection into the soil by knives or spoke injector, spraying on the surface and surface banding are techniques used to apply fertilizer N solutions. Dry sources can be broadcast or placed in a band. The need to incorporate N sources placed on the surface depends on the tillage system and whether the N source contains urea.

The enzyme urease hydrolyzes urea to ammonia and carbon dioxide ( $\text{NH}_2\text{CONH}_2 + \text{H}_2\text{O} \rightarrow 2\text{NH}_3 + \text{CO}_2$ ). The ammonia vaporizes and is lost if this occurs at the soil surface.

Urease is an enzyme common to soil organic matter and plant residue. Factors that enhance ammonia volatilization losses are: soil factors — high soil pH and low buffering capacity; environmental factors — warm temperature, moist soil surface that is drying and rapid air movement; management factors — surface application of high rates of urea-containing fertilizer, broadcast application, liquid fertilizer and crop residue on soil surface. Injecting or incorporating urea-containing fertilizer or receiving  $\frac{1}{2}$  inch or more of rainfall before hydrolysis occurs reduces or eliminates volatilization losses. Data shown in Tables 3 and 4 illustrate the effect of application method in no-tillage for various N sources. Dribble or band application of urea-ammonium nitrate (UAN) solution concentrates the N solution, which reduces contact with urease enzyme. This application technique slows the



Table 3.  
**THE EFFECT ON GRAIN YIELD OF NO-TILL CORN BY N SOURCES AND METHOD OF APPLICATION IN INDIANA.<sup>1</sup>**

<i>N treatment</i>	<i>Average grain yield bu/acre at 15.5% water</i>
NH <sub>3</sub> injected	139
UAN injected	135
UAN surface	118
urea surface	123

<sup>1</sup>Adapted from D.B. Mengel et al. 1982. Placement of nitrogen fertilizers for no-till and conventional corn. *Agron. J.* 74:515-518.

conversion of urea to ammonia and carbon dioxide and lengthens the time N solutions can remain on the surface with minimum losses. Urease inhibitors show some promise in reducing volatilization losses. Though there is an advantage to soil incorporation on some soils, incorporating fertilizers containing urea conflicts with the objectives of maintaining crop residues on the surface and reducing tillage operations. The development of the spoke-wheel and high-pressure liquid applicators provides a method of injecting urea-ammonium

Table 4.  
**CORN GRAIN YIELDS AS AFFECTED BY SEVERAL N MANAGEMENT STRATEGIES AT WOOSTER AND SPRINGFIELD, OHIO, 1984-1985.<sup>1</sup>**

Rate <i>lb/acre</i>	<i>N Source<sup>2</sup></i>	<i>Application</i>		<i>Corn following</i>	
		Time	Method	Corn	Soybean
0				86	97
150	AA	Preplant	Knife	154	162
150	UAN	Preplant	Broadcast	145	154
150	UAN	Preplant	Dribbled (30" spacing)	154	155
150	UAN	Split 1/3 preplant 2/3 sidedress	Dribbled	150	157
150	UAN	Split 2/3 preplant 1/3 sidedress	Dribbled	151	156

<sup>1</sup>Adapted from D.J. Eckert. 1987. UAN management practices for no-tillage corn production. *Journal of Fertilizer Issues*. Vol 4:13-18.

<sup>2</sup>AA = anhydrous ammonia; UAN = urea ammonium nitrate solution.

nitrate solutions into the soil with minimum disturbance of crop residue and controlling the placement relative to the corn row.

Knife spacing is a consideration for sidedressing ammonia and in controlled traffic such as ridge-tillage systems. Data

in Table 5 show that an ammonia band between every other pair of rows is satisfactory compared to injecting in the middle of every inter-row. Ammonia applied preplant diagonally will result in corn roots reaching the N band at different times. This may result in a rolling appearance to the cornfield. The use of 20 to 40 pounds of N per acre applied as starter fertilizer with the planter or as a preplant broadcast application will minimize the rolling appearance of corn. This practice will also ensure adequate N nutrition early in the season before the corn roots reach the N in the ammonia band.

## NITROGEN TIMING

The timing of N fertilizer applications is an important factor affecting the efficiency of fertilizer N because the interval between application and crop uptake determines the length of exposure of fertilizer N to loss processes such as leach-

Table 5.  
**EFFECT OF KNIFE SPACING OF AMMONIA APPLIED AT VARYING RATES OF N ON CORN YIELD AT DEKALB, ILL.<sup>1</sup>**

Knife spacing (inches)	lb N/acre		
	120	180	240
	—bu/acre— Sidedress — 1985-1986 av.		
30	171	176	182
60	170	171	182
	Preplant — 1986 <sup>2</sup>		
30	159	178	190
60	166	179	180

<sup>1</sup>Adapted from R.G. Hoelt. 1987. Effect of ammonia knife spacing on yield. In *Proceedings of the Seventeenth North Central Extension-Industry Soil Fertility Workshop*. St. Louis, Missouri.

<sup>2</sup>Applied beneath the planted row.

ing and denitrification. Timing N applications to reduce the chance of N losses through these processes can increase the efficiency of fertilizer N use.

Ideally, N applications should coincide with the N needs of the crop. This approach requires application of most of the N requirement for corn during a period 6 to 10 weeks after planting. Application of N during the period of maximum crop demand may not be practical or possible; other methods and times of application may be equally efficient and appropriate. The efficacy of time of application depends on soil texture, drainage characteristics of the soil, amount and frequency of rainfall or irrigation, soil temperature and, in some situations, the fertilizer N source. Nitrogen timing options usually include fall applications, spring preplant applications, sidedress or delayed applications made after planting, and split or multiple treatments added in two or more increments during the growing season.

### Fall vs. Spring Applications

Fall applications of N are feasible only in areas where low winter soil temperatures retard nitrification of ammonium. This limits fall application to the northern portion of the United States. The concern with fall application is that losses of N will occur between application and crop uptake in the next growing season. This may lower crop yield and recovery of applied N, compared with spring applications. Recommendations for fall applications are to use an ammonium form of N, preferably anhydrous ammonia, and delay application until the soil temperature is below 50 degrees F.

Considerable year-to-year variation in the effectiveness of fall N application occurs, as shown in Table 6.

These data illustrate that fall N applications are usually less effective than spring applications. In general, fall-applied N is 10 to 15 percent less effective than N applied in the spring. Higher N application rates should not be used in the fall to try to make up for potential N losses. Use of a nitrification inhibitor with fall-applied N can improve the effectiveness of these treatments. Most studies show, however, that spring-applied N is more effective than inhibitor-treated fall N when conditions

favoring N loss from fall applications develop. In Table 7, inhibitor-treated anhydrous ammonia was superior to anhydrous ammonia when applied in the fall, but not when applied in the spring. Spring-applied anhydrous ammonia, however, was on the average better than the fall inhibitor-treated ammonia. To increase the effectiveness of fall-applied N with an inhibitor, delay the application until soil temperatures are below 50 degrees F.

### Preplant vs. Sidedress Applications

Benefits from delayed or sidedress N applications are most likely where there is a high risk of N loss between planting and crop N use. Preplant N losses occur from sandy soils through leaching and from poorly drained soils through denitrification.

Sidedress applications of N on irrigated sandy soils produce consistently greater yields than a preplant application, as shown in Table 8. In areas where rainfall greatly exceeds evapotranspiration, the same results are expected. Sidedress applications on coarse-textured/low CEC soils are usually more effective in increasing corn yields than

Table 6.  
**YIELD OF CORN AS AFFECTED BY NITROGEN RATE, TIME OF NITROGEN APPLICATION AND SOIL TYPE IN MICHIGAN, 1977-1984.**<sup>1</sup>

Nitrogen rate lb/acre	Time of application	
	Fall	Spring
-----bu/acre-----		
Loamy soils (5 experiments)		
100	118	133
150	127	154
Irrigated sandy loam soils (6 experiments)		
100	162	172
150	176	181

<sup>1</sup>Adapted from M.L. Vitosh. 1985. Nitrogen management strategies for corn producers. Michigan State University Extension Bulletin WQ06.

Table 7.  
**EFFECT OF N RATE, TIME OF APPLICATION, N SOURCE AND NITRIFICATION INHIBITOR ON 8-YEAR AVERAGE CORN YIELD IN OHIO.**<sup>1</sup>

N rate lb/acre	Fall-applied			Spring-applied		
	Urea	AA	AA+NI	Urea	AA	AA+NI
-----bu/acre-----						
0	56					
80	85	94	111	101	116	117
160	111	127	133	125	139	140
240	—	—	—	139	—	—
320	—	—	—	139	—	—

<sup>1</sup>Adapted from R.C. Stehouwer and J.W. Johnson. 1990. Urea and anhydrous ammonia management for conventional tillage corn production. J. Prod. Agri. 3:507-513.

preplant treatments containing a nitrification inhibitor.

For medium- and fine-textured soils, yields seldom differ between preplant and sidedress application. Occasionally, sidedress application can be superior to preplant application when early season rainfall is excessive. The advantage to delaying N application is to assess crop needs based on soil moisture and crop conditions. The disadvantages of delaying the major fertilizer N application are: the crop may have been under N deficiency stress before fertilizer N is applied, resulting in a yield loss; wet conditions during the sidedress application period can prevent application, and later additions may not be possible because of corn growth; and dry conditions at and after sidedressing will limit N uptake.

## Split or Multiple Applications

Application of N fertilizer in several increments 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 simultaneous

application are often used to apply N in multiple applications. The timing and distribution of N additions in a multiple application system are important. To match N uptake by corn, application of some N must occur by the sixth week after planting and most of the N requirement should be applied by the tenth week after planting. Research data suggest that a well timed sidedress application can be as effective as multiple applications in irrigated corn production. A combination of sidedress applications and N additions in irrigation water may be needed to maximize corn yields on some sandy soils. Preplant additions of one-third to two-thirds of the total N requirement, with the remainder applied later, are not as effective as sidedress applications on irrigated sandy soils.

