A3557
University of Wisconsin-Extension - Cooperative Extension
College of Agricultural and Life Sciences, University of Wisconsin - Madison

Nutrient Management

Practices for Wisconsin Corn Production and Water Quality Protection

Introduction

Soil nutrients, like all agricultural inputs, need to be managed properly to meet the fertility requirements of corn without adversely affecting the quality of our water resources. The corn nutrients of greatest concern relative to water quality are nitrogen (N) and phosphorus (P). Nitrogen not recovered by a corn crop can contribute nitrate to groundwater through leaching. Nitrate is the most common groundwater contaminant found in Wisconsin, and the United States as a whole. Nitrate levels that exceed the established drinking water standard of 10 ppm nitrate-N have the potential to adversely affect the health of infants and livestock. Surface water quality is the concern with P management. Erosion and runoff from fertile cropland add nutrients to surface waters that stimulate the excessive growth of aquatic weeds and algae. Of all crop nutrients, P is the most important to prevent from reaching surface water since the biological productivity of aquatic plants and algae is most limited by its availability. Consequences of increased aquatic plant and algae growth include the depletion of dissolved oxygen contents of lakes resulting in fish kills, as well as reduced aesthetic and recreational values of lakes.

Appropriate nutrient management practices for corn production vary widely due to cropping, topographical, environmental, and economic conditions. With the variety of factors to consider in corn fertility management, it is nearly impossible to recommend best management practices applicable to all Wisconsin farms. Nutrient management practices for preserving water quality while maintaining or improving farm profitability must be tailored to the unique conditions of individual farms. A number of options for improved nutrient management are available to Wisconsin corn growers and are discussed in this publication.

Nutrient Application Rates

The most important consideration in sound nutrient management for corn production is application rate. Nutrient applications in excess of crop needs are unwise from both an environmental and economic viewpoint. Applications of N greater than corn requirements increase the potential for nitrate leaching to groundwater. Similarly, overapplications of P can increase the detrimental impacts of cropland runoff and erosion on surface water quality.

Soil nutrients removed from cropping systems via leaching or erosion are investments lost by the grower. However, soil nutrient levels that are inadequate to meet the requirements of a crop often result in yields below those needed for reasonable profit. Because of the overall importance of nutrient application rates, accurate assessments of corn nutrient needs are essential for minimizing threats to water quality while maintaining economically sound production. Soil testing is imperative in the accurate determination of supplemental fertilizer requirements of corn.

Wisconsin Soil Test Recommendations

The importance of a regular soil testing program has long been recognized by most corn growers. The goals of Wisconsin's soil testing program are to determine existing levels of available soil nutrients and recommend fertilizer applications to prevent any nutrient deficiency which may hinder crop production. Proper soil testing will give a relative index of soil supplied nutrients and nutrients previously supplied from manure, legume crops or commercial fertilizer. When the nutrient supply drops below a "critical" level for a particular soil and crop, yield reduction will occur. Since nutrient demands are not uniform throughout the entire growing season, an adequate supply must be planned for the period of peak demand. Supplemental fertilizer applications based on soil test results allow the nutrient demand to be met. As farmers apply increasing amounts of nutrients, and as soil fertility levels increase, water quality problems associated with excess nutrients may become evident. At this point, soil tests are needed to keep soils within optimum nutrient supply ranges.

The Wisconsin soil testing program is research-based, reflects environmental concerns, and recognizes the need for profitability in crop production. Soil testing has some limitations, but it is the best available tool for predicting crop nutrient needs. Nutrient application recommendations can only be accurate if soil samples representative of the field of interest are collected. Complete instructions for proper soil sampling are included in UWEX publication A2100, *Sampling Soils for Testing*. Samples that are unrepresentative of fields often result in recommendations that are misleading. In addition, field history information must be provided with the soil samples in order to accurately adjust the fertility recommendations to account for nutrient credits from field-specific activities such as manure applications and legumes in the rotation.

The following sections of this publication focus mainly on N and P management for minimizing threats to water quality. However, it should not be forgotten that overall soil fertility management involves monitoring ***all*** crop nutrient levels. Likewise, soil pH must be properly adjusted and maintained to maximize the availability and efficient use of soil nutrients.

Nitrogen

Nitrogen application rate is often the single most important factor affecting the efficiency of N use by corn and the extent of nitrate loss to groundwater. It is imperative that N application rate recommendations accurately predict the amount of N needed to obtain acceptable corn yields and minimize environmental impacts.

Wisconsin's N recommendations for corn are based on soil yield potential, soil organic matter content, and soil texture. Yield goal estimates—which were often over-optimistic and led to excessive N applications—are no longer a direct component of N recommendations. Nitrogen recommendations for corn are based on N response research conducted on a range of Wisconsin soils. Data generated from this research indicates that the optimum N rate for corn on a given soil is similar in high or low yielding years (Fig. 1). Recovery of N by corn is high under favorable growing conditions, but N recovery is low under poor growing conditions, such as during seasons with drought stress.

The University of Wisconsin N recommendations for corn are shown in Table 1. Sandy soils (sands and loamy sands) are given separate recommendations depending on whether they are irrigated. The lower recommendations for non-irrigated sandy soils reflect the lower corn yield potential in an environment where moisture is often inadequate. For medium and fine-textured soils, N recommendations are based on soil yield potential and organic matter content. Every soil series in Wisconsin is assigned a yield potential ranking of very high, high, medium or low. The ranking is based on length of the growing season and soil characteristics such as drainage, depth, and water holding capacity. Soils with very high or high yield potentials receive a higher N recommendation than those with a medium or low yield potential ranking. When the yield potential of a soil is unknown (due to the soil series name not being identified with a soil sample), the 2,300 growing degree day (GDD) accumulation line (May 1 to September 30, 50° F base) is used to separate the northern soils, with lower optimum N rates, from the southern soils (Fig. 2).

