Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin

Carrie A.M. Laboski and John B. Peters

A2809

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Preface

The Wisconsin soil testing program and nutrient application guidelines were originally developed in the early 1960s. The guidelines have since been revised several times to reflect research advances, additional correlation and calibration data, and shifts in philosophical viewpoint. The latest revision incorporates additional research data, including an update to the maximum return to nitrogen (MRTN) philosophy for corn N rate guidelines along with a new approach for defining soil groups and soil yield potential using data from the U.S. Department of Agriculture-Natural Resource Conservation Service (USDA-NRCS) database. The Wisconsin routine farm soils (RFS) computer program, which is used by Wisconsin Department of Agriculture, Trade, and Consumer Protection (WDATCP) certified soil testing laboratories to generate nutrient and lime recommendations, has been updated to reflect the changes in this document. The guidelines in this publication have been incorporated into the nutrient management planning software SnapPlus (http://snapplus.wisc.edu/).

This publication is intended to guide farmers regarding the appropriate amount of nutrients to apply to maximize yield and profitability. Wisconsin Department of Natural Resources (WDNR) and WDATCP, along with USDA-NRCS, reference this document in several nutrient management codes and rules.

We gratefully acknowledge L.G. Bundy, K.A. Kelling, E.E. Schulte, and L.M. Walsh, professors emeriti of soil science, for their contributions to earlier versions. Appreciation is also expressed to members of the University of Wisconsin–Madison departments of soil science, agronomy, and horticulture for their input—in particular Laura Ward Good, associate scientist and Matt Ruark, assistant professor of soil science—along with Chris Baxter, associate professor of crop and soil sciences, University of Wisconsin-Platteville.

Introduction

Over 200,000 soil samples are analyzed in Wisconsin each year, and the results of these tests guide Wisconsin farmers in the use of lime and nutrient applications. The appropriate use of lime, fertilizer, manure, and other nutrient sources significantly increases Wisconsin farm income. Just as importantly, following nutrient application guidelines prevents over-application of nutrients. This, in turn, enhances profitability and reduces the potential for environmental degradation.

Most farmers recognize the importance of a good soil testing program. Soil testing has some limitations, but it is still the best tool available for predicting lime and fertilizer needs. With representative sampling, soil tests can accurately predict lime, phosphorus, and potassium requirements. Soil tests can also serve as a guide for nitrogen and some of the secondary nutrients and micronutrients; however, these require special testing and, in the case of nitrogen, special sampling systems.

The underlying goal of Wisconsin's recommendation program is to supply enough nutrients to the crop for optimum growth throughout the season. Because nutrient demands are not uniform throughout the season, an adequate supply must be available during the period of peak demand. The Wisconsin program defines the "critical" level as the cutoff between the "optimum" and "high" soil test levels. If the nutrient supply drops below the critical level, growers face economic losses from reduced yields or poor crop quality. If the supply exceeds the critical level, there is an increased risk of mobile nutrients moving into the groundwater and surface water. In addition, there is no profit in applying nutrients that will not be used. The Wisconsin nutrient application guidelines are designed to help a grower anticipate crop needs and monitor nutrient availability.

The goals of Wisconsin's soil testing program are to:

1. Provide an accurate index of the level of available nutrients in the soil.
2. Indicate the degree of nutrient deficiency that may exist for the various crops grown.
3. Suggest how the deficiency might be corrected.
4. Provide the results in an understandable and meaningful way so that the grower can make the appropriate decision as to what nutrients to add.

Nutrient Application Guidelines for Field, Vegetable, and Fruit Crops in Wisconsin (A2809) describes how to interpret soil test results, provides nutrient application guidelines, and outlines the assumptions underlying the guidelines.

Notes:

2. Sampling soils for testing

A soil test is the only practical way of determining whether lime and fertilizer are needed for a specific crop. However, if a soil sample does not represent the general soil conditions of the field, the recommendations based on the sample may be misleading. An acre of soil to a 6-inch depth weighs about 1,000 tons, yet less than 1 ounce of soil is used for each test in the laboratory. Therefore, it is very important that the soil sample be representative of the entire field.

Before collecting soil samples, you should determine the overall approach of the nutrient management program. This will affect the number of samples needed and method by which samples will be taken. Specifically, will nutrient and lime applications be made at a single uniform rate for the whole field being tested or will applications be made at variable rates to field areas that have been identified as having different soil test levels?

Goals of a soil sampling program

When sampling soils for testing and obtaining fertilizer and lime recommendations, the most common objectives are to:

1. Obtain samples that accurately represent the field from which they were taken.
2. Estimate the amount of nutrients that should be applied to provide the greatest economic return to the grower.
3. Estimate the variation that exists within the field and how the nutrients are distributed spatially.
4. Monitor the changes in nutrient status of the field over time.

Selecting a soil sampling strategy

Before selecting a sampling strategy, consider analytical costs, time and equipment available, field fertilization history, and the likelihood of a response to applied nutrients.

Sampling fields for a single whole field (uniform) recommendation

With conventional sampling, you will receive a single set of nutrient and lime application guidelines that are based on sample averages. The sampling guidelines in Table 2.1 are based on when a field was last tested (more or less than 4 years ago) and whether the field was responsive or nonresponsive the last time it was tested. The field is considered to be in the responsive range if either soil test phosphorus (P) or potassium (K) levels are in the high (H) category or lower. A nonresponsive field is one where both soil test P and K levels are in the very high (VH) or excessively high (EH) categories.

Each sample should be made up of a minimum of 10 cores to ensure accurate representation of the nutrient needs of the field. Research has shown that taking 10 to 20 cores provides a more representative sample of the area than when samples are made up of fewer cores. When gathering soil cores to make a composite sample, use a W-shaped sampling pattern (as shown in Figure 2.1) over the whole area the sample represents. Be sure to thoroughly mix the cores before placing approximately 2 cups in the sample bag.

For best results, submit multiple samples for all fields. When at least three samples are provided for a field, samples that are significantly higher than the field average may be discarded and an adjusted average calculated. Using an adjusted average helps ensure that no part of the field is under-fertilized.

Where only one or two samples are taken in a field, no sample will be discarded, whereas one sample can be discarded if three or four samples are taken, and up to two samples may be discarded from fields having five or more samples. The criteria that determine if soil samples should be omitted from the field average include:

Table 2.1. Recommended sample intensity for uniform fields.

Field characteristics	Field size (acres)	Suggested number of samples[a]
Fields tested more than 4 years ago **OR** fields testing in the responsive range	All fields	1 sample/5 acres
Nonresponsive fields tested within past 4 years	5–10	2
	11–25	3
	26-40	4
	41-60	5
	61-80	6
	81-100	7

[a] Collect a minimum of 10 cores per sample.

- If the average soil test P for a field is 35 parts per million (ppm) or less, samples that exceed the field average by more than 5 ppm may be removed and the field average recalculated.
- If the field average is greater than 35 ppm P, no samples will be discarded.
- If the average soil test K for a field is 175 ppm or less, samples that exceed the field average by more than 20 ppm may be discarded and the field average recalculated.
- If the field average is greater than 175 ppm K, no samples will be discarded.

It is not appropriate to vary nutrient application rates across sampling areas when using the whole field (uniform) soil sampling scheme.

Sampling fields for site-specific management

Site-specific management requires a distinct picture of the magnitude and location of soil test variability. Sampling soils for site-specific management usually involves taking many more composite samples than sampling for a single recommendation. A global positioning system (GPS) is used to record the geographical coordinates of each sample. This information is used to generate an application map by using various mathematical techniques to interpolate the nutrient application rate between sampling points. Using variable rate application technology, these fields can be managed more intensively than the conventional approach of one fertilizer and lime rate per field. A careful evaluation of the economics of this intensive of a sampling system needs to be done before proceeding.

Figure 2.1. Recommended W-shaped sampling pattern for a 15-acre field. Each sample should be composed of at least 10 cores.

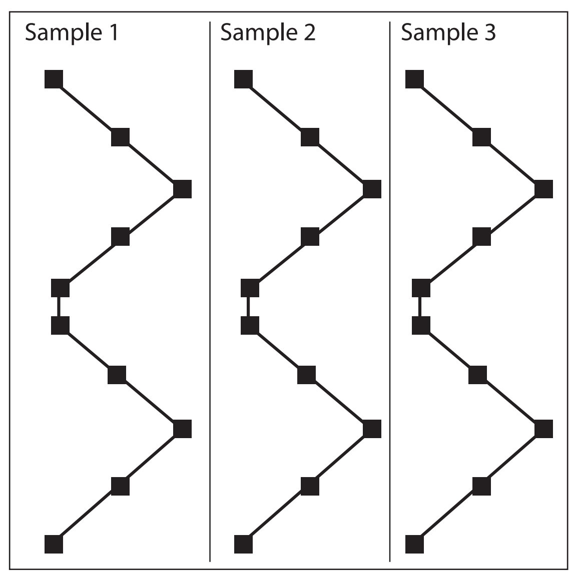
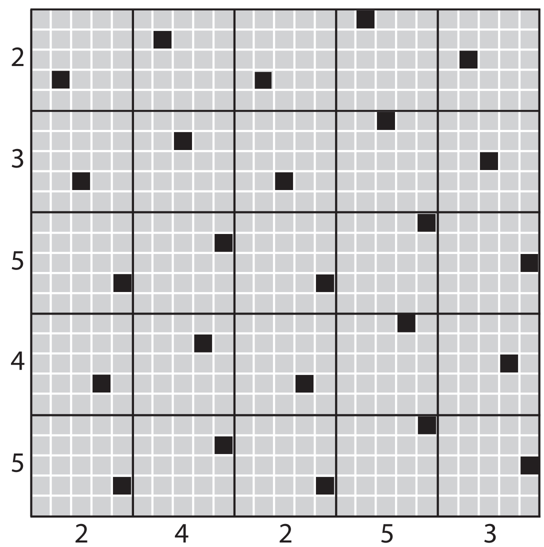


Figure 2.2. An example of an unaligned grid pattern for grid sampling fields.



When using a site-specific approach to soil sampling, sample handling and testing are similar to the traditional system, but recommendations may vary from one part of the field to another, and these areas must be managed separately to realize the potential advantages of intensive soil sampling.

Several sampling strategies can be used to guide variable-rate fertilizer and lime applications. Grid sampling uses a systematic approach that divides the field into squares of approximately equal size (grid cells). The sampling technique used is known as grid-point sampling. A grid-point sample consists of at least 10 cores collected from a small area (10-foot radius) around a geo-referenced point. When using a grid sampling approach, Wisconsin research recommends a sampling strategy based on an unaligned systematic grid (Figure 2.2). Sampling points should be unaligned because sampling in a uniform grid arrangement may lead to biased results if aligned with row patterns. Fields that have soil test P and K levels in the nonresponsive categories should be grid-point sampled on a 300-foot grid. This is equivalent to one soil sample for every 2 to 2.5 acres. Where there is no information about the P or K status of the field or where previous tests were in the responsive range, a 200-ft grid size should be used. This is equivalent to approximately one soil sample per acre. Wisconsin research indicates these small grid cell sizes are needed to adequately characterize the variability in soil fertility. A larger grid cell size (such as 5 acres) may not adequately describe the field variability and may limit the potential economic benefits of site-specific management.

Other considerations in selecting a sampling strategy

The sampling strategy selected must also be appropriate for the field size and topography.

Contour strips. On contour strip fields, sample each strip separately if it is approximately 5 acres or more in size, following the sampling intensity guidelines provided in Table 2.1. Cores from two or three small strips that have identical cropping and management histories may be combined following these same recommended sampling intensity guidelines. Using a grid-point sampling approach on contour strips or small fields is not appropriate, regardless of grid cell size. This is because a grid technique may result in many soil samples being collected from one contour strip but none in other strips; additionally, grid-point samples may be on the edge of the strips and not adequately represent the strip.

Five-acre grid-point sampling. The 5-acre grid point sampling system for whole field management recommendations has recently become popular with soil samplers because it takes less time to collect cores, compared to the traditional W pattern. Another advantage of this approach is its ability to track changes in soil test levels over time, because soil samples are collected from the same geo-referenced point each time the field is sampled. Five-acre grid-point sampling can likely be used in some situations and not in others. For example, in fields that were soil sampled within the past 4 years and tested in the nonresponsive range, averaging the soil test results from 5-acre grid-point sampling is reasonable. This is because there previously had not been a fertilizer recommendation on these fields and some variability at excessively high soil test levels does not change the fact that no fertilizer was recommended. For fields that were sampled more than 4 years ago or where past soil test results were in the responsive range, 5-acre grid-point sampling may not be the best choice of sampling techniques. This is because 5-acre grid-point sampling may not adequately represent the variability within a field, and a comparatively small change in soil test level of 5 to 10 ppm could mean a large change in the amount of nutrients recommended. For small fields and contour strips, taking a few 5-acre grid-point samples in each field and averaging them likely does not provide a very representative sample of the field. Additionally, the total number of samples may be so few that none of them can be eliminated from the field average if it appears that one is an outlier.

Smart (zone or directed) sampling. Another approach gaining support among researchers is smart sampling, also known as directed or management zone sampling. This approach uses information that has been collected using other precision agricultural technologies such as yield maps, aerial photographs of bare soil or crop canopy, or soil electrical conductivity measurements. Directed sampling evaluates the spatial distribution of several factors that may influence nutrient availability and crop productivity to help define sampling areas with similar characteristics. With previous comments in mind, either the W pattern or grid-point method can be used to collect samples within management zones. If the results of grid or management zone sampling do not warrant variable-rate application (for example, relatively little between-sample variation), average them to determine the appropriate single-rate treatment.

Procedures for taking soil samples

When to take soil samples

Take soil samples at any convenient time. Studies examining the effect of sampling time on soil test results suggest that test values for pH and phosphorus (P) are typically slightly higher in early spring samples than in fall samples. The effect of time of sampling on soil test potassium (K) results is dependent upon clay mineralogy and soil test level. Soil test K results may be higher in spring compared to fall on lower testing soils, but on higher testing soils, soil test K may be lower in spring compared to fall. To receive your recommendations early enough to enable you to apply the lime and fertilizer needed, it may be best to sample in the fall. Another benefit of fall testing is that fertilizer prices are more likely to be discounted then. Hayfields can be sampled after any cutting. Regardless of when you sample, it is best to be consistent from one year to the next.

Winter sampling, or sampling when the soil is frozen, is permissible only when it is possible to take a uniform boring or core of soil to the appropriate depth. This may require using a portable power boring tool. Using a pick or spade to remove a few chunks of frozen soil from the surface will give inaccurate results.

How to take soil samples

Certain government agency programs require nutrient management plans prepared according to the current USDA-NRCS nutrient management standard (590). Soil sampling and testing procedures and nutrient application rates based on these soil tests must be consistent with the provisions of the 590 standard to be eligible for many cost-sharing programs. These provisions currently include: following the soil sampling techniques outlined above and contained in the University of Wisconsin-Extension publication *Sampling Soils for Testing* (A2100), soil testing by a Wisconsin certified laboratory, and use of nutrient application rates consistent with the guidelines contained in this publication.

When ready to sample, use a sampling probe or auger. You can obtain these tools on loan from most county Extension offices (counties.uwex.edu) or fertilizer dealers. Avoid sampling the following areas:

- Dead furrows or back furrows
- Lime, sludge, or manure piles
- Animal droppings
- Near fences or roads
- Rows where fertilizer has been banded
- Eroded knolls
- Low spots
- Where stalks or large bales were stacked
- Headlands

In addition, avoid sampling areas that vary widely from the rest of the field in color, fertility, slope, texture (sandy, clayey, etc.), drainage, or productivity. If the distinctive area is large enough to receive lime or fertilizer treatments different from the rest of the field, sample it separately.

The following steps will help you take full advantage of the Wisconsin nutrient application guidelines and must be followed to be consistent with the 590 standard.

1. If manure or crop residues are on the surface, push them aside to keep from including them in the soil sample.
2. Insert the probe or auger into the soil to plow depth or at least 6 inches. The sampling depth should be consistent. To aid year-to-year comparisons, it is important to take repeated samplings from the same field to exactly the same depth.
3. Take at least 10 soil cores or borings for each composite sample and, preferably, at least two composite samples for every field. For nonresponsive fields greater than 5 acres in size, obtain, at a minimum, the number of samples specified in Table 2.1. For responsive fields, as well as all fields that have not been sampled in the past 4 years, take one composite sample for every 5 acres.
4. Thoroughly mix the sample, then place about 2 cups of soil in a sample bag.
5. Identify the bag with your name, field identification, and sample number.
6. Record the field and sample location on an aerial photo or sketch of the farm and retain for your reference. Record the GPS coordinates, if available.
7. Fill out the soil information sheet. A completely and carefully filled out information sheet will provide the most accurate nutrient recommendations.

Always include a soil test information sheet when submitting soil samples to a laboratory for testing. The soil test information sheet used by the UW Soil Testing Laboratories can be found at: http://uwlab.soils.wisc.edu/files/forms/rfs_front.pdf.

Provide the soil name and field history whenever possible for more accurate recommendations. Information about legume crops previously grown on the soil and manure application history is essential for proper nutrient crediting from these sources. Include soil names and/or map unit symbols from county soil survey reports, web soil survey (http://websoilsurvey.nrcs.usda.gov/app/), or individual farm conservation plans. For assistance obtaining this information, contact your county Extension agent, NRCS district conservationist, or the County Land Conservation Department (LCD).

How often to sample

Most fields should be retested at least every 4 years to monitor soil fertility levels of immobile nutrients and pH to prevent nutrient deficiencies and avoid excess nutrient accumulation. Crop nutrient removals over a 4-year period in most cropping systems will not change soil test levels enough to affect recommended nutrient application rates. Exceptions include sands and loamy sands, which should be tested every 2 years. Also, depending on the initial soil test P and K levels, cropping systems such as high-yielding corn silage or alfalfa may require more frequent testing to adequately monitor changes in soil test levels.

What to do with soil samples

The soil samples and a completed soil information sheet can be taken to your county Extension office for forwarding to a certified soil testing laboratory. Alternatively, samples can be sent directly to the soil testing laboratory or delivered in person.

To receive nutrient application rate guidelines consistent with those found in this publication, submit your soil samples to one of the Wisconsin certified laboratories. The College of Agricultural and Life Sciences, University of Wisconsin–Madison and the University of Wisconsin-Extension, through the Department of Soil Science, operate soil testing laboratories at Madison and Marshfield. Several private laboratories are also certified, and are listed at http://uwlab.soils.wisc.edu/wdatcp/. To become certified, laboratories must use the soil testing methods and nutrient application rate guidelines specified by WDATCP. Certified laboratories must also meet quality control standards through periodic analysis of quality control soil samples.

To have your soil tested by the University of Wisconsin, send your samples to either of the following laboratories listed below. A sample submission form can be found at https://uwlab.soils.wisc.edu/farm-soil/.

Soil and Plant Analysis Laboratory
8452 Mineral Point Road
Verona, WI 53593-8696
(608) 262-4364

Soil and Forage Analysis Laboratory
2611 Yellowstone Drive
Marshfield, WI 54449-8401
(715) 387-2523

Tillage system considerations when sampling

Moldboard plowing. Sample to the depth of tillage.

Chisel plowing and offset disking. Take soil samples to ¾ of the tillage depth. When possible, take soil samples before spring or fall tillage. Sampling before tillage lets you determine the sampling depth more accurately and avoid fertilizer bands applied for the previous crop.

Till-plant and ridge tillage. Sample ridges to a 6-inch depth and furrows (between rows) to a depth of 4 inches. Combine equal numbers of soil cores from ridges and furrows to make up the composite sample.

No-till. Fields that have not been tilled for 5 or more years may develop an acid layer on the surface from the use of nitrogen fertilizer. This acid layer could reduce the effectiveness of triazine herbicides. Unincorporated phosphorus (P) and potassium (K) are also likely to build up in the surface soil. If an acid layer is suspected, take a separate sample to a depth of only 2 inches. When sending the soil to the lab, indicate that the sampling depth was only 2 inches. This sample will be tested for pH only, unless P and K are specifically requested. For fertilizer recommendations, take a separate sample to a depth of 6 to 7 inches. Fertilizer recommendations require this sampling depth because fertilizer calibration studies are based on plow-depth sampling. Sample between rows to avoid fertilizer bands.

Notes:

3. Soil test procedures

The routine soil testing program for laboratories using the Wisconsin soil test recommendation program includes soil pH, organic matter content, lime requirement (buffer pH), and extractable phosphorus (P) and potassium (K). In addition, special tests may be requested for nitrate-nitrogen, calcium, magnesium, sulfur, boron, manganese, and zinc. Soil tests for copper, iron, molybdenum, and chlorine have not been calibrated to crop response in Wisconsin; these nutrients are rarely deficient in Wisconsin soils.

Several other tests can be performed on request. These tests include physical analysis for particle size distribution (% sand, % silt, % clay), exchangeable sodium, soluble salts, total nitrogen, inorganic nitrogen, total organic carbon, and heavy metals (arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, selenium, zinc).

In Wisconsin, a soil testing laboratory must be certified by the Wisconsin Department of Agriculture, Trade, and Consumer Protection (WDATCP) if results are to be used in nutrient management planning or related to any government cost-sharing program. A current list of the Wisconsin certified laboratories can be found at http://uwlab.soils.wisc.edu/wdatcp/. Table 3.1 briefly describes the procedures used for each soil test performed at University of Wisconsin laboratories and other WDATCP-approved laboratories.

Table 3.1. Analytical procedures for soil tests performed at University of Wisconsin laboratories and Wisconsin DATCP-approved private laboratories.

Soil Test	Procedures[a]
Soil pH	Prepare a 1:1 soil to water mixture and measure the pH with a glass electrode.
Buffer pH (BpH)	Prepare a 1:1:1 soil to water to Sikora buffer mixture and measure the pH with a glass electrode.
Phosphorus (P)	Extract with Bray 1, develop color, and measure colorimetrically using a spectrophotometer.
Potassium (K)	Extract with Bray 1 and measure with atomic absorption, flame photometer, or ICP-OES.
Organic matter (OM)	Loss of weight on ignition at 360°C for 2 hours. OM = 0.07 + 0.89 (LOI)[b]
Calcium (Ca), magnesium (Mg), sodium (Na)	Extract with neutral 1 N[c] ammonium acetate and measure with atomic absorption, flame photometer, or ICP-OES.
Sulfur (S)	Extract with 500 ppm phosphorus in acetic acid, develop turbidity, and measure with a photoelectric nephelometer.
Boron (B)	Extract with hot water, develop color, and measure colorimetrically using a spectrophotometer.
Manganese (Mn)	Extract with 0.1 N phosphoric acid and measure by atomic absorption or ICP-OES.
Zinc (Zn)	Extract with 0.1 N hydrochloric acid and measure by atomic absorption or ICP-OES.
Nitrate-nitrogen (NO_3-N)	Extract soil with 2 N KCl and analyze colorimetrically using a spectrophotometer.
Physical analysis (% sand, silt, clay)	Prepare 50 or 100 g soil with dispersing solution and measure with hydrometer.
Soluble salts	Prepare 1:2 soil to water mixture and measure with conductivity bridge.

[a] Detailed descriptions of the procedures can be found at uwlab.soils.wisc.edu/

[b] LOI = percent weight loss on ignition

[c] N = normal solution

To maintain certification in Wisconsin, a WDATCP-certified laboratory is required to meet specific analytical quality standards. However, with any soil test there is a level of inherent variability that can be expected both within a lab and between certified laboratories. The variability within a lab should be lower than between labs. In general, soil pH and Sikora buffer pH results should be within 0.2 pH units when the results of two laboratories are compared. Soil test levels for P and K should be within 10% of the "true value." For example, a soil with 20 ppm P should test in the range of 18–22 ppm when run by different certified labs, and a soil with 100 ppm K should test in the range of 90–110 ppm.

If exchangeable calcium (Ca) and magnesium (Mg) are run on a sample along with the routine analysis, an estimated cation exchange capacity (CEC) will be calculated and reported with the other soil test results. The estimated CEC is calculated from the soil test levels for Ca, Mg, and K using the following equation, and the results are reported in $cmol_c/kg$, which is equivalent to meq/100g of soil.

Est CEC = (ppm Ca/200 + ppm Mg/122 + ppm K/391) x (5 grams/wt of soil in 5-gram scoop)

Sample density is used in the equation to estimate CEC because soil density varies with soil texture and CEC is strongly related to

Table 3.2. Codes and descriptions of soil test interpretation categories.

--------Category-------			
Name	**Symbol**	**Description**	**Probability of a yield increase to applied nutrients** (%)
Very low	VL	Substantial quantities of nutrients are required to optimize crop yield. Buildup should occur over a 4- to 8-year period. Response to secondary or micronutrients is likely or possible for high or medium demanding crops, respectively.	>90
Low	L	Somewhat more nutrients than those removed by crop harvest are required. Response to secondary or micronutrients is possible for high demanding crops, but unlikely for medium or low demanding crops.	60-90
Optimum	O	This is economically and environmentally the most desirable soil test category. Yields are optimized at nutrient additions approximately equal to amounts removed in the harvested portion of the crop. Response to secondary or micronutrients is unlikely regardless of crop demand level.	30-60
High	H	Some nutrients are required, and returns are optimized at rates equal to about one-half of nutrient removal by the crop.	5-30
Very high	VH	Used only for potassium. Soil tests are above the optimum range and gradual drawdown is recommended. Approximately one-fourth of nutrient removal is recommended.	2-5
Excessively high	EH	No fertilizer is recommended for most soils since the soil test level will remain in the non-responsive range for at least two to three years. On medium- and fine-textured soils, a small amount of starter fertilizer is advised for some crops (for more detail, see Chapter 10: Starter fertilizers).	<2

soil texture. Sample density is the weight of oven-dried soil in a 5-gram scoop, which has a volume of approximately 4.25 cubic centimeters. This value is expressed as grams per cubic centimeter (g/cm^3) and is provided on the soil test report. Sample density is listed on the soil test report, but is only used in the estimation of CEC.

Soil test values for P and K are interpreted from very low to excessively high. The category is based on the soil test value in combination with the crop demand level. The probability of a yield response to applied nutrients is much greater for the very low (VL) and low (L) categories than for the high (H), very high (VH), and excessively high (EH) categories. Probability of a response to fertilizer applied at each soil test category is described in Table 3.2.

Notes:

4. Soil and crop information

Several key components are necessary to customize fertilizer and lime recommendations to each field's needs. The first component, a current soil test, has already been discussed in Chapter 2: Sampling soils for testing. Two other necessary components include specific information about the soil and crops to be grown.