On adequately drained medium- to fine-textured soils, the potential for N loss is low and the use of delayed or multiple N applications usually will not improve corn yields. Adjusting the sidedress fertilizer N rate using the pre-sidedress or late spring soil nitrate test is an advantage to a split application on these soils. This approach would permit adjusting for factors that affect N loss or gain and cannot be predicted.

## NITROGEN LOSSES FROM SOIL

Nitrogen (N) can be lost from the field through three principal pathways: denitrification, leaching and surface volatilization.

The form of N a farmer chooses should depend on how serious a problem he has with the above N losses. Cost of N, labor, equipment and power availability are other considerations when choosing a fertilizer source.

**Denitrification** occurs when nitrate N ( $\text{NO}_3^-$ ) is present in a soil and not enough oxygen ( $\text{O}_2$ ) is present to supply the needs of the bacteria and microorganisms in the soil. If  $\text{O}_2$  levels are low, microorganisms strip the oxygen from the nitrate, producing N gas ( $\text{N}_2$ ) or nitrous oxide ( $\text{N}_2\text{O}$ ), which volatilizes from the soil. Three conditions that create an environment that promotes denitrification are wet soils, compaction and warm temperatures.

**Leaching** losses of N occur when soils have more incoming water (rain or irrigation) than the soil can hold. As water moves through the soil, the nitrate ( $\text{NO}_3^-$ ) that is in soil solution moves along with the water. Ammonium ( $\text{NH}_4^+$ ) forms of N have a positive charge and are held by the negative sites on the clay in the soil; therefore,  $\text{NH}_4^+$  forms of N leach very little. In sands where there is very little clay, ammonium forms of N can leach. Coarse-textured sands and some muck soils are the only soils where ammonium leaching may be significant.

One way to minimize N leaching and denitrification is to minimize the time the N is in the soil before plant uptake. This cuts down on the time when conditions are favorable for losses. Most of the N is needed by corn after the plant is 3 to 4 weeks old (June 1).

**Surface volatilization** of N occurs when urea forms of N break down and form ammonia gases and where there is little soil water to absorb them. This condition occurs when urea forms of N are placed in the field but not in direct contact with the soil. This situation can occur when urea is spread on corn residues or 28 percent is sprayed on heavy residues of cornstalk or cover crop.

Table 8.

### EFFECT OF N RATE AND TIME OF APPLICATION ON CORN YIELD FOR AN IRRIGATED McBRIDE SANDY LOAM SOIL IN MICHIGAN.<sup>1</sup>

N rate lb N/acre	Time of application	
	Preplant	Sidedress
	-bu/acre-	
0	75	75
120	149	155
180	155	161
240	157	167

<sup>1</sup> Adapted from M.L. Vitosh. 1969-72 Montcalm Farm Research Reports.

The rate of surface volatilization depends on moisture level, temperature and the surface pH of the soil. If the soil surface is moist, the water evaporates into the air. Ammonia released from the urea is picked up in the water vapor and lost. On dry soil surfaces, less urea N is lost. Temperatures greater than 50 degrees F and a pH greater than 6.5 significantly increase the rate of urea conversion to ammonia gases. Applying urea-type fertilizers when weather is cooler slows down N loss. If the surface of the soil has been limed within the past three months with 2 tons or more of limestone per acre, DO NOT apply urea-based fertilizers unless they can be incorporated into the soil.

To stop ammonia volatilization from urea, the urea must be tied up by the soil. To get the urea in direct contact with the soil requires enough rain to wash the urea from the residue or placement of urea-based fertilizer in direct contact with soil by tillage, banding or dribbling. If the residue is light (less than 30 percent cover), 0.25 to 0.5 inch of rain is enough to dissolve the urea and wash it into the soil. If the residue is heavy (greater than 50 percent cover), 0.5 inch or greater of rainfall is required.

Ammonia volatilization of N may also occur when ammonium forms of N — ammonium sulfate (AS), ammonium nitrate (AN), diammonium phosphate (DAP), monoammonium phosphate (MAP) and ammonium polyphosphate (APP) — are surface applied to calcareous soils (soil pH greater than 7.5). The extent of loss is related to the reaction

products formed when ammonium fertilizers react with calcium carbonate. Ammonium fertilizers that form insoluble precipitates (AS, DAP, MAP and APP) are subject to greater ammonia volatilization losses than AN, which forms a soluble reaction product. To prevent ammonia volatilization, ammonium fertilizers should be knifed in or incorporated on calcareous soils.

## SELECTING FORMS OF NITROGEN FERTILIZER

The common N fertilizers are anhydrous ammonia (82 percent N), urea (46 percent N), solutions (28 to 32 percent N), ammonium sulfate (21 percent N) and ammonium nitrate (34 percent N).

Anhydrous ammonia (82 percent) is the slowest of all N fertilizer forms to convert to nitrate N. Therefore, it would have the least chance of N loss due to leaching or denitrification. It must be injected into the soil; therefore, it would have no loss due to surface volatilization. The disadvantage of anhydrous ammonia is that it is hazardous to handle. It must be injected into the soil, and on steep slopes erosion can be a problem.

Urea (46 percent) converts to nitrate N fairly quickly, usually in less than two weeks in the spring. Denitrification on wet or compacted soils can be serious. Leaching can be a problem in coarse soils. In no-till situations, surface volatilization can be a problem if the urea is not placed in contact with the

soil and the weather is dry for several days after spreading.

UAN solutions (28 to 32 percent N) are usually made up of urea and ammonium nitrate. The nitrate in this product is subject to leaching and denitrification from the time it is placed in the field. The urea components are subject to the same loss mechanisms as urea. Nitrogen solutions can be banded on the soil surface easily by dribbling. This method of application minimizes the amount that sticks to the residue and, therefore, minimizes surface volatilization but may not eliminate it.

Ammonium sulfate (21 percent) is a nitrogen source with little or no surface volatilization loss when applied to most soils. Ammonium sulfate is a good source of sulfur when it is needed. Its disadvantage is that it is the most acidifying form of N fertilizer — it requires approximately 2 to 3 times as much lime to neutralize the same amount of acidity as formed by other common N carriers.

Ammonium nitrate (34 percent) is 50 percent ammonium N and 50 percent nitrate N when added to the soil. The ammonium N quickly converts to nitrate N. For soils subject to leaching or denitrification, ammonium nitrate would not be preferred. Ammonium nitrate has no urea in it; therefore, it would be a good choice for surface application where ammonia volatilization is expected.



## NITROGEN RECOMMENDATIONS FOR CORN

The following N recommendations (Table 9) for corn assume the crop is planted during the optimum planting period on mineral soils with either good natural or improved drainage.

Table 9.

### NITROGEN RECOMMENDATIONS FOR CORN BASED ON YIELD POTENTIAL AND PREVIOUS CROP.

Previous crop	Corn yield potential (bu per acre)					
	80	100	120	140	160	180+
	<i>pounds N to apply per acre</i>					
Corn and most other crops	80	110	140	160	190	220
Soybeans	50	80	110	130	160	190
Grass sod	40	70	100	120	150	180
Established forage legume <sup>1</sup>						
Average stand (3 plants/sq ft)	0	10	40	60	90	120
Good stand (5 plants/sq ft)	0	0	0	20	50	80
Annual legume cover crop <sup>2</sup>	50	80	110	130	160	190

<sup>1</sup>Any legume established for more than one year.

<sup>2</sup>Any legume or legume-grass mixture that has been established for less than one year. Nitrogen credit may be more or less (0 to 100 lb/acre), depending on plant species, stand, growing conditions and date of destruction.

### ADDITIONAL COMMENTS

- N fertilizer rates are based on the following relationship:

$$N \text{ (lb/acre)} = -27 + (1.36 \times \text{yield potential}) - N \text{ credit}$$

$$\text{or } 110 + [1.36 \times (\text{yield potential} - 100)] - N \text{ credit}$$

N credits:	Soybeans	30
	Grass sod/pastures	40
	Annual legume cover crop	30
	Established forage legume	40 + 20 x (plants/ft <sup>2</sup> ) to maximum of 140
	Corn and most other crops	0
	Organic waste	Consult individual state recommendations

- For corn silage, assume 1 ton/acre is equivalent to 6 bu/acre of grain.

- For inadequately drained soils with high denitrification potentials, N should be either:

- Applied in a split application.
- Applied as anhydrous ammonia with a nitrification inhibitor.
- Or concentrated in a band to minimize soil contact.

- Corn grown on coarse-textured/low CEC soils with high leaching potentials may benefit from split or multiple N applications.

- For soils with greater than 30 percent residue cover, the majority of applied N should be either:

- Injected below the soil surface.
- Dribbled in bands using N solutions.

- Or broadcast only if the material contains no urea (i.e., ammonium nitrate or ammonium sulfate).

- No-till corn, corn planted into cold, wet soils, corn following anhydrous ammonia applied less than 2 weeks prior to planting, and corn following spring-tilled legumes or cover crops should receive some N at planting, either:

- 20 to 40 lb N/acre banded near the row.
- Or 40 to 60 lb N/acre broadcast.

- For organic soils with greater than 20 percent organic matter, adjust rates using a pre-sidedress N soil test (consult individual state recommendations) or reduce N rates by 40 lb/acre.

- For fall applications (after October 20, well drained soils only) or early spring applications (before April 15) on wet soils, use only anhydrous ammonia with a nitrification inhibitor. Fall applications of N are not recommended on coarse-textured soils in the tri-state region. In addition, fall N is not recommended on any soil in Michigan and south of U.S. 40 in Indiana.

- If planting is delayed past the optimum planting period, reduce N rate to reflect loss of yield potential.

- When soils are limed and the lime is not incorporated, surface application of urea forms of nitrogen fertilizer are not recommended within one year of the lime application. Ammonium nitrate, anhydrous ammonia, ammonium sulfate or injected 28 percent solutions are suitable materials for this case.

- Incorporation of materials with a high carbon:nitrogen ratio, such as sawdust and leaves, can cause a temporary shortage of N due to immobilization.

## NITROGEN RECOMMENDATIONS FOR WHEAT

The following N recommendations for 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.

