TRI-STATE FERTILIZER RECOMMENDATIONS *FOR* CORN, SOYBEANS, WHEAT & ALFALFA

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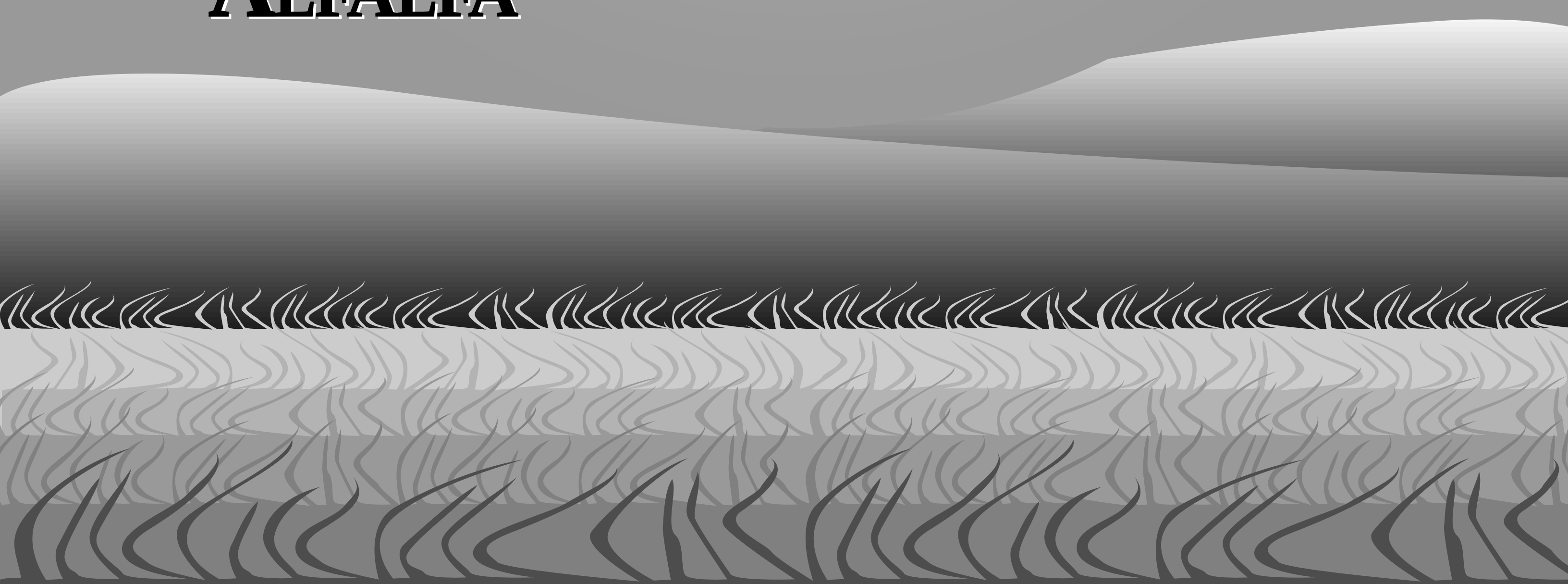

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Tri-state Fertilizer Recommendations for Corn, Soybeans, Wheat and Alfalfa

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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.

ACKNOWLEDGEMENTS

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CONTENTS

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.

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[1]	Desired pH levels				
	Mineral soils			Organic soils	
	6.8	6.5	6.0	Soil pH	5.3
	tons agricultural limestone/acre[2]				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

[1]Lime test index is the SMP buffer pH x 10.

[2]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.

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 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.

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

Crop	Mineral soils with subsoil pH > pH 6	Mineral soils with subsoil pH < pH 6	Organic soils
	pH		
Alfalfa	6.5	6.8	5.3
Other forage legumes	6.0	6.8[1]	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

[1] 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 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 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.

NITROGEN

Profitability, 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 ($NH_2CONH_2 + H_2O \dashrightarrow 2NH_3 + CO_2$). 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 ½ 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.[1]

N treatment	*Average grain yield bu/acre at 15.5% water*
NH_3 injected	139
UAN injected	135
UAN surface	118
urea surface	123

[1]Adapted from D.B. Mengel et al. 1982. Placement of nitrogen fertilizers for no-till and conventional corn. Agron. J. 74:515-518.

Table 4.
CORN GRAIN YIELDS AS AFFECTED BY SEVERAL N MANAGEMENT STRATEGIES AT WOOSTER AND SPRINGFIELD, OHIO, 1984-1985.[1]

N		*Application*		*Corn following*	
Rate	Source[2]	Time	Method	Corn	Soybean
lb/acre				*bu/acre*	
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 ⅓ preplant ⅔ sidedress	Dribbled	150	157
150	UAN	Split ⅔ preplant ⅓ sidedress	Dribbled	151	156

[1]Adapted from D.J. Eckert. 1987. UAN management practices for no-tillage corn production. Journal of Fertilizer Issues. Vol 4:13-18.