Soil

Soil groups are based upon a soil's taxonomic classification using soil properties like texture (percentage of sand, silt, and clay) and organic matter content. Soil groups are used to help interpret phosphorus (P) and potassium (K) soil test levels. There are three soil groups in Wisconsin: sandy (S), loamy (L), and organic (O). Soils are grouped by soil properties as defined by USDA-NRCS. A soil is considered to be O if its taxonomic soil order is histosol. A mineral soil is in the S group if 1) the upper 8 inches has a weighted average sand content greater than or equal to 75%, 2) the subgroup or great group contains "Psam" and the weighted average sand content in the upper 8 inches is 65% or more, or 3) the taxonomic particle size class matches sandy, and the weighted average sand content in the upper 8 inches is 65% or more. In general, group S soils have a sand or loamy sand texture. If a soil is not group S or O, then it is group L (loamy, medium- to fine-textured, sandy loam or finer textured soils).

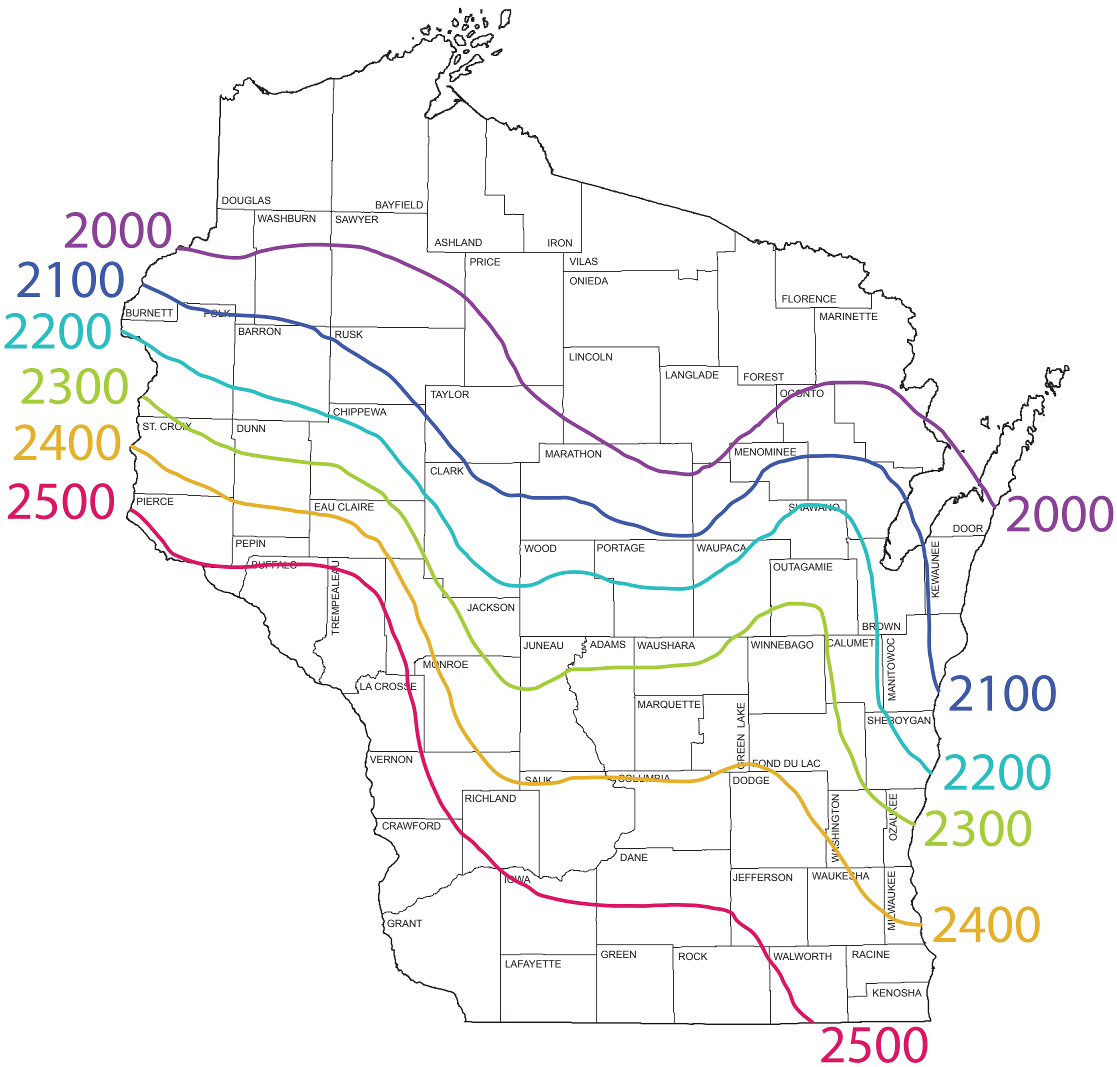
Soil yield potential is a relative ranking of a soil's ability to produce high corn yields along with the responsiveness of corn yield to nitrogen (N) fertilizer. Soil properties in the NRCS database were used to determine soil yield potential. All soils in the sandy soil group have a low yield potential. For yield potential rankings, these soils are called sandy (S). An organic soil has a high yield potential if the soil temperature regime is mesic and has a medium yield potential if the soil temperature regime is frigid. Three soil properties are used to determine the yield potential of loamy soils: soil drainage class, available water in the upper 60 inches of soil, and depth to bedrock. If at least one of these soil properties is limiting, then the yield potential is medium. If none of the soil properties is limiting, then the soil has a high yield potential.

- Soil drainage classes that limit crop production include: excessively drained, somewhat excessively drained, poorly drained, and very poorly drained. Well-drained, moderately well drained, and somewhat poorly drained soils do not limit yield potential.
- Very low (< 3 inches) and low (3–6 inches) available water capacity in the upper 60 inches of soil limit yield potential to medium. Moderate (6–9 inches), high (9–12 inches), and very high (> 12 inches) available water capacities do not limit yield potential.
- Soil series with less than 30 inches of soil over bedrock are considered shallow and limit yield potential. Shallow soils often have low or very low available water capacity.

Map units within a soil series may differ with regard to soil drainage class, available water capacity, and/or depth to bedrock. When this occurs, the soil property interpretation of the majority of the map units is used to determine soil yield potential.

In addition to soil properties, if a soil's location has, on average, less than 2100 growing degree days (GDD, modified base 50, maximum 86, May 1 through September 30), it should be considered medium yield potential regardless of soil property limitations because the length of growing season restricts yield potential. Soils with no soil property limitations on yield potential in locations with: 1) 2100 to 2200 GDD; or 2) less than 2100 GDD and a mesic temperature regime are in a transition area; in

Figure 4.1. Average accumulated (May 1 to September 30) growing degree day (GDD) isolines for Wisconsin,1997–2011.



The GDD map in Figure 4.1 was developed using temperature measurements, from airport automated weather stations maintained by National Weather Service and Federal Aviation Administration, that were collected and interpolated into grids by the UW Extension Ag Weather project. The accumulated GDD from May 1 through September 30 were calculated using the modified base 50, maximum 86 method used for corn growth and development. The accumulated GDD for each year from 1997 (the year UWEX Ag Weather began operating) through 2011 were averaged, and GrADS software was used to create the GDD isolines in Figure 4.1. The average GDD at any location in Wisconsin can be obtained using the location's latitude and longitude along with the UWEX Ag Weather thermal model at: http://www.soils.wisc.edu/uwex_agwx/thermal_models.

some cases these soils are high yield potential, in others medium. In the transition area, growers and agronomists should choose the most appropriate yield potential based upon experience. Average GDD isolines for Wisconsin are provided in Figure 4.1. Loamy soils that are irrigated because of low available water capacity or that are artificially drained (e.g., tiled) because of poor drainage can be considered high yield potential if the location has more than 2200 GDD or is in a transition area. If loamy soils are limited by shallow depth to bedrock and field evaluation demonstrates that there is more than 30 inches of soil over bedrock throughout a majority of the field, then the soil can be considered high yield potential.

Each map unit in a soil series was evaluated individually to place it into soil group and soil yield potential categories. There are soil series where not every map unit meets the criteria to be placed in the same soil group. For example, some map units may be sandier and are grouped as S, while other map units in the same soil series are group L. In addition, for some soil series, not every map unit has identical soil properties. In some cases, this results in different interpretations for soil yield potential. Where differences in soil group or soil yield potential occur between map units in a soil series, the interpretation for the majority of the map units was used to determine the soil group and soil yield potential for the soil series. Table 4.1 provides the soil group and soil yield potential for each mapped soil series in Wisconsin. Also included in this table are the soil properties that were used to evaluate soil yield potential. Growers and agronomists who wish to create more site-specific fertilizer recommendations may do so by using the soil group and yield potential for each individual map unit. This information may be accessed at http://uwlab.soils.wisc.edu/a2809-soil-map-unit-info/ and in SnapPlus nutrient management software.

If a soil series name is not known, generic N, P, K, and lime recommendations can be made. Soil testing lab staff will make an assessment of soil group based on soil organic matter content and texturing the soil by hand.

Crop

Four key items unique to each crop impact P and K fertilizer recommendations and lime requirement.

- The P and K demand level for the crop. Each crop requires varying levels of available P and K to optimize yield. Crops are placed into one of four P and K demand levels based on their relative nutrient needs: 1) corn, soybean, small grains (but not wheat), grasses, oilseeds, and pasture; 2) alfalfa, corn silage, wheat, beans, sweet corn, peas, and fruits; 3) tomato, pepper, brassicas, leafy greens, and root, vine, and truck crops ; and 4) potatoes. The demand levels for specific crops are identified in Table 4.2.
- The amount of phosphate (P_2O_5) and potash (K_2O) removed in the harvested portion of the crop is used to establish the amount of fertilizer to apply. Table 4.2 lists the amount of P_2O_5 and K_2O removed in pounds per unit of yield.
- The yield goal for each crop is required to determine the application rate of P_2O_5 and K_2O fertilizer for all crops and the nitrogen (N) fertilizer rate for potatoes. Realistic yield goals should not be higher than 10 to 15% above the previous 3- to 5-year field average. Typical yield ranges and the moisture content at which yield is reported are provided in Table 4.2.
- Target pH is the optimal pH for production of a particular crop. Target pH is used to determine lime requirement and other pH adjustments. Refer to Table 4.2 for target pH values for various crops.

Table 4.1. Codes assigned to Wisconsin soils for soil group and soil yield potential (YP) along with soil properties used to evaluate soil yield potential. See footnotes for code descriptions.

			Properties used to assess soil YP			
Soil name	Soil group	Soil YP	Drainage class	AWC	Bed-rock depth	Soil temp. regime
Abbaye	L	M	MW	L	.	F
Absco	S	S	MW	L	.	M
Abscota	S	S	MW	L	.	M
Ackmore	L	H	SP	H	.	M
Adder	O	H	VP	H	.	M
Adolph	L	M	VP	M	.	F
Adrian	O	H	VP	VH	.	M
Aftad	L	H	MW	H	.	F
Alango	L	H	SP	M	.	F
Alban*	L	H	W	H	.	F
Alcona*	L	H	W	H	.	F
Aldo	S	S	MW	L	.	M
Algansee	S	S	SP	M	.	M
Allendale	S	S	SP	L	.	F
Almena	L	H	SP	H	.	F
Alpena	S	S	E	VL	.	F
Alstad	L	H	SP	H	.	F
Altdorf	L	M	P	H	.	F
Amasa*	L	M	W	L	.	F
Amery*	L	M	W	L	.	F
Amnicon*	L	H	MW	M	.	F
Angelica	L	M	P	H	.	F
Anigon	L	H	W	M	.	F
Ankeny	L	H	W	H	.	M
Annalake*	L	H	MW	M	.	F
Annriver	L	M	VP	M	.	F
Antigo*	L	H	W	M	.	F
Anton	L	H	MW	M	.	F
Arbutus	S	S	E	L	S	F
Arenzville	L	H	MW	VH	.	M
Argonne	L	H	MW	M	.	F
Arland*	L	M	W	L	.	F
Arnheim	L	M	P	H	.	F
Ashdale	L	H	W	H	.	M
Ashippun	L	H	SP	H	.	M
Ashkum	L	M	P	H	.	M
Ashwabay	S	S	MW	M	.	F
Atterberry	L	H	SP	H	.	M
Au Gres*	S	S	SP	L	.	F
Auburndale	L	M	P	H	.	F
Augwood	S	S	SP	L	.	F
Ausable	L	M	VP	H	.	F
Aztalan	L	H	SP	H	.	M
Bach	L	M	VP	H	.	M
Badriver	L	H	SP	M	.	F
Balmoral	L	H	MW	H	.	M
Banat	L	M	SP	L	.	F
Baraboo*	L	M	MW	L	.	M
Barremills	L	H	MW	VH	.	M
Barronett	L	M	P	H	.	F
Barry	L	M	P	H	.	M
Basco	L	M	W	L	.	M

* At least one map unit for the soil has a different interpretation for soil yield potential and/or soil group. The interpretations presented are based on the interpretation of the majority of the map units. For more detailed information about individual map units see: http://uwlab.soils.wisc.edu/a2809-soil-map-unit-info/ or SnapPlus nutrient management software.

Abbreviations

Soil group: L=loamy soils (medium and fine-textured); O=organic soils; S=sandy soils (sands and loamy sands)

Soil yield potential (YP): H=high; M=medium; S=sandy

Drainage class: E=excessively drained; SE=somewhat excessively drained; W=well drained; MW=moderately well drained; SP=somewhat poorly drained; P=poorly drained; VP=very poorly drained

Available water capacity (AWC): VL=very low; L=low; M=moderate; H=high; VH=very high

Bedrock depth: S=shallow; bedrock is within 30 inches of the soil surface

Soil temperature regime: M=mesic; F=frigid

Table 4.1 continued. Codes assigned to Wisconsin soils for soil group and soil yield potential (YP) along with soil properties used to evaluate soil yield potential. See footnotes for code descriptions.

			Properties used to assess soil YP			
Soil name	Soil group	Soil YP	Drainage class	AWC	Bed-rock depth	Soil temp. regime
Batavia	L	H	W	H	.	M
Bearpen	L	H	SP	H	.	M
Beartree	L	M	VP	VL	S	F
Beaverbay	L	H	MW	M	.	F
Beavercreek	L	H	W	M	.	M
Beecher*	L	H	SP	H	.	M
Bellechester	S	S	E	L	S	M
Belleville	S	S	P	M	.	M
Bellevue*	L	H	MW	H	.	M
Bergland	L	M	P	M	.	F
Bertrand	L	H	W	H	.	M
Beseman	O	M	VP	VH	.	F
Bigisland	S	S	SE	L	.	F
Billett*	L	H	W	M	.	M
Billyboy	L	H	MW	M	.	F
Bilmod	L	H	MW	M	.	M
Bilson*	L	H	W	M	.	M
Bjorkland	L	M	VP	M	.	F
Blackhammer	L	H	W	H	.	M
Blackriver	L	H	MW	H	.	F
Blount	L	H	SP	M	.	M
Bluffton	L	M	VP	H	.	F
Boaz	L	H	SP	VH	.	M
Boguscreek	L	H	W	VH	.	M
Bonduel	L	M	SP	L	S	F
Boone	S	S	E	VL	.	M
Boots	O	H	VP	VH	.	M
Boplain	S	S	E	VL	.	M
Borea	L	H	SP	M	.	F
Borth*	L	M	MW	L	.	M
Bowstring	O	M	VP	VH	.	F
Boyer*	S	S	W	L	.	M
Braham	S	S	W	M	.	F
Brander	L	H	MW	M	.	F
Branstad	L	H	MW	H	.	F
Brems	S	S	MW	L	.	M
Brennyville	L	H	SP	M	.	F
Brevort	S	S	VP	M	.	F
Brice	S	S	E	M	.	M
Briggsville	L	H	W	H	.	M
Brill*	L	H	MW	M	.	F
Brimley	L	H	SP	H	.	F
Brinkman	L	H	MW	VH	.	M
Brodale	L	M	E	L	S	M
Brookston	L	M	P	H	.	M
Brownchurch	L	H	W	H	.	M
Brownstone	S	S	E	VL	.	F
Bruce	L	M	VP	H	.	F
Burkhardt	S	S	E	L	.	M
Bushville	S	S	SP	L	.	F
Butternut	L	H	MW	M	.	F
Cable	L	M	P	M	.	F
Cadiz	L	H	MW	H	.	M
Calamine	L	M	P	M	.	M
Campia	L	H	W	H	.	F
Capitola	L	M	VP	L	.	F
Carbondale	O	M	VP	VH	.	F
Caryville*	L	H	W	M	.	F
Casco*	L	M	W	L	.	M
Cathro	O	M	VP	VH	.	F
Cebana	L	M	VP	M	.	F
Ceresco	L	H	SP	M	.	M
Chabeneau*	L	M	MW	L	.	F
Champion	L	M	MW	L	.	F
Channahon	L	M	MW	L	S	M
Channing	L	M	SP	L	S	F

Table 4.1 continued. Codes assigned to Wisconsin soils for soil group and soil yield potential (YP) along with soil properties used to evaluate soil yield potential. See footnotes for code descriptions.

			Properties used to assess soil YP			
Soil name	Soil group	Soil YP	Drainage class	AWC	Bed-rock depth	Soil temp. regime
Charlevoix	L	H	SP	M	.	F
Chaseburg	L	H	W	VH	.	M
Chelmo	L	M	P	L	.	F
Chelsea	S	S	E	L	.	M
Chequamegon	L	H	MW	H	.	F
Chetek	L	M	SE	L	.	F
Chinwhisker	S	S	MW	L	.	F
Chippeny	O	M	VP	VH	.	F
Churchtown	L	H	W	VH	.	M
Citypoint	O	M	VP	VH	.	F
Clemens	L	M	SP	L	.	F
Clyde	L	M	P	H	.	M
Coffeen	L	H	SP	H	.	M
Coland	L	M	P	H	.	M
Coloma	S	S	E	L	.	M
Colwood	L	M	P	H	.	M
Comstock	L	H	SP	H	.	F
Conover	L	H	SP	M	.	M
Cormant	S	S	VP	L	.	F
Cornucopia	L	H	W	M	.	F
Cosad	S	S	SP	M	.	M
Council	L	H	W	H	.	M
Cress	S	S	SE	L	.	F
Crex	S	S	MW	L	.	F
Cromwell	S	S	SE	L	.	F
Crossett	L	H	SP	H	.	F
Croswell	S	S	MW	L	.	F
Croswood	S	S	MW	L	.	F
Crystal Lake	L	H	MW	VH	.	F
Cublake	S	S	MW	L	.	F
Cunard	L	M	W	L	S	F
Curran	L	H	SP	H	.	M
Cushing	L	H	W	M	.	F

			Properties used to assess soil YP			
Soil name	Soil group	Soil YP	Drainage class	AWC	Bed-rock depth	Soil temp. regime
Cutaway	S	S	MW	M	.	F
Cuttre	L	H	SP	M	.	F
Dairyland	S	S	MW	L	.	F
Daisybay	O	M	VP	VH	.	F
Dakota*	L	H	W	M	.	M
Dancy	L	M	P	M	.	F
Darroch	L	H	SP	H	.	M
Dawsil	O	M	VP	VH	.	F
Dawson	O	M	VP	VH	.	F
Dechamps	S	S	SP	L	.	F
Deerton	S	S	W	VL	.	F
Deford	S	S	P	L	.	F
Del Rey	L	H	SP	M	.	M
Dells	L	H	SP	M	.	M
Delton*	S	S	W	M	.	M
Denomie	L	H	W	H	.	F
Denrock*	L	H	SP	M	.	M
Depere	L	H	MW	M	.	M
Derinda*	L	M	MW	L	.	M
Dickinson*	L	M	SE	L	.	M
Dickman	S	S	W	L	.	M
Dillon	S	S	VP	L	.	M
Dishno	L	M	MW	L	S	F
Dobie	L	H	W	M	.	F
Dodge	L	H	W	H	.	M
Dodgeville*	L	M	W	L	.	M
Dody	S	S	VP	L	.	F
Dolph	L	H	SP	H	.	F
Dora	O	M	VP	VH	.	F
Dorchester	L	H	MW	VH	.	M
Dorerton	L	M	W	L	.	M
Doritty	L	H	MW	H	.	F
Downs	L	H	W	H	.	M

Table 4.1 continued. Codes assigned to Wisconsin soils for soil group and soil yield potential (YP) along with soil properties used to evaluate soil yield potential. See footnotes for code descriptions.

Soil name	Soil group	Soil YP	Properties used to assess soil YP: Drainage class	AWC	Bed-rock depth	Soil temp. regime
Drammen	S	S	SE	L	.	M
Dresden*	L	H	W	M	.	M
Drummer	L	M	P	H	.	M
Drylanding	L	M	SE	VL	S	F
Dubuque*	L	M	W	L	.	M
Duel	S	S	W	VL	S	F
Duelm*	S	S	SP	L	.	F
Dunbarton	L	M	W	L	S	M
Dunnbot	L	H	MW	M	.	M
Dunnville*	L	H	W	M	.	F
Durand	L	H	W	H	.	M
Eauclaire	S	S	MW	M	.	F
Eaupleine*	L	H	W	M	.	F
Edmund	L	M	W	VL	S	M
Edwards	O	H	VP	VH	.	M
Elbaville*	L	M	W	L	.	M
Elburn	L	H	SP	H	.	M
Elderon	S	S	SE	L	.	F
Eleroy	L	H	MW	M	.	M
Eleva	L	M	W	L	.	M
Elevasil*	L	M	W	L	.	M
Elizabeth	L	M	SE	VL	S	M
Elkmound*	L	M	W	VL	.	M
Ella	L	H	MW	H	.	M
Elliott	L	H	SP	M	.	M
Ellwood	L	H	MW	H	.	F
Elm Lake	S	S	P	L	.	F
Elvers	L	M	VP	VH	.	M
Emmert	S	S	E	VL	.	F
Emmet	L	H	W	M	.	F
Ensley	L	M	VP	M	.	F
Ettrick	L	M	P	VH	.	M
Fabius	L	M	SP	L	.	M
Fairchild	S	S	SP	L	.	F
Fairport*	L	M	W	L	.	F
Fallcreek	L	H	SP	M	.	F
Farrington	S	S	SP	L	.	M
Fayette	L	H	W	H	.	M
Fenander	L	M	P	M	.	F
Fence*	L	H	MW	H	.	F
Fenwood*	L	H	W	M	.	F
Festina	L	H	W	VH	.	M
Finchford	S	S	E	L	.	M
Fisk	S	S	SP	M	.	M
Fivepoints	L	M	W	L	.	M
Flagg	L	H	W	H	.	M
Flambeau	L	H	MW	H	.	F
Flink*	S	S	SP	L	.	F
Floyd	L	H	SP	H	.	M
Forada	L	M	VP	L	.	F
Fordum	L	M	P	M	.	F
Forkhorn	L	M	W	L	.	M
Fox*	L	H	W	M	.	M
Foxpaw	L	M	P	M	.	F
Frechette	L	H	W	H	.	F
Freeon*	L	H	MW	M	.	F
Fremstadt	S	S	W	L	.	F
Freya	S	S	SP	L	.	F
Friendship	S	S	MW	L	.	F
Friesland	L	H	W	H	.	M
Frogcreek*	L	H	MW	M	.	F
Gaastra	L	H	SP	H	.	F
Gale*	L	H	W	M	.	M
Gaphill	L	M	W	L	.	M
Gardenvale	L	H	W	M	.	M
Garne	S	S	SE	L	.	M

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Table 4.1 continued. Codes assigned to Wisconsin soils for soil group and soil yield potential (YP) along with soil properties used to evaluate soil yield potential. See footnotes for code descriptions.

Soil name	Soil group	Soil YP	Properties used to assess soil YP: Drainage class	AWC	Bed-rock depth	Soil temp. regime
Garwin	L	M	P	VH	.	M
Gastrow	L	H	SP	H	.	F
Gay	L	M	P	M	.	F
Gichigami	L	H	MW	H	.	F
Giese	L	M	VP	H	.	F
Gilford	L	M	VP	M	.	M
Gillingham	S	S	W	L	.	M
Glendenning	L	H	SP	M	.	F
Glendora	S	S	P	L	.	M
Glenflora	L	M	VP	H	.	F
Glidden	L	H	W	M	.	F
Gogebic*	L	M	MW	L	.	F
Goodman	L	H	W	M	.	F
Goodwit	L	H	MW	M	.	F
Gosil	S	S	SE	L	.	M
Gotham	S	S	W	L	.	M
Granby*	S	S	VP	L	.	M
Graycalm	S	S	SE	L	.	F
Grayling	S	S	E	L	.	F
Grays	L	H	W	H	.	M
Greenridge	L	H	W	H	.	M
Greenwood	O	M	VP	VH	.	F
Grellton	L	H	W	H	.	M
Grettum	S	S	MW	L	.	F
Griswold	L	H	W	M	.	M
Guenther	S	S	W	M	.	F
Halder	L	H	SP	M	.	F
Hatley	L	H	SP	M	.	F
Haugen*	L	H	MW	M	.	F
Haustrup	L	M	SE	L	S	F
Hayfield	L	H	SP	M	.	M
Hayriver	L	M	W	L	.	F
Hebron	L	H	W	H	.	M
Hennepin	L	H	W	M	.	M
Herbster	L	H	SP	M	.	F
Hersey	L	H	MW	VH	.	M
Hesch*	L	H	W	M	.	M
Hibbing	L	H	MW	M	.	F
Hiles*	L	H	MW	M	.	F
Hixton*	L	M	W	L	.	M
Hochheim*	L	H	W	M	.	M
Hoop*	L	M	SP	L	.	M
Hoopeston	L	H	SP	M	.	M
Hortonville*	L	H	W	H	.	M
Houghton	O	H	VP	VH	.	M
Hubbard	S	S	E	L	.	F
Humbird*	L	M	MW	L	.	F
Huntsville	L	H	MW	VH	.	M
Impact	S	S	E	L	.	M
Indus	L	M	P	M	.	F
Ingalls	S	S	SP	M	.	F
Ionia*	L	H	MW	M	.	M
Iosco*	S	S	SP	M	.	F
Ironrun	S	S	SP	L	.	F
Ishpeming*	S	S	SE	L	S	F
Jackson	L	H	MW	H	.	M
Jasper	L	H	W	H	.	M
Jewett	L	H	W	M	.	F
Joy	L	H	SP	VH	.	M
Juda	L	H	MW	H	.	M
Judson	L	H	MW	H	.	M
Juneau	L	H	W	H	.	M
Kalmarville	L	M	P	M	.	M
Kane	L	H	SP	M	.	M
Karlin*	L	M	SE	L	.	F
Karlsborg	S	S	MW	L	.	F

Table 4.1 continued. Codes assigned to Wisconsin soils for soil group and soil yield potential (YP) along with soil properties used to evaluate soil yield potential. See footnotes for code descriptions.