Table 10.  
**TOTAL NITROGEN RECOMMENDATIONS FOR WHEAT BASED ON YIELD POTENTIAL.**

<i>Yield potential bu/acre</i>	<i>Pounds N to apply lb N/acre</i>
50	40
70	75
90+	110

### ADDITIONAL COMMENTS

1. Recommended N rate is based on the relationship:  
$$N \text{ (lb/acre)} = 40 + [1.75 \times (\text{yield potential} - 50)]$$
2. No credits are given for the previous crop. Consult individual state recommendations concerning credits for organic waste materials such as manure.
3. Apply 15 to 30 lb N/acre at planting and the remainder near green-up in spring; or, apply all N at planting as anhydrous ammonia plus a nitrification inhibitor, injected on 15-inch or narrower row spacing.
4. To prevent serious lodging on high organic matter soils (greater than 20 percent organic matter), reduce the N rate by 30 to 50 lb N/acre.

## PHOSPHORUS AND POTASSIUM

**T**ri-state phosphorus (P) and potassium (K) fertilizer recommendations are based on the nutrient needs of the crop to be grown and the quantity of those nutrients available in the soil as measured by a soil test. In the tri-state region, the Bray P1 test is used to estimate P availability and the 1 normal ammonium acetate test is used to estimate K availability. Tri-state recommendations are designed to provide adequate nutrition for the crop, and to create or maintain a soil capable of providing sufficient nutrients without fertilizer addition for one or more years. Thus, the tri-state recommendations utilize a buildup and maintenance approach to fertilizer management.

The key to these recommendations is field calibration and correlation studies that have been conducted over the past 40 years. The conceptual model for these recommendations is illustrated in Figure 1. The fundamental component of the model is the establishment of a "critical level" — the soil test level above which the soil can supply adequate quantities of a nutrient to

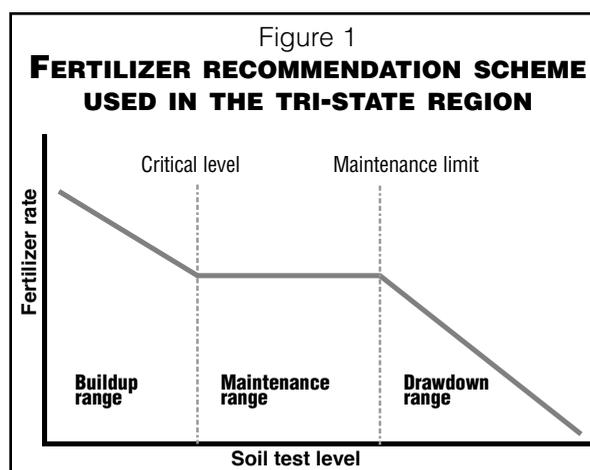
support optimum economic growth. The critical level is determined in the field and represents the results of hundreds of field experiments. There are two important concepts to keep in mind. First, some crops are more responsive to a nutrient than others, so the critical level can vary between crops. In the tri-state region, research has shown that wheat and alfalfa are more responsive to P than corn or soybeans. Thus, the critical P level for wheat and alfalfa is higher than the critical level for corn and soybeans. Second, the critical level can vary between soils. Recent research has shown that some soils, especially high clay soils in Ohio, require higher K levels to support optimum crop

growth than other lower clay content soils. This information has been incorporated into the recommendations and is seen as an increase in critical level for K as the cation exchange capacity (CEC) increases.

When soil tests are below the critical level, the soil is not able to supply the P and K requirements of the crop. The tri-state recommendations are designed to supply additional nutrients and to raise the soil test to the critical level over a four-year period. **Soil tests below the critical level should be considered as indicating a soil that is nutrient deficient for crop growth.** For deficient soils, recommended rates of fertilizer should be applied annually.

Placement techniques to enhance nutrient availability, such as banding or stripping, 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.

Above the critical soil test level, the soil is capable of supplying the nutrients required by the crop and no



response to fertilizer would be expected. The tri-state recommendations use a maintenance plateau concept to make recommendations at or slightly above the critical level. The maintenance plateau is designed to safeguard against sampling or analytical variation. Recommendations for soil test values on the maintenance plateau are designed to replace the nutrients lost each year through crop removal. Because the purpose of fertilizer applications in the maintenance plateau range is to maintain fertility, no response to fertilizer in the year of application would be expected. Therefore, farmers may choose to make multiple year applications. No response to placement techniques such as banding or stripping or the use of P and K starter fertilizers would be expected in the maintenance plateau region.

When soil test levels exceed the maintenance plateau level, the objective of the fertilizer recommendation is to utilize residual soil nutrients. Fertilizer recommendations are rapidly reduced from maintenance levels to zero. There

is no agronomic reason to apply fertilizer when soil tests are above the maintenance plateau level.

Actual fertilizer recommendations are calculated using one of three relationships — one applicable to buildup, another for maintenance and a third for drawdown:

Tables 11 and 12 provide the critical soil test values and crop removal values used for calculating tri-state fertilizer recommendations at various soil test levels.

#### BUILDUP EQUATION

for P:  $\text{lb P}_2\text{O}_5/\text{A to apply} = [(\text{CL} - \text{STL}) \times 5] + (\text{YP} \times \text{CR})$

for K:  $\text{lb K}_2\text{O}/\text{A to apply} = [(\text{CL} - \text{STL}) \times ((1 + (0.05 \times \text{CEC})))] + (\text{YP} \times \text{CR}) + 20$

#### MAINTENANCE EQUATION

for P:  $\text{lb P}_2\text{O}_5/\text{A to apply} = \text{YP} \times \text{CR}$

for K:  $\text{lb K}_2\text{O}/\text{A to apply} = (\text{YP} \times \text{CR}) + 20$  (for non-forage crops)

#### DRAWDOWN EQUATION

for P:  $\text{lb P}_2\text{O}_5/\text{A to apply} = (\text{YP} \times \text{CR}) - [(\text{YP} \times \text{CR}) \times (\text{STL} - (\text{CL} + 15))/10]$

for K:  $\text{lb K}_2\text{O}/\text{A to apply} = (\text{YP} \times \text{CR}) + 20 - [((\text{YP} \times \text{CR}) + 20) \times (\text{STL} - (\text{CL} + 30))/20]$   
(for non-forage crops)

**Note:** The K maintenance and drawdown equation for forages, including corn silage, is:

$\text{lb K}_2\text{O}/\text{A to apply} = [(\text{YP} \times \text{CR}) + 20] - [((\text{YP} \times \text{CR}) + 20) \times (\text{STL} - \text{CL})/50]$

where:

CL = critical soil test level (ppm)

STL = existing soil test level (ppm)

YP = crop yield potential (bu per acre for grains, tons per acre for forages)

CR = nutrient removed per unit yield (lb/unit)

CEC = soil cation exchange capacity (meq/100g)

Table 11.  
**CRITICAL SOIL TEST LEVELS (CL)  
FOR VARIOUS AGRONOMIC CROPS.**

Crop	Critical soil test levels				
	P	K at CEC <sup>1</sup>			
		5	10	20	30
ppm (lb/acre)	ppm (lb/acre)				
Corn	15 (30) <sup>2</sup>	88 (175)	100 (200)	125 (250)	150 (300)
Soybean	15 (30)	88 (175)	100 (200)	125 (250)	150 (300)
Wheat	25 (50)	88 (175)	100 (200)	125 (250)	150 (300)
Alfalfa	25 (50)	88 (175)	100 (200)	125 (250)	150 (300)

<sup>1</sup> Critical level for ppm K = 75 + (2.5 × CEC) for all crops

<sup>2</sup> Values in parentheses are lb/acre.

**Note:** A CEC of 15 is used to calculate the K<sub>2</sub>O recommendation for calcareous soils (soils with pH equal to or greater than 7.5 and a calcium saturation of 80 percent or greater) and organic soils (soils with an organic matter content of 20 percent or greater or having a scooped density of less than 0.8 grams per cubic centimeter).

Table 12.  
**NUTRIENTS REMOVED IN HARVESTED  
PORTIONS OF AGRONOMIC CROPS.**

Crop	Unit of yield	Nutrient removed per unit of yield	
		P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O
		lb/unit	
Corn			
Feed grain	bushel	0.37	0.27
Silage	ton	3.30	8.00
Soybeans	bushel	0.80	1.40
Wheat			
Grain	bushel	0.63	0.37
Straw	bushel	0.09	0.91
Alfalfa	ton	13.00	50.00

## PHOSPHORUS AND POTASSIUM FERTILIZER PLACEMENT AND TIMING

Most soil test report forms do not provide information on how farmers should apply their fertilizer. To be used efficiently, P and K fertilizers should be applied properly and at the appropriate time. Because the choices of application depend greatly on the fertilizer material used and the equipment available, it is up to the farmer to see that the fertilizer is properly applied. When plants are small, soil test levels low, soil surface residues high and soil temperatures cold, starter fertilizers become very important for optimum plant growth. For well established crops such as forage legumes, topdressing is the normal recommended practice.

### Starter Fertilizers

In many instances, applying some or all of the fertilizer needed with the planting unit 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.

The amount of  $P_2O_5$  added in the band is non-limiting except that most P fertilizers are combined with N such as diammonium phosphate (DAP), monoammonium phosphate (MAP) and ammonium polyphosphate (APP). When these fertilizers are used as a starter, do not band more than 40 lb N per acre on corn and 20 lb N per acre on 30-inch-row soybeans. Nitrogen and P are the most important major nutrients for early

plant growth, particularly in no-till production systems. On high P testing soils (greater than 30 ppm P), N is the most important nutrient for corn and should not be omitted from the starter in high residue no-till systems unless at least 40 to 60 lb N per acre has been broadcast applied prior to emergence. It is not necessary to include K in the starter fertilizer unless the soil test K levels are very low (less than 75 ppm K).

For drilled soybeans, wheat and forage legumes, it is unlikely that any P can be banded beside and below the seed at planting time because most new drills do not have fertilizer attachments. In this situation, all nutrients should be broadcast before planting. Only on extremely low P testing soils (less than 10 ppm P) will this create any significant P deficiency problems.