[2]AA = anhydrous ammonia; UAN = urea ammonium nitrate solution.

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 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.

Table 5.
EFFECT OF KNIFE SPACING OF AMMONIA APPLIED AT VARYING RATES OF N ON CORN YIELD AT DEKALB, ILL.[1]

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[2]		
30	159	178	190
60	166	179	180

[1] Adapted from R.G. Hoeft. 1987. Effect of ammonia knife spacing on yield. In Proceedings of the Seventeenth North Central Extension-Industry Soil Fertility Workshop. St. Louis, Missouri.

[2] Applied beneath the planted row.

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 leaching 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.

Table 6.
YIELD OF CORN AS AFFECTED BY NITROGEN RATE, TIME OF NITROGEN APPLICATION AND SOIL TYPE IN MICHIGAN, 1977-1984.[1]

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

[1]Adapted from M.L. Vitosh. 1985. Nitrogen management strategies for corn producers. Michigan State University Extension Bulletin WQ06.

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 7.
EFFECT OF N RATE, TIME OF APPLICATION, N SOURCE AND NITRIFICATION INHIBITOR ON 8-YEAR AVERAGE CORN YIELD IN OHIO.[1]

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

[1] 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.

Table 8. Effect of N rate and time of application on corn yield for an irrigated McBride sandy loam soil in Michigan.[1]

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

[1] Adapted from M.L. Vitosh. 1969-72 Montcalm Farm Research Reports.

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 presidedress 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 (NO_3^-) is present in a soil and not enough oxygen (O_2) is present to supply the needs of the bacteria and microorganisms in the soil. If O_2 levels are low, microorganisms strip the oxygen from the nitrate, producing N gas (N_2) or nitrous oxide (N_2O), 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 (NO_3^-) that is in soil solution moves along with the water. Ammonium (NH_4^+) forms of N have a positive charge and are held by the negative sites on the clay in the soil; therefore, 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.

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+*
			pounds N to apply per acre			
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[1]						
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[2]	50	80	110	130	160	190

[1]Any legume established for more than one year.

[2]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

1. N fertilizer rates are based on the following relationship:

   N (lb/acre) = -27 + (1.36 x yield potential) - N credit

   or 110 + [1.36 x (yield potential - 100)] - N credit

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

2. For corn silage, assume 1 ton/acre is equivalent to 6 bu/acre of grain.
3. 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.
4. Corn grown on coarse-textured/low CEC soils with high leaching potentials may benefit from split or multiple N applications.
5. 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).
6. 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.
7. 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.
8. 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.
9. If planting is delayed past the optimum planting period, reduce N rate to reflect loss of yield potential.
10. 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.
11. 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.

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

Additional comments

1. Recommended N rate is based on the relationship:

   N (lb/acre) = 40 + [1.75 x (yield potential - 50)]

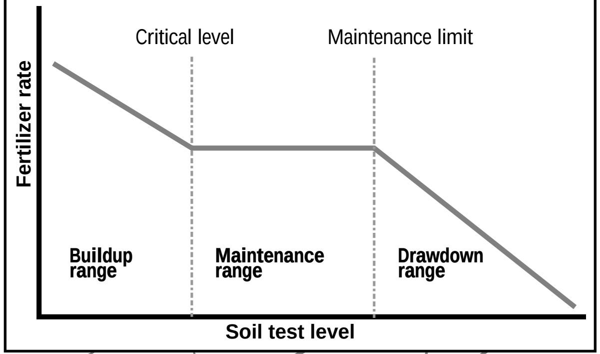
2. No credits are given for the previous crop. Consult individual state recommendations concerning credits for organic waste materials such as manure.
3. Apply 15 to 30 lb N/acre at planting and the remainder near green-up in spring; or, apply all N at planting as anhydrous ammonia plus a nitrification 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

Tri-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.

Figure 1
Fertilizer recommendation scheme used in the tri-state region



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:

Buildup equation

for P: lb P_2O_5/A to apply = [(CL - STL) x 5] + (YP x CR)

for K: lb K_2O/A to apply = [(CL - STL) x ((1 + (0.05 x CEC))] + (YP x CR) + 20

Maintenance equation

for P: lb P_2O_5/A to apply = YP x CR

for K: lb K_2O/A to apply = (YP x CR) + 20 (for non-forage crops)

Drawdown equation

for P: lb P_2O_5/A to apply = (YP x CR) - [(YP x CR) x (STL - (CL + 15))/10]

for K: lb K_2O/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_2O/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)

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.