Soil name	Soil group	Soil YP	Properties used to assess soil YP: Drainage class	AWC	Bed-rock depth	Soil temp. regime
Kasson	L	H	MW	H	.	M
Kato	L	M	P	M	.	M
Kaukauna	L	H	MW	H	.	M
Kegonsa	L	H	W	M	.	M
Kellogg	S	S	MW	M	.	F
Keltner	L	H	MW	M	.	M
Kendall	L	H	SP	H	.	M
Kennan	L	H	W	M	.	F
Keowns	L	M	P	M	.	M
Kert*	L	H	SP	M	.	F
Keshena	L	H	MW	H	.	F
Kewaunee*	L	H	W	M	.	M
Keweenaw	S	S	W	L	.	F
Keyesville	L	M	SE	VL	.	M
Kibbie	L	H	SP	H	.	M
Kickapoo	L	H	MW	M	.	M
Kidder*	L	H	W	M	.	M
Kingsville	S	S	P	L	.	M
Kinross	S	S	P	L	.	F
Kiva	S	S	W	L	.	F
Knowles*	L	H	W	M	.	M
Kolberg	L	M	W	L	S	F
Komro	S	S	MW	L	.	M
Korobago	L	H	SP	M	.	M
Kost	S	S	E	L	.	F
Kranski	S	S	SE	L	.	M
La Farge	L	H	W	M	.	M
Lablatz	L	H	SP	H	.	F
Lacrescent	L	M	W	M	S	M
Lamartine	L	H	SP	H	.	M
Lambeau	L	H	W	H	.	M
Lamoille	L	H	W	M	.	M
Lamont	L	H	W	M	.	M
Langlade	L	H	W	H	.	F
Laona	L	M	W	L	.	F
Lapeer*	L	H	W	M	.	M
Lapoin	L	M	MW	L	.	F
Lara	S	S	MW	L	.	F
Lawler	L	H	SP	M	.	M
Lawson	L	H	SP	VH	.	M
Lenroot	S	S	MW	VL	.	F
Leola	S	S	SP	L	.	M
Lerch	L	M	P	M	.	F
LeRoy	L	H	W	M	.	M
Lilah	S	S	E	L	.	M
Lindquist	S	S	SE	L	.	F
Lindstrom	L	H	W	VH	.	M
Lino	S	S	SP	L	.	F
Lobo	O	M	VP	VH	.	F
Locke	L	H	SP	H	.	M
Lomira	L	H	W	H	.	M
Longrie	L	M	W	L	S	F
Lorenzo*	L	M	W	L	.	M
Lows	L	M	P	M	.	F
Loxley	O	M	VP	VH	.	F
Loyal	L	H	MW	M	.	F
Ludington	S	S	MW	L	.	F
Lundeen	L	M	W	L	S	F
Lupton	O	M	VP	VH	.	F
Lutzke	L	M	W	VL	.	M
Magnor*	L	H	SP	M	.	F
Magroc	L	H	SP	M	.	F
Mahalasville	L	M	VP	H	.	M
Mahtomedi	S	S	E	L	.	F
Maincreek*	L	M	SP	L	.	F
Majik	S	S	SP	L	.	M

Table 4.1 continued. Codes assigned to Wisconsin soils for soil group and soil yield potential (YP) along with soil properties used to evaluate soil yield potential. See footnotes for code descriptions.

			Properties used to assess soil YP			
Soil name	Soil group	Soil YP	Drainage class	AWC	Bed-rock depth	Soil temp. regime
Makwa	L	M	VP	L	.	F
Manawa	L	H	SP	H	.	M
Mancelona	S	S	SE	L	.	F
Manistee	S	S	W	M	.	F
Manitowish	S	S	MW	L	.	F
Mann	L	M	VP	M	.	F
Maplehurst	L	H	SP	H	.	F
Marathon*	L	H	W	M	.	F
Marcellon	L	H	SP	M	.	M
Markesan	L	H	W	M	.	M
Markey	O	M	VP	VH	.	F
Markham	L	H	MW	H	.	M
Marshan	L	M	VP	M	.	M
Marshfield	L	M	VP	M	.	F
Martinton	L	H	SP	H	.	M
Matherton*	L	M	SP	L	.	M
Maumee	S	S	VP	L	.	M
Mayville	L	H	MW	H	.	M
McHenry	L	H	W	H	.	M
Meadland	L	H	SP	M	.	F
Mecan*	S	S	SE	M	.	M
Mecosta	S	S	SE	L	.	M
Medary	L	H	MW	H	.	M
Meehan*	S	S	SP	L	.	F
Meenon	S	S	SP	L	.	F
Menahga	S	S	E	L	.	F
Menasha	L	M	P	M	.	M
Mendota	L	H	W	H	.	M
Menomin	L	H	MW	M	.	M
Menominee*	S	S	W	M	.	F
Mequithy*	L	M	W	L	S	F
Mequon	L	H	SP	H	.	M
Meridian	L	H	W	M	.	M

			Properties used to assess soil YP			
Soil name	Soil group	Soil YP	Drainage class	AWC	Bed-rock depth	Soil temp. regime
Merimod	L	H	MW	M	.	M
Merit	L	H	W	M	.	M
Merrillan*	L	M	SP	L	.	F
Metea*	L	H	W	M	.	M
Metonga	L	M	W	L	S	F
Miami	L	H	W	M	.	M
Michigamme	L	M	W	L	S	F
Mickle	L	H	MW	VH	.	M
Mifflin*	L	H	W	M	.	M
Milaca*	L	H	MW	M	.	F
Milford	L	M	VP	VH	.	M
Military*	L	M	W	L	.	M
Milladore	L	H	SP	M	.	F
Millington	L	M	P	VH	.	M
Millsdale	L	M	P	L	.	M
Milton	L	M	W	L	.	M
Mindoro	S	S	MW	L	.	M
Minocqua	L	M	P	M	.	F
Miskoaki	L	H	W	M	.	F
Moberg	L	M	SE	L	.	F
Monico*	L	H	SP	M	.	F
Montello	L	H	MW	H	.	M
Montgomery	L	M	VP	H	.	M
Moodig	L	H	SP	M	.	F
Moppet	L	H	MW	M	.	F
Moquah	L	H	MW	H	.	F
Mora*	L	H	SP	M	.	F
Morganlake	S	S	MW	M	.	F
Morley	L	H	MW	M	.	M
Morocco	S	S	SP	L	.	M
Mosel	L	H	SP	M	.	M
Moshawquit	S	S	W	M	.	F
Mosinee*	L	M	W	L	.	F

Table 4.1 continued. Codes assigned to Wisconsin soils for soil group and soil yield potential (YP) along with soil properties used to evaluate soil yield potential. See footnotes for code descriptions.

			Properties used to assess soil YP			
Soil name	Soil group	Soil YP	Drainage class	AWC	Bed-rock depth	Soil temp. regime
Moundville	S	S	MW	L	.	M
Mt. Carroll	L	H	W	VH	.	M
Mudlake	L	H	SP	M	.	F
Mundelein	L	H	SP	H	.	M
Munuscong	L	M	P	M	.	F
Muscatine	L	H	SP	H	.	M
Muscoda	S	S	W	L	.	M
Muskego	O	H	VP	VH	.	M
Mussey	L	M	P	L	.	M
Mylrea	L	H	SP	M	.	F
Myrtle	L	H	W	H	.	M
Nadeau	L	M	W	L	.	F
Nahma	L	M	P	M	.	F
Namur	L	M	W	VL	S	F
Navan	L	M	P	H	.	M
Nebago	S	S	SP	M	.	M
Neconish	S	S	MW	L	.	F
Neda*	L	H	MW	H	.	M
Neenah	L	H	SP	M	.	M
Nenno	L	H	SP	M	.	M
Neopit	L	H	MW	M	.	F
Nester	L	H	W	M	.	F
NewGlarus*	L	H	W	M	.	M
Newhouse	L	H	W	H	.	M
Newlang	S	S	P	L	.	M
Newood*	L	M	MW	L	.	F
Newot*	L	M	W	L	.	F
Newson	S	S	VP	L	.	F
Nichols	L	H	W	M	.	M
Nickin	L	H	W	M	.	F
Nokasippi	S	S	VP	M	.	F
Norden*	L	H	W	M	.	M
Norgo	L	M	W	L	.	F

			Properties used to assess soil YP			
Soil name	Soil group	Soil YP	Drainage class	AWC	Bed-rock depth	Soil temp. regime
Northbend	L	H	SP	H	.	M
Northfield	L	M	W	L	.	M
Northmound	L	M	W	L	S	F
Norwalk	L	H	MW	M	.	M
Noseum	L	M	MW	L	.	F
Nuxmaruha-nixete	L	H	W	M	.	M
Nymore	S	S	E	L	.	F
Oakville	S	S	W	L	.	M
Ockley	L	H	W	H	.	M
Oconto*	L	H	W	M	.	F
Odanah	L	H	W	M	.	F
Oesterle*	L	M	SP	L	.	F
Ogden	O	H	VP	VH	.	M
Ogle	L	H	W	H	.	M
Okee	S	S	SE	M	.	M
Omega	S	S	SE	L	.	F
Omena	L	H	W	M	.	F
Omro	L	H	W	M	.	M
Onamia*	L	H	W	M	.	F
Onaway*	L	H	W	M	.	F
Orion*	L	H	SP	VH	.	M
Oronto	L	H	SP	M	.	F
Oshkosh	L	H	W	M	.	M
Oshtemo*	S	S	W	M	.	M
Osseo	L	H	SP	VH	.	M
Ossian	L	M	P	VH	.	M
Ossmer	L	H	SP	M	.	F
Otter	L	M	P	VH	.	M
Otterholt	L	H	W	H	.	F
Ozaukee	L	H	W	H	.	M
Padus*	L	M	W	L	.	F
Padwet*	L	M	MW	L	.	F

Table 4.1 continued. Codes assigned to Wisconsin soils for soil group and soil yield potential (YP) along with soil properties used to evaluate soil yield potential. See footnotes for code descriptions.

			Properties used to assess soil YP			
Soil name	Soil group	Soil YP	Drainage class	AWC	Bed-rock depth	Soil temp. regime
Padwood*	L	H	MW	M	.	F
Palms	O	H	VP	VH	.	M
Palsgrove*	L	H	W	M	.	M
Pardeeville	L	H	W	M	.	M
Parkfalls*	L	M	SP	L	.	F
Partridge*	S	S	SP	VL	.	M
Pearl	S	S	MW	L	.	M
Pecatonica	L	H	W	H	.	M
Pecore	L	H	W	H	.	F
Peebles	L	H	MW	M	.	M
Peeksville	L	M	SP	L	.	F
Pelissier*	L	M	E	L	.	F
Pelkie	S	S	MW	L	.	F
Pella	L	M	P	VH	.	M
Pence*	S	S	SE	L	.	F
Pepin	L	H	W	H	.	M
Pequaming	S	S	SP	L	.	F
Perchlake	S	S	SP	L	.	F
Perida	S	S	MW	L	.	F
Perote	L	H	W	H	.	F
Pesabic	L	H	SP	M	.	F
Peshekee	L	M	W	L	S	F
Peshtigo	L	H	SP	H	.	F
Pickford	L	M	P	M	.	F
Pillot	L	H	W	H	.	M
Pinconning	S	S	P	L	.	F
Pistakee	L	H	SP	H	.	M
Plainbo	S	S	E	VL	.	F
Plainfield	S	S	E	L	.	M
Plano	L	H	W	H	.	M
Pleine	L	M	P	M	.	F
Plover	L	H	SP	H	.	F
Plumcreek	L	H	W	H	.	M
Point*	S	S	SP	M	.	F
Pomroy	S	S	MW	L	.	F
Ponycreek	S	S	P	L	.	F
Port Byron	L	H	W	VH	.	M
Portwing	L	H	MW	M	.	F
Poskin	L	H	SP	M	.	F
Poy	L	M	P	L	.	M
Poygan	L	M	P	M	.	M
Prissel	S	S	MW	L	.	M
Puchyan	S	S	MW	H	.	M
Quarderer	L	H	MW	VH	.	F
Rabe	S	S	W	M	.	F
Radford	L	H	SP	VH	.	M
Rasset	L	H	W	M	.	M
Redrim	L	M	E	VL	S	F
Reedsburg	L	H	SP	M	.	M
Renova	L	H	W	M	.	M
Rib	L	M	P	M	.	F
Ribhill	L	M	SE	L	.	F
Ribriver	L	H	MW	H	.	F
Richford	S	S	SE	L	.	M
Richwood	L	H	W	H	.	M
Rietbrock	L	H	SP	M	.	F
Rifle	O	M	VP	VH	.	F
Rimer*	L	H	SP	M	.	M
Ringwood	L	H	W	H	.	M
Ripon	L	H	W	M	.	M
Ritchey	L	M	W	L	S	M
Robago	L	H	SP	H	.	F
Roby	L	H	SP	M	.	M
Rockbluff	S	S	E	L	.	M
Rockbridge	L	H	W	M	.	M
Rockdam	S	S	MW	L	.	F

Table 4.1 continued. Codes assigned to Wisconsin soils for soil group and soil yield potential (YP) along with soil properties used to evaluate soil yield potential. See footnotes for code descriptions.

Soil name	Soil group	Soil YP	Properties used to assess soil YP			
			Drainage class	AWC	Bed-rock depth	Soil temp. regime
Rockers	S	S	SP	M	.	F
Rockland	L	H	W	H	.	F
Rockmarsh	L	M	SP	L	.	F
Rockton*	L	M	W	L	.	M
Rodman*	L	M	E	L	.	M
Rollin	O	H	VP	VH	.	M
Rondeau	O	M	VP	VH	.	F
Root	L	M	P	M	.	M
Roscommon*	S	S	P	L	.	F
Rosholt*	L	M	W	L	.	F
Rotamer	L	H	W	M	.	M
Rousseau	S	S	W	L	.	F
Rowley	L	H	SP	H	.	M
Rozellville	L	H	W	M	.	F
Rozetta	L	H	MW	H	.	M
Rubicon	S	S	E	L	.	F
Ruse	L	M	VP	VL	S	F
Rusktown	L	M	MW	L	.	M
Sable	L	M	P	VH	.	M
Salter*	L	H	MW	H	.	M
Sanborg	L	H	MW	M	.	F
Santiago	L	H	W	H	.	F
Sargeant	L	H	SP	H	.	M
Sarona*	L	H	W	M	.	F
Sarwet	L	H	MW	M	.	F
Sattre*	L	H	W	M	.	M
Sawmill	L	M	P	H	.	M
Saybrook	L	H	W	H	.	M
Saylesville	L	H	W	H	.	M
Sayner	S	S	E	L	.	F
Schapville*	L	M	MW	L	.	M
Schweitzer	L	M	W	L	S	F
Scoba	L	M	MW	L	.	F
Sconsin*	L	H	MW	M	.	F
Scotah	S	S	MW	L	.	M
Scott Lake*	L	M	MW	L	.	F
Seaton	L	H	W	VH	.	M
Sebbo	L	H	MW	H	.	M
Sebewa	L	M	P	M	.	M
Sechler	L	M	SP	L	.	M
Sedgwick*	S	S	SP	M	.	F
Seelyeville	O	M	VP	VH	.	F
Selkirk	L	H	SP	M	.	F
Seward	S	S	MW	L	.	M
Shag	L	M	P	H	.	F
Shanagolden	L	M	MW	L	.	F
Shawano	S	S	E	L	.	F
Sherry	L	M	P	M	.	F
Shiffer*	L	H	SP	M	.	M
Shiocton	L	H	SP	M	.	F
Shullsburg*	L	H	SP	M	.	M
Silverhill	L	H	W	M	.	M
Simescreek	S	S	E	L	.	F
Siouxcreek	L	M	SP	L	.	F
Siren	L	H	SP	M	.	F
Sissabagama	S	S	MW	L	.	F
Sisson	L	H	W	H	.	M
Skog	L	M	MW	L	.	F
Skyberg	L	H	SP	H	.	M
Slimlake	S	S	MW	L	.	F
Smestad	S	S	SP	M	.	F
Soderbeck	L	M	SP	L	.	F
Sogn	L	M	SE	VL	S	M
Solona	L	H	SP	M	.	F
Sooner	L	H	SP	M	.	M
Soperton	L	H	W	M	.	F

Table 4.1 continued. Codes assigned to Wisconsin soils for soil group and soil yield potential (YP) along with soil properties used to evaluate soil yield potential. See footnotes for code descriptions.

Soil name	Soil group	Soil YP	Properties used to assess soil YP			
			Drainage class	AWC	Bed-rock depth	Soil temp. regime
Sparta	S	S	E	L	.	M
Spear	L	H	SP	H	.	F
Spencer	L	H	MW	H	.	F
Spiderlake	L	H	MW	M	.	F
Spillville	L	H	MW	H	.	M
Spinks	S	S	W	L	.	M
Spoonerhill	S	S	MW	L	.	F
Springstead*	L	M	MW	L	.	F
St. Charles	L	H	W	H	.	M
Stambaugh	L	H	W	M	.	F
Stanberry*	L	M	MW	L	.	F
Stengel	S	S	SP	VL	.	F
Stinnett	L	H	SP	M	.	F
Stronghurst	L	H	SP	H	.	M
Sturgeon	L	H	SP	M	.	F
Suamico	O	H	VP	VH	.	M
Sultz	S	S	W	M	.	F
Summerville	L	M	W	VL	S	F
Sunia	S	S	MW	L	.	F
Superior	L	H	MW	M	.	F
Sylvester	L	H	W	M	.	M
Symco*	L	H	SP	H	.	M
Symerton	L	H	W	M	.	M
Tacoosh	O	M	VP	VH	.	F
Tama	L	H	W	H	.	M
Tarr	S	S	E	L	.	M
Tawas	O	M	VP	VH	.	F
Taylor	L	H	MW	M	.	F
Tedrow	S	S	SP	L	.	M
Tell	L	H	W	M	.	M
Thackery	L	H	MW	M	.	M
Theresa	L	H	W	M	.	M
Tilleda	L	H	W	M	.	F
Timula	L	H	W	H	.	M
Tint	S	S	MW	L	.	M
Tintson	S	S	MW	L	.	M
Tipler*	L	M	MW	L	.	F
Toddville	L	H	MW	H	.	M
Tonkey	L	M	P	M	.	F
Torch	L	H	SP	M	.	F
Totagatic	S	S	P	H	.	F
Tourtillotte	S	S	MW	L	.	F
Tradelake	L	H	MW	M	.	F
Trempe	S	S	E	L	.	M
Trempealeau	L	H	W	M	.	M
Troxel	L	H	MW	H	.	M
Tula	L	M	SP	L	.	F
Tuscola	L	H	MW	H	.	M
Tustin	S	S	W	M	.	M
Twinmound	S	S	E	VL	.	F
Urne*	L	M	W	L	.	M
Valton	L	H	W	M	.	M
Vancecreek	L	M	P	VH	.	F
Vanzile	L	H	MW	M	.	F
Varna	L	H	W	H	.	M
Vasa	L	H	SP	VH	.	M
Veedum	L	M	VP	L	.	F
Vesper	L	M	P	M	.	F
Vilas	S	S	E	L	.	F
Virgil	L	H	SP	H	.	M
Vlasaty	L	H	MW	M	.	M
Wabeno	L	H	MW	M	.	F
Wacousta	L	M	VP	VH	.	M
Wainola	S	S	SP	L	.	F
Wakefield*	L	M	MW	L	.	F
Wakeley	S	S	VP	L	.	F

Table 4.1 continued. Codes assigned to Wisconsin soils for soil group and soil yield potential (YP) along with soil properties used to evaluate soil yield potential. See footnotes for code descriptions.

			Properties used to assess soil YP			
Soil name	Soil group	Soil YP	Drainage class	AWC	Bed-rock depth	Soil temp. regime
Wallkill	L	M	VP	VH	.	M
Warman*	S	S	SP	L	.	F
Warsaw	L	H	W	M	.	M
Wasepi	L	M	SP	L	.	M
Washtenaw*	L	M	P	H	.	M
Watseka	S	S	SP	L	.	M
Wauconda	L	H	SP	H	.	M
Waukegan	L	H	W	M	.	M
Waupaca	L	M	P	M	.	F
Wauseon	L	M	VP	M	.	M
Wautoma	S	S	VP	M	.	M
Wayka	L	M	SP	L	S	F
Waymor	L	H	W	M	.	M
Wega	L	H	SP	M	.	F
Westville	L	H	W	H	.	M
Whalan*	L	M	W	L	.	M
Wheatley	S	S	P	L	.	F
Whisklake	L	M	SP	L	.	F
Whitehall	L	H	W	H	.	M
Wickware	L	H	W	VH	.	F
Wildale*	L	H	W	M	.	M
Wildwood	L	M	VP	L	.	F
Will	L	M	P	L	.	M
Willette	O	H	VP	VH	.	M
Windward	S	S	SE	L	.	M
Winnebago	L	H	W	H	.	M
Winneconne	L	H	W	M	.	M
Winneshiek	L	M	W	L	.	M
Winterfield	S	S	SP	L	.	F
Withee*	L	H	SP	M	.	F
Worcester*	L	M	SP	L	.	F
Wormet*	L	M	SP	L	.	F
Worthen	L	H	W	VH	.	M
Worwood	L	H	SP	M	.	F
Wozny	L	M	VP	M	.	F
Wurtsmith	S	S	MW	L	.	F
Wyeville	S	S	SP	M	.	M
Wykoff*	L	M	W	L	.	M
Wyocena*	L	M	W	L	.	M
Yahara*	L	H	SP	H	.	M
Zeba	L	M	SP	L	.	F
Zittau*	L	H	SP	M	.	M
Zurich	L	H	W	H	.	M

* At least one map unit for the soil has a different interpretation for soil yield potential and/or soil group. The interpretations presented are based on the interpretation of the majority of the map units. For more detailed information about individual map units see: http://uwlab.soils.wisc.edu/a2809-soil-map-unit-info/ or SnapPlus nutrient management software.

Abbreviations

Soil group: L=loamy soils (medium and fine-textured); O=organic soils; S=sandy soils (sands and loamy sands)

Soil yield potential (YP): H=high; M=medium; S=sandy

Drainage class: E=excessively drained; SE=somewhat excessively drained; W=well drained; MW=moderately well drained; SP=somewhat poorly drained; P=poorly drained; VP=very poorly drained

Available water capacity (AWC): VL=very low; L=low; M=moderate; H=high; VH=very high

Bedrock depth: S=shallow; bedrock is within 30 inches of the soil surface

Soil temperature regime: M=mesic; F=frigid

Table 4.2. Crop codes, typical yield range, moisture content at which yield is reported, phosphorus (P) and potassium (K) crop removal values and demand levels, and target soil pH values for each crop.

Crop name	Crop code	Yield range (per acre)	Reporting moisture content[a] (%)	Crop removal P_2O_5	Crop removal K_2O	P and K demand level	Target pH Mineral	Target pH Organic
				-------lb/unit yield-------				
Alfalfa, established	1	2.6–9.5 ton	DM	13	60	2	6.8	—
Alfalfa, seeding	2	1.5–2.5 ton	DM	13	60	2	6.8	—
Apple, establishment[b]	60	all	fresh	—	—	2	6.5	—
Asparagus	3	2,000–4,000 lb	fresh	0.0033	0.0067	3	6	5.6
Barley, grain	74	25–100 bu	14.5	0.4	0.35	1	6.6	5.6
Barley, grain + straw[c]	4	25–100 bu	—	—	—	1	6.6	5.6
Barley, straw[d]	—	1–3 ton	DM	10	32	—	—	—
Bean, dry (kidney, navy)	5	10–40 cwt	18	1.2	1.6	2	6	5.6
Bean, lima	6	2,000–5,000 lb	fresh	0.0086	0.017	2	6	5.6
Bean, snap	44	1.5–6.5 ton	fresh	5	20	2	6.8	5.6
Beet, table	7	5–20 ton	fresh	1.3	8	3	6	5.6
Blueberry, establishment[b]	61	all	fresh	—	—	2	5.6	5.4
Brassica, forage	8	2–3 ton	DM	10	48	2	6	5.6
Broccoli	9	4–6 ton	fresh	2	8	3	6	5.6
Brussels sprouts	10	4–6 ton	fresh	3.2	9.4	3	6	5.6
Buckwheat	11	1,200–2,000 lb	~15	0.013	0.013	1	5.6	5.4
Cabbage	12	8–30 ton	fresh	1.6	7.2	3	6	5.6
Canola	13	30–50 bu	8	1.1	2	1	5.8	5.6
Carrot	14	20–30 ton	fresh	1.8	9.6	3	5.8	5.6
Cauliflower	15	6–8 ton	fresh	2.9	7.1	3	6	5.6
Celery	16	25–35 ton	fresh	3.3	10	3	6	5.6
Cherry, establishment[b]	62	all	fresh	—	—	2	6.5	—
Clover, red	42	1–6.5 ton	DM	13	60	1	6.3	5.6
Corn, grain	17	70–290 bu	15.5	0.38	0.29	1	6	5.6
Corn, popcorn	38	60–80 bu	~14	0.36	0.29	2	6	5.6
Corn, silage	18	10–40 ton	65	3.6	8.3	2	6	5.6
Corn, stover[d]	—	1–5 ton	DM	4.6	32	—	—	—
Corn, sweet	19	2–10 ton	fresh	3.3	6	2	6	5.6
Cranberry, establishment[b]	63	all	fresh	—	—	2	5.6	5.4
CRP, alfalfa	66	—	—	0	0	2	6.6	—
CRP, grass	68	—	—	0	0	1	5.6	5.4
CRP, red clover	67	—	—	0	0	1	6.3	5.6
Cucumber	20	5–10 ton	fresh	1.2	3.6	3	5.8	5.6
Flax	21	20–40 bu	9	0.67	0.67	1	6	5.6
Ginseng	22	1,000–3,000 lb	DM	0.0075	0.03	3	—	—

Table 4.2 continued. Crop codes, typical yield range, moisture content at which yield is reported, phosphorus (P) and potassium (K) crop removal values and demand levels, and target soil pH values for each crop.