### Fertilizer with the Seed

The general practice of applying fertilizer in contact with seed is not recommended. Band placement to the side and below the seed is usually superior to any other placement. Some farmers, however, have grain drills or planters that place fertilizer in contact with the seed. In this case, caution should be used to prevent seed or seedling injury from fertilizer salts. For corn, do not place more than 5 lb N +  $K_2O$  per acre in contact with the seed on low CEC soils (CEC less than 7) and no more than 8 lb N +  $K_2O$  per acre when the CEC is greater than 8. Soybean seed is very sensitive to salt injury; consequently, all fertilizer for drilled soybeans should be broadcast before planting. 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 40 lb N per acre as urea in contact with small

grain seed. Young germinating seeds and seedlings are very sensitive to salt injury. Dry weather will accentuate the 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 1½ inches below the seed, the seeding time fertilizer may include all of 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 topdressed in the fall before plants go dormant (approximately October 1) or after the first cutting in the spring.



## Phosphorus Recommendations

TABLES 13-17 PROVIDE ACTUAL  $P_2O_5$  FERTILIZER RATE RECOMMENDATIONS DERIVED FROM THE EQUATIONS GIVEN ON PAGE 11.

Table 13.  
**PHOSPHATE ( $P_2O_5$ ) RECOMMENDATIONS FOR CORN.**

Soil test	Yield potential — bu per acre				
	100	120	140	160	180
ppm (lb/acre)	—lb $P_2O_5$ per acre—				
5 (10) <sup>1</sup>	85	95	100	110	115
10 (20)	60	70	75	85	90
15-30 (30-60) <sup>2</sup>	35	45	50	60	65
35 (70)	20	20	25	30	35
40 (80)	0	0	0	0	0

<sup>1</sup> Values in parentheses are lb/acre.  
<sup>2</sup> Maintenance recommendations are given for this soil test range.

Table 16.  
**PHOSPHATE ( $P_2O_5$ ) RECOMMENDATIONS FOR WHEAT.**

Soil test	Yield potential — bu per acre				
	50	60	70	80	90
ppm (lb/acre)	—lb $P_2O_5$ per acre—				
15 (30) <sup>1</sup>	80	90	95	100	105
20 (40)	55	65	70	75	80
25-40 (50-80) <sup>2</sup>	30	40	45	50	55
45 (90)	15	20	20	25	30
50 (100)	0	0	0	0	0

<sup>1</sup> Values in parentheses are lb/acre.  
<sup>2</sup> Maintenance recommendations are given for this soil test range.

Table 14.  
**PHOSPHATE ( $P_2O_5$ ) RECOMMENDATIONS FOR CORN SILAGE.**

Soil test	Yield potential — tons per acre				
	20	22	24	26	28
ppm (lb/acre)	—lb $P_2O_5$ per acre—				
5 (10) <sup>1</sup>	115	125	130	135	140
10 (20)	90	100	105	110	115
15-30 (30-60) <sup>2</sup>	65	75	80	85	90
35 (70)	35	40	40	45	45
40 (80)	0	0	0	0	0

<sup>1</sup> Values in parentheses are lb/acre.  
<sup>2</sup> Maintenance recommendations are given for this soil test range.

Table 17.  
**PHOSPHATE ( $P_2O_5$ ) RECOMMENDATIONS FOR ALFALFA.**

Soil test	Yield potential — tons per acre				
	5	6	7	8	9
ppm (lb/acre)	—lb $P_2O_5$ per acre—				
15 (30) <sup>1</sup>	115	130	140	155	165
20 (40)	90	105	115	130	140
25-40 (50-80) <sup>2</sup>	65	80	90	105	115
45 (90)	35	40	45	50	60
50 (100)	0	0	0	0	0

<sup>1</sup> Values in parentheses are lb/acre.  
<sup>2</sup> Maintenance recommendations are given for this soil test range.

Table 15.  
**PHOSPHATE ( $P_2O_5$ ) RECOMMENDATIONS FOR SOYBEANS.**

Soil test	Yield potential — bu per acre				
	30	40	50	60	70
ppm (lb/acre)	—lb $P_2O_5$ per acre—				
5 (10) <sup>1</sup>	75	80	90	100	105
10 (20)	50	55	65	75	80
15-30 (30-60) <sup>2</sup>	25	30	40	50	55
35 (70)	10	15	25	25	30
40 (80)	0	0	0	0	0

<sup>1</sup> Values in parentheses are lb/acre.  
<sup>2</sup> Maintenance recommendations are given for this soil test range.

## Potassium Recommendations

TABLES 18-22 PROVIDE ACTUAL  $K_2O$  FERTILIZER RATE RECOMMENDATIONS DERIVED FROM THE EQUATIONS GIVEN ON PAGE 11.

Table 18.

### POTASH ( $K_2O$ ) RECOMMENDATIONS FOR CORN AT VARIOUS YIELD POTENTIALS, CATION EXCHANGE CAPACITIES (CEC's) AND SOIL TEST LEVELS.

Yield potential	bu/ acre	100	120	140	160	180
Soil test K	lb $K_2O$ per acre					
ppm (lb/acre)	CEC	-----5 meq/100g-----				
25 (50) <sup>1</sup>		125	130	135	140	145
50 (100)		95	100	105	110	115
75 (150)		65	70	75	80	85
88-118 (175-235) <sup>2</sup>		45	50	60	65	70
130 (260)		20	20	20	25	25
140 (280)		0	0	0	0	0
	CEC	-----10 meq/100g-----				
25 (50)		160	165	170	175	180
50 (100)		120	125	135	140	145
75 (150)		85	90	95	100	105
100-130 (200-260) <sup>2</sup>		45	50	60	65	70
140 (280)		25	25	30	30	35
150 (300)		0	0	0	0	0
	CEC	-----20 meq/100g-----				
50 (100)		195	200	210	215	220
75 (150)		145	150	160	165	170
100 (200)		95	100	110	115	120
125-155 (250-310) <sup>2</sup>		45	50	60	65	70
165 (330)		25	25	30	35	35
175 (350)		0	0	0	0	0
	CEC	-----30 <sup>3</sup> meq/100g-----				
75 (150)		235	240	245	250	255
100 (200)		170	175	185	190	195
125 (250)		110	115	120	125	130
150-180 (300-360) <sup>2</sup>		45	50	60	65	70
190 (380)		25	25	30	30	35
200 (400)		0	0	0	0	0

<sup>1</sup> Values in parentheses are lb/acre.

<sup>2</sup> Maintenance recommendations are given for this soil test range.

<sup>3</sup> For Michigan, do not use CEC's greater than 20 meq/100g.

Table 19.

### POTASH ( $K_2O$ ) RECOMMENDATIONS FOR SOYBEANS AT VARIOUS YIELD POTENTIALS, CATION EXCHANGE CAPACITIES (CEC's) AND SOIL TEST LEVELS.

Yield potential	bu/ acre	30	40	50	60	70
Soil test K	lb $K_2O$ per acre					
ppm (lb/acre)	CEC	-----5 meq/100g-----				
25 (50) <sup>1</sup>		140	155	170	180	195
50 (100)		110	125	135	150	165
75 (150)		80	90	105	120	135
88-118 (175-235) <sup>2</sup>		60	75	90	105	120
130 (260)		25	30	35	40	45
140 (280)		0	0	0	0	0
	CEC	-----10 meq/100g-----				
25 (50)		175	190	205	215	230
50 (100)		135	150	165	180	195
75 (150)		100	115	130	140	155
100-130 (200-260) <sup>2</sup>		60	75	90	105	120
140 (280)		30	40	45	50	60
150 (300)		0	0	0	0	0
	CEC	-----20 meq/100g-----				
50 (100)		210	225	240	255	270
75 (150)		160	175	190	205	220
100 (200)		110	125	140	155	170
125-155 (250-310) <sup>2</sup>		60	75	90	105	120
165 (330)		30	40	45	50	60
175 (350)		0	0	0	0	0
	CEC	-----30 <sup>3</sup> meq/100g-----				
75 (150)		250	265	280	290	300
100 (200)		185	200	215	230	245
125 (250)		125	140	155	165	180
150-180 (300-360) <sup>2</sup>		60	75	90	105	120
190 (380)		30	40	45	50	60
200 (400)		0	0	0	0	0

<sup>1</sup> Values in parentheses are lb/acre.

<sup>2</sup> Maintenance recommendations are given for this soil test range.

<sup>3</sup> For Michigan, do not use CEC's greater than 20 meq/100g.

Table 20.

**POTASH (K<sub>2</sub>O) RECOMMENDATIONS FOR WHEAT AT VARIOUS YIELD POTENTIALS, CATION EXCHANGE CAPACITIES (CEC's) AND SOIL TEST LEVELS.**

Yield potential	bu/ acre	50	60	70	80	90
Soil test K		lb K <sub>2</sub> O per acre				
ppm (lb/acre)	<b>CEC</b>	<b>-----5 meq/100g-----</b>				
25 (50) <sup>1</sup>		115	120	125	130	130
50 (100)		85	90	95	95	100
75 (150)		55	60	60	65	70
88-118 (175-235) <sup>2</sup>		40	40	45	50	55
130 (260)		15	15	15	20	20
140 (280)		0	0	0	0	0
	<b>CEC</b>	<b>-----10 meq/100g-----</b>				
25 (50)		150	155	160	160	165
50 (100)		115	115	120	125	130
75 (150)		75	80	85	85	90
100-130 (200-260) <sup>2</sup>		40	40	45	50	55
140 (280)		20	20	25	25	25
150 (300)		0	0	0	0	0
	<b>CEC</b>	<b>-----20 meq/100g-----</b>				
50 (100)		190	190	195	200	205
75 (150)		140	140	145	150	155
100 (200)		90	90	95	100	105
125-155 (250-310) <sup>2</sup>		40	40	45	50	55
165 (330)		20	20	25	25	25
175 (350)		0	0	0	0	0
	<b>CEC</b>	<b>-----30<sup>3</sup> meq/100g-----</b>				
75 (150)		225	230	235	235	240
100 (200)		165	165	170	175	180
125 (250)		100	105	110	110	115
150-180 (300-360) <sup>2</sup>		40	40	45	50	55
190 (380)		20	20	25	25	30
200 (400)		0	0	0	0	0

<sup>1</sup> Values in parentheses are lb/acre.