Table 11.
Critical soil test levels (CL) for various agronomic crops.

Crop	*Critical soil test levels*				
	P	*K at CEC*[1]			
		5	*10*	*20*	*30*
	ppm (lb/acre)	ppm (lb/acre)			
Corn	15 (30)[2]	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)

1 Critical level for ppm K = 75 + (2.5 x CEC) for all crops

2 Values in parentheses are lb/acre.

Note: A CEC of 15 is used to calculate the K_2O 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_2O_5	*K_2O*
		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)[1]	85	95	100	110	115
10 (20)	60	70	75	85	90
15-30 (30-60)[2]	35	45	50	60	65
35 (70)	20	20	25	30	35
40 (80)	0	0	0	0	0

[1] Values in parentheses are lb/acre.
[2] 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)[1]	80	90	95	100	105
20 (40)	55	65	70	75	80
25-40 (50-80)[2]	30	40	45	50	55
45 (90)	15	20	20	25	30
50 (100)	0	0	0	0	0

[1] Values in parentheses are lb/acre.
[2] 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)[1]	115	125	130	135	140
10 (20)	90	100	105	110	115
15-30 (30-60)[2]	65	75	80	85	90
35 (70)	35	40	40	45	45
40 (80)	0	0	0	0	0

[1] Values in parentheses are lb/acre.
[2] 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)[1]	115	130	140	155	165
20 (40)	90	105	115	130	140
25-40 (50-80)[2]	65	80	90	105	115
45 (90)	35	40	45	50	60
50 (100)	0	0	0	0	0

[1] Values in parentheses are lb/acre.
[2] 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)[1]	75	80	90	100	105
10 (20)	50	55	65	75	80
15-30 (30-60)[2]	25	30	40	50	55
35 (70)	10	15	25	25	30
40 (80)	0	0	0	0	0

[1] Values in parentheses are lb/acre.
[2] 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)[1]		125	130	135	140	145
50 (100)		95	100	105	110	115
75 (150)		65	70	75	80	85
88-118 (175-235)[2]		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)[2]		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)[2]		45	50	60	65	70
165 (330)		25	25	30	35	35
175 (350)		0	0	0	0	0
	CEC	30[3] 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)[2]		45	50	60	65	70
190 (380)		25	25	30	30	35
200 (400)		0	0	0	0	0

1 Values in parentheses are lb/acre.
2 Maintenance recommendations are given for this soil test range.
3 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)[1]		140	155	170	180	195
50 (100)		110	125	135	150	165
75 (150)		80	90	105	120	135
88-118 (175-235)[2]		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)[2]		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)[2]		60	75	90	105	120
165 (330)		30	40	45	50	60
175 (350)		0	0	0	0	0
	CEC	30[3] 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)[2]		60	75	90	105	120
190 (380)		30	40	45	50	60
200 (400)		0	0	0	0	0

1 Values in parentheses are lb/acre.
2 Maintenance recommendations are given for this soil test range.
3 For Michigan, do not use CEC's greater than 20 meq/100g.

Table 20.
Potash (K_2O) 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_2O per acre				
ppm (lb/acre)	**CEC**	**5 meq/100g**				
25 (50)[1]		115	120	125	130	130
50 (100)		85	90	95	95	100
75 (150)		55	60	60	65	70
88-118 (175-235)[2]		40	40	45	50	55
130 (260)		15	15	15	20	20
140 (280)		0	0	0	0	0
	CEC	**10 meq/100g**				
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)[2]		40	40	45	50	55
140 (280)		20	20	25	25	25
150 (300)		0	0	0	0	0
	CEC	**20 meq/100g**				
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)[2]		40	40	45	50	55
165 (330)		20	20	25	25	25
175 (350)		0	0	0	0	0
	CEC	**30[3] meq/100g**				
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)[2]		40	40	45	50	55
190 (380)		20	20	25	25	30
200 (400)		0	0	0	0	0

1 Values in parentheses are lb/acre.
2 Maintenance recommendations are given for this soil test range.
3 For Michigan, do not use CEC's greater than 20 meq/100g.