Crop name	Crop code	Yield range (per acre)	Reporting moisture content[a] (%)	Crop removal P_2O_5	Crop removal K_2O	P and K demand level	Target pH Mineral	Target pH Organic
				-------lb/unit yield--------				
Grape, establishment[b]	79	all	fresh	—	—	2	6.5	5.6
Grass, hay[e]	84	0.5–8 ton	DM	15	55	1	6	5.6
Grass, sod for turf, establishment	45	all	—	—	—	1	6	5.6
Grass, reed canarygrass	41	4–7 ton	DM	7.3	33	1	6	5.6
Grass, switchgrass	85	1–5 ton	DM	12	20	1	6	5.6
Hop	86	1,000–1,500 lb	fresh	—	—	1	5.8	—
Lettuce	23	15–20 ton	fresh	2.3	9.1	3	5.8	5.6
Lupine	24	40–60 bu	~16	1	1.2	1	6.3	5.6
Melon	25	8–10 ton	fresh	4.4	16	3	5.8	5.6
Millet	26	40–60 bu	10	0.4	0.4	1	5.6	5.4
Mint, oil	27	35–55 lb	—	1.1	4.4	3	—	5.6
Oat, grain	75	30–120 bu	14	0.29	0.19	1	5.8	5.6
Oat, grain + straw[c]	28	30–120 bu	—	—	—	1	5.8	5.6
Oat, straw[d]	—	1–3 ton	DM	9.4	47	—	—	—
Onion	31	400–600 cwt	fresh	0.12	0.26	3	5.6	5.4
Pasture, grass[e]	33	0.5–5 ton	DM	15	55	1	6	5.6
Pasture, ≤ 30% legume-grass	34	0.5–5 ton	DM	13	51	1	6	—
Pasture, > 30% legume-grass	83	0.5–5 ton	DM	13	60	1	6.3	5.6
Pasture, unimproved	32	1–4 ton	DM	16	36	1	6	5.6
Pea, canning	35	1,000–6,000 lb	fresh	0.0046	0.0092	2	6	5.6
Pea, chick/field/cow	36	1–2 ton	10	20	24	2	6	5.6
Pepper	37	8–10 ton	fresh	1.1	5.6	3	6	5.6
Potato[f]	39	250–650 cwt	fresh	0.12	0.5	4	5.2/6.0	5.2/5.6
Pumpkin	40	15–20 ton	fresh	2.9	6.3	3	6	5.6
Raspberry, establishment[b]	64	all	fresh	—	—	2	6.5	5.6
Rye, grain	76	15–70 bu	14	0.41	0.31	1	5.6	5.4
Rye, grain + straw[c]	43	15–70 bu	—	—	—	1	5.6	5.4
Rye, straw[d]	—	1–2 ton	DM	3.7	21	—	—	—
Rye, winter, silage	87	2–3 ton	DM	18	80	1	5.6	5.4
Small grain silage[g]	81	2.0–3.5 ton	DM	11	44	1	6	—
Small grain silage, underseeded with alfalfa[g]	29	2.0–3.5 ton	DM	11	44	1	6.8	—
Small grain & legume silage[g,h]	82	2.0–3.5 ton	DM	11	44	1	6	—
Small grain & legume silage, under-seeded with alfalfa [g,h]	30	2.0–3.5 ton	DM	11	44	1	6.8	—

Table 4.2 continued. Crop codes, typical yield range, moisture content at which yield is reported, phosphorus (P) and potassium (K) crop removal values and demand levels, and target soil pH values for each crop.

Crop name	Crop code	Yield range (per acre)	Reporting moisture content[a] (%)	Crop removal P_2O_5 (lb/unit yield)	Crop removal K_2O (lb/unit yield)	P and K demand level	Target pH Mineral	Target pH Organic
Sorghum, grain	46	50–100 bu	14	0.4	0.4	1	5.6	5.4
Sorghum-sudan, forage	47	5–7 ton	65	15	60	1	5.6	5.4
Soybean, grain	48	15–105 bu	13	0.8	1.4	1	6.3	5.6
Soybean, grain + straw[c]	77	15–105 bu	—	—	—	1	6.3	5.6
Soybean, straw[d]	—	2–4 ton	DM	5.4	19	—	—	—
Spinach	49	4–6 ton	fresh	4	10	3	6	5.6
Squash	50	12–16 ton	fresh	2.8	6.4	3	6	5.6
Strawberry, establishment[b]	65	all	fresh	—	—	2	6.5	5.6
Sunflower	51	500–4,000 lb	10	0.012	0.024	1	6	5.6
Tobacco	52	1,600–2,800 lb	cured leaf	0.0091	0.057	3	5.8	5.6
Tomato	53	20–25 ton	fresh	1.8	8	3	6	5.6
Trefoil, birdsfoot	54	1.5–5.5 ton	DM	13	60	1	6	5.6
Triticale, grain	55	1,000–5,000 lb	~13	0.011	0.0092	1	6	5.6
Triticale, grain + straw[c]	80	1,000–5,000 lb	—	—	—	1	6	5.6
Triticale, straw[d]	—	1–2 ton	DM	3.7	21	—	—	—
Truck crops	56	all	fresh	—	—	3	6	5.6
Vetch, crown/hairy	57	2–3 ton	DM	16	48	1	6	5.6
Wheat, grain	78	20–120 bu	13.5	0.5	0.35	2	6	5.6
Wheat, grain + straw[c]	58	20–120 bu	—	—	—	2	6	5.6
Wheat, straw[d]	—	1.5–3.5 ton	DM	6	28	—	—	—
Wildlife food plot, corn/forage brassicas	69	—	—	—	—	1	6	—
Wildlife food plot, legume-grass pasture	70	—	—	—	—	1	6	—
Wildlife food plot, oats/wheat/rye	71	—	—	—	—	1	6	—
Wildlife food plot, soybean	72	—	—	—	—	1	6	—
Wildlife food plot, sugar beet/turnip	73	—	—	—	—	1	6.3	—

[a] Reporting moisture content is the moisture content at which yield is reported. Dry matter (DM) = yield is reported on a dry matter basis; fresh = yield is reported on a fresh, as harvested basis; cured leaf = yield is sold/reported on a cured leaf basis.

[b] Lime recommendations for apples and cherries apply only to pre-plant tests. Adjustment of pH is impractical once an orchard is established. Other perennial fruit crops must also be limed or amended with an acidifying material and incorporated prior to establishment.

[c] Use when both grain and straw are removed.

[d] Straw and stover do not have a crop code because no nutrient application guidelines are provided. Yield ranges and crop removals for straw and stover are given for information only. Crop removals for straw are used in calculating the phosphate and potash fertilizer recommendations for small grains, grain + straw, see Table 7.4.

[e] Includes bromegrass, fescue, orchardgrass, ryegrass, and timothy.

[f] Use higher target pH for scab-resistant varieties and lower pH for varieties that are not scab resistant.

[g] Small grains include barley, oats, rye, triticale, and wheat.

[h] Legumes may include leguminous vegetables (pea, bean) and soybean, but not forage legumes (alfalfa, red clover).

5. Soil pH and lime requirement

The optimum (target) pH for a soil depends on the crops that will be grown. Table 4.2 lists the optimum pH levels for crops grown in Wisconsin. The amount of lime recommended is the amount needed to reach the target pH for the most acid-sensitive crop (the one with the highest target pH) that is to be grown during the next 4 years. If alfalfa will be grown on a field in the future but is not indicated in the present rotation, the lime needs for the field may be underestimated.

Once a soil reaches the desired pH level, it will tend to remain at that level for a relatively long time without additional application of lime. This is because soils are naturally highly buffered against changes in pH. Coarse-textured soils (sands and loamy sands) are not as highly buffered against pH change as medium- and fine-textured soils, so they will generally not maintain their pH level as long. Sandy soils may need to be limed more frequently, but at much lower rates.

Table 5.1. Formulas used to calculate lime requirement at various target pH levels.

Target pH	Lime requirement formula[a] (tons/a 60–69 lime to apply[b])
5.2	36.1 – (3.29 x BpH) – (2.67 x WpH)
5.4	48.2 – (4.84 x BpH) – (3.03 x WpH)
5.6	51.0 – (5.40 x BpH) – (2.67 x WpH)
5.8	57.2 – (5.55 x BpH) – (3.50 x WpH)
6.0	72.7 – (7.59 x BpH) – (3.78 x WpH)
6.3	103 – (12.6 x BpH) – (3.18 x WpH)
6.5	134 – (17.2 x BpH) – (2.73 x WpH)
6.6	152 – (20.3 x BpH) – (2.17 x WpH)
6.8	195 – (28.4 x BpH) + (0.144 x WpH)

[a] Abbreviations: BpH = buffer pH, WpH = water pH.
[b] An adjustment to compensate for inefficient field mixing and incomplete dissolution of ground limestone is already factored into the equation.
Note: These equations lack accuracy at very low liming rates. It is possible to calculate lime rates that are less than 2 tons/acre or even negative. In these cases, the minimum recommended lime rate is 1.5 or 2 tons/acre. Read the section “Other factors affecting lime recommendations” for other relevant information.

Lime requirement calculations

Lime should be applied if the soil pH is more than 0.2 units below the target pH. Minor fluctuations inherent in both sampling and pH measurement preclude calculating lime needs when the pH is within 0.2 units of the target. The lime requirement equations listed in Table 5.1 use soil pH and buffer pH values in calculating lime requirement for a sample.

The recommendations obtained using equations in Table 5.1 are for liming materials with a neutralizing index (NI) of 60–69. Because 80–89 NI lime is commonly used in much of the state, the necessary rate of 80–89 lime is normally listed on a soil test report along with the 60–69 rate. If using lime with an NI other than 60–69, adjust the lime requirement using the following formula:

Lime requirement (ton/a) of lime being used = (ton/a of 60–69 lime recommended) x (65 ÷ NI* of lime being used)

* When a range is given, use the midpoint (e.g., for 80–89 grade lime, use 85 in the calculation).

Lime requirement for 60–69 lime should be rounded to the nearest ton, while lime requirement for liming materials with a greater NI should be rounded to the nearest 0.5 ton/a. The lime requirement for potato should be rounded to the nearest 0.1 ton/a because potatoes are typically grown on poorly buffered soils and it is not desirable to over-lime potato fields.

Plow depth adjustment

Adjusting the lime requirement for the depth of tillage is critical for reaching the desired soil pH. In the past, most tillage operations were limited to the top 7 inches of the soil, so lime needs are based on that assumption. If tillage extends below 7 inches, the lime requirement is greater, as more soil is being mixed with the applied lime. To adjust the lime recommendation for deeper tillage, multiply the lime requirement by the factor listed in Table 5.2.

An application rate of 1 ton/a of topdressed 60–69 lime or 80–89 lime is recommended for fields that have been under no-till management for more than 5 years and have a surface (0–2 inches) pH that is more than 0.2 units below the target pH. These fields should be retested in 3 to 4 years to determine if additional lime applications are needed.

Averaging the lime requirement

On fields where multiple samples have been taken, a field average is normally used to determine the best overall rate. For samples where the lime requirement exceeds the field average by more than 2 tons/a, apply a higher rate of lime to the more acid part of the field. If a sample from the field indicates that the lime requirement is more than 2 tons/a below the mean, that sample should be excluded and an adjusted mean calculated using the remaining values. If only three or four samples were submitted from a field, no more than one sample will be eliminated from consideration. If five or more samples are taken to represent the field, no more than two samples will be excluded. This adjusted average is the value that is used to determine the lime needs for fields that are to be amended by applying a single uniform rate. If fewer than one-half of the samples in a field have a lime requirement, then the field lime requirement should be considered to be zero. However, growers should be aware that some parts of this field may benefit from liming and should consult the laboratory results section of the soil test report. If at least one-half of the samples in a field have a lime requirement, the field lime requirement should be based on the average of the samples with a lime requirement. Again, the laboratory results section of the soil test report should be consulted to determine which parts of the field may not benefit from liming.

Table 5.2. Plow depth adjustment: multiply lime requirement by adjustment factor based on plow depth.

Plow depth (inches)	**Multiplier** used to adjust lime requirement
0–7.0	1.00
7.1–8.0	1.15
8.1–9.0	1.31
> 9.0	1.46

Other factors affecting lime recommendations

Coarse-textured soils are not as well buffered against changes in soil pH as are medium- and fine-textured soils. To help prevent overliming on sandy soils with an average organic matter content of less than 1%, only 1 ton/a of lime should be applied when the calculated lime requirement is less than 1.5 tons/a. For sandy soils with more than 1% organic matter content as well as silt loam and clay soils, the minimum application should be 2 tons/a of 60–69 NI lime or 1.5 tons/a of 80–89 grade lime. The rate of lime applied should never exceed 8 tons/a for potato or 12 tons/a for other crops even though more lime may be required to completely neutralize soil acidity. Where the lime need is greater than these levels, the field may not reach the desired target pH, but the smaller application is recommended for economic reasons.

If the field has been limed in the last 2 years, additional lime may not be needed, even though the target pH has not been reached.

No additional lime should be applied until the most recent application has had 2 to 3 years to equilibrate with the soil and the pH has been retested.

Choosing a liming material

When choosing a liming material, several factors should be considered: the amount of pH change required, how long it will be before the most acid-sensitive crop is planted, the availability of local liming materials, and land ownership or tenure.

If the grower either owns the land or is assured of long-term use of a field, applying the full recommended rate of lime is justified in most cases. On the other hand, if the access to a field is uncertain from year to year, smaller applications may be worth considering. If a local source of ground limestone is available, it will most likely be the most economical source of lime because shipping costs are a large part of the cost of purchasing ground limestone. Local lime deposits are found in many parts of the state, with the exception of the north central and northern areas.

It is advisable to base the selection of a liming material on the cost per acre after adjusting for the neutralizing index. The cheapest lime is not always the best choice. Multiply the rate per acre required by the cost per ton to determine the cost per acre. For example, if 60–69 grade lime costs $25/ton and you need to apply 4 tons/a, the total cost would be $100/a. By contrast, the equivalent amount of 80–89 required would be 3.1 tons/a. If this material costs $30/ton, the total cost would be $93/a. In this case, the more expensive material is actually the better buy.

Several other factors, which are difficult to quantify economically, can also influence your choice of a liming material. For example, if you are liming a no-till field or will be seeding an acid-sensitive crop like alfalfa immediately after liming, you may want to select a finer ground lime to react more quickly with soil acidity even if you have to pay a premium. If large changes in pH are required, it may be wise to delay the planting of acid-sensitive crops for a year and select the most economical liming material for your situation following the guidelines above.

Lowering soil pH

Most horticulture and agronomic crops grow best when soil pH is between 6.0 and 6.8. Many crops can adapt to higher or lower pH levels with no drop in crop quality or yield. However, some crops, like blueberries, require acid soil conditions (soil pH of 5.5 or less) to grow and perform as expected.

Many soils, especially those in southeastern Wisconsin, are alkaline (high pH) and may contain free carbonate, which is a source for alkalinity. Such soils require high levels of management to successfully grow crops that require acid soil conditions. If the soil pH is 7.5 or greater, growing crops that require low soil pH conditions is not recommended.

In the rest of Wisconsin, most soils with a pH of less than 7.5 can be amended to lower the pH to the desired level (Table 5.3). The most common materials used are elemental sulfur (S) and aluminum sulfate. To lower the soil pH, elemental sulfur must be converted (oxidized) to sulfate by soil bacteria. As a result, the change in pH takes several months or longer. Sometimes the soil contains very small numbers of this special kind of bacteria. Under these conditions, the process may take 6 or more months. The oxidizing reaction brought about by the organisms is as follows:

$$\mathbf{S + {}^{3}\!/_{2}O_2 + H_2O \dashrightarrow 2H^+ + SO_4^{2-}}$$

Applying more than 20 lb S/1,000 sq ft per year is not recommended. If more is required, use split applications of 20 lb S/1,000 sq ft and apply in succeeding years. Check the soil pH

Table 5.3. Amount of finely ground elemental sulfur (S) needed to lower soil pH (increase acidity).

	Soil organic matter content (%)					
Desired reduction in soil pH	0.5–2	2–4	4–6	6–8	8–10	> 10
	---------- lb S/1,000 sq ft ----------					
0.25	6	18	28*	40*	53*	62*
0.50	12	35*	56*	80*	106*	125*
1.00	24*	70*	112*	120*	212*	250*

* Do not apply more than 20 lb S/1,000 sq ft per year. Retest soil between applications.

before making a second application to see how much change has taken place.

Aluminum sulfate [$Al_2(SO_4)_3$] can also be used to lower soil pH. Its effect is nearly immediate, but the cost is higher than using elemental sulfur. The amount of aluminum sulfate needed to achieve the same decrease in pH is six times the amount of elemental sulfur required. Because too much aluminum can be toxic to plants, aluminum sulfate should not be applied at rates exceeding 50 lb $Al_2(SO_4)_3$/1,000 sq ft at any one application. Keep in mind that fertilizer products containing sulfate-sulfur are not effective in lowering soil pH. This includes products such as potassium sulfate (K_2SO_4) and gypsum ($CaSO_4$).

6. Nitrogen

Nitrogen application rate guidelines

Most non-legume crops need additional nitrogen (N) to improve crop yield and quality and to optimize economic return to the grower. However, excess N can reduce yields and lower the quality of some crops. Excess N can also cut economic returns to producers, degrade water quality, and cause other undesirable environmental effects. Wisconsin's N rate guidelines are based on crop yield, quality, and economic return. Using these guidelines will help to minimize excess N applications and reduce environmental risks. These guidelines are based on field studies where crop responses to several rates of N are measured on soils typically used for production of various crops. Nitrogen application rate guidelines vary according to the crop to be grown, soil characteristics and yield potential, and soil organic matter content.

Corn nitrogen rate guidelines

As noted above, the optimum N rate for corn grain and silage was developed through experiments that measured corn yield response to several rates of N on soils typically used for corn production. These studies found that the economic optimum N rate for corn grown on a given soil tends to be similar in high- and low-yielding years. Apparent recovery of fertilizer N by corn is high under favorable growing conditions and low when growing conditions are poor or include stress such as drought. The characteristic for optimum N rates to remain fairly constant across a wide yield range on similar soils has recently been called nitrogen resiliency.

Soil fertility specialists in several Midwestern states, including Wisconsin, have agreed upon a uniform approach to developing N rate guidelines for corn. The group recognized that yield objectives or yield goals are not good predictors of the economic optimum N rate. Instead, they focused on the relationship between corn and N prices. The specialists examined the results from hundreds of corn N response experiments conducted throughout the region. This N rate guideline strategy, based on the data, is designed to maximize economic return to the grower. Because the philosophy of this approach is based on maximizing economic return to nitrogen (MRTN), that acronym is widely used to refer to these guidelines.

Although the MRTN approach emerged from a regional effort, the Wisconsin MRTN rate guidelines in this publication are based entirely on experiments conducted on numerous Wisconsin soils. The MRTN guidelines for corn (Table 6.1) are based on soil characteristics, previous crop, and the nitrogen:corn price ratio that is applicable to the specific production situation. Wisconsin's MRTN rate guidelines are soil-specific. As shown in Table 6.1, medium- and fine-textured (loamy) soils are separated into two soil yield potential categories: high and medium (see Chapter 4: Soil and crop information). This separation is needed because corn grown on soils in these two categories shows a different response to N fertilization. Sandy soils (sands and loamy sands) are given separate N rate guideline values depending on whether or not they are irrigated. The lower N rates for non-irrigated sandy soils reflect the lower yield potential where moisture is often inadequate.

Selecting soil yield potential and previous crop options

The soil name is the key to placing soils in the appropriate yield potential category, and the yield potential category for each soil is given in Table 4.1. The predominant agronomic soil in the field should be selected for use in determining a nutrient application rate. If a soil's location has, on average, fewer than 2100 growing degree days (GDD, modified base 50, maximum 86, May 1 through September 30), it should be considered medium yield poten-

Table 6.1. Suggested nitrogen (N) application rates for corn at different nitrogen:corn grain price ratios.

Soil and previous crop	Nitrogen:Corn price ratio 0.05	0.10	0.15	0.20
	---------- total lb N/a to apply[a] ----------			
Loamy: high yield potential soil				
Corn, forage legumes, legume vegetables, green manures[d]	**190**[b] 170 -------- 210[c]	**165** 155 -------- 180	**150** 140 -------- 160	**135** 125 -------- 150
Soybean, small grains[e]	**140** 125 -------- 160	**120** 105 -------- 130	**105** 95 -------- 115	**90** 80 -------- 105
Loamy: medium yield potential soil				
Corn, forage legumes, legume vegetables, green manures[d]	**145** 130 -------- 160	**125** 115 -------- 140	**115** 105 -------- 125	**105** 95 -------- 110
Soybean, small grains[e]	**130** 110 -------- 150	**100** 85 -------- 120	**85** 70 -------- 95	**70** 60 -------- 80
Sands/ loamy sands				
Irrigated—all crops[d]	**215** 200 -------- 230	**200** 185 -------- 210	**185** 175 -------- 195	**175** 165 -------- 185
Non-irrigated—all crops[d]	**140** 130 -------- 150	**130** 120 -------- 140	**120** 110 -------- 130	**110** 100 -------- 120

[a] Includes N in starter.
[b] Rate is the N rate that provides the maximum return to nitrogen (MRTN).
[c] Range is the range of profitable N rates that provide an economic return to N within $1/a of the MRTN rate.
[d] Subtract N credits for forage legumes, legume vegetables, animal manures, and green manures. This includes first-, second-, and third-year credits where applicable. Do not subtract N credits for leguminous vegetables on sand and loamy sand soils.
[e] Subtract N credits for animal manures and second-year forage legumes.

tial, regardless of soil property limitations, because the length of growing season restricts yield potential. Soils with no soil property limitations on yield potential in locations with 1) 2100 to 2200 GDD or 2) less than 2100 GDD and a mesic temperature regime are in a transition area; in some cases these soils are high yield potential, in others medium. In the transition area, growers and agronomists should choose the most appropriate yield potential based upon experience. Average GDD isolines for Wisconsin are provided in Figure 4.1. Loamy soils that are irrigated because of low available water capacity or that are artificially drained (e.g., tiled) because of poor drainage can be considered high yield potential if the location has more than 2200 GDD or is in a transition area. If loamy soils are limited by shallow depth to bedrock and field evaluation demonstrates that there is more than 30 inches of soil over bedrock throughout a majority of the field, then the soil can be considered high yield potential.

For medium- and fine-textured (loamy) soils, the suggested application rate varies according to the previous crop (Table 6.1). Where corn follows a forage legume, leguminous vegetable, or green manure crop or where manure has been applied, the appropriate N credits must be subtracted from the N rate values shown in Table 6.1. (See Chapter 9 for information on crediting N from legumes and manure.) Previously, N application rates for corn following soybean involved subtracting a soybean N credit. Now the N needs are determined directly from the N response information for this cropping system. Although N response data for corn following small grains is somewhat limited, these results show that corn N needs in this cropping system are similar to those found where corn follows soybean. Suggested N rates for sands and loamy sands are appropriate for all previous crops, but N credits for previous forage legumes and manure applications must be subtracted from these values.

Where N rates are adjusted for N contributions from organic sources such as manure or other land-applied waste materials, it is important to recognize that this adjustment should be made on the basis of first-year available N content of the material and not its total N content. See Chapter 9: Nutrient credits for details.

Calculating nitrogen:corn price ratios

MRTN rate guidelines are based on the nitrogen:corn price ratio that is applicable to the specific production situation. This allows the user flexibility in identifying the N rate likely to maximize economic return at prevailing N and corn prices. To determine the nitrogen:corn price ratio, divide the cost of N ($/lb) by the price of corn ($/bu). For example, if the cost of N is $0.50/lb and the price of corn is $5.00/bu, the nitrogen:corn price ratio is $0.50 ÷ $5.00 = 0.10. If the per ton price for fertilizer N is known, the N cost can be calculated as follows:

Price of N ($/lb) = [$/ton of fertilizer N x (100 ÷ % N in fertilizer)] ÷ 2,000

Table 6.1 shows the N rates likely to maximize economic return for four price ratios. Also shown is a range of N rates that would be within $1.00/a of maximizing economic return. With this approach, growers can select rates higher or lower than the MRTN rate depending on their experience with using various N rates and their risk tolerance. In general, corn yields will be at or near maximum levels if the N rates indicated for the 0.05 price ratio are used. At rates shown for the higher ratios, yields will likely be somewhat lower, but economic return to the grower will be maximized. For all soil types, the nitrogen rate at the MRTN for the 0.20 nitrogen:corn price ratio produces, on average, 94–95% of maximum yield. For a given price ratio, the MRTN rate will not vary with price level (e.g., $5/bu versus $7/bu). The range in profitable N rates is influenced by price level, such that for a given nitrogen:corn price ratio, the profitable range narrows at higher price levels demonstrating that there is greater risk to over- and under-application of N at high price levels. The MRTN profitable range was determined using a price level of $4/bu.

Valuing corn grain and manure nitrogen

While the value of purchased fertilizer N is relatively easy to determine, estimating a realistic value for corn grain and manure N requires some calculations based on anticipated end use. The value of grain will vary depending on where the grain is sold and how it is marketed. For example, grain that will be used on the farm as livestock feed should be valued at what it would cost to purchase the grain if feedstocks ran short.

The value of N in manure may vary between farms and between fields on farms depending upon the availability of land on which to spread manure. If a large enough land base is available to spread all manure, then the value of the N in manure could be considered to be equivalent to fertilizer N. In this case it would be more useful to spread the manure on as many acres as possible and reduce purchased N fertilizer. If the land base is limited, then spreading manure at a rate not to exceed the amount needed to maximize yield (top end of the profitability range for a nitrogen:corn price ratio of 0.05) would be appropriate. On some farms, there may be some fields that cannot receive manure and others that can. Thus, N application rates may be higher for fields receiving manure and lower for fields receiving fertilizer N.

Selecting nitrogen rates for corn silage

The relationship between silage yield and N application rate is similar to that for grain yield and N rate. Silage quality is not greatly influenced by N application rates over the range of rates provided in Table 6.1. If growing silage for on-farm feed, usually growers want to maximize yield to minimize purchased feed. In this situation, using a N rate in the mid to upper end of the 0.05 price ratio would be appropriate. If silage is being sold, and a producer would like to reduce N rates to improve profitability, select a N rate using a nitrogen:corn price ratio that reflects typical prices for N and grain.

Deciding which end of the MRTN range to use

Additional suggestions for selecting optimum N rates from Table 6.1 are listed below:

- If residue covers more than 50% of the soil at planting, use the upper end of the range.
- If 100% of the recommended N will come from organic sources, use the top end of the range. In this situation, up to 20 lb/a additional N may be applied in starter fertilizer.
- For corn following small grains on medium- and fine-textured (loamy) soils, the middle to low end of the range is most appropriate.
- If there is a likelihood of residual N (carryover N), use the low end of the range or use the high end of the range and subtract preplant nitrate test (PPNT) credits.
- For medium- and fine-textured (loamy) soils with more than 10% organic matter, use the low end of the range.
- For all soils with less than 2% organic matter, use the high end of the range.
- For coarse-textured (sandy) soils with 2 to 9.9% organic matter, use the middle to low end of the range.
- For coarse-textured (sandy) soils with 10 to 20% organic matter, use the non-irrigated guidelines, regardless of irrigation status.
- For coarse-textured (sandy) soils with more than 20% organic matter, apply 80 lb N/a for all previous crops with or without irrigation.

Wheat nitrogen rate guidelines

The MRTN approach used for corn N rate guidelines has been refined for use in wheat (Table 6.2). In order to obtain a N rate for wheat, one must know the soil group (Table 4.1), previous crop, and nitrogen:wheat price ratio. Concepts of the nitrogen:wheat price ratio are similar to corn, and readers should refer to the previous section for details.

For wheat following corn on loamy soils, the MRTN has been further refined based on the preplant nitrate test (PPNT) results. Substantial residual N may remain from the corn crop, particularly if excess N was applied to corn or drought conditions prevented the use of all the N that was applied. Accounting for this N will improve the N use efficiency of wheat, increase profitability, and reduce potential for nitrate losses to groundwater. Soils with a PPNT less than or equal to 50 lb N/a have higher N rate guidelines than soils

Table 6.2. Suggested nitrogen (N) application rates for wheat at different nitrogen:wheat price ratios.