<sup>2</sup> Maintenance recommendations are given for this soil test range.

<sup>3</sup> For Michigan, do not use CEC's greater than 20 meq/100g.

Table 21.

**POTASH (K<sub>2</sub>O) RECOMMENDATIONS FOR CORN SILAGE AT VARIOUS YIELD POTENTIALS, CATION EXCHANGE CAPACITIES (CEC's) AND SOIL TEST LEVELS.**

Yield potential	tons/ acre	20	22	24	26	28
Soil test K		lb K <sub>2</sub> O per acre <sup>3</sup>				
ppm (lb/acre)	<b>CEC</b>	<b>-----5 meq/100g-----</b>				
25 (50) <sup>1</sup>		260	275	290	300	300
50 (100)		225	245	260	275	290
75 (150)		195	210	230	245	260
88 (175) <sup>2</sup>		180	195	210	230	245
110 (220)		100	110	115	125	135
130 (260)		25	30	30	35	35
140 (280)		0	0	0	0	0
	<b>CEC</b>	<b>-----10 meq/100g-----</b>				
25 (50)		295	300	300	300	300
50 (100)		255	270	285	300	300
75 (150)		220	235	250	265	280
100 (200) <sup>2</sup>		180	195	210	230	245
120 (240)		110	120	125	135	145
140 (280)		35	40	40	45	50
150 (300)		0	0	0	0	0
	<b>CEC</b>	<b>-----20 meq/100g-----</b>				
50 (100)		300	300	300	300	300
75 (150)		280	295	300	300	300
100 (200)		230	245	260	280	295
125 (250) <sup>2</sup>		180	195	210	230	245
145 (290)		110	120	125	135	145
165 (330)		35	40	40	45	50
175 (350)		0	0	0	0	0
	<b>CEC</b>	<b>-----30<sup>4</sup> meq/100g-----</b>				
75 (150)		300	300	300	300	300
100 (200)		300	300	300	300	300
125 (250)		245	260	275	290	300
150 (300) <sup>2</sup>		180	195	210	230	245
170 (340)		110	120	125	135	145
190 (380)		35	40	40	45	50
200 (400)		0	0	0	0	0

<sup>1</sup> Values in parentheses are lb/acre.

<sup>2</sup> Maintenance recommendations are given for this soil test level.

<sup>3</sup> Potash recommendations should not exceed 300 lb per acre.

<sup>4</sup> For Michigan, do not use CEC's greater than 20 meq/100g.

Table 22.

**POTASH (K<sub>2</sub>O) RECOMMENDATIONS FOR ALFALFA AT VARIOUS YIELD POTENTIALS, CATION EXCHANGE CAPACITIES (CEC's) AND SOIL TEST LEVELS.**

Yield potential	tons/ acre	5	6	7	8	9
Soil test K		—————lb K <sub>2</sub> O per acre <sup>3</sup> —————				
ppm (lb/acre)	<b>CEC</b>	<b>-----5 meq/100g-----</b>				
25 (50) <sup>1</sup>		300	300	300	300	300
50 (100)		300	300	300	300	300
75 (150)		285	300	300	300	300
88 (175) <sup>2</sup>		270	300	300	300	300
110 (220)		150	175	205	230	260
130 (260)		40	50	55	65	70
140 (280)		0	0	0	0	0
	<b>CEC</b>	<b>-----10 meq/100g-----</b>				
25 (50)		300	300	300	300	300
50 (100)		300	300	300	300	300
75 (150)		300	300	300	300	300
100 (200) <sup>2</sup>		270	300	300	300	300
120 (240)		160	190	220	250	280
140 (280)		55	65	75	85	95
150 (300)		0	0	0	0	0
	<b>CEC</b>	<b>-----20 meq/100g-----</b>				
50 (100)		300	300	300	300	300
75 (150)		300	300	300	300	300
100 (200)		300	300	300	300	300
125 (250) <sup>2</sup>		270	300	300	300	300
145 (290)		160	190	220	250	280
165 (330)		55	65	75	85	95
175 (350)		0	0	0	0	0
	<b>CEC</b>	<b>-----30 meq/100g-----</b>				
75 (150)		300	300	300	300	300
100 (200)		300	300	300	300	300
125 (250)		300	300	300	300	300
150 (300) <sup>2</sup>		270	300	300	300	300
170 (340)		160	190	220	250	280
190 (380)		55	65	75	85	95
200 (400)		0	0	0	0	0

<sup>1</sup> Values in parentheses are lb/acre.

<sup>2</sup> Maintenance recommendations are given for this soil test level.

<sup>3</sup> Potash recommendations should not exceed 300 lb per acre.

<sup>4</sup> For Michigan, do not use CEC's greater than 20 meq/100g.

## SECONDARY NUTRIENTS

Calcium (Ca), magnesium (Mg) and sulfur (S) are the three secondary nutrients required by plants. They are less likely to be added as fertilizer than the macronutrients (N-P-K). Most soils in Indiana, Michigan and Ohio will adequately supply these nutrients for plant growth. The 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 will maintain an adequate level for crop production.

The required soil exchangeable Mg level is 50 ppm or greater. Low levels of Mg are commonly found in eastern Ohio and southern Indiana and on acid sandy soils in Michigan. High levels of

exchangeable K tend to reduce the uptake of Mg. Therefore, 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 lime 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.

Excessive use of K fertilizers can greatly reduce the uptake of Ca and Mg. High K/low Mg forages 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 plateau concept above the critical K soil test level. Potassium recommendations

above the critical level are less than crop removal so as to discourage luxury consumption of K and improve Mg uptake.

Sulfur is taken up as sulfate by plants. Sulfate sulfur is supplied primarily by microbial decomposition of soil organic matter. Sulfate is a negative ion and easily leaches in soils. Most soils in Indiana, Michigan and Ohio will adequately supply needed sulfur for plant growth. Sandy soils low in organic matter that are subject to excessive leaching may not supply adequate sulfur. Crops such as wheat and alfalfa that grow rapidly at cool temperatures when mineralization of S is slow 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 the S to be converted to the plant-available sulfate form by the soil bacteria. Sulfur should be added in the sulfate form if added less than 2 months before plant uptake.

## MICRONUTRIENTS

Micronutrients are required by plants in small amounts. Those essential for plant growth are boron (B), chloride (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo) and zinc (Zn).

Most soils in Michigan, Indiana and Ohio contain adequate quantities of micronutrients. Field crop deficiencies of Cl, Mo and Fe have not been observed in this region of the United States. Some soils, however, may be deficient in B, Cu, Mn and Zn, and deficiencies can

Table 23.  
**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	Soybeans, wheat, oats, sugar beets, corn
Zinc (Zn)	Peats, mucks and mineral soils with pH > 6.5	Corn and soybeans
Molybdenum (Mo)	Acid prairie soils	Soybeans

cause plant abnormalities, reduced growth and even 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 23 lists the soil and crop conditions under which micronutrient deficiencies are most likely to occur.

## DIAGNOSING MICRONUTRIENT DEFICIENCIES

Both soil testing and plant analysis can be useful in diagnosing micronutrient deficiencies. Soil testing for micronutrients has become a widely accepted practice in recent years. Micronutrient soil tests, however, are not as reliable as tests for soil acidity (pH) or for phosphorus (P) and potassium (K). For this reason, plant analysis is also very important in diagnosing micronutrient deficiencies. Combining plant analysis with soil tests provides more accurate assessment of the micronutrient status of crops and soils.

Plant analysis can be used in two ways. One is to monitor the crop's micronutrient status; the other is to diagnose a problem situation. By monitoring, plant analysis can point out an existing or potential problem before visual symptoms develop. Table 24 is a guide to interpreting the adequacy of primary, secondary and micronutrients in specific plant tissues sampled at the suggested times. These sufficiency ranges should not be used when other plant parts are sampled or when samples are taken at different times.

If you suspect a nutrient deficiency problem, don't wait for the suggested sampling time to get a plant analysis.

Table 24.  
**NUTRIENT SUFFICIENCY RANGES FOR CORN, SOYBEANS, ALFALFA AND WHEAT.**

Element	Corn	Soybeans	Alfalfa	Wheat
	Ear leaf sampled at initial silking	Upper fully developed leaf sampled prior to initial flowering	Top 6 inches sampled prior to initial flowering	Upper leaves sampled prior to initial bloom
Percent (%)				
Nitrogen	2.90-3.50	4.25-5.50	3.76-5.50	2.59-4.00
Phosphorus	0.30-0.50	0.30-0.50	0.26-0.70	0.21-0.50
Potassium	1.91-2.50	2.01-2.50	2.01-3.50	1.51-3.00
Calcium	0.21-1.00	0.36-2.00	1.76-3.00	0.21-1.00
Magnesium	0.16-0.60	0.26-1.00	0.31-1.00	0.16-1.00
Sulfur	0.16-0.50	0.21-0.40	0.31-0.50	0.21-0.40
Parts per million (ppm)				
Manganese	20-150	21-100	31-100	16-200
Iron	21-250	51-350	31-250	11-300
Boron	4-25	21-55	31-80	6-40
Copper	6-20	10-30	11-30	6-50
Zinc	20-70	21-50	21-70	21-70
Molybdenum	—	1.0-5.0	1.0-5.0	—

Collect plant samples from both problem and normal-appearing plants. Take whole plants if the plants are small; take leaf samples if the plants are large. Corresponding soil samples should also be taken from each area to help confirm the deficiency.

## MICRONUTRIENT PLACEMENT AND AVAILABILITY

Table 23 lists the soil and crop conditions under which micronutrient deficiencies are most likely to occur. When these conditions exist and soil or plant tissue analysis confirms a need, micronutrient fertilizers should 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. 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 Zn-deficient soils. Broadcast applications of Mn, however, are not recommended because of high soil fixation. Residual carryover of available Mn in deficient soils is very limited. Therefore, Mn fertilizers should be applied every year on these soils. Foliar-applied micronutrients are more frequently used when deficiency symptoms are present or suspected and when banded soil applications are not practical.

Soil acidification with sulfur or aluminum sulfate to improve micronutrient uptake is usually not practical on

large fields. 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.