Table 21.
Potash (K_2O) 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_2O per acre[3]				
ppm (lb/acre)	**CEC**	**5 meq/100g**				
25 (50)[1]		260	275	290	300	300
50 (100)		225	245	260	275	290
75 (150)		195	210	230	245	260
88 (175)[2]		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
	CEC	**10 meq/100g**				
25 (50)		295	300	300	300	300
50 (100)		255	270	285	300	300
75 (150)		220	235	250	265	280
100 (200)[2]		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
	CEC	**20 meq/100g**				
50 (100)		300	300	300	300	300
75 (150)		280	295	300	300	300
100 (200)		230	245	260	280	295
125 (250)[2]		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
	CEC	**30[4] meq/100g**				
75 (150)		300	300	300	300	300
100 (200)		300	300	300	300	300
125 (250)		245	260	275	290	300
150 (300)[2]		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

1 Values in parentheses are lb/acre.
2 Maintenance recommendations are given for this soil test level.
3 Potash recommendations should not exceed 300 lb per acre.
4 For Michigan, do not use CEC's greater than 20 meq/100g.

Table 22.

Potash (K_2O) 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_2O per acre[3]				
ppm (lb/acre)	**CEC**	**5 meq/100g**				
25 (50)[1]		300	300	300	300	300
50 (100)		300	300	300	300	300
75 (150)		285	300	300	300	300
88 (175)[2]		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
	CEC	**10 meq/100g**				
25 (50)		300	300	300	300	300
50 (100)		300	300	300	300	300
75 (150)		300	300	300	300	300
100 (200)[2]		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
	CEC	**20 meq/100g**				
50 (100)		300	300	300	300	300
75 (150)		300	300	300	300	300
100 (200)		300	300	300	300	300
125 (250)[2]		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
	CEC	**30[4] meq/100g**				
75 (150)		300	300	300	300	300
100 (200)		300	300	300	300	300
125 (250)		300	300	300	300	300
150 (300)[2]		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

1 Values in parentheses are lb/acre.
2 Maintenance recommendations are given for this soil test level.
3 Potash recommendations should not exceed 300 lb per acre.
4 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.

Table 24.
Nutrient sufficiency ranges for corn, soybeans, alfalfa and wheat.

Element	Corn Ear leaf sampled at initial silking	Soybeans Upper fully developed leaf sampled prior to initial flowering	Alfalfa Top 6 inches sampled prior to initial flowering	Wheat 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	—

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. 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.

Table 25.
MICRONUTRIENT SOURCES COMMONLY USED FOR CORRECTING MICRONUTRIENT DEFICIENCIES IN PLANTS.

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[1] (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[1] (50 to 80% Zn) Zinc chelate (9 to 14% Zn)

® Registered trade name of U.S. Borax.
[1] Granular oxides are not effective sources of micronutrients.

Table 26.
MANGANESE FERTILIZER RECOMMENDATIONS FOR RESPONSIVE CROPS GROWN ON MINERAL SOILS.[1]

Soil test Mn[2]	Soil pH						
	6.3	6.5	6.7	6.9	7.1	7.3	7.5+
ppm	*lb Mn per acre*[3]						
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

[1] Recommendations are for band applications of soluble inorganic Mn sources with acid-forming fertilizers. Broadcast applications of Mn fertilizer are not recommended.

[2] 0.1 N HCl extractable Mn

[3] Recommendations are calculated from the following equation and rounded to the nearest pound:

XMn = -36 + 6.2 x pH - 0.35 x 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.[1]

Soil test Mn[2]	Soil pH						
	5.8	6.0	6.2	6.4	6.6	6.8	7.0+
ppm	*lb Mn per acre*[2]						
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

[1] Recommendations are for band applications of soluble inorganic Mn sources with acid-forming fertilizers. Broadcast applications of Mn fertilizer are not recommended.

[2] 0.1 N HCl extractable Mn

[3] Recommendations are calculated from the following equation and rounded to the nearest pound:

XMn = -46 + 8.38 x pH - 0.31 x 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.[1]

Soil test Zn^2	Soil pH 6.6	6.8	7.0	7.2	7.4	7.6+
ppm	*lb Zn per acre*[3]					
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

[1] 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.

[2] 0.1 N HCl extractable Zn

[3] Recommendations are calculated from the following equation and rounded to the nearest pound:

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

Where XZn = lb Zn per acre
pH = soil pH
ST = ppm Zn soil test

Table 29.
COPPER RECOMMENDATIONS FOR CORN GROWN ON ORGANIC SOILS.[1]

Soil test Cu^2	Copper recommendation
ppm	*lb Cu per acre*[3]
1	4
4	4
8	3
12	2
16	1
20+	0

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

[2] 1.0 N HCl extractable Cu

[3] Recommendations are calculated from the following equation and rounded to the nearest pound:

$$XCu = 6.3 - 0.3 \times ST$$

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.[1]

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%)

[1] Use sufficient water (20 to 30 gallons) to get good coverage of foliage.

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