Soil group	Previous crop	PPNT (lb NO_3-N/a)	Nitrogen:Wheat price ratio 0.05	0.075	0.1	0.125
			---- total lb N/a to apply[a] ----			
Loamy						
	Corn	< 50[b] or no PPNT	**75** 65--------85	**70** 55--------80	**60** 50--------70	**55** 40 -------- 65
		51 to 100	**45** 35--------55	**40** 30--------50	**35** 25--------40	**30** 20 -------- 35
		> 100	**0** 0--------0	**0** 0--------0	**0** 0--------0	**0** 0 -------- 0
	Soybean, small grain	All[c]	**55** 45--------65	**50** 40--------60	**45** 35--------50	**40** 35 -------- 45
Sandy						
	All	—[d]	**105** 95--------115	**100** 95--------110	**90** 80--------100	**85** 70 -------- 95

[a] On loamy soils with < 2% organic matter, add 30 lb N/a to all rates. On soils with more than 10% organic matter, reduce rates by 30 lb N/a. Reduce N rates by 10 lb N/a for spring wheat on all soils. No N is required on organic soils. Manure N credits must be subtracted from these values.

[b] If wheat follows a forage legume or leguminous vegetable, use the MRTN rate for wheat following corn with PPNT< 50 and take the legume credit.

[c] Previous crop soybean or small grain: If a PPNT is taken and the PPNT is < 50 lb N/a, use the top end of the profitable range; if the PPNT is 51 to 100 lb N/a, use the bottom end of the profitable range; if the PPNT is > 100 lb/a, no additional N is needed. Do not take a soybean legume credit.

[d] PPNT is not recommended on group S (sand and loamy sand) soils.

with a PPNT of 51 to 100 lb N/a, reflecting a lesser amount of nitrogen in the soil profile. On soils where the PPNT is more than 100 lb N/a, wheat will not respond profitably to N additions and the MRTN rate is 0 lb N/a. If the previous crop is corn and a PPNT was not taken, then the N rate guidelines for a PPNT of less than 50 lb N/a should be followed.

As with corn, the N response of wheat on loamy soils is similar for previous crops of soybean or small grains. Based on Wisconsin's current N response database, a clear distinction in N need is not apparent between soils with varying PPNT values. Thus, there is no differentiation in MRTN guidelines based on PPNT when wheat follows soybean or small grain. However, if a PPNT is taken in this situation and it is less than or equal to 50 lb N/a, then the top end of the profitable range should be used. If, on the other hand, the PPNT is 51 to 100 lb N/a, consider using the bottom end of the profitable range. (See Using soil nitrate tests to adjust nitrogen application rates later in this chapter for more detail on how to collect PPNT samples.) Soybean rotational N credits should not be used with the MRTN approach to selecting a N rate for wheat.

Wheat's N response does not vary with previous crop when grown on sandy (sand and loamy sand) soils. The PPNT is not suggested for use on sandy soils. At this time, the MRTN guidelines for wheat on sandy soils are the same regardless of whether or not the field is irrigated.

Additional considerations for selecting a N rate for wheat:

- When wheat follows a forage legume or leguminous vegetable, use the MRTN rate for wheat following corn with a PPNT less than or equal to 50 lb N/a and take the legume credit.
- Manure N credits must be subtracted from the rates provided in Table 6.2.
- If 100% of the N will come from organic sources, use the top end of the range.
- Reduce N rates by 10 lb N/a for spring wheat.
- On loamy soils with less than 2% organic matter, add 30 lb N/a to all rates.
- On soils with more than 10% organic matter, reduce rates by 30 lb N/a.
- No N is required on organic soils.

Nitrogen rate guidelines for other crops

Nitrogen rate guidelines for crops other than potato are also based on the concept that desired yield or yield goal is not a good predictor of optimum N rates in the production of these crops. Available N response data from research studies on a range of Wisconsin soils is insufficient to allow application of the MRTN approach to N rate guidelines for these crops. Therefore, a single N rate suggestion is given regardless of yield level for the crops in Table 6.3. The suggested N rates are adjusted for soil organic matter content. When the crops in Table 6.3 follow a legume crop, reduce N applications according to the legume N credits shown in Tables 9.4–9.6. Take appropriate credits if manure has been applied (Tables 9.1–9.3).

Considerations for potato

The potato N recommendations (Table 6.3) use yield as a criteria primarily to help separate early short-season varieties from longer full-season varieties. On medium- to fine-textured soils, apply the entire amount at planting; there is no advantage to splitting applications. On sandy soils, however, apply 25–50% of the crop N need at emergence and the remainder at tuberization or apply the remaining N in multiple split applications. During years with high precipitation, multiple split applications improve yield and quality; during years with normal to low precipitation, splitting N applications at emergence and tuberization consistently produces high-yielding, high-quality potatoes. Excessive N splitting may increase the percentage of cull potatoes. Nitrogen can be applied up to 60 days after emergence. Later applications do not improve yield or quality.

When potatoes follow a legume crop, reduce N applications according to the legume N credits shown in Tables 9.4–9.6. Take appropriate credits if manure has been applied (Tables 9.1–9.3). Broadcasting or applying N with the irrigation water, especially early in the season, results in less efficient N use because as water moves downward in the furrows, the N bypasses the plant roots.

Petiole nitrate (NO_3-N) testing can help determine the need for late N application. Table 6.4 indicates optimum petiole NO_3-N levels for several potato varieties and stages of growth. If petiole NO_3-N levels are below optimum and the crop has at least 45 days to vine kill, apply 30–50 lb N/a. This additional N may be applied through fertigation. If petiole NO_3-N testing will be used to monitor crop N status, early season N rates applied at hilling can be reduced by 25–30%.

Table 6.3. Nitrogen (N) rate guidelines for crops other than corn and wheat.

Crop	Yield range per acre	Soil organic matter content (%) < 2.0	2.0–9.9	10.0–20.0	> 20.0
		----lb N/a to apply[a]----			
Alfalfa, seeding	1.0–2.5 ton	30	0	0	0
Alfalfa, established	2.6–9.5 ton	0	0	0	0
Apple, establishment[b]	—	2	2	2	2
Asparagus	2,000–4,000 lb	80	60	40	20
Barley[c]	25–100 bu	70	50	30	15
Bean, dry (kidney, navy)	10–40 cwt	40	30	20	10
Bean, lima	2,000–5,000 lb	60	40	20	10
Bean, snap	1.5–6.5 ton	60	40	20	0
Beet, table	5–20 ton	120	100	80	30
Blueberry, establishment[d]	—	30	30	30	30
Brassica, forage	2–3 ton	120	100	80	40
Broccoli	4–6 ton	100	80	60	25
Brussels sprouts	4–6 ton	100	80	60	25
Buckwheat	1,200–2,000 lb	50	30	20	0
Cabbage	8–30 ton	180	140	100	40
Canola	30–50 bu	80	60	40	20
Carrot	20–30 ton	120	100	80	40
Cauliflower	6–8 ton	120	100	80	40
Celery	25–35 ton	140	120	100	50
Cherry, establishment[b]	—	2	2	2	2
Clover, red, seeding	1-2.5 ton	30	0	0	0
Clover, red, established	2.6–6.5 ton	0	0	0	0
Corn, popcorn	60–80 bu	110	90	70	50
Corn, sweet	2–10 ton	150	130	110	70
Cranberry, establishment[d]	—	150	150	150	150
CRP, alfalfa[e]	—	20	0	0	0
CRP, grass[e]	—	30	15	0	0
CRP, red clover[e]	—	20	0	0	0
Cucumber	5–10 ton	100	80	60	30
Flax	20–40 bu	50	30	20	0
Ginseng	1,000–3,000 lb	60	40	20	0
Grapes, establishment[b]	—	2	2	2	2
Grass, hay[f, g]	0.5–8 ton	160	130	100	50
Grass, sod for turf, establishment[h]	all	250	250	250	250

Table 6.3 continued. Nitrogen (N) rate guidelines for crops other than corn and wheat.

Crop	Yield range per acre	Soil organic matter content (%)			
		< 2.0	2.0–9.9	10.0–20.0	> 20.0
		----lb N/a to apply[a]----			
Grass, reed canarygrass	4–7 ton	270	250	220	100
Grass, switchgrass, seeding[i]	1–3 ton	0	0	0	0
Grass, switchgrass, established[i]	1–5 ton	120	100	75	50
Hop[j]	1,000–1,500 lb	200	180	150	120
Lettuce	15–20 ton	120	100	80	40
Lupine	40–60 bu	10	0	0	0
Melon	8–10 ton	100	80	60	30
Millet	40–60 bu	80	60	40	20
Mint, oil	35–55 lb	120	100	80	50
Oat[c]	30–120 bu	60	40	20	0
Onion	400–600 cwt	150	140	130	120
Pasture, grass[f, g]	0.5–5 ton	160	130	100	50
Pasture, ≤ 30% legume-grass, seeding	0.5–1.9 ton	40	20	0	0
Pasture, ≤ 30% legume-grass, established	2–5 ton	0	0	0	0
Pasture, > 30% legume-grass, seeding	0.5–1.9 ton	30	10	0	0
Pasture, > 30% legume-grass, established	2–5 ton	0	0	0	0
Pasture, unimproved[f]	1–4 ton	120	100	70	30
Pea, canning	1,000–6,000 lb	40	30	20	0
Pea, chick/field/cow	1–2 ton	40	30	20	0
Pepper	8–10 ton	100	80	60	30
Potato[k]	250–350 cwt	145	120	100	60
	351–450 cwt	180	155	130	75
	451–550 cwt	220	180	150	85
	551–650 cwt	250	210	175	95
Pumpkin	15–20 ton	100	80	60	30
Raspberry, establishment[d]	—	30	30	30	30
Rye	15–70 bu	60	40	20	0
Rye, winter, silage	2–3.5 ton	80	60	40	0
Small grain silage	2–3.5 ton	60	40	20	0
Small grain silage, underseeded with alfalfa	2–3.5 ton	30	20	10	0
Small grain + legume silage	2–3.5 ton	25	15	0	0
Small grain + legume silage, underseeded with alfalfa	2–3.5 ton	15	10	0	0
Sorghum, grain	50–100 bu	130	100	80	40
Sorghum-sudan, forage	5–7 ton	120	100	80	40

Table 6.3 continued. Nitrogen (N) rate guidelines for crops other than corn and wheat.

Crop	Yield range per acre	Soil organic matter content (%) < 2.0	2.0–9.9	10.0–20.0	> 20.0
		---lb N/a to apply[a]---			
Soybean	15–105 bu	0	0	0	0
Spinach	4–6 ton	100	80	60	30
Squash	12–16 ton	80	60	40	20
Strawberry, establishment[d]	—	30	30	30	30
Sunflower	500–4000 lb	100	80	60	30
Tobacco	1,600–2,800 lb	140	120	100	0
Tomato	20–25 ton	140	120	100	50
Trefoil, birdsfoot, seeding	0.5–1.4	30	0	0	0
Trefoil, birdsfoot, established	1.5–5.5 ton	0	0	0	0
Triticale	1,000–5,000 lb	60	40	20	0
Truck crops	all	140	120	120	60
Vetch, crown/hairy, seeding	0.5–1.9 ton	30	0	0	0
Vetch, crown/hairy, established	2–3 ton	0	0	0	0
Wildlife food plot, corn/forage brassicas	—	100	100	100	100
Wildlife food plot, legume grass pasture	—	0	0	0	0
Wildlife food plot, oats/wheat/rye	—	40	40	40	40
Wildlife food plot, soybean	—	0	0	0	0
Wildlife food plot, sugar beet/turnip	—	100	100	100	100

[a] This is the total amount of N to apply including starter fertilizer.

[b] These rates are in ounces per plant, not pounds per acre. The rates apply for the establishment year only. The rate to apply is 1 oz/plant two times during the establishment year. After establishment, use tissue testing to guide fertilizer application.

[c] Where barley or oat are underseeded with a legume forage, eliminate or reduce N by half.

[d] These rates apply for the establishment year only. After establishment, use tissue testing to guide fertilizer application. For blueberry, raspberry, and strawberry, split that total application rate into two or three applications in the establishment year. For cranberries apply no more than 15 lb N/a at any one time during the establishment year.

[e] Apply N in the seeding year only.

[f] Split N applications into two to three applications per year.

[g] Includes bromegrass, fescue, orchardgrass, ryegrass, and timothy.

[h] Apply total amount of N in split applications and/or use slow release fertilizers. These guidelines are for sod farms only.

[i] Apply N in one application in late May or when the grass is 12 to 18 inches tall.

[j] Assumes vines and leaves are not returned to the hop yard. Reduce rates by 50 lb N/a if residues are returned. Split-apply N on coarse-textured soils.

[k] Rates include nitrogen in starter fertilizer. Reduce nitrogen rate by 25% if petiole nitrate test is used to guide in-season N applications.

Table 6.4. Optimum petiole NO_3-N levels for several potato varieties at different growth stages.

Stage of growth (days after emergence)	Dry weight basis: Norkota, Norland, Atlantic, Kennebec	Dry weight basis: Shepody, R. Burbank, Snowden	Dry weight basis: Onaway, Superior	Sap basis: Norkota, Norland, Atlantic, Kennebec	Sap basis: Shepody, R. Burbank, Snowden	Sap basis: Onaway, Superior
	% NO_3-N			ppm NO_3-N		
30	2.5–2.8	2.0–2.3	2.3–2.5	1,900–2,100	1,600–1,800	1,800–1,900
40	2.3–2.5	1.7–2.2	2.0–2.3	1,800–2,000	1,600–1,700	1,600–1,800
50	1.8–2.3	1.2–1.6	1.5–1.9	1,400–1,800	1,000–1,300	1,200–1,500
60	1.3–1.9	0.8–1.1	0.9–1.2	1,100–1,500	700–900	500–1,000
70	0.8–1.1	0.5–0.8	0.4–0.6	700–900	500–700	400–600

Using soil nitrate tests to adjust nitrogen application rates

Nitrogen application rates suggested for corn, sweet corn, and winter wheat grown on medium-and fine-textured (loamy) soils can be adjusted using soil nitrate tests. Soil nitrate testing is not reliable on coarse-textured sandy soils because their nitrate content can change rapidly. Soil nitrate testing allows N fertilizer recommendations to be adjusted for field-specific conditions that can influence crop N need. These adjustments can lower costs by avoiding N applications in excess of crop needs. They also help the environment by lowering the potential for nitrate movement to groundwater by avoiding over-application of nitrogen.

Soil nitrate tests estimate the amount of plant-available nitrate-nitrogen in the root zone. This N may have carried over from fertilizer applications during the previous growing season or the N may have been supplied by preceding legume crops, manure applications, or mineralization of soil organic matter. If the amount of soil nitrate-nitrogen is significant, subsequent N fertilizer applications can be reduced or, in some cases, eliminated.

In Wisconsin, two tests are available: a preplant nitrate test (PPNT) that is appropriate for corn, sweet corn, and winter wheat and a pre-sidedress nitrate test (PSNT) that can be used for corn and sweet corn. The PPNT involves deep soil sampling, to a depth of 2 feet, before planting the crop. This test measures the amount of residual or carryover nitrate in the soil. The second test, the PSNT, consists of shallower soil sampling, to a depth of 1 foot, when corn is 6 to 12 inches tall. This test is intended to predict the amount of plant-available N that will be released from organic sources during the growing season.

Choosing which of the soil nitrate tests to use depends on a grower's cropping system and field management. Generally, the PPNT works best under the following field conditions:

- Medium- and fine-textured (loamy) soils
- Previous growing season and overwinter precipitation normal or below normal
- Previous crop N application in excess of crop need

Using the PPNT is not recommended in the following situations:

- Medium- and fine-textured (loamy) soils when the previous season and overwinter precipitation was above normal
- Sandy soils
- When the previous crop was N-deficient
- On first-year crops following alfalfa or other forage legume; refer to Table 9.4 for N credits for previous forage legume crops.

Some nitrate carryover occurs in most years on well-drained medium-textured soils in Wisconsin. The PPNT should be used when a grower suspects nitrate carryover, while the PSNT is most useful for confirming legume and manure N credits and providing a site-specific estimate of soil N availability. More information on using the PPNT and PSNT in various production situations follows.

Using the preplant soil nitrate test

For corn and sweet corn, soil samples for the PPNT should be collected in early spring after frost has left the soil and prior to planting or any preplant applications of nitrogen. For winter wheat, samples should be taken in late summer. Soil samples need to be collected in 1-foot increments to a depth of 2 feet. The laboratory nutrient recommendation program predicts the soil nitrate content in the 2- to 3-foot depth based on the nitrate content in the 1- to 2-foot depth, eliminating the need for deeper sampling. For best results, take a minimum of 15 soil cores randomly from 20 acres. Be sure to take separate samples from field areas that differ in soil characteristics or past management practices. After collection, soil samples should be kept cool because the nitrate content in moist soil samples stored under warm conditions can increase quickly and cause erroneous test results. If samples cannot be delivered to the soil testing laboratory within 1 to 2 days after collection, they should be frozen or air-dried to prevent changes in soil nitrate content.

Nitrogen credits for recent manure applications (Tables 9.1–9.3) must be taken separately and in addition to any credits based on PPNT results. Another option for assessing recent manure credits would be the use of the PSNT. See the following section for further information on using the PSNT.

Nitrogen credits for corn based on the PPNT can be calculated using the information given in Table 6.5. These N credits should be subtracted from the N application rates for corn and sweet corn (Tables 6.1 and 6.3) to arrive at an adjusted N application rate. The N credit is adjusted for background soil nitrate content by subtracting 50 lb N/a from the nitrate test result. For wheat, the PPNT is built into the MRTN rate guidelines (Table 6.2) and no additional adjustment is needed. More information on the PPNT is available in UW-Extension publication *Wisconsin's Preplant Soil Nitrate Test* (A3512).

Using the pre-sidedress soil nitrate test

The pre-sidedress nitrate test (PSNT) provides a diagnostic tool for adjusting corn N application rates. It measures the amount of plant-available N released from organic N sources such as previous forage legume crops, manure applications, and soil organic matter. The PSNT can be a valuable technique for confirming the amount of N that should be credited from manure or previous legume crops where

Table 6.5. Nitrogen (N) credits to corn and sweet corn crops based on preplant nitrate test (PPNT) results.

PPNT results (lb NO_3-N/a)	**N credit** (lb N/a to credit)
0–50	0
50–200	PPNT–50 lb N/a (Apply a minimum of 50 lb N/a)
> 200	—*

* No additional N is needed.

Table 6.6. Nitrogen (N) credits to corn and sweet corn crops based on the pre-sidedress nitrate test (PSNT).

PSNT value (ppm NO_3-N)	Soil yield potential: High	Soil yield potential: Medium
	------ lb N/a to credit ------	
> 21	—*	—*
18–20	100	80
15–17	60	80
13–14	35	40
11–12	10	40
< 10	0	0

* No additional N is needed.

insufficient information is available to assign these credits.

Samples for the PSNT should be taken when corn plants are 6 to 12 inches tall, usually 4 to 6 weeks after planting. Unlike preplant nitrate test (PPNT) samples, PSNT soil samples are collected only to a depth of 1 foot. As with PPNT, a minimum of 15 soil cores should be randomly taken from every 20 acres. Samples should be refrigerated. (See previous section on sampling for the preplant test). The PSNT is not recommended on sandy soils (sands and loamy sands). While soil sampling for the PSNT is easier than for the PPNT, growers using the PSNT are locked into sidedress applications if additional N is needed. Users of this test should also be aware that all operations including soil sampling, laboratory analysis, and sidedress N applications must be completed within 1 to 2 weeks.

For corn and sweet corn, soil nitrate measured by the PSNT is credited against the N application rate (Table 6.1 or 6.3) using the values shown in Table 6.6. For example, if the unadjusted rate for a corn field on high yield potential soils is 165 lb N/a and the PSNT value is 16 ppm N, a credit of 60 lb N/a would be subtracted from the unadjusted N rate (165 – 60 = 105 lb N/a) to arrive at the N rate to apply.

Because mineralization of N from organic sources is a biological process, the amounts measured by the PSNT are influenced by average temperatures during the period before sample collection. When early growing season temperatures are cool, mineralization occurs more slowly, causing the PSNT to underestimate the amount of organic N that will become available during the growing season. When this occurs, N credits based on the PSNT will be low, resulting in application rates that are higher than necessary.

Wisconsin research with the PSNT shows that optimum N rates for corn are sometimes overestimated when average temperatures in May and June are more than 1°F below the long-term average. When average temperatures in May and June are normal or higher, the PSNT seldom overestimates crop N needs. Where the PSNT is used to adjust N rates for N contributions from organic N sources in growing seasons with below-normal average temperatures for May and June, users should consider the book value N credit for the manure application, or the previous legume crop together with the PSNT nitrogen credit, in arriving at a N application rate decision. If the PSNT value is > 21 ppm N, no additional N is needed. If the PSNT nitrogen credit is substantially less than the book value N credits, the book value credits are likely to be more reliable. Low PSNT nitrogen credits are most likely to occur with spring manure applications or following spring killed or spring tilled alfalfa.

Using soil nitrate tests in Wisconsin cropping systems

Selecting the soil nitrate test that is most appropriate for a particular production situation depends on the cropping system, management practices, and climatic conditions. The following suggestions are intended to provide guidance on the most useful test for various cropping systems common to Wisconsin.

Corn following corn. Where corn follows corn in a crop rotation, residual soil nitrate accumulation is likely on medium- and fine-textured soils if previous precipitation was normal or below normal and/or previous N applications exceeded crop uptake. In this cropping system, the PPNT is the preferred soil nitrate test because the deeper sampling depth allows more complete assessment of the amount of residual nitrate in the soil profile. The PSNT can be used to provide a partial estimate of N carryover and to estimate the amounts of available N likely to be released from organic sources. In the corn following corn crop sequence, the PSNT can identify sites that do not need additional N fertilization based on the 21 ppm critical level.

Manured sites. Both the PPNT and the PSNT can be used on manured fields; however, there are differences in the interpretation of the test results depending on which test is used. The PSNT provides a direct estimate (N credit) of the amount of available N likely to be released during the growing season. The PPNT measures only nitrate nitrogen present when the sample is taken and thus will not reflect N release from the manure. When using the PPNT, a separate manure N credit (Tables 9.1–9.3) must be taken in addition to the credit based on the test result.

Corn following alfalfa. When corn follows alfalfa in a crop rotation, the previous alfalfa crop can provide most, if not all, of the N required by the corn crop. The best method for determining corn N needs following alfalfa is to subtract the appropriate legume N credit (Table 9.4) from the unadjusted N application rate. Corn following a good or fair stand of alfalfa on medium- and fine-textured soils usually does not need additional nitrogen. Where there is a need to confirm the alfalfa N credit, the PSNT should be used. If the PSNT result is less than 21 ppm N, no more than 40 lb N/a should be applied. The PPNT should not be used for corn following alfalfa.

Corn following soybean. Nitrogen rate guidelines for corn following soybean (Table 6.1) reflect the effect of the soybean-corn rotation on corn N needs. The PPNT can be used to refine these N rate suggestions for the effect of residual soil nitrate. Where PPNT results are available, subtract the nitrate test nitrogen credit from the appropriate N rate guideline value for the soybean-corn crop sequence in Table 6.1. The PSNT should not be used for adjusting N application rates in soybean-corn sequences.

Confirming second-year manure and legume credits. Manure and legume residues release N and other crop nutrients as they decompose. While the largest release of available N occurs in the first year after manure or legume residues are added to the soil, this process is not complete after 1 year. Additional N is released during the second growing season after manure application or alfalfa plow down. Where corn follows corn, the PPNT is the preferred soil nitrate test. However, this test will not measure any N released by manure or legume residues during the second cropping year. Therefore, second-year manure or legume N credits in Tables 9.1–9.3 and Table 9.4, respectively, must be taken in addition to the adjustment for the PPNT. With the later sampling date of the PSNT, second-year N contributions due to mineralization of organic sources have already been converted to nitrate-nitrogen and will be measured by the test. Therefore, N credits for the PSNT should not be adjusted further for second-year manure or legume N credits.

Managing nitrogen to avoid losses

The N application rate guidelines, N credits, and soil nitrate test suggestions presented in this publication assume that best management practices will be used to control N losses. If best management practices are not followed and losses occur, the N rates suggested are likely to be inadequate to meet crop needs. Nitrogen losses hurt both the bottom line and the environment. The major N management options to help avoid N losses are summarized below.

Nitrogen rate

Deciding how much N to apply is the most important N management practice affecting profitability and N use efficiency. Applying more N than the crop needs is the primary source of nitrate losses to the environment. Using the N rate guidelines in this publication, together with appropriate N crediting for manure and previous legume crops, is essential for arriving at the best N rate decision. Application rates can be further refined for some crops through use of soil nitrate testing.

Note also that as N rates increase, crop recovery of N decreases and the potential for nitrate loss to the environment increases. Therefore, the risk of nitrate loss to groundwater is reduced at lower N rates; however, yields and economic returns are also likely to be less. See Chapter 11 in the UW-Extension publication *Management of Wisconsin Soils* (A3588) for additional information on this subject. Nitrogen rates below those specified for maximum economic return can be selected to accomplish individual management or environmental objectives. Yields will vary depending on growing conditions and management. Nitrogen deficiencies become more likely as N rates are decreased from those shown in this publication.

Nitrogen source

All fertilizer N sources are effective in supplying N to crops, but ammonia volatilization or nitrate leaching can lower the effectiveness of some. Urea and urea-containing fertilizers such as urea-ammonium nitrate (UAN) solutions will volatilize if surface-applied and conditions favoring loss develop. Losses are usually 25–30% of the applied N and can seriously reduce the fertilizer's effectiveness. Control measures include injecting or incorporating the fertilizer materials, including a urease inhibitor, or using a N source that does not contain urea. Rainfall of at least ¼ inch within a few days after application will also minimize losses to volatilization.

Fertilizers that contain nitrate such as UAN solution, ammonium nitrate, calcium nitrate are susceptible to N losses through leaching if substantial rainfall occurs soon after application. Under conditions where leaching is likely, using all-ammonium N sources, slow-release fertilizer materials, or delaying the N application to match crop uptake can help control these losses.

Nitrogen timing

Timing of N applications can play an important role in controlling N losses. Ideally, N would be applied just before the period of crop N use, providing adequate N to the crop when it needs it and avoiding N losses that could occur when applied earlier than needed. In practice, though, other times of N application can be used with equal effectiveness. Typically, N timing options for corn include fall, preplant, and sidedress or split applications. Fall applications are subject to higher risks of N loss than other timing

Table 6.7. Relative probability of increasing corn yield by using a nitrification inhibitor.

	Time of N application		
Soil type	**Fall**	**Spring preplant**	**Spring sidedress**
Sands and loamy sands	not recommended	good	poor
Sandy loams and loams	fair	good	poor
Silt loams and clay loams			
Well drained	fair	poor	poor
Somewhat poorly drained	good	fair	poor
Poorly drained	good	good	poor

options and require specific management practices to obtain acceptable performance. In all cases, fall applications should be limited to well-drained medium- and fine-textured soils. Fall applications should be delayed until soil temperatures remain below 50ºF, and N should be applied as anhydrous ammonia containing a nitrification inhibitor. Even when these practices are employed, fall applications are usually 10–15% less effective than spring applications of the same amount of nitrogen.