## SELECTING MICRONUTRIENT SOURCES

The three main classes of micronutrient sources are inorganic, synthetic chelates and natural organic complexes. Inorganic sources consist of oxides, carbonates and metallic salts such as sulfates, chlorides and nitrates. Sulfates of Cu, Mn and Zn are the most common metallic salts used in the fertilizer industry because of their high water solubility and plant availability. Oxides of Zn are relatively water insoluble and thus must be finely ground to be effective in soils. Broadcast applications of Zn oxides should be applied at least 4 months before planting to be effective. Oxysulfates are oxides that are partially acidulated with sulfuric acid. Studies have shown granular Zn oxysulfates to be about 35 to 50 percent water-soluble and immediately available to plants. Metal-ammonia complexes such as ammoniated Zn sulfate are also used by the fertilizer industry. Such complexes appear to decompose in soils and provide good agronomic effectiveness.

Chelates can be synthetic (manufactured) or natural organic decomposition products such as organic acids and amino acids, but they all contain known chemical bonds that increase micronutrient solubility. Synthetic chelates usually have higher stability than natural chelates. Chelates such as Zn-EDTA are

more stable in soils than Zn citrate or Zn-ammonia complexes and thus are more effective in correcting Zn deficiency.

Natural organic micronutrient complexes are often produced by reacting metal inorganic salts with organic byproducts, mainly those of the wood pulp industry. Lignosulfonates, phenols and polyflavonoids are common natural organic complexes. These complexes are often quite variable in their composition and are less effective than the synthetic chelates.

Selecting a micronutrient source requires consideration of many factors, such as compatibility with N-P-K fertilizers, convenience in application, agronomic effectiveness and cost per unit of micronutrient.

Table 25 lists several commonly used micronutrient fertilizer sources. The inorganic sulfates are generally preferred to oxide forms of micronutrients when blending with N-P-K fertilizers because of their greater water solubility and greater effectiveness. Zinc and Mn

oxides, however, are acceptable sources of micronutrients when finely ground. Finely ground materials may present segregation problems when used with granular fertilizers, so the use of a fertilizer sticker is highly recommended. Zinc EDTA, a synthetic chelate, has been found to be more effective than Zn sulfate in Michigan and Ohio field trials and may be used at one-fifth the rate of Zn sulfate. Natural organic chelates and complexes such as Zn citrate or Zn lignosulfonate are considered less effective than true (100 percent) synthetic chelates and should be used at the same rate as inorganic sources. Chelated Mn reactions in soil are quite different from chelated Zn reactions. Manganese chelates, when applied to soil, are usually ineffective because of high levels of available Fe in our soils (Fe replaces the Mn in soil-applied Mn chelates). Therefore, they are unacceptable sources of Mn when soil applied. Foliar applications of Zn chelates are effective sources and should be used at their labeled rates.

Micronutrient	Common fertilizer sources
Boron (B)	Sodium tetraborate (14 to 20% B) Solubor® (20% B) Liquid boron (10%)
Copper (Cu)	Copper sulfate (13 to 35% Cu) Copper oxide <sup>1</sup> (75 to 89% Cu)
Manganese (Mn)	Manganese sulfate (23 to 28% Mn) Manganese oxysulfates (variable % Mn)
Zinc (Zn)	Zinc sulfate (23 to 36% Zn) Zinc-ammonia complex (10% Zn) Zinc oxysulfates (variable % Zn) Zinc oxide <sup>1</sup> (50 to 80% Zn) Zinc chelate (9 to 14% Zn)

® Registered trade name of U.S. Borax.  
<sup>1</sup> Granular oxides are not effective sources of micronutrients.

Table 26.

**MANGANESE FERTILIZER RECOMMENDATIONS FOR RESPONSIVE CROPS GROWN ON MINERAL SOILS.<sup>1</sup>**

Soil test Mn <sup>2</sup>	Soil pH						
	6.3	6.5	6.7	6.9	7.1	7.3	7.5+
ppm	<i>lb Mn per acre<sup>3</sup></i>						
2	2	4	5	6	7	9	10
4	2	3	4	5	7	8	9
8	0	2	3	4	5	6	8
12	0	0	0	3	4	5	6
16	0	0	0	0	2	4	5
20	0	0	0	0	0	2	4
24	0	0	0	0	0	0	2

<sup>1</sup> Recommendations are for band applications of soluble inorganic Mn sources with acid-forming fertilizers. Broadcast applications of Mn fertilizer are not recommended.

<sup>2</sup> 0.1 N HCl extractable Mn

<sup>3</sup> Recommendations are calculated from the following equation and rounded to the nearest pound:

$$XMn = -36 + 6.2 \times pH - 0.35 \times ST$$

Where XMn = lb Mn per acre

pH = soil pH

ST = ppm Mn soil test

Table 27.

**MANGANESE FERTILIZER RECOMMENDATIONS FOR RESPONSIVE CROPS GROWN ON ORGANIC SOILS.<sup>1</sup>**

Soil test Mn <sup>2</sup>	Soil pH						
	5.8	6.0	6.2	6.4	6.6	6.8	7.0+
ppm	<i>lb Mn per acre<sup>2</sup></i>						
2	2	4	5	7	9	10	12
4	1	3	5	6	8	10	11
8	0	1	3	5	7	8	10
12	0	0	2	4	6	7	9
16	0	0	1	3	4	6	8
20	0	0	0	1	3	5	6
24	0	0	0	0	2	4	5
28	0	0	0	0	1	2	4
32	0	0	0	0	0	1	3
36	0	0	0	0	0	0	1

<sup>1</sup> Recommendations are for band applications of soluble inorganic Mn sources with acid-forming fertilizers. Broadcast applications of Mn fertilizer are not recommended.

<sup>2</sup> 0.1 N HCl extractable Mn

<sup>3</sup> Recommendations are calculated from the following equation and rounded to the nearest pound:

$$XMn = -46 + 8.38 \times pH - 0.31 \times ST$$

Where XMn = lb Mn per acre

pH = soil pH

ST = ppm Mn soil test

**MICRONUTRIENT RECOMMENDATIONS**

Tables 26-29 give recommended rates of soil-applied inorganic sources of micronutrients based on soil type, soil test and pH. These rates are recommended only for the responsive crops listed in Table 23. 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. Micronutrient availability in both mineral and organic soils is highly regulated by soil pH. The higher the soil pH, the higher the soil test should be before a deficiency is eliminated. 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 the 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. Boron applications on fine-textured high clay soils have not proven to be beneficial.

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

Table 28.  
**ZINC FERTILIZER RECOMMENDATIONS FOR RESPONSIVE CROPS GROWN ON MINERAL AND ORGANIC SOILS.**<sup>1</sup>

Soil test Zn <sup>2</sup>	Soil pH					
	6.6	6.8	7.0	7.2	7.4	7.6+
ppm	lb Zn per acre <sup>3</sup>					
1	1	2	3	4	5	6
2	0	1	2	3	4	5
4	0	0	1	2	3	4
6	0	0	1	2	3	4
8	0	0	0	1	2	3
10	0	0	0	0	1	2
12	0	0	0	0	0	1

<sup>1</sup> Recommendations are for band applications of soluble inorganic Zn sources. Synthetic Zn chelates may be used at one-fifth this rate. For broadcast applications, use 5 to 10 lb Zn/acre.

<sup>2</sup> 0.1 N HCl extractable Zn

<sup>3</sup> Recommendations are calculated from the following equation and rounded to the nearest pound:

$$XZn = -32 + 5.0 \times \text{pH} - 0.4 \times \text{ST}$$

Where XZn = lb Zn per acre

pH = soil pH

ST = ppm Zn soil test

Table 29.  
**COPPER RECOMMENDATIONS FOR CORN GROWN ON ORGANIC SOILS.**<sup>1</sup>

Soil test Cu <sup>2</sup>	Copper recommendation
ppm	lb Cu per acre <sup>3</sup>
1	4
4	4
8	3
12	2
16	1
20+	0

<sup>1</sup> Recommendations are for band applications of soluble inorganic Cu sources. For broadcast applications, use 5 to 10 lb Cu/acre.

<sup>2</sup> 1.0 N HCl extractable Cu

<sup>3</sup> Recommendations are calculated from the following equation and rounded to the nearest pound:

$$XCu = 6.3 - 0.3 \times \text{ST}$$

Where XCu = lb Cu per acre

ST = ppm Cu soil test

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.

Table 30 gives foliar micronutrient recommendations for responsive crops listed in Table 23. Foliar rates of suggested sources should be based on the size of the plant — use higher rates for larger plants and lower rates with smaller plants. Use 20 to 30 gallons of water for sufficient coverage of the foliage to ensure good uptake of the micronutrient. When foliar sprays of chelates are used, follow the labeled rate — using too much can cause foliar injury and reduced uptake. At reduced rates, chelate foliar sprays are usually less effective than the suggested inorganic sources.

Table 30.  
**COMMON MICRONUTRIENT FERTILIZER SOURCES AND SUGGESTED RATES FOR FOLIAR APPLICATION.**<sup>1</sup>

Micronutrient	lb of element per acre	Common fertilizer sources
Boron (B)	0.1-0.3	Sodium borate (20 %B) Boric acid (17%B)
Copper (Cu)	0.5-1.0	Copper sulfate (13 to 25% Cu)
Manganese (Mn)	1.0-2.0	Manganese sulfate (28% Mn)
Zinc (Zn)	0.3-0.7	Zinc sulfate (36% Zn)
Molybdate (Mo)	0.01-0.07	Ammonium molybdate (49%) Sodium molybdate (46%)

<sup>1</sup> Use sufficient water (20 to 30 gallons) to get good coverage of foliage.



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# How to Sample Manure for Nutrient Analysis

A field-by-field nutrient management program requires multiple components to maintain adequate fertility for crop growth and development. A well-designed soil sampling plan, including proper soil test interpretations along with manure sampling, manure nutrient analysis, equipment calibration, appropriate application rates and application methods are all necessary components of a nutrient management plan. Implementing these components allows manure to be recognized and used as a credible nutrient resource, potentially reducing input costs and the potential of environmental impacts.