Preplant N applications are as effective as other timing options on most medium- and fine-textured soils with moderate or better drainage. Sidedress N applications can be used effectively on these soils; however, reduced optimum N rates or yield enhancements should not be expected solely from the use of sidedress nitrogen unless there is excessive rainfall in the first few weeks after planting. In contrast, sidedress or split applications are essential for controlling N losses on coarse-textured sandy soils (leaching) and on some poorly drained soils (denitrification).

In some situations, use of a nitrification inhibitor with preplant-applied ammonium forms of N or use of slow-release N fertilizers may also be effective in controlling N losses. The relative probability of obtaining a corn yield increase from use of a nitrification inhibitor is influenced by soil characteristics and the timing of the N applications (Table 6.7). Usually, a positive response will occur only where use of the inhibitor reduced or eliminated N losses due to leaching or denitrification.

Nutrient management planning

Nitrogen recommendations provided to producers by land grant universities and extension services are receiving increasing scrutiny because of continuing concerns about the effects of agricultural N use on water quality. Specifically, N losses from agricultural systems have been identified as likely contributors to elevated groundwater nitrate concentrations and to the hypoxic (low-oxygen) zone in the Gulf of Mexico. In addition, university N recommendations are being widely used as the technical criteria for nutrient management regulatory policy. These policies often view university recommendations as a vehicle for achieving environmental objectives, while the basis for developing the recommendations is agronomic. These issues and the need to provide producers with reasonable economic returns from N use in crop production emphasize the need for reliable, science-based N recommendations.

Notes:

7. Phosphorus and potassium

Soil tests for phosphorus (P) and potassium (K) are indices of available nutrients present in the soil. These indices provide estimates of the amount of additional phosphate (P_2O_5) or potash (K_2O) that should be added to optimize profit for the grower. Phosphorus and potassium soil test levels are reported in parts per million (ppm).

Soil test P and K interpretation categories vary by soil group because soils in each group vary in the amount of P and K that the soil can supply. Additionally, crops have been grouped into categories (demand levels) based on their responsiveness to P and K (Table 4.2). Tables 7.1 and 7.2 provide the soil test interpretation categories for each crop demand level. Definitions of the interpretive levels used to indicate the soil's relative nutrient supply of P and K are provided in Table 3.2. Crops grown on soils testing in the optimum range will have optimum yield and profit when the quantity of nutrients applied is about equal to the amount removed in the harvested portion of the crop. The optimum soil test ranges for P and K are set somewhat higher for vegetables, potato, and irrigated field crops because of their high crop values.

Each soil's ability to hold P and K along with its P and K buffering capacity (the amount of fertilizer required to change soil test level by 1 ppm) is related to soil texture, mineralogy, and organic matter content. The approximate nutrient buffer capacity of each soil group is provided in Table 7.3.

Table 7.1. Soil test phosphorus (P) interpretation categories. Choose the highest demanding crop in your rotation to set the soil test interpretation categories for the rotation. If the desired crop is not listed on the table, consult Table 4.2 to determine its demand level.

	Soil test category				
	Very low (VL)	**Low (L)**	**Optimum (O)**	**High (H)**	**Excessively high (EH)**
Soil group[a]	----------soil test P ppm[b]----------				
Demand level 1: corn grain, soybean, clover, small grains (but not wheat), grasses, oilseed crops, pasture					
Loamy	< 10	10–15	16–20	21–30	> 30
Sandy, Organic	< 12	12–22	23–32	33–42	> 42
Demand level 2: alfalfa, corn silage, wheat, beans, sweet corn, peas, fruits					
Loamy	< 12	12–17	18–25	26–35	> 35
Sandy, Organic	< 18	18–25	26–37	38–55	> 55
Demand level 3: tomato, pepper, brassicas, leafy greens, root, vine, and truck crops					
Loamy	< 15	15–30	31–45	46–75	> 75
Sandy, Organic	< 18	18–35	36–50	51–80	> 80
Demand level 4: potato					
Loamy	< 100	100–160	161–200	> 200	
Sandy, Organic	< 30	30–60	61–90	91–120	> 120

[a] See Chapter 4: Soil and crop information for more details on soil groups.

[b] ppm (wt/vol; g/m^3)

Table 7.2. Soil test potassium (K) interpretation categories. Choose the highest demanding crop in your rotation to set the soil test interpretation categories for the rotation. If the desired crop is not listed on the table, consult Table 4.2 to determine its demand level.

	Soil test category					
	Very low (VL)	Low (L)	Optimum (O)	High (H)	Very high (VH)	Excessively high (EH)
Soil group[a]	----------soil test K ppm[b]----------					
Demand level 1: corn grain, soybean, clover, small grains (but not wheat), grasses, oilseed crops, pasture						
Loamy	< 70	70–100	101–130	131–160	161–190	> 190
Sandy, Organic	< 45	45–65	66–90	91–130	—	> 130
Demand level 2: alfalfa, corn silage, wheat, beans, sweet corn, peas, fruits						
Loamy	< 90	90–110	111–140	141–170	171–240	> 240
Sandy, Organic	< 50	50–80	81–120	121–160	161–200	> 200
Demand level 3: tomato, pepper, brassicas, leafy greens, root, vine, and truck crops						
Loamy	< 80	80–140	141–200	201–220	221–240	> 240
Sandy, Organic	< 50	50–100	101–150	151–165	166–180	> 180
Demand level 4: potato						
Loamy	< 80	80–120	121–170	171–190	191–220	> 220
Sandy, Organic	< 70	70–100	101–130	131–160	161–190	> 190

[a] See Chapter 4: Soil and crop information for more details on soil groups.
[b] ppm (wt/vol; g/m^3)

Phosphorus and potassium application rate guidelines

The first item that is needed in determining a P or K application rate is to select the crop demand level for the rotation. The crop in the planned rotation that has the highest demand level (Table 4.2) is the one the sets the soil test P and K interpretation categories for the rotation (Tables 7.1 and 7.2). If all of the crops to be grown on a field have a demand level of 1 (e.g., corn and soybean) and the field will be irrigated, then demand 2 soil test interpretation categories should be used. The second item that is needed in determining a P or K application rate is the soil group for the predominate agronomic soil in the field. Soil groups are given in Table 4.1.When the soil test is optimum (O), the fertilizer application rate is equivalent to the amount of phosphate and potash removed in the harvested portion of the crop. This is considered a maintenance application, resulting in little change in soil test level. For soils that test greater than optimum, the objective of the nutrient application guidelines is to 1) rely on the soil to supply the bulk of the nutrients needed for crop growth and 2) reduce the soil test level to optimum. For soils testing high (H), the P and K application rate is one-half the rate at optimum. On very high (VH) testing soils (used only for soil test K interpretation), the K fertilizer application rate is one-quarter of the rate at optimum.

For soils testing excessively high (EH), the application rate is zero, with the exception of potato. Potato has a high probability of a profitable response to phosphate and potash even at excessively high soil test levels. Thus, 30 lb/a each of P_2O_5 and K_2O is recommended at excessively high soil test levels for potato. Corn may respond to an application of 20 lb/a each of P_2O_5 and K_2O as starter fertilizer on excessively high testing soils even though no fertilizer is recommended. For details, see Chapter 10: Starter fertilizers. The lower limit for the excessively high category is set such that 2 to 4 years of crop nutrient removal without fertilizing will not reduce soil test levels below the optimum category, except for crops where the whole plant is removed (corn silage, alfalfa, and other forage legumes). These crops remove large amounts of K, so retest soils with very high and excessively high soil test levels every 2 years.

For soils that test less than optimum, it is desirable to build up soil test levels to the optimum category. The fertilizer application rates in the low (L) and very low (VL) categories include the amount of fertilizer that will be removed by the harvested portion of the crop (application rate at optimum) plus an additional amount to build up soil test levels over a 4- to 8-year period. In the low category, the buildup amount is calculated as the change in soil test level that is desired (ppm difference between the middle of the optimum category and the middle of the low category) multiplied by the nutrient buffering capacity for the soil group divided by 4 to 8 years. In the very low category, the buildup amount is calculated as the change in soil test level that is desired (ppm difference between the middle of the optimum category and the top of the very low category) multiplied by the nutrient buffering capacity for the soil group, divided by 4 to 8 years.

Table 7.3. Phosphorus (P) and potassium (K) buffer capacities; the rate of fertilizer (oxide basis) required to increase soil test level 1 ppm.

Soil group[a]	P buffer capacity (lb P_2O_5/a per 1 ppm soil test P)	K buffer capacity (lb K_2O/a per 1 ppm soil test K)
Loamy	18	6–7
Sandy	12	6
Organic	18	5

[a] See Chapter 4: Soil and crop information for more details on soil groups.

Once the soil test interpretation categories have been identified, the P_2O_5 and K_2O fertilizer application rates may be determined. Table 7.4 provides the P_2O_5 and K_2O fertilizer application rate based on the soil test interpretation category for the rotation.

If the realistic yield goal for a particular crop on a given field is greater than the yield levels provided in Table 7.4, a fertilizer application rate for the optimum category can be determined by multiplying the yield goal by the amount of P_2O_5 and K_2O that will be removed in the harvested portion of the crop (see Table 4.2). If the soil test interpretation category is something other than optimum, the fertilizer rate can be determined using the approach outlined above.

Additional considerations

- Nutrient recommendations for crops grown on sands and organic soils are limited by the nutrient holding capacity of these soils, particularly for potassium. Because K leaches readily from organic soils and irrigated sands, and because specialty crop growers tend to use larger amounts of fertilizer, soil test values may fluctuate rapidly. For this reason, irrigated fields and fields in vegetable production should be soil sampled every year or every other year.

- Soils with relatively low K buffering capacities (soil groups S and O, along with some L) should be monitored more closely by testing every 2 years. These soils do not hold sufficient K to allow for several years of high-yielding crops when the whole plant is removed. Because group O soils hold so little K, these soils are not suited for growing alfalfa or other crops where large amounts of K are removed (corn silage, forage legumes).

- Where alfalfa is to be grown, increase the recommended K_2O application rate by 20% if stand persistence is of primary importance and the stand is to be maintained for more than 3 years.

- If P and K fertilizer applications were made for corn grain but corn silage was harvested, increase fertilizer application rates for the next crop by 30 lb P_2O_5/a and 90 lb K_2O/a if soil test P and K were less than excessively high. If soil test P or K were excessively high, then there is no need to apply an additional amount of those nutrients.

- For fruit crops, P and K nutrient application rates are provided for establishment of the crop. Nutrient application rates after the establishment year should be based on tissue testing, with the goal of achieving and maintaining tissue nutrient concentration sufficiency.

- Soils containing carbonates that are calcitic ($CaCO_3$) in origin may neutralize the Bray 1 extractant for P and result in very low soil test P values. There are relatively few soils like this in Wisconsin. If the soil test P value is less than 5 ppm and the soil pH is greater than 7.5, use the NRCS's Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/) to determine if the soil contains carbonates that are calcitic in origin (e.g., marl). If so, then assume that the soil test is in the optimum category and monitor the crop for P deficiency symptoms. The Bray extractant will not be affected by soils with carbonates that are dolomitic [$CaMg(CO_3)_2$] in origin.

Environmental considerations

Phosphorus loss from the soil via surface runoff and leaching is a concern with regard to water quality. Wisconsin research has found that as soil test P levels increase, P loss to surface water also increases. A balance must be struck between crop production and environmental quality. For most field and forage crops (demand levels 1 and 2) there is very little probability of a yield response to additional P (from fertilizer or manure) once the soil test level exceeds about 30 ppm (Table 3.2). Thus, it is not desirable to maintain excessively high soil test levels for these crops. If crop rotations do not contain a high P-demanding crop (demand levels 3 and 4) and soil test P levels are between 50 and 100 ppm, P applications from fertilizer and manure should be reduced and crops with a high P removal should be grown. If soil test P exceeds 100 ppm, no additional P should be applied until soil test levels are drawn down. Maintaining soil test P levels near optimum will ensure adequate yield and provide flexibility in nutrient management planning.

For more information on P and water quality, see *Understanding Soil Phosphorus* (A3771).

Table 7.4. Phosphorus (P) and potassium (K) fertilizer application rate guidelines.

		P_2O_5 rate guidelines					K_2O rate guidelines					
Crop name	**Yield goal** (per acre)	**VL**	**L**	**O**	**H**	**EH**	**VL**	**L**	**O**	**H**	**VH**	**EH**
		----------lb P_2O_5/a to apply[a]----------					----------------lb K_2O/a to apply[b]----------------					
Alfalfa, seeding	1.5–2.5 ton	65	55	25	15	0	160	145	105	55	25	0
Alfalfa, established[c]	2.6–3.5 ton	80	70	40	20	0	235	220	180	90	45	0
	3.6–4.5 ton	90	80	50	25	0	295	280	240	120	60	0
	4.6–5.5 ton	105	95	65	35	0	355	340	300	150	75	0
	5.5–6.5 ton	120	110	80	40	0	415	400	360	180	90	0
	6.6–7.5 ton	130	120	90	45	0	475	460	420	210	105	0
	7.6–8.5 ton	145	135	105	55	0	535	520	480	240	120	0
	8.6–9.5 ton	155	145	115	60	0	595	580	540	270	135	0
Apple, establishment[d]	all	200	150	—	—	—	275	200	—	—	—	—
Asparagus	2,000–4,000 lb	90	65	10	5	0	120	90	20	10	5	0
Barley, grain	25–50 bu	55	45	15	10	0	60	45	15	10	5	0
	51–75 bu	65	55	25	15	0	65	50	20	10	5	0
	76–100 bu	75	65	35	20	0	75	60	30	15	10	0
Barley, grain + straw[e]	25–50 bu	75	65	35	20	0	120	105	75	40	20	0
	51–75 bu	85	75	45	25	0	130	115	85	45	20	0
	76–100 bu	95	85	55	30	0	140	125	95	50	25	0
Bean, dry (kidney, navy)	10–20 cwt	60	50	20	10	0	80	65	25	15	5	0
	21–30 cwt	70	60	30	15	0	95	80	40	20	10	0
	31–40 cwt	80	70	40	20	0	110	95	55	30	15	0
Bean, lima	2,000–3,000 lb	60	50	20	10	0	100	85	45	25	10	0
	3,001–4,000 lb	70	60	30	15	0	115	100	60	30	15	0
	4,001–5,000 lb	80	70	40	20	0	130	115	75	40	20	0
Bean, snap	1.5–2.5 ton	50	40	10	5	0	95	80	40	20	10	0
	2.6–3.5 ton	55	45	15	10	0	115	100	60	30	15	0
	3.6–4.5 ton	60	50	20	10	0	135	120	80	40	20	0
	4.6–5.5 ton	65	55	25	15	0	155	140	100	50	25	0
	5.6–6.5 ton	70	60	30	15	0	175	160	120	60	30	0
Beet, table	5–10 ton	90	65	10	5	0	160	130	60	30	15	0
	10.1–15 ton	95	70	15	10	0	200	170	100	50	25	0
	15.1–20 ton	105	80	25	15	0	240	210	140	70	35	0
Blueberry, establishment[d]	all	200	150	—	—	—	275	200	—	—	—	—
Brassica, forage	2–3 ton	65	55	25	15	0	175	160	120	60	30	0
Broccoli	4–6 ton	90	65	10	5	0	140	110	40	20	10	0
Brussels sprouts	4–6 ton	95	70	15	10	0	145	115	45	25	10	0

Table 7.4 continued. Phosphorus (P) and potassium (K) fertilizer application rate guidelines.

Crop name	Yield goal (per acre)	P_2O_5 rate guidelines VL	L	O	H	EH	K_2O rate guidelines VL	L	O	H	VH	EH
		-----------lb P_2O_5/a to apply[a]-----------					-----------------lb K_2O/a to apply[b]-----------------					
Buckwheat	1,200–2,000 lb	60	50	20	10	0	65	50	20	10	5	0
Cabbage	8–12 ton	95	70	15	10	0	170	140	70	35	20	0
	12.1–20 ton	105	80	25	15	0	215	185	115	60	30	0
	20.1–30 ton	120	95	40	20	0	280	250	180	90	45	0
Canola	30–50 bu	85	75	45	25	0	125	110	80	40	20	0
Carrot	20–30 ton	125	100	45	25	0	340	310	240	120	60	0
Cauliflower	6–8 ton	100	75	20	10	0	150	120	50	25	15	0
Celery	25–35 ton	180	155	100	50	0	400	370	300	150	75	0
Cherry, establishment[d]	all	200	150	—	—	—	275	200	—	—	—	—
Clover, red, seeding	1–2.5 ton	65	55	25	15	0	150	135	105	55	25	0
Clover, red, established	2.6–3.5 ton	80	70	40	20	0	225	210	180	90	45	0
	3.6–4.5 ton	90	80	50	25	0	285	270	240	120	60	0
	4.6–5.5 ton	105	95	65	35	0	345	330	300	150	75	0
	5.5–6.5 ton	120	110	80	40	0	405	390	360	180	90	0
Corn, grain[f]	71–90 bu	70	60	30	15	0	70	55	25	15	5	0
	91–110 bu	80	70	40	20	0	75	60	30	15	10	0
	111–130 bu	85	75	45	25	0	80	65	35	20	10	0
	131–150 bu	95	85	55	30	0	85	70	40	20	10	0
	151–170 bu	100	90	60	30	0	90	75	45	25	10	0
	171–190 bu	110	100	70	35	0	95	80	50	25	15	0
	191–210 bu	115	105	75	40	0	105	90	60	30	15	0
	211–230 bu	125	115	85	45	0	110	95	65	35	15	0
	231–250 bu	130	120	90	45	0	115	100	70	35	20	0
	251–270 bu	140	130	100	50	0	120	105	75	40	20	0
Corn, popcorn	60–80 bu	65	55	25	15	0	75	60	20	10	5	0
Corn, silage	10–15 ton	85	75	45	25	0	160	145	105	55	25	0
	15.1–20 ton	105	95	65	35	0	200	185	145	75	35	0
	20.1–25 ton	120	110	80	40	0	240	225	185	95	45	0
	25.1–30 ton	140	130	100	50	0	285	270	230	115	60	0
	30.1–35 ton	155	145	115	60	0	325	310	270	135	70	0
	35.1–40 ton	175	165	135	70	0	365	350	310	155	80	0
Corn, sweet[f]	2–4 ton	50	40	10	5	0	75	60	20	10	5	0
	4.1–6 ton	55	45	15	10	0	85	70	30	15	10	0
	6.1–8 ton	65	55	25	15	0	95	80	40	20	10	0
	8.1–10 ton	70	60	30	15	0	110	95	55	30	15	0

Table 7.4 continued. Phosphorus (P) and potassium (K) fertilizer application rate guidelines.

Crop name	Yield goal (per acre)	P_2O_5 rate guidelines VL	L	O	H	EH	K_2O rate guidelines VL	L	O	H	VH	EH
		----------lb P_2O_5/a to apply[a]----------					----------lb K_2O/a to apply[b]----------					
Cranberry, establishment[d]	all	200	150	—	—	—	275	200	—	—	—	—
CRP, alfalfa	—	40	30	0	0	0	55	40	0	0	0	0
CRP, grass	—	40	30	0	0	0	45	30	0	0	0	0
CRP, red clover	—	40	30	0	0	0	45	30	0	0	0	0
Cucumber	5–10 ton	90	65	10	5	0	125	95	25	15	5	0
Flax	20–40 bu	60	50	20	10	0	65	50	20	10	5	0
Ginseng	1,000–3,000 lb	95	70	15	10	0	160	130	60	30	15	0
Grape, establishment[d]	all	200	150	—	—	—	275	200	—	—	—	—
Grass, hay[g]	0.5–1.9 ton	60	50	20	10	0	115	100	70	35	20	0
	2–3 ton	80	70	40	20	0	185	170	140	70	35	0
	3.1–4 ton	95	85	55	30	0	240	225	195	100	50	0
	4.1–5 ton	110	100	70	35	0	295	280	250	125	65	0
	5.1–6 ton	125	115	85	45	0	350	335	305	155	75	0
	6.1–7 ton	140	130	100	50	0	405	390	360	180	90	0
	7.1–8 ton	155	145	115	60	0	460	445	415	210	105	0
Grass, reed canarygrass	4–7 ton	80	70	40	20	0	225	210	180	90	45	0
Grass, sod for turf, establishment[h]	all	130	90	45	45	45	90	45	45	45	45	45
Grass, switchgrass	1–5 ton	75	65	35	20	0	105	90	60	30	15	0
Hop	1,000–1,500	70	60	30	15	0	145	130	100	50	25	0
Lettuce	15–20 ton	120	95	40	20	0	260	230	160	80	40	0
Lupine	40–60 bu	90	80	50	25	0	105	90	60	30	15	0
Melon	8–10 ton	120	95	40	20	0	245	215	145	75	35	0
Millet	40–60 bu	60	50	20	10	0	65	50	20	10	5	0
Mint, oil	35–55 lb	130	105	50	25	0	300	270	200	100	50	0
Oat, grain	30–60 bu	55	45	15	10	0	55	40	10	5	5	0
	61–90 bu	60	50	20	10	0	60	45	15	10	5	0
	91–120 bu	70	60	30	15	0	65	50	20	10	5	0
Oat, grain + straw[e]	30–60 bu	70	60	30	15	0	150	135	105	55	25	0
	61–90 bu	80	70	40	20	0	155	140	110	55	30	0
	91–120 bu	90	80	50	25	0	160	145	115	60	30	0
Onion	400–600 cwt	140	115	60	30	0	230	200	130	65	35	0
Pasture, grass[g, i]	0.5–1.9 ton	60	50	20	10	0	115	100	70	35	20	0
	2–3 ton	80	70	40	20	0	185	170	140	70	35	0
	3.1–4 ton	95	85	55	30	0	240	225	195	100	50	0
	4.1–5 ton	110	100	70	35	0	295	280	250	125	65	0

Table 7.4 continued. Phosphorus (P) and potassium (K) fertilizer application rate guidelines.

Crop name	Yield goal (per acre)	P_2O_5 rate guidelines VL	L	O	H	EH	K_2O rate guidelines VL	L	O	H	VH	EH
		----------lb P_2O_5/a to apply[a]----------					----------lb K_2O/a to apply[b]----------					
Pasture, ≤ 30% legume-grass[i]	0.5–1.9 ton	55	45	15	10	0	110	95	65	35	15	0
	2–3 ton	75	65	35	20	0	175	160	130	65	35	0
	3.1–4 ton	85	75	45	25	0	225	210	180	90	45	0
	4.1–5 ton	100	90	60	30	0	275	260	230	115	60	0
Pasture, > 30% legume-grass[i]	0.5–1.9 ton	55	45	15	10	0	120	105	75	40	20	0
	2–3 ton	75	65	35	20	0	195	180	150	75	40	0
	3.1–4 ton	85	75	45	25	0	255	240	210	105	55	0
	4.1–5 ton	100	90	60	30	0	315	300	270	135	70	0
Pasture, unimproved[i]	1–2 ton	65	55	25	15	0	100	85	55	30	15	0
	2.1–3 ton	80	70	40	20	0	135	120	90	45	25	0
	3.1–4 ton	95	85	55	30	0	170	155	125	65	30	0
Pea, canning	1,000–2,500 lb	50	40	10	5	0	70	55	15	10	5	0
	2,501–4,000 lb	55	45	15	10	0	85	70	30	15	10	0
	4,001–6,000 lb	65	55	25	15	0	100	85	45	25	10	0
Pea, chick/field/cow	1–2 ton	70	60	30	15	0	90	75	35	20	10	0
Pepper	8–10 ton	90	65	10	5	0	150	120	50	25	15	0
Potato	250–350 cwt	185	135	65	50	30	245	225	180	120	75	30
	351–450 cwt	200	150	80	55	30	295	275	230	145	90	30
	451–550 cwt	210	160	90	60	30	345	325	280	170	100	30
	551–650 cwt	220	170	100	65	30	395	375	330	195	115	30
Pumpkin	15–20 ton	130	105	50	25	0	210	180	110	55	30	0
Raspberry, establishment[d]	all	200	150	—	—	—	275	200	—	—	—	—
Rye, grain	15–30 bu	50	40	10	5	0	50	35	5	5	0	0
	31–50 bu	55	45	15	10	0	55	40	10	5	5	0
	51–70 bu	65	55	25	15	0	65	50	20	10	5	0
Rye, grain + straw[e]	15–30 bu	55	45	15	10	0	85	70	40	20	10	0
	31–50 bu	60	50	20	10	0	90	75	45	25	10	0
	51–70 bu	70	60	30	15	0	95	80	50	25	15	0
Rye, winter, silage	2.0–3.5 ton	90	80	50	25	0	265	250	220	110	55	0
Small grain silage	2.0–3.5 ton	70	60	30	15	0	165	150	120	60	30	0
Small grain silage, underseeded with alfalfa	2.0–3.5 ton	70	60	30	15	0	165	150	120	60	30	0
Small grain + legume silage	2.0–3.5 ton	70	60	30	15	0	165	150	120	60	30	0
Small grain + legume silage, underseeded with alfalfa	2.0–3.5 ton	70	60	30	15	0	165	150	120	60	30	0

Table 7.4 continued. Phosphorus (P) and potassium (K) fertilizer application rate guidelines.