Animal manure has long been used as a source of nutrients for crop growth. Standard nutrient values are guides to determine the amount of nutrients that animal manure will supply as a fertilizer source. Iowa State University Extension publication, *Managing Manure Nutrients for Crop Production* (PM 1811), recommends manure nutrient content and credits by type of animal, handling system and application methods.

While “book values” like those in PM-1811 are reasonable average values, an individual farm’s manure analyses can vary from those averages by 50 percent or more. Species, age of animal, feed rations, water use, bedding type, management, and other factors make every farm’s manure different. Two key factors affecting the nutrient content of manure are manure handling and type of storage structures used. Each handling system results in different types of nutrient losses—some unavoidable and others that can be controlled to a certain degree. Because every livestock production and manure management system is unique, the best way to assess manure nutrients is by sampling and analyzing the manure at a laboratory.

This publication describes how to sample solid, semi-solid, and liquid manure. Manure with greater than 20 percent solids (by weight) is classified as dry manure and is handled as a solid, usually with box-type spreaders. Manure with 10 to 20 percent solids is classified as semi-solid manure and can usually be handled as a liquid. Semi-solid manure usually requires the use of chopper pumps to provide thorough agitation before pumping. Manure with less than 10 percent solids is classified as liquid manure and is handled with pumps, pipes, tank wagons, and irrigation equipment.

A representative manure sample is needed to provide an accurate reflection of the nutrient content. Unfortunately, manure nutrient content is not uniform within storage structures, so obtaining a representative sample can be challenging. Mixing and sampling strategies should therefore insure that samples simulate as closely as possible the type of manure that will be applied.

## When to Sample Manure

Sampling manure prior to application will ensure that you receive the analysis in time to adjust nutrient application rates based on the nutrient concentration of the manure. However, sampling manure prior to application may not completely reflect the nutrient concentration of the manure due to storage and handling losses if long periods of time pass before application begins or when liquid storage facilities are not adequately agitated while sampling. “Pre-sampling” such as dipping samples off the top of storage structure for nitrogen (N) and potassium (K) concentrations, can be done to estimate application rates. (See page 3 for more on pre-sampling). Producers must remember to go back and determine the actual nutrient rates applied by using manure samples collected during application and calculating volumes.

For best results, manure should be sampled at the time of application or as close as possible to application. Sampling during application will help to ensure that samples are well-mixed and representative of the manure being applied. Because manure nutrient analysis typically takes several days at a lab, sampling at the time of application will not provide immediate manure nutrient recommendations. The results can, however, be used for subsequent manure applications and to adjust commercial fertilizer application. This is why it is important to develop a manure sampling history and use those analyses in a nutrient management plan. A manure sampling history will also help you recognize if unplanned changes have occurred to your system if management and other factors have remained constant. A manure sampling history will give you confidence in using manure, and show you how consistent nutrient concentration is from year to year.

Take manure samples annually for three years for new facilities, followed with samples every three to five years, unless animal management practices, feed rations, or manure handling and storage methods change drastically from present methods. If you apply manure several times a

year, take samples when you plan to apply the bulk of manure. For example, it may be appropriate to sample in the spring when manure that has accumulated all winter will be applied. If storages are emptied twice a year, it may be necessary to sample in both spring and fall since the different storage temperatures in summer versus winter will affect manure nutrient levels. *NOTE: Implementation of future federal regulations may require concentrated animal feeding operations (> 1,000 animal units) to sample annually. Please check state and federal requirements to determine sampling frequency.*

## How to Sample Semi-Solid or Liquid Manure

In liquid and semi-solid systems, settled solids can contain over 90 percent of the phosphorus (P), so complete agitation is needed to accurately sample the entire storage if all the manure in the storage structure is going to be applied. If, however, solids will purposely be left on the bottom of the storage structure when the manure is pumped out, as is sometimes the case with lagoons, then complete agitation during sampling may generate artificially high nutrient values. In this case agitation of the solids or sludge on the bottom of a lagoon is not needed for nutrient analysis.

Liquid manure is best sampled during land application, for it is potentially more difficult and dangerous to sample from liquid storage facilities than dry manure systems. When sampling manure during application is not possible, or pre-application analysis is desired for determining rates, refer to the section on sampling from a storage facility. If sampling from a liquid storage facility, use caution to prevent accidents, such as falling into the manure storage facility or being overcome with hazardous gases produced by manure. Have two people present at all times. Never enter confined manure storage spaces without appropriate safety gear such as a self-contained breathing apparatus.

Ideally, liquid manure should be agitated so a representative sample can be obtained for laboratory analysis. When agitating a storage pit below a building, be sure to provide adequate ventilation for both animals and humans. When agitating outdoor unformed pits, monitor activities closely to prevent erosion of berms or destruction of pit liners.

### Liquid Manure Sample Preparation

All liquid samples should be handled as follows:

- Prior to sampling label a plastic bottle with your name, date and sample identification number using a waterproof pen.
- If the sample cannot be mailed or transported to a laboratory within a few hours, it should be frozen. Place the container in a tightly sealed plastic bag and keep it cold or frozen until it arrives at the laboratory.
- Most manure analysis laboratories do have plastic bottles available for sample collection. Do not use glass containers, as expansion of the gases in the sample can cause the container to break.

### Liquid Manure Sampling During Land Application

#### Liquid Manure Applied with Tank Wagons

- Since settling begins as soon as agitation stops, samples should be collected as soon as possible after the manure tank wagon is filled unless the tanker has an agitator.
- Immediately after filling the tank wagon, use a clean plastic pail to collect manure from the loading or unloading port or the opening near the bottom of the tank. Be

sure the port or opening does not have a solids accumulation from prior loads.

- Use a ladle to stir the sample in the bucket to get the solids spinning in suspension. While the liquid is spinning remove a ladle full and carefully pour in the sample bottle. See Figure 1.
- Repeat this procedure and take another sample until the sample bottle is three-quarters full (Make sure the manure solids have not settled to the bottom of the bucket as each ladle is extracted; it is important to

include the solids in the sample). Screw the lid on tightly.

### Liquid Manure Applied by Irrigation Systems

- Place catch pans or buckets randomly in the field to collect liquid manure that is applied by an irrigation system. Inexpensive aluminum roasting



**Figure 1. Collecting a liquid manure sample.**

pans or plastic buckets can be used as catch pans. Use several pans at different distances from the sprinkler head.

- Immediately after the manure has been applied, collect manure from catch pans or buckets and combine the manure in one bucket to make one composite sample.
- Use a ladle to stir the sample in the bucket. While the liquid is spinning remove a ladle full and carefully pour into a sample bottle. See Figure 1.
- Repeat this procedure and take another sample until the sample bottle is three-quarters full. Screw the lid on tightly.

### Liquid Manure Sampling from Storage Facilities

For best sampling results, samples should be taken with a sampling probe or tube (see Figure 2). Probes can be constructed out of 1.5-inch diameter PVC pipe. Cut the PVC pipe a foot longer than the depth of the pit. Run a 1/4-inch rod or string through the length of the pipe and attach a plug such as a rubber stopper or rubber ball (see Figure 3). The rod or the string must be longer than the pipe. If using a rod, bend the top over to prevent it from falling out of the pipe.

- Insert the pipe slowly into the pit or lagoon, with the stopper open, to the full depth of the pit.



**Figure 2. Sampling earthen basin with sampling probe.**

- Pull the string or rod to close the bottom of the pipe and extract the vertical profile sample inside the pipe (be careful not to tip the pipe and dump the sample).
- Release the sample carefully into a bucket.
- Repeat the process at least three times around the pit or lagoon creating a composite sample in the bucket.
- Use a ladle to stir the sample in the bucket to get the solids spinning in suspension. While the liquid is spinning,

take a ladle full and carefully pour into a sample bottle.

- Repeat again and take another sample until sample bottle is three-quarters full. Make sure the manure solids have not settled to the bottom of the bucket as each dipper is extracted; it is important to include the solids in the sample. Screw the lid on tightly.



**Figure 3. Rubber stopper attached to a metal rod to serve as a stopper for PVC manure sampling tube.**

## Pre-Sampling Nitrogen and Potassium from Liquid Manure

If the procedures described above for sampling liquid manure are impractical due to lack of sampling equipment, or the inability to agitate the manure, manure samples can be dipped off the top of stored liquid manure to analyze for N and K concentrations. Research has shown that top-dipped liquid samples represent approximately 90 percent of the N concentration measured in mixed, field-collected samples. Multiply the results of the N concentration from top-dipped samples by 1.1 for a better estimate of the N concentration of the liquid storage facility. Dipping a sample from the surface of a liquid storage pit does NOT provide a good estimate of P concentration in the pit and is not recommended.

## How to Sample Dry or Solid Manure

In solid manure handling systems, many of which include bedding, the proportions of fecal matter, urine, and bedding will vary from one location to another within sites, and often from season to season as well. It is necessary to take samples from various places in the manure pile, stack, or litter to obtain a representative sample for analysis. It may even be beneficial to sample several times per year based on the bedding content.

Manure sampling is best done in the field as manure is applied. This ensures that losses that occur during handling, storage, and application are taken into account and that manure is better mixed, reducing stratification found during sampling storage facilities. As with field sampling of liquid manure, results will not be available in time to adjust current application rates. However, sampling during application will still allow producers to adjust any planned future commercial fertilizer rates and manure application in subsequent years. The following method describes a procedure for collecting dry or solid manure samples from the field.

## Dry Manure Sampling During Land Application

Collect manure samples according to the following field sampling procedure.

- Spread a sheet of plastic or tarp on the field. A 10-foot-by-10-foot sheet works well for sampling manure.
- Fill the spreader with a load of manure.
- Drive the tractor and manure spreader over the top of the plastic to spread manure over the sheet.
- Collect subsamples as described below (Steps 1-3, Com-

posite Sample Collection).

- Samples should be collected to represent the first, middle and last part of the storage facility or loads applied and should be correlated as to which loads are applied on certain fields to track changes in nutrient concentrations throughout the storage facility.