Crop name	Yield goal (per acre)	P_2O_5 rate guidelines VL	L	O	H	EH	K_2O rate guidelines VL	L	O	H	VH	EH
		----------lb P_2O_5/a to apply[a]----------					----------lb K_2O/a to apply[b]----------					
Sorghum, grain	50–100 bu	70	60	30	15	0	75	60	30	15	10	0
Sorghum-sudan, forage	5–7 ton	130	120	90	45	0	405	390	360	180	90	0
Soybean, grain	15–25 bu	55	45	15	10	0	75	60	30	15	10	0
	26–35 bu	65	55	25	15	0	85	70	40	20	10	0
	36–45 bu	70	60	30	15	0	100	85	55	30	15	0
	46–55 bu	80	70	40	20	0	115	100	70	35	20	0
	56–65 bu	90	80	50	25	0	130	115	85	45	20	0
	66–75 bu	95	85	55	30	0	145	130	100	50	25	0
	76–85 bu	105	95	65	35	0	155	140	110	55	30	0
	86–95 bu	110	100	70	35	0	170	155	125	65	30	0
	96–105 bu	120	110	80	40	0	185	170	140	70	35	0
Soybean, grain + straw[e]	15–25 bu	70	60	30	15	0	130	115	85	45	20	0
	26–35 bu	80	70	40	20	0	145	130	100	50	25	0
	36–45 bu	90	80	50	25	0	160	145	115	60	30	0
	46–55 bu	95	85	55	30	0	170	155	125	65	30	0
	56–65 bu	105	95	65	35	0	185	170	140	70	35	0
	66–75 bu	110	100	70	35	0	200	185	155	80	40	0
	76–85 bu	120	110	80	40	0	215	200	170	85	45	0
	86–95 bu	130	120	90	45	0	230	215	185	95	45	0
	96–105 bu	135	125	95	50	0	240	225	195	100	50	0
Spinach	4–6 ton	100	75	20	10	0	150	120	50	25	15	0
Squash	12–16 ton	120	95	40	20	0	190	160	90	45	25	0
Strawberry, establishment[d]	all	200	150	—	—	—	275	200	—	—	—	—
Sunflower	500–1,200 lb	50	40	10	5	0	65	50	20	10	5	0
	1,201–2,500 lb	60	50	20	10	0	90	75	45	25	10	0
	2,501–4,000 lb	80	70	40	20	0	125	110	80	40	20	0
Tobacco	1,600–2,000 lb	95	70	15	10	0	205	175	105	55	25	0
	2,001–2,400 lb	100	75	20	10	0	225	195	125	65	30	0
	2,401–2,800 lb	105	80	25	15	0	250	220	150	75	40	0
Tomato	20–25 ton	120	95	40	20	0	280	250	180	90	45	0
Trefoil, birdsfoot	1–2.5 ton	65	55	25	15	0	150	135	105	55	25	0
	2.6–3.5 ton	80	70	40	20	0	225	210	180	90	45	0
	3.6–4.5 ton	90	80	50	25	0	285	270	240	120	60	0
	4.6–5.5 ton	105	95	65	35	0	345	330	300	150	75	0

Table 7.4 continued. Phosphorus (P) and potassium (K) fertilizer application rate guidelines.

Crop name	Yield goal (per acre)	P_2O_5 rate guidelines VL	L	O	H	EH	K_2O rate guidelines VL	L	O	H	VH	EH
		----------lb P_2O_5/a to apply[a]----------					----------lb K_2O/a to apply[b]----------					
Triticale, grain	1,000–5,000 lb	75	65	35	20	0	75	60	30	15	10	0
Triticale, grain + straw[e]	1,000–5,000 lb	80	70	40	20	0	105	90	60	30	15	0
Truck crops	all	120	95	40	20	0	220	190	120	60	30	0
Vetch, crown/hairy	2–3 ton	80	70	40	20	0	165	150	120	60	30	0
Wheat, grain	20–40 bu	55	45	15	10	0	65	50	10	5	5	0
	41–60 bu	65	55	25	15	0	75	60	20	10	5	0
	61–80 bu	75	65	35	20	0	80	65	25	15	5	0
	81–100 bu	85	75	45	25	0	85	70	30	15	10	0
	101–120 bu	95	85	55	30	0	95	80	40	20	10	0
Wheat, grain + straw[e]	20–40 bu	65	55	25	15	0	120	105	65	35	15	0
	41–60 bu	75	65	35	20	0	130	115	75	40	20	0
	61–80 bu	85	75	45	25	0	135	120	80	40	20	0
	81–100 bu	95	85	55	30	0	145	130	90	45	25	0
	101–120 bu	105	95	65	35	0	150	135	95	50	25	0
Wildlife food plot, corn/forage brassicas	—	40	30	0	0	0	45	30	0	0	0	0
Wildlife food plot, legume grass pasture	—	40	30	0	0	0	45	30	0	0	0	0
Wildlife food plot, oats/wheat/rye	—	40	30	0	0	0	45	30	0	0	0	0
Wildlife food plot, soybean	—	40	30	0	0	0	45	30	0	0	0	0
Wildlife food plot, sugar beet/turnip	—	40	30	0	0	0	45	30	0	0	0	0

[a] This is the total amount of P_2O_5 to apply, including starter fertilizer.

[b] This is the total amount of K_2O to apply, including starter fertilizer.

[c] If stand will be maintained for more than 3 years, increase topdressed K_2O by 20%.

[d] Rates only applicable prior to establishment of fruit crops. Incorporate all P_2O_5 and K_2O before planting. For established fruit crops, use tissue testing to guide fertilizer application rates.

[e] Includes removal of both mature grain and straw. Recommendations at optimum were calculated by adding P_2O_5/K_2O removal in the grain for each yield level to a fixed amount of P_2O_5/K_2O removed by straw. Phosphate and potash removals by straw were calculated assuming the following constant straw yield: barley, 2 ton/a; oat, 2 ton/a; rye, 1.5 ton/a; soybean, 3 ton/a; triticale, 1.5 ton/a; wheat, 2 ton/a. Straw yield level assumptions are based on Wisconsin research and data in Havlin et al. 1999.

[f] At EH soil test levels P_2O_5 and K_2O is not recommended; however, there are some situations where corn will benefit from up to 20 lb/a each of P_2O_5 and K_2O in starter fertilizer. See Chapter 10: Starter fertilizer for more detail.

[g] Includes bromegrass, fescue, orchardgrass, ryegrass, and timothy.

[h] Most P_2O_5 and K_2O should be incorporated prior to seeding. These guidelines are for sod farms only.

[i] P_2O_5 and K_2O guidelines for pasture make no assumptions about manure/urine deposition. Nutrient credits for manure/urine deposition should be subtracted from these rates.

8. Secondary and micronutrients

Secondary nutrients

Sulfur

Research studies in recent years have shown that sulfur (S) may be deficient in some parts of Wisconsin. Sulfur deficiencies are most likely to occur when high S-demanding crops such as alfalfa, canola, or forage brassicas are grown on sandy soils or on other soils that are low in organic matter, far from urbanized areas, or have not received manure within the last 2 years.

Several factors affect S availability to crops: soil organic matter, clay content, pH, atmospheric deposition of sulfate, and history of manure application. Soil organic matter contains approximately 0.56% total S, and about 2.5% of this becomes available annually. This translates to 2.8 lb S/a per 1% organic matter in the plow layer. On loamy soils in Wisconsin, soil organic matter will supply less than half of the S removed in an alfalfa crop. Sulfate (SO_4) in soil solution can be leached into the subsoil, but it does not leach as readily as nitrate. Sulfate can also be held on soil clays, with more SO_4 being held at lower soil pH. In general, sandy, low-organic matter soils have a greater probability of being S-deficient than higher organic matter silt loams. Table 8.1 provides some guidance on a soil's relative ability to hold SO_4 within the crop root zone.

The atmospheric deposition of S to Wisconsin fields has decreased dramatically over the past few decades and is approximately one-third of the level found 30 years ago. The annual deposition ranges from 3 to 10 lb S/a, with higher concentrations in southeast Wisconsin and lower concentrations in northwest Wisconsin. As a result of these large reductions in S deposition, S deficiency is becoming more common on loamy soils, particularly in alfalfa fields.

Sulfur deficiency is not often seen on fields with a recent history of manure application.

Table 8.1. Potential for a soil to retain sulfate in the root zone.

Surface texture[a]	Subsoil texture	Potential for retaining sulfate in the root zone
Sandy	sandy	low
Sandy	loamy	medium
Loamy	sandy	medium
Loamy	loamy	high
Organic	—	very high

[a] Refer to Chapter 4 for definitions of sandy, loamy, or organic.

Manure S is mineralized in a similar manner to organic nitrogen in manure. Dairy manure will supply approximately 1 lb/ton or 1 lb/1,000 gal of crop-available S in the first year of application. For more details, see Chapter 9: Nutrient credits.

Guidelines for determining when sulfur application may be needed

- If the potential for a soil to retain SO_4 (Table 8.1) is low or medium and no manure has been applied in the past two years, a S application will most likely be needed for crops with a medium or high relative need for S. Sulfur application guidelines are provided in Table 8.2. The relative S need for each crop is provided in Table 8.3.
- If the soil is organic or if a significant amount of manure was recently applied, a profitable yield response to applied fertilizer S is unlikely.
- For most other soil and cropping conditions, verify the need for S using tissue testing while considering the relative S need of the crop to be grown.

All SO_4 forms of fertilizer are equally effective when surface-applied or incorporated. Elemental S, however, is insoluble and must be transformed into sulfate-sulfur by soil bacteria before plants can use it. The rate of this transformation depends on particle size, degree of mixing with the soil, and soil temperature. To be effective, elemental S should be worked into the soil well in advance of the time the crop needs it. Without mechanical incorporation, elemental S is incorporated to some extent by falling into cracks when the soil dries or by the activity of earthworms and burrowing insects.

Crops such as alfalfa and corn silage can remove large amounts of S in one season. Table 8.3 provides a relative ranking of a crop's S requirement based on crop removal of S. Be sure to evaluate S need through soil and tissue testing when growing crops with a high S need.

Shallow-rooted crops grown on low-sulfur soils will generally benefit from annual applications of smaller amounts of S. If alfalfa will be grown on soils needing S, either elemental S or SO_4 forms such as potassium sulfate, ammonium sulfate, potassium-magnesium sulfate, or calcium sulfate (gypsum) can be used. If the soil is known to be deficient in S, include some sulfate-sulfur in topdress applications for immediate S availability. When applied at recommended rates, sulfate-sulfur will generally last for two or more years, while elemental S should last for the term of the stand. Sandy soils may require annual applications of SO_4 forms of S because the SO_4 leaches through these soils more rapidly than loamy soils. Irrigation water, however, may contain sufficient sulfate-sulfur for the crop. In these cases, response to fertilizer S is likely only in years with above-average rainfall, when little irrigation water is applied. Additional information on sulfur is available in UW-Extension publication *Understanding Plant Nutrients: Soil and Applied Sulfur* (A2525).

Table 8.2. General sulfur (S) fertilizer recommendations.

Crop	S application rate (lb S/a)
Forage legumes	
Incorporated at seeding	25–50
Topdressed on established stands	15–25
Corn, small grains, vegetable, and fruit crops	10–25

Calcium

Calcium (Ca) is unlikely to be deficient for most crops if lime recommendations are followed. Under Wisconsin conditions, the soil pH would likely have to be below 5.0 before Ca deficiency becomes apparent for most crops. Where plant storage organs are not part of the plant water transpiration stream (such as with potato and apples) and where soil test Ca is low, supplemental Ca may be needed. Assuming that a pH increase is appropriate, the most effective way to supply this Ca is with application of the most economical liming material available in your area.

Soil test interpretation categories for Ca are provided in Table 8.4. For soils testing optimum or greater, response to calcium is unlikely. Except for potato, response to calcium is also unlikely for soils testing low and very low. If potato is to be grown and there is no lime recommendation, 200 lb Ca/a should be applied to soils testing very low and 100 lb Ca/a should be applied to soils testing low. If potato is to be grown and there is a lime recommendation, the Ca applied in the lime will be adequate for low testing soils; for very low testing soils, apply 50–100 lb Ca/a in addition to the lime.

For additional information on Ca, see UW-Extension publication *Understanding Plant Nutrients: Soil and Applied Calcium* (A2523).

Table 8.3. Relative micronutrient and sulfur (S) requirements of Wisconsin crops.

Crop	Boron (B)	Copper (Cu)	Manganese (Mn)	Molybdenum (Mo)	Zinc (Zn)	Sulfur[a] (S)
Alfalfa, seeding	high	medium	low	medium	low	medium
Alfalfa, established	high	medium	low	medium	low	high
Apple	medium	medium	—[b]	—	medium	—
Asparagus	medium	low	low	low	low	—
Barley, grain	low	medium	medium	low	medium	low
Barley, grain + straw	low	medium	medium	low	medium	medium
Bean, dry (kidney, navy)	low	low	high	medium	medium	medium
Bean, lima	low	low	high	medium	medium	—
Bean, snap	low	low	—	—	—	—
Beet, table	high	high	medium	high	medium	—
Blueberry	—	—	—	—	—	—
Brassica, forage	high	—	—	high	—	high
Broccoli	medium	medium	medium	high	—	—
Brussels sprouts	medium	medium	medium	high	—	—
Buckwheat	low	—	—	—	—	—
Cabbage	medium	medium	medium	medium	low	high
Canola	high	medium	medium	medium	medium	high
Carrot	medium	medium	medium	low	low	—
Cauliflower	high	medium	medium	high	—	—
Celery	high	medium	medium	low	—	—
Cherry	—	—	—	—	—	—
Clover, Red	medium	medium	low	medium	low	medium
Corn, grain	low	medium	medium	low	high	medium
Corn, popcorn	—	—	—	—	—	—
Corn, silage	low	medium	medium	low	high	high
Corn, sweet	low	medium	medium	low	high	—
Cranberry	—	—	—	—	—	—
CRP, alfalfa	high	medium	low	medium	low	—
CRP, grass	low	low	medium	low	low	—
CRP, red clover	medium	medium	low	medium	low	—
Cucumber	low	medium	medium	low	medium	—
Flax	—	—	—	—	—	low
Ginseng	—	—	—	—	—	—
Grape	—	—	—	—	—	—
Grass, hay	low	low	medium	low	low	—
Grass, reed canarygrass	low	low	medium	low	low	—

Table 8.3 continued. Relative micronutrient and sulfur (S) requirements of Wisconsin crops.

Crop	Boron (B)	Copper (Cu)	Manganese (Mn)	Molybdenum (Mo)	Zinc (Zn)	Sulfur[a] (S)
Grass, sod for turf	low	low	medium	low	low	—
Grass, switchgrass	low	low	medium	low	low	low
Hop	—	—	—	—	—	—
Lettuce	medium	high	high	high	medium	—
Lupine	low	low	low	medium	medium	—
Melon	medium	—	—	—	—	—
Millet	low	—	—	—	—	low
Mint, oil	low	low	medium	low	low	—
Oat, grain	low	medium	high	low	low	low
Oat, grain + straw	low	medium	high	low	low	medium
Onion	low	high	high	high	high	high
Pasture, grass	low	low	medium	low	low	—
Pasture, ≤ 30% legume-grass	low	low	medium	low	low	—
Pasture, > 30% legume-grass	high	medium	low	high	low	—
Pasture, unimproved	low	low	medium	low	low	—
Pea, canning	low	low	medium	medium	low	—
Pea, chick/field/cow	low	low	medium	medium	low	—
Pepper	—	—	—	—	—	—
Potato	low	low	medium	low	medium	medium
Pumpkin	—	—	—	—	—	—
Raspberry	—	—	—	—	—	—
Rye, grain	low	low	low	low	low	low
Rye, grain + straw	low	low	low	low	low	low
Rye, winter, silage	low	low	low	low	low	low
Small grain silage	low	medium	high	low	low	—
Small grain silage, underseeded with alfalfa	low	medium	high	low	low	—
Small grain & legume silage	low	medium	high	low	low	—
Small grain & legume silage, under-seeded with alfalfa	low	medium	high	low	low	—
Sorghum, grain	low	medium	high	low	high	medium
Sorghum-sudan, forage	low	medium	high	low	medium	high
Soybean, grain	low	low	high	medium	medium	low
Soybean, grain + straw	low	low	high	medium	medium	high
Spinach	medium	high	high	high	high	—
Squash	—	—	—	—	—	—
Strawberry	—	—	—	—	—	—

Table 8.3 continued. Relative micronutrient and sulfur (S) requirements of Wisconsin crops.

Crop	Boron (B)	Copper (Cu)	Manganese (Mn)	Molybdenum (Mo)	Zinc (Zn)	Sulfur[a] (S)
Sunflower	high	high	—	—	—	low
Tobacco	medium	low	medium	—	medium	medium
Tomato	high	high	medium	medium	medium	high
Trefoil, birdsfoot	high	—	—	—	—	—
Triticale	low	low	medium	—	—	—
Truck crops	medium	medium	—	—	—	—
Vetch, crown/hairy	medium	—	—	—	—	—
Wheat, grain	low	medium	high	low	low	low
Wheat, grain + straw	low	medium	high	low	low	medium
Wildlife food plot, corn/forage brassicas	—	—	—	—	—	—
Wildlife food plot, legume grass pasture	—	—	—	—	—	—
Wildlife food plot, oats/wheat/rye	—	—	—	—	—	—
Wildlife food plot, soybean	—	—	—	—	—	—
Wildlife food plot, sugar beet/turnip	—	—	—	—	—	—

[a] Relative sulfur needs are based on average annual crop removal rates: low = < 10 lb S/a, medium = 10–20 lb S/a, and high = > 20 lb S/a.
[b] — = no data

Magnesium

The magnesium (Mg) content of Wisconsin soils varies widely, but in most instances use of dolomitic limestone has prevented deficiency. Some soils, however, are low in magnesium. These soils usually are: 1) where applied liming materials are low in Mg (examples include paper mill waste, marl, or calcitic limestone); 2) very acid and sandy soils (usually in central and north-central areas of the state) where large amounts of potassium (K) have been applied repeatedly; or 3) calcareous organic soils. In sandy soils, high application rates of K or fertilizers containing ammonium often heighten Mg deficiency. High concentrations of these cations in the soil solution interfere with Mg uptake by plants. This interference, called antagonism, usually does not occur when the soil contains more exchangeable magnesium than exchangeable potassium.

Soil test interpretation categories for Mg are provided in Table 8.4. For soils testing high or above, a response to Mg is unlikely. For optimum testing soils, Mg levels should be maintained through the use of dolomitic limestone. Magnesium deficiencies can be expected on sands and loamy sand soils that test less than optimum and have a soil test K level above optimum. On these soils, application of Mg is necessary, and potash application should be reduced. For all other soils with a very low or low Mg soil test, Mg should be applied to increase soil test levels.

The most economical way to apply Mg and/or avoid a Mg deficiency is to follow a good liming program with dolomitic limestone. When Mg is recommended, a row application of 10–20 lb Mg/a can be applied annually where liming with dolomitic lime is undesirable or where rapid correction is needed. Broadcast

Table 8.4. Soil test interpretation categories for secondary nutrients and micronutrients.

		Soil test category				
Nutrient	**Soil group**[a]	**Very low (VL)**	**Low (L)**	**Optimum (O)**	**High (H)**	**Excessively high (EH)**
		---soil test ppm---				
Calcium (Ca)	Sandy	0–200	201–400	401–600	> 600	—
	Loamy, Organic	0–300	301–600	601–1000	> 1000	—
Magnesium (Mg)	Sandy	0–25	26–50	51–250	> 250	—
	Loamy, Organic	0–50	51–100	101–500	> 500	—
Boron (B)	Sandy	0.0–0.2	0.3–0.4	0.5–1.0	1.1–2.5	> 2.5
	Loamy	0.0–0.3	0.4–0.8	0.9–1.5	1.6–3.0	> 3.0
	Organic	0.0–0.5	0.6–1.0	1.1–2.0	2.1–4.0	> 4.0
Zinc (Zn)	All	0.0–1.5	1.6–3.0	3.1–20.0	20.1–40.0	> 40.0
Manganese[b] (Mn)	Sandy, Loamy	—	0–10	11–20	> 20	—

[a] See Chapter 4: Soil and Crop Information for more details on soil groups.

[b] For manganese, soil tests are only used for soils with an organic matter content less than or equal to 6.0%. If soils have organic matter content greater than 6.0%, then soil pH is used as the basis for determining Mg requirements. See text for more detail.

applications of Mg are generally not recommended except when applying dolomitic lime. Additional information on Mg is available in UW-Extension publication *Understanding Soil Nutrients: Soil and Applied Magnesium* (A2524).

Calcium versus magnesium

Claims are made that an imbalance sometimes exists between Ca and Mg levels in the soil. Proponents of this theory have suggested that Wisconsin soils are adequate in Ca but contain excessive or harmful levels of magnesium. They suggest that calcitic limestone ($CaCO_3$) or gypsum ($CaSO_4$) is needed to correct this condition. At present, no research data exists to support this claim. Soil test level has proven to be a much more reliable predictor of nutrient need than the ratio of nutrients. Similarly, there is no evidence to support claims that Mg is toxic or that Wisconsin soils have Ca:Mg ratios that are too low. Research shows that Ca:Mg ratios for virtually all Wisconsin soils fall within a rather wide optimum range. Applying calcitic limestone or gypsum solely to add calcium or change the Ca:Mg ratio is not recommended. Dolomitic limestone has a Ca:Mg ratio close to that found in most crops. For additional information on Ca:Mg ratios, see UW-Extension publications *Soil Calcium to Magnesium Ratios—Should You Be Concerned?* (A2986) and *Soil Cation Ratios for Crop Production* (NCR 533, FO-06437-GO).

Micronutrients

Plants only need very small amounts of micronutrients for maximum growth. When present in the soil at excessive concentrations, micronutrients can harm plants. Thus, while a deficiency of any essential element will greatly reduce plant growth, the overuse of micronutrients can produce a harmful level of these nutrients in the soil, which may be more difficult to correct than a deficiency. This is particularly true on coarse-textured soils such as sands, loamy sands, and sandy loams.

Micronutrients should be applied when the soil test is low, when verified deficiency symptoms appear in the plant, or when certain crops have very high requirements, such as beets have for boron. Relative micronutrient requirements of crops are provided in Table 8.3. Currently, Wisconsin soil tests are available for boron, manganese, and zinc. The tests are interpreted in Table 8.4. Soil tests for copper, iron, and molybdenum are not sufficiently calibrated for accurately predicting the supply of these nutrients in Wisconsin soils. Analysis of plant tissue is a more reliable diagnostic tool than soil testing for identifying micronutrient problems.

Boron

The interpretation of the soil test for boron (B) depends on the texture of the soil. Sandy soils do not hold B as tightly as clayey soils. A high test in a sandy soil may be only optimum in a silt loam. See Table 8.4 for interpretation of the soil test categories. Table 8.5 provides B application rate guidelines based on the soil test interpretation category and a crop's relative need for boron. On sandy soils where alfalfa is grown, 1 lb B/a should be applied annually because of the relatively low B retention of these soils. For more information about B, consult UW-Extension publication *Understanding Plant Nutrients: Soil and Applied Boron* (A2522).

Manganese

Manganese (Mn) deficiency is usually associated with neutral or calcareous mineral soils, with calcareous muck, and with organic soils that have been burned. Manganese deficiency is highly unlikely on soils that have a pH below 6.8. Interpretation of Mn soil tests is appropriate for soils with organic matter contents less than or equal to 6.0%; see Table

8.4 for interpretation categories. If soils have an organic matter content greater than 6.0%, then Mn fertilizer recommendations are based on soil pH. For these soils, Mn is considered to be low if soil pH is > 6.9, optimum if soil pH is 6.0–6.9, and high if soil pH is < 6.0.

Application rates for Mn are based on soil test interpretation categories (Table 8.4) and relative crop need (Table 8.3). For soils testing optimum or high, crop response to applied Mn is unlikely. Additionally, crop response is unlikely on soils testing low for crops with a low relative need for Mn. For low testing soils, apply 3 lb Mn/a for crops with a medium relative need and 5 lb Mn/a for crops with high relative need. Because of rapid soil fixation, broadcast Mn applications are not effective. Instead, Mn should be applied in the row, for row crops, or in the grain drill, for small grains. Sulfate forms are recommended for soil application. Mixing Mn with ammonium in a fertilizer band further improves its availability as a result of the acidity produced as ammonium converts to nitrate. Chelate forms of Mn are not effective when applied to the soil. For crops with a medium relative need growing on low testing soils, foliarly apply 1 lb Mn/a as a sulfate or 0.15 lb Mn/a as a chelate. For crops with a high relative need and low soil test, foliarly apply 1.25 or 0.2 lb Mn/a as sulfate or chelate forms, respectively.

To correct in-season Mn deficiencies, foliar applications can be used at 1 lb Mn/a as sulfate or 0.15 lb Mn/a as chelate. Multiple foliar applications may be necessary to alleviate the deficiency. Recent research has shown that foliar applications of Mn to soybean fields that were not exhibiting Mn deficiency symptoms and had more than 30 ppm Mn in a tissue sample taken at the R1 growth stage did not result in yield increases. Additional information on Mn is available in UW-Extension publication *Understanding Plant Nutrients: Soil and Applied Manganese* (A2526).

Zinc

Scalped or severely eroded soils are more likely to be deficient in zinc (Zn) than well-managed soils. Zinc deficiencies are more common on sands, sandy loams, and organic soils because these soils originally contain low total Zn levels. Zinc availability decreases markedly as the soil pH increases; therefore, Zn deficiency usually is limited to soils with a pH above 6.5. Zinc deficiency has been observed in tree fruits and ornamentals in southern Wisconsin where irrigation with alkaline or hard water has resulted in high soil pH.

Application rates for Zn are based on soil test interpretation category (Table 8.4) and

Table 8.5. Boron (B) application rate guidelines.

	Relative crop need[a]		
Soil test category	**Low**	**Medium**	**High**
		lb B/a to apply	
Very low (VL)	plant analysis[b]	2	3
Low (L)	plant analysis[b]	1	2
Optimum (O)	response unlikely	response unlikely	response unlikely
High (H)	response unlikely	response unlikely	response unlikely
Excessively high (EH)	do not apply	do not apply	do not apply

[a] Refer to Table 8.3 for a list of relative crop needs for boron.

[b] Confirm need for boron with plant analysis.

Table 8.6. Copper (Cu) fertilizer application rate guidelines.[a]

Crop	Soil group[b]					
	Sandy		Loamy		Organic	
	broad[c]	band[c]	broad	band	broad	band
	lb Cu/a					
Lettuce, onion, spinach	10	2	12	3	13	4
Alfalfa, carrot, cauliflower, celery, clover, corn, oat, radish, sudangrass, wheat	4	1	8	2	12	3
Asparagus, barley, bean, beet, broccoli, cabbage, cucumber, mint, pea, potato, rye, soybean	0	0	0	0	0	2

[a] Guidelines are for inorganic sources of copper. Copper chelates can also be used at one-sixth of the rates recommended above. Do not apply Cu unless a deficiency has been verified by plant analysis.
[b] See Chapter 4: Soil and Crop Information for more details on soil groups.
[c] Broad = broadcast application; band = banded application.

relative crop need (Table 8.3). Zinc should not be applied to soils testing excessively high. Response to Zn fertilizer is unlikely on soils testing optimum or high and on low testing soils where the crop to be grown has a low relative need. For crops with a medium and high relative need and a low or very low soil test, confirm the need for Zn with plant analysis.

Zinc deficiencies may be corrected with either banded or broadcast applications of 2–4 lb Zn/a or 4–8 lb Zn/a, respectively. If using a chelated form, apply 0.5–1.0 lb Zn/a in the band or 1–2 lb Zn/a broadcast. Deficiencies may also be corrected with a foliar application by using 1.0 lb Zn/a of zinc sulfate or 0.15 lb Zn/a of zinc chelate. More than one foliar application may be required for severe deficiencies. Additional information on Zn is available in UW-Extension publication *Understanding Plant Nutrients: Soil and Applied Zinc* (A2528).

Copper

Copper (Cu) deficiency is usually only seen on very acid soils, particularly mucks. Because Cu is not easily leached from the soil and it is not readily fixed in unavailable forms, repeated fertilization with Cu is not necessary. It is unlikely that there is any benefit from additions of more than a total of 30 lb Cu/a to a soil over several years. In addition, some toxicities have been reported at high levels of use. Copper application rate guidelines are listed in Table 8.6. Additional information on Cu is available in UW-Extension publication *Understanding Plant Nutrients: Soil and Applied Copper* (A2527).

Molybdenum

The availability of molybdenum (Mo) decreases as soil pH decreases. On soils with a pH below 5.5, crops with a high Mo requirement (e.g., broccoli and table beets) should be seed-treated with 0.2 oz Mo/a as ammonium or sodium molybdate. Foliar treatment with 0.8 oz Mo/a is an alternative treatment. Liming soils to optimal pH levels usually eliminates Mo problems. Additional information on Mo is available in UW-Extension publication *Understanding Plant Nutrients: Soil and Applied Molybdenum* (A3555).

Iron

Iron (Fe) deficiency has not been observed on any field or vegetable crops in Wisconsin. Turfgrass, pin oak trees, and some ornamentals such as yews have shown Fe deficiency on soils with a pH greater than 7.5. This deficiency can be corrected by spraying the foliage with Fe compounds such as ferrous sulfate or iron chelates or by decreasing soil pH where practical. Additional information on Fe is available in UW-Extension publication *Understanding Plant Nutrients: Soil and Applied Iron* (A3554).

Chlorine

Crops require only very small amounts of chlorine (Cl). Chlorine deficiency has never been observed in Wisconsin fields. This micronutrient is unlikely to become deficient in Wisconsin because it is often applied in fertilizer salts such as potassium chloride, is present in manure, and is a universal contaminant in dust and rainwater. Additional information on Cl is available in UW-Extension publication *Understanding Plant Nutrients: Soil and Applied Chlorine* (A3556).

9. Nutrient credits

Animal manures and leguminous crops contain nutrients. When animal manures are applied to a field, nitrogen, phosphorus, and/or potassium fertilizer application rates should be reduced. When legumes, including green manures, are part of a crop rotation, nitrogen fertilizer (or manure) application rates should be reduced. Reducing fertilizer application rates to account for the nutrients supplied by manures and legumes is economically profitable, improves fertilizer use efficiency, and enhances water quality.

Manure

Nutrient credits from a manure application should be taken the first crop year after the application. Because the nutrients in manure are not 100% available the first year after application, nutrient credits may also be taken for the second and third years after application for nitrogen (N) and sulfur (S). Estimated nutrient availabilities are given in Table 9.1.

First-year N availability varies with animal species and depends upon whether or not the manure is incorporated and how much time has elapsed between application and incor-

Table 9.1. Estimated nutrient availability for various manures.

	N					
	------Time to incorporation------			P_2O_5	K_2O	S
	> 72 hours or not incorporated	1 to 72 hours	< 1 hour or injected			
First-year availability			**% of total**			
Beef: liquid (≤ 11.0% DM)[a]	30	40	50	80	80	55
Beef: solid (> 11.0% DM)	25	30	35	80	80	55
Dairy: liquid (≤ 11.0% DM)[a]	30	40	50	80	80	55
Dairy: solid (> 11.0% DM)	25	30	35	80	80	55
Goat	25	30	35	80	80	55
Horse	25	30	35	80	80	55
Poultry (chicken, duck, and turkey)	50	55	60	80	80	55
Sheep	25	30	35	80	80	55
Swine	40	50	65	80	80	55
Veal calf	30	40	50	80	80	55
Second-year availability			**% of total**			
All species	10	10	10	0	0	10
Third-year availability			**% of total**			
All species	5	5	5	0	0	5

[a] If dry matter (DM) is < 2.0% and NH_4-N is > 75% of total N, the following equation for first-year N availability may be used in an effort to better account for the high concentration of NH_4-N that may be found in these manures: first-year available N = NH_4-N + [0.25 x (Total N – NH_4-N)], assuming manure is injected or incorporated in < 1 hour.

poration (Table 9.1). This is because nitrogen in manure is in both inorganic (immediately available) and organic (not immediately available) forms. Nearly all the inorganic form is present as ammonium. Ammonium is easily volatilized to ammonia and lost if manure lays on the soil surface. After 1 hour, a large portion of the ammonium is assumed to have volatilized unless significant rainfall has occurred. This volatilization loss may continue at a lower rate for several more days unless the manure is incorporated. For this reason, the N credits for surface-applied, unincorporated manure are less than when manure is incorporated or injected. Organic N availability is dependent upon animal species and management plus environmental factors such as moisture and temperature that affect microbial decomposition.

Phosphorus (P) in manures is present in both inorganic and organic forms. For most animal species, the inorganic P forms are dominant. Wisconsin research has demonstrated that first-year availability of manure P is equivalent to the availability of commercial fertilizer applied at the same rate of total P_2O_5. Potassium (K) in manures is in the inorganic form and is readily available to plants. Because there is some inherent variability in spreading manure evenly across the field and also variability with the nutrient content of each load of manure, the first-year availability of P and K is 80%. No second- or third-year credit is given for manure P or K. Any manure P or K applied, but not credited in the first year, is best accounted for by subsequent soil testing.

Manure sulfur (S) is in both inorganic and organic forms. First-year availability of manure S is estimated at 55%.

Manure nutrients are available to crops the second and third years after application. For all nutrients other than P and K, second- and third-year availabilities are estimated at 10% and 5%, respectively, of the total amount applied in the first year. The sum of the first-, second-, and third-year availabilities for a nutrient does not equal 100%. This is because some losses will occur, particularly with N, and because manure applications are not always uniform in rate and composition across a field. These estimates of nutrient availability are agronomically conservative to ensure that adequate nutrients are available for the crop.

To calculate the nutrient credits from manure, it is necessary to know the application rate and total nutrient content of the manure. Total nutrient content can be measured on a manure sample sent to most soil testing laboratories. For details on how to sample manure for testing, see UW-Extension publication *Recommended Methods of Manure Analysis* (A 3769). Where specific nutrient analysis for a manure is unknown, typical nutrient contents (also called book values) based on animal species and management can be used. Typical nutrient contents of Wisconsin manures are provided in Table 9.2. Because manure nutrient content can vary greatly from farm to farm, and book values represent an average nutrient content, it is preferable to occasionally have all manure types on a farm analyzed. Once manure application rate and total nutrient content are known, nutrient credits can be calculated as follows.

First-year credits = total nutrient content x % of nutrient that is available the 1st year after application x application rate

Second-year credits = total nutrient content x % of nutrient that is available the 2nd year after application x application rate

Third-year credits = total nutrient content x % of nutrient that is available the 3rd year after application x application rate

If manure is applied in multiple years, the credits are additive. In other words, take credits for current year nutrients plus any nutrient credits from the previous 2 years.

Table 9.2. Typical total nutrient content of manures tested in Wisconsin (1998–2012).

	Dry Matter (DM)	N	P_2O_5	K_2O	S
Solid manure	%	-----	-----	lb/ton	-----
Beef	29	13	8	12	1.9
Dairy: semi-solid (11.1–20.0% DM)	15	8	4	6	0.8
Dairy: solid (> 20.0% DM)	33	9	4	7	1.2
Goat	43	13	7	10	2.0
Horse	33	10	6	8	1.3
Poultry: chicken	57	49	44	33	3.0
Poultry: duck	36	12	10	9	1.8
Poultry: turkey	59	51	44	31	3.8
Sheep	34	19	9	24	2.2
Swine	19	18	13	10	2.0
Liquid manure	%	-----	-----	lb/1,000 gal	-----
Beef	3	16	7	15	1.6
Dairy: liquid (< 4.0% DM)	2	14	4	14	1.1
Dairy: slurry (4.1–11.0% DM)	6	24	8	21	2.2
Goat	4	17	8	19	1.7
Poultry	2	12	7	9	1.3
Swine: finish (indoor pit)	5	43	18	28	3.2
Swine: finish (outdoor pit)	2	18	7	10	1.0
Swine: (farrow-nursery, indoor pit)	2	21	8	13	1.0
Veal calf	1	9	3	16	0.6

1. Example calculations:

What are the first-year nutrient credits from solid dairy manure that is surface-applied without incorporation at a rate of 15 tons/a?

From Table 9.2, the total N, P_2O_5, and K_2O content are 9, 4, and 8 lb/ton, respectively for a manure with more than 20% DM. From Table 9.1, the first-year nutrient availability is 25%, 80%, and 80% for N, P_2O_5, and K_2O, respectively.

N credit = 9 lb/ton x 0.25 x 15 ton/a = 34 lb N/a

P_2O_5 credit = 4 lb/ton x 0.8 x 15 ton/a = 48 lb P_2O_5/a

K_2O credit = 8 lb/ton x 0.8 x 15 ton/a = 96 lb K_2O/a

What are the second-year nutrient credits from dairy manure that is surface-applied without incorporation at a rate of 20 tons/a?

From Table 9.2 the total N, P_2O_5, and K_2O content are 9, 4, and 8 lb/ton, respectively for a manure with more than 20% DM. From Table 9.1 the second-year nutrient availability is 10% for N. There is no second-year credit given for P_2O_5, and K_2O.

N credit = 9 lb/ton x 0.1 x 20 ton/a = 18 lb N/a

2. Example calculation:

From the previous example, let's say that 20 tons/a of dairy manure was surface-applied without incorporation last year and 15 tons/a of dairy manure was surface-applied without incorporation this year.

What are the total amount of manure nutrient credits for this year's crop?

Total nutrient credits this season:

N credit = 34 + 18 = 52 lb N/a

P_2O_5 credit = 48 + 0 = 48 lb P_2O_5/a

K_2O credit = 96 + 0 = 96 lb K_2O/a

Estimates of first-year available nutrients from typical manures in Wisconsin are provided in Table 9.3. This table should be used if manure has not been tested and book value nutrient contents will be used to determine nutrient credits. First-year nutrient credits are calculated by multiplying the estimated available nutrients (Table 9.3) by the manure application rate.

Guidelines for using manure as a nutrient source can be found in UW-Extension publication *Guidelines for Applying Manure to Pasture and Cropland in Wisconsin* (A3392). Before applying manure, be sure you understand all applicable state and federal regulatory requirements.

Table 9.3. Estimated first-year available nutrient content of manures.[a]

	N					
	Time to incorporation			P_2O_5	K_2O	S
	> 72 hours or not incorporated	1 to 72 hours	< 1 hour or injected			
Solid manure	lb/ton					
Beef	3	4	5	6	10	1
Dairy: semi-solid (11.1–20.0% DM[b])	2	2	3	3	5	1
Dairy: solid (> 20.0% DM)	2	3	3	3	6	1
Goat	3	4	5	6	8	1
Horse	2	3	4	5	6	1
Poultry: chicken	24	27	29	35	26	2
Poultry: duck	6	7	7	8	7	1
Poultry: turkey	26	28	31	35	25	2
Sheep	5	6	7	7	19	1
Swine	7	9	12	10	8	1
Liquid manure	lb/1000 gal					
Beef	5	6	8	6	12	1
Dairy: liquid (< 4.0% DM)	4	6	7	3	11	1
Dairy: slurry (4.1–11.0% DM)	7	10	12	6	17	1
Goat	4	5	6	6	15	1
Poultry	6	7	7	6	7	1
Swine: finish (indoor pit)	17	22	28	14	22	2
Swine: finish (outdoor pit)	7	9	12	6	8	1
Swine: (farrow-nursery, indoor pit)	8	10	14	6	10	1
Veal calf	3	4	4	2	13	1

[a] These estimates are based on the typical total nutrient contents of manures tested in Wisconsin (Table 9.2) multiplied by the estimated first-year nutrient availability (Table 9.1).
[b] DM = dry matter

Municipal biosolids and other wastes

Municipal biosolids, also known as municipal sewage sludge, are the residual solid material created from the treatment of wastewater. Municipal biosolids are commonly land-applied in Wisconsin. Wastewater and residuals from other sources (e.g., cheese factories, food processing, paper mills) as well as solid wastes (municipal solid waste compost, construction debris, fly ash) are also often land-applied. These materials can supply nutrients to crops and in some cases are used as liming agents. Many also supply organic material that helps to improve soil structure and enhance other soil physical properties.

The Wisconsin Department of Natural Resources (WDNR) regulates the application of these materials according to a site-specific permit granted for each material. The application rate is based on an analysis of each material. Most municipal biosolids application rates are based on meeting the N need of the crop with the amount of first-year available N rather than the total N content of the biosolids. This rate assumes that all the ammonium-nitrogen will be available in the year of application if the material is incorporated (or 50% if not incorporated) and that 25% of the organic N will become plant available in the first year. The remaining organic N from an initial application must be credited in the second and third year following application at a value of 12% and 6%, respectively.

First-year available N, incorporated = NH_4-N + [0.25 x (Total N – NH_4-N)]

First-year available N, not incorporated = (0.5 x NH_4-N) + [0.25 x (Total N – NH_4-N)]

Biosolids contain a disproportionately greater amount of P relative to N, which often results in the over-application of P when the selected rate is intended to meet the N need of the crop. The availability of P in biosolids is generally thought to be less than 100% and is variable between different treatment processes. Research data to support estimated P availability is unavailable at this time. The WDNR has exempted the P in biosolids in nutrient management planning. However, biosolids application may affect future nutrient management planning if soil test levels become elevated from biosolids and its use is discontinued. The K in biosolids should be considered to be similar in availability to K in manures: 80% available the first year after application. Soil testing every three to four years can be used to monitor changes in soil test P and K levels with application of biosolids and other wastes.

Several municipalities have opted to use lime stabilization in their biosolid management process. Lime-stabilized biosolids are an excellent liming material and could be used as a substitute for aglime as well as N fertilizer.

Consult with the local WDNR office before applying municipal biosolids or industrial waste materials. More information on site requirements and nutrient use from these materials can be obtained by consulting NR 204 Wis. Adm. Code *Domestic Sewage Sludge Management*, NR 214 Wis. Adm. Code *Land Treatment of Industrial Liquid Wastes, By-product Solids, and Sludge*, and NR 518 Wis. Adm. Code *Landspreading of Solid Waste*.

Legumes

Forage legumes

Forage legume N credits are provided in Table 9.4. The N credit is the amount of fertilizer N that can be subtracted from the recommended application rate for a particular crop on a given soil type. The same crediting system is used for pure legume as well as mixed legume-grass stands. The amount of N available to a first-year crop is dependent on the density of the stand, the amount of

Table 9.4. Forage legume nitrogen (N) credits.

	Medium-/fine-textured soils		Sands/loamy sands	
Crop/stand density	> 8″ regrowth	< 8″ regrowth	> 8″ regrowth	< 8″ regrowth
First-year credit	----------Ib N/a to credit----------			
Alfalfa				
Good (70–100% alfalfa, > 4 plants/ft^2)	190	150	140	100
Fair (30–70% alfalfa, 1.5–4 plants/ft^2)	160	120	110	70
Poor (0–30% alfalfa, < 1.5 plants/ft^2)	130	90	80	40
Red clover, birdsfoot trefoil	----------80% of alfalfa credit for similar stands----------			
Vetch	160	90	110	40
Second-year credit	----------Ib N/a to credit----------			
All crops, good or fair stand	50	50	0	0

regrowth, and soil type. Research in Wisconsin has shown that a substantial amount of plant-available N is released in the second year following a forage legume crop on medium- and fine-textured soils. Nitrogen credits are not affected by time or method of killing (tillage or herbicide) the forage legume stand. Forage legume nitrogen credits can be confirmed with a pre-sidedress nitrate test (PSNT) as described in Chapter 6: Nitrogen.

Some varieties of alfalfa have been bred to fix more N than others. As there has not been research showing that these varieties significantly change the amount of N available to the following crop or affect yields of the following crop, forage varieties should be selected for yield performance rather than N-fixing capability. There is not sufficient Wisconsin data to recommend changing N fertilizer replacement value based on variety.

Green manure crops

Forage legumes that are grown for only one growing season without forage harvest and then incorporated into the soil provide somewhat lower amounts of N than forage legumes grown for several seasons. The amount of N depends on the length of time that the legume has had to grow. A summer- or fall-seeded legume that is incorporated into the soil in the spring will have comparatively little time to grow and will therefore provide less N than one that is seeded in the spring or early summer.

Green manure N credits are provided in Table 9.5. The age of a green manure stand should be taken into account when determining what credit to take from the ranges provided.

Table 9.5. Green manure nitrogen (N) credits.

Crop	< 6″ growth	> 6″ growth
	------Ib N/a to credit------	
Alfalfa	40	60–100[a]
Clover, red	40	50–80[a]
Clover, sweet	40	80–120[a]
Vetch	40	40–90[a,b]

[a] Use the upper end of the range for spring-seeded green manures that are plowed under the following spring. Use the lower end of the range for fall seedings.
[b] If top growth is more than 12 inches before tillage, credit 110–160 lb N/a.

For spring-seeded green manures that are plowed under the following spring, use the upper end of the range given in the table, whereas fall-seeded green manure credits should be the lower end of the range.

Field crop legumes

Leguminous field crops provide much smaller N credits compared to forage legumes and green manures. Rotational N credits for crops following leguminous field crops are given in Table 9.6. Do not take a soybean credit when corn (grain or silage) or wheat is grown. The rotational effect of soybean grown prior to corn or wheat is already accounted for in the new N rate guidelines outlined in Chapter 6: Nitrogen.

Table 9.6. Field crop legume rotational nitrogen (N) credits.

Crop	Medium-/ fine-textured soils	Sandy soils
	------lb N/a to credit--------	
Soybean[a]	20	0
Leguminous vegetables: pea, snap, lima, or dry bean	20	0

[a] Soybean credit does not apply to corn or wheat grown after soybean. See Chapter 6: Nitrogen for N rate guidelines for corn or wheat grown after soybean.

Carbon to nitrogen ratio

Knowing the carbon to nitrogen (C:N) ratio of manure, biosolids, or green manures may be useful as a predictor of potential N availability. In general, materials with a C:N ratio < 20:1 will mineralize N, while material with a C:N ration > 30:1 will tend to immobilize N. Several factors beside C:N ratio govern whether or not N will be mineralized or immobilized. One important factor is the digestibility of C in the material. It is possible to have two materials with identical C:N ratios but different N mineralization potential. Therefore, C:N ratio should not be used as the sole factor in determining N mineralization potential of a manure, biosolid, or green manure.

The C:N ratio can be measured using a CN analyzer or estimated from ash content. The ash content is determined by drying the sample for 2 hours at 500°C. To estimate the C:N ratio from the ash content, use the following equations.

(100 – % ash) x 0.58 = estimated % C

% C ÷ % N = C:N ratio

10. Starter fertilizer

Use of relatively low fertilizer rates placed near the seed at planting (starter fertilizer) is a well-established and often profitable practice for several crops commonly grown in Wisconsin, especially for corn and potato. In addition to enhancing yields, starter fertilizers often increase early season plant growth and development and may result in lower corn grain moisture content at harvest.

Corn

Factors affecting response to starter fertilizer

Mechanisms of crop response to starter fertilizers are not always clear, but several factors frequently influence these responses, including existing soil fertility status (soil test level), rate, placement, composition of the fertilizer, date of planting, soil compaction, and tillage. Where soil test levels are in the responsive range, starter fertilizers usually increase yields because plants require more nutrients than the soil can supply. This response is likely regardless of other management practices. At high soil fertility levels, the response to starter, when it occurs, is probably caused by a placement effect that enhances early season plant growth or helps overcome limitations to nutrient uptake imposed by the management system. Broadcast applications of nutrients at similar rates are not likely to duplicate this placement response. Although soil test phosphorus levels in major corn-producing areas are often in the non-responsive range, results from numerous studies indicate profitable responses to various starter fertilizer treatments.

Starter composition, rates, and placement

Most fertilizers used as starters contain nitrogen (N) and phosphorus (P) or nitrogen, phosphorus, and potassium (K). While the influence of starter composition on crop response varies by geographic region, numerous experiments with no-till corn in the Midwest have shown consistent, significant yield increases from application of complete (N-P-K) starter fertilizers in a 2- by 2-inch placement relative to the seed. Frequently these responses occurred where soil test levels were in the optimum or high categories. This consistent response to starter fertilizer across a wide range of production conditions and geographic locations indicates the importance of using N-P-K starter fertilizers, especially in no-till or high-residue corn production systems. In addition, band applications of fertilizers containing K have been shown to partially offset corn yield reductions caused by soil compaction.

Rates and placement of starter fertilizers can influence their performance. Typical placements include with the seed at planting (pop-up) and 2- by 2-inch band placement. Seed-placed starter rates must be limited to avoid seedling damage and reduced plant populations. Fertilizer burn is more likely when seed-placed fertilizer is used on sandy and/or dry soils. Additionally, sweet corn is more sensitive to seed-placed fertilizer than field corn is. Nitrogen and potassium rather than phosphorus are the rate-limiting factors, and the N + K_2O in the fertilizer should not exceed 10 lb/a. Maximum application rates for both seed- and side-placed starter fertilizer are shown in Table 10.1. In addition, fertilizers containing urea or ammonium thiosulfate should never be used as the N source in starter fertilizers.

Table 10.1. Maximum recommended starter fertilizer rates for corn.

	Soil type	
Placement method	**Medium- and fine-textured soils**	**Sands/ loamy sands**
	--- lb/a of fertilizer material ---	
With seed (pop-up)	50[a]	50[a]
Side placement (2″ by 2″)	500	300

[a] Limit combined nitrogen plus potash (K_2O) to 10 lb/a.

Table 10.2. Probability of obtaining a positive economic return from starter fertilizer for several corn relative maturity ratings at various planting dates on soils with excessively high P and K levels.[a]

Relative maturity	Planting date							
	4/25	5/1	5/5	5/10	5/15	5/20	5/25	5/30
	probability %							
90	10	15	20	25	30	35	40	45
95	15	20	25	30	35	40	45	50
100	20	25	30	35	40	45	50	55
105	25	30	35	40	45	50	55	60
110	30	35	40	45	50	55	60	65

[a] This table does not alter current recommendations for early planting and selection of corn hybrids with appropriate relative maturities for the production zone.

Urea breakdown in soil produces gaseous ammonia that inhibits germination and damages seedlings.

Application rates typically recommended for seed-placed starters may not maximize corn yield response. Past Wisconsin research indicates that corn response to 2- by 2-inch side-placed starter on a high-P testing soils is maximized with an application of about 10-20-20 (N-P_2O_5-K_2O), and rates typically recommended for seed-placed starters are inadequate to maximize response. This work also found that rates higher than 10-20-20 gave no additional response and that no differences were detected between liquid and dry fertilizer materials at similar nutrient application rates. Higher starter rates may be needed to optimize production where soil P and K tests are in the responsive range than where the tests are in the high categories.

In environments such as Wisconsin, where the available growing period is not always adequate to achieve the full crop yield potential, the early acceleration of plant development from starter use often translates into improved yield even at high soil test levels. Wisconsin research shows that yield increases caused by starter use on soils with high P and K tests are likely if soil test K levels are less than 140 ppm and/or the combined effect of corn hybrid relative maturity (RM) and planting date result in an inadequate growth period for the crop to achieve its full yield potential. Results from numerous on-farm studies with corn response to starter fertilizer in Wisconsin showed more frequent response to starter with later planting dates and longer season RM hybrids. Table 10.2 shows the probabilities of response to starter fertilizer with various hybrid RM and planting date combinations and illustrates the increasing probabilities of economic response (value of yield increase exceeds starter cost) to starter fertilizer as planting dates become later.

Potato

For potato, starter fertilizer rates up to 800 lb/a of fertilizer material may be applied at planting if these amounts of nutrients are required according to soil test results. Where soil test levels are in the excessively high range for potato, a minimal starter application of about 30-30-30 (N-P_2O_5-K_2O) may be applied, and these nutrients must be counted against the total crop nutrient requirement.

Soybean and snap bean

Starter fertilizer research with soybean and snap bean generally indicates little or no advantage to banded fertilizer treatments relative to broadcast applications. In addition, seed placement of fertilizer may be risky, as these crops are salt-sensitive.

Accounting for nutrients in starter fertilizers

For all crops, all nutrients (N, P, and K) in starter fertilizers are counted against the amounts of nutrients recommended based on the crop to be grown and soil test results. The exceptions to this are 1) Phosphate and potash may be applied to corn and sweet corn grown on excessively high testing soils where the recommended rate is zero. 2) If 100% of the recommended N rate will come from organic sources, up to 20 lb/a additional N may be applied in starter fertilizer.

Notes:

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Available from the University of Minnesota Extension Store (http://shop.extension.umn.edu):

Soil Cation Ratios for Crop Production (FO-06437-GO).

Fertilizer analysis

	N	P_2O_5	K_2O	other
Nitrogen				
Ammonium nitrate	34	0	0	
Ammonium sulfate (AMS)	21	0	0	24 (S)
Ammonium thiosulfate (ATS)	12	0	0	26 (S)
Anhydrous ammonia	82	0	0	
Aqueous ammonia	20	0	0	
Calcium nitrate	15	0	0	17 (Ca)
Urea	46	0	0	
28% Urea ammonium nitrate (UAN)	28	0	0	
32% Urea ammonium nitrate (UAN)	32	0	0	
Phosphorus				
Ammonium polyphosphate (dry)	15	62	0	
Ammonium polyphosphate (liquid)	10	34	0	
Diammonium phosphate (DAP)	18	46	0	
Monoammonium phosphate (MAP)	11	52	0	
Triple superphosphate (TSP)	0	46	0	
Potassium				
Potassium chloride (muriate of potash)	0	0	60–62	
Potassium-magnesium sulfate	0	0	22	22(S),11(Mg)
Potassium nitrate	13	0	44	
Potassium sulfate	0	0	50	18 (S)

Liquid weights:

1 gallon water weighs 8.3 pounds

1 gallon UAN (28%) weighs 10.6 pounds

1 gallon 10-34-0 weighs 11.6 pounds

1 gallon 9-18-9 weighs 11.1 pounds

Conversions

1	2	3
acre (a)	43,560	square feet (ft^2)
acre (a)	0.405	hectare (ha)
square mile (mi^2)	640	acres (a)
cubic yard (yd^3)	27	cubic feet (ft^3)
cubic feet (ft^3)	7.48	gallons (gal)
ounces (oz)	29.6	milliliters (ml)
gallon (gal)	3.78	liters (l)
gallon (gal)	128	fluid ounces (fl oz)
gallon (gal)	4	quart (qt)
acre-foot	43,560	cubic feet (ft^3)
acre-foot	325,851	gallons (gal)
mile (mi)	5,280	feet (ft)
ton (short)	2,000	pounds (lb)
pounds/acre (lb/a)	1.12	kilograms/hectare (kg/ha)
P_2O_5 (lb)	0.44	P (lb)
K_2O (lb)	0.83	K (lb)
ppm-plow layer (6 in)	2	lb/acre (lb/a)
ppm-top soil (12 in)	4	lb/acre (lb/a)
1	2	3

To get column 1,
divide column 3 by column 2

(column 3 / column 2 = column 1)

To get column 3,
multiply column 1 by column 2

(column 1 x column 2= column 3)

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