## Sampling from Dry or Solid Storage Facilities and Open Lots

Manure should be sampled at the time of application, but if time and management practices prevent this, manure samples can be collected from the storage facility. Sampling from storages is not generally recommended due to difficulty in collecting a representative sample. Although solid manure storages are generally not fully enclosed and gases are somewhat diluted, always exercise caution when sampling from storage facilities. If you have to enter a confined storage facility, follow the safety recommendations described previously in the section on sampling liquid manure storages.

### Open Paved Lots

Manure that accumulates on paved feedlots and is scraped and hauled to the field is classified as scrape-and-haul feedlot manure. Manure is usually removed from the feedlot daily or several times a week.

- Collect manure by scraping a shovel across approximately 25 feet of the paved feedlot. This process should be repeated ten or more times, taking care to sample in a direction that slices through the large-scale variations of moisture, bedding, depth, age, etc. (See Figure 4). Avoid manure that is excessively wet (near waterers) or contains unusual amounts of feed and hay.
- Use the shovel to thoroughly mix manure by continuously scooping the outside of the pile to the center of the pile.
- Collect subsamples from this pile using the hand-in-bag



**Figure 4. Sampling a feed-lot for manure sample.**

method that is described below (Steps 1-3 Composite Sample Collection).

- This may need to be done several times to collect several composite samples for analysis.

### Barn Gutter

Manure that accumulates in a barn or housing facility, is temporarily stored in a gutter, and then removed by a barn cleaner is classified as barn gutter manure. Manure is usually removed from the barn once or twice daily.

- Shovel a vertical “slice” of manure from the gutter, making sure the shovel reaches to the bottom of the gutter.
- Remove manure from the gutter and pile it on the barn floor. Mix the manure with a shovel or pitchfork to ensure that bedding is mixed thoroughly with manure. When collecting samples from a gutter, be sure to include the liquid that accumulates in the gutter’s bottom. Discard foreign material and also take care not to add large amounts of barn lime.
- Repeat steps one and two from various locations along the gutter.
- Mix each pile thoroughly and collect subsamples from each pile using the hand-and-bag method that is described below (Steps 1-3, Composite Sample Collection).

### Dry Stack and Manure with Litter

Manure that is stored outside in a solid waste storage facility, such as a stacking shed or horizontal concrete silo located above ground, is classified as a dry stack. These facilities are usually covered to prevent the addition of extra water. Dry

manure with litter should also be sampled in the following manner.

- Remove manure from 10 to 20 locations throughout the dry stack and place it in a pile using a pitchfork or shovel. Manure should be collected from the center of the stack as well as from near the outside walls, to get samples that represent all ages and moisture levels of manure in the stack. A bucket loader can cut a path into the center of the pile to provide access for sampling. Subsamples should be collected to the depth the litter will be removed for application.
- Thoroughly mix manure with the shovel by continuously scooping the outside of the pile to the center of the pile.
- Collect a composite manure sample as described below (Steps 1-3, Composite Sample Collection).

### Composite Sample Collection for Dry or Solid Samples

1. Whether collecting from a plastic tarp in the field, a feedlot, a storage facility, or a barn, sample in a grid pattern so that all areas are represented. Combine 10 to 20 subsamples in a bucket or pile and mix thoroughly. More subsamples will produce more accurate results and are often required to produce a composite that best represents nutrient levels.
2. The final composite sample that will be submitted for nutrient analysis should be collected using the hand-in-bag method. To collect a composite sample from the mixed subsamples, place a one-gallon resealable freezer bag turned inside out over one hand. With the covered hand, grab a representative handful of manure and turn the freezer bag right side out over the sample with the free hand. Be careful not to get manure in the sealable tracks.
3. Squeeze excess air out of the bag, seal, and place it in another plastic bag to prevent leaks. Label the bag with your name, date, and sample identification number with a waterproof pen and freeze it immediately to prevent nutrient losses and minimize odors. For manure with a high degree of variability, multiple samples may need to be analyzed. Manure samples should be mailed or delivered to the laboratory as soon as possible after sampling.

Manure samples should be sent to a lab for chemical analysis as quickly as possible to avoid nutrient losses. For a list of commercial laboratories, please call your ISU Extension office or visit the Web at: <http://extension.agron.iastate.edu/immag/sp.html>.

**Table 1. Conversion Factors**

To switch from	Multiply by	To get
mg/l	1.0	ppm
ppm	0.0001	percent
ppm	0.00834	lb/1,000 gal
ppm	0.002	lb/ton
ppm	0.2265	lb/acre-inch
lb/1,000 gal	0.012	percent
lb/ton	0.05	percent
percent	83.4	lb/1,000 gal
percent	20.0	lb/ton
percent	2265	lb/acre-inch
P (elemental)	2.29	P <sub>2</sub> O <sub>5</sub>
K (elemental)	1.2	K <sub>2</sub> O

## Additional Information and Resources

Basic manure analyses determined by laboratories include total nitrogen, total phosphorus, and total potassium. Results from commercial laboratories are presented either as a percent of the sample weight, as pounds per ton, as pounds per 1,000 gallons of manure, or in parts per million (ppm). Table 1 shows factors used to convert between measurements. Usually, nutrients are expressed as N, P<sub>2</sub>O<sub>5</sub>, or K<sub>2</sub>O on a wet or “as received” basis, but some labs may instead report data on an elemental (P instead of P<sub>2</sub>O<sub>5</sub>, K instead of K<sub>2</sub>O) or dry (without water) basis; so, be sure to confirm the units. In any case, manure values from commercial laboratories express nutrients as the total amount of nutrient in the manure sample. Some primary nutrients, such as N and P, may not be completely available for plant growth the first year manure is applied. A portion of some nutrients present in manure are in an organic form and unavailable for immediate plant uptake. Organic forms require transformation to an inorganic form to be available for plant uptake. This transformation is dependent on temperature, moisture, chemical environment, and time. Availability of nutrients can be limited by field losses, which are affected by the type of manure and by manure application methods. These losses are not accounted for in laboratory results. Refer to the ISU Extension publication *Managing Manure Nutrients for Crop Production* (PM 1811) for nutrient availability estimates and losses due to types of manure application methods.

- PM 1518k *Manure Storage Poses Invisible Risks*
- PM 1941 *Calibration and Uniformity of Solid Manure Spreaders* (12/03)
- PM 1948 *Calibrating Liquid Manure Applicators* (02/04)
- PM 1811 *Managing Manure Nutrients for Crop Production*

Additional resources may be found on the Iowa Manure Management Action Group (IMMAG) Web page at: <http://extension.agron.iastate.edu/immag/default.htm>

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# Additional Resources

This section contains various links and sources of information that are available on the web and otherwise as well as some economic rationale to emphasize the importance of nutrient management.

Acknowledgement of contributing partners and sources of information can also be found within this section.



# Nutrient Recommendations Comparison

Field	Year	Crop	Yield Goal	Nitrogen Recommendations			P <sub>2</sub> O <sub>5</sub> Recommendations			K <sub>2</sub> O Recommendations		
				Private Rec's	Tri-State Rec's	Difference	Private Rec's	Tri-State Rec's	Difference	Private Rec's	Tri-State Rec's	Difference
<b>21-1</b>	2014	Soybeans	60	20	0	20	17	0	17	29	0	29
Size (ac)	2015	Wheat	100	109	110	-1	19	0	19	20	0	20
12	2016	Corn	180	230	220	10	21	0	21	30	0	30
<b>21-2</b>	2014	Corn	180	246	220	26	97	68	29	152	70	82
Size (ac)	2015	Soybeans	60	20	0	20	71	50	21	118	105	13
21	2016	Wheat	100	117	110	7	100	63	37	81	60	21
<b>21-3</b>	2014	Soybeans	60	20	0	20	0	0	0	42	0	42
Size (ac)	2015	Wheat	100	112	110	2	0	0	0	26	0	26
42	2016	Corn	180	236	220	16	0	0	0	43	0	43
<b>21-4</b>	2014	Corn	180	249	220	29	60	0	60	103	0	103
Size (ac)	2015	Soybeans	60	20	0	20	48	0	48	91	0	91
36	2016	Wheat	100	119	110	9	53	63	-10	59	0	59
<b>21-5</b>	2014	Wheat	100	116	110	6	20	0	20	82	0	82
Size (ac)	2015	Corn	180	244	220	24	22	0	22	51	0	51
16	2016	Soybeans	60	20	0	20	18	0	18	85	0	85
<b>Estimated Nutrient Costs</b>												
N Cost		\$ 0.50	/ pound	Year	Corn	Soybeans	Wheat	Total				
P <sub>2</sub> O <sub>5</sub> Cost		\$ 0.60	/ pound		\$/Ac	\$/Ac	\$/Ac	\$				
K <sub>2</sub> O Cost		\$ 0.60	/ pound	2014	\$ 100.25	\$ 35.73	\$ 64.20	\$ 8,671.20				
				2015	\$ 55.80	\$ 70.19	\$ 18.00	\$ 5,865.60				
				2016	\$ 34.20	\$ 71.80	\$ 35.52	\$ 5,020.30				
				Total				\$ 19,557.10				



# Web Links

**OhioLine** ~ OSU extension website housing various fact sheets and bulletins.

<http://ohioline.osu.edu/>

**Shelby Soil and Conservation District Website** ~ Home to printable farm record sheets as well as a printable version of this binder.

<http://www.shelbyswcd.org>

**National Weather Service** ~ Website that is customizable based on location, we are recommending that forecast information be printed and kept as a record to coincide with application information.

<http://www.weather.gov/>

**National Resources Conservation Service** ~ Website contains information and links to various conservation topics and resources.

<http://www.nrcs.usda.gov/wps/portal/nrcs/site/oh/home/>

**4R Tomorrow** ~ A program created by the Ohio Federation of Soil and Water Conservation Districts (OFSWCD), with the support of the Ohio Soybean Council, to educate and promote wise nutrient management to conserve water quality and soil health using the 4R nutrient stewardship principles and conservation practices.

<http://www.4rtomorrow.org/>

**Cargill** ~ Cargill's corporate website is the gateway to worldwide company information and resources.

<http://www.cargill.com/>

**Ohio Farm Bureau Federation** ~ For information on policy, regulations, and education.

<http://ofbf.org/>





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# Water Quality and Nutrient Management



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