The soil test N recommendations for corn in Table 1 should be considered the maximum amount of N needed for economically optimum yields. These N recommendations are adjusted for manure and legume N contributions if information on manure applications and crop rotation is provided with the soil sample. Further adjustments for residual soil nitrate need to be made separately if a soil nitrate test is performed on the field.

Figure 1. Corn yield response to N application over several years on a Plano silt loam soil.

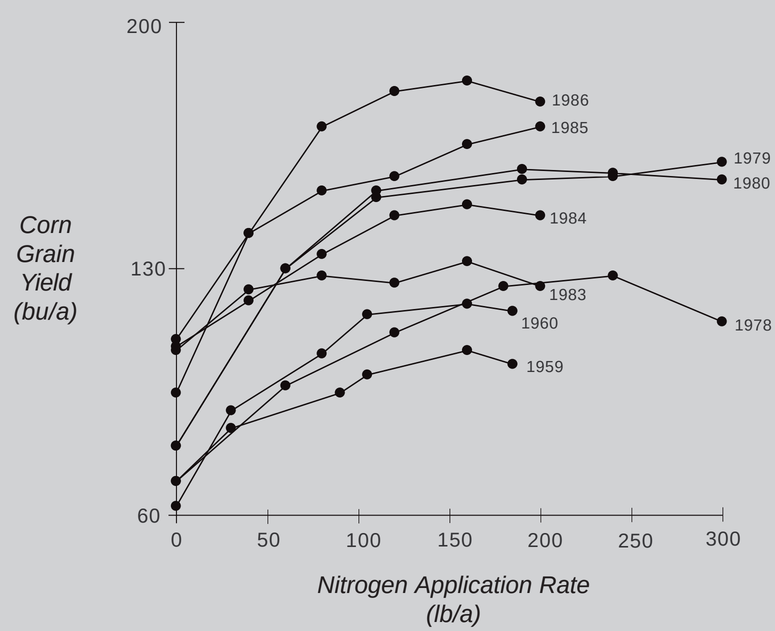


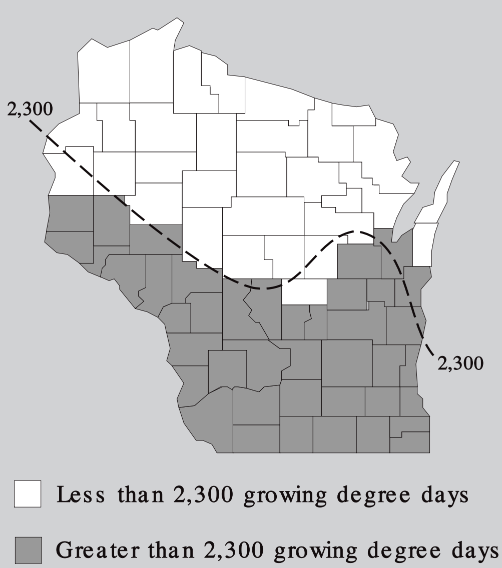
Table 1. Nitrogen recommendations for corn.

Soil organic matter	Sands and loamy sands: Irrigated	Sands and loamy sands: Non-irrigated	Other soils: Medium and low yield potential[1]	Other soils: Very high and high yield potential[1]
(%)	(lbs N/a)			
< 2.0	200	120	150	180
2.0 – 9.9	160	110	120	160
10.0 – 20.0	120	100	90	120
> 20.0	80	80	80	80

[1] *To determine soil yield potential, see Table 16 of UWEX bulletin A2809,* ***Soil Test Recommendations for Field, Vegetable, and Fruit Crops,*** *or contact your agronomist or county agent.*

Users of the University of Wisconsin N recommendations should be aware of the relationship between increased returns from the use of N at rates needed for economic optimum yields and the risk of nitrate loss to groundwater. The data illustrated in Table 2 provide a typical example of the relationships among N rate, yield, profitability, and crop recovery of applied N. In this case, it is clear that yields and economic return increase up to the 160 lb N/acre rate. However, crop recovery of N decreases and the potential for nitrate loss to the environment increases as N rates are increased to, and especially above, the economic optimum. Although the risk of nitrate loss to groundwater is lower at N rates below the economic optimum, yields and economic returns are also likely to be lower.

Figure 2. The separation of very high/high and medium/low yield potential soils according to 2,300 growing degree day (GDD) accumulation and county boundries (2,300 GDD = May 1 to Sept. 30, 50° base).



Methods for Improving Nitrogen Recommendations

The recent development of soil tests for assessing soil N levels has provided new tools for improving the efficiency of N fertilizer applications to corn. Soil testing for N allows corn N recommendations to be adjusted for the numerous year and site-specific conditions that can influence N availability. Two soil N tests are currently available. One is a technique for assessing N requirements based on measuring the residual soil profile nitrate present before planting. The other is a pre-sidedress soil nitrate test that provides an index of N availability and predicts sidedress N requirements.

In humid climates such as Wisconsin, it had been assumed that N applied to crops was utilized, immobilized, or lost through leaching or denitrification prior to the following growing season. However, research has shown that in some years, significant amounts of residual nitrate remain in the root zone where it can be utilized by subsequent crops. Soil nitrate testing can determine the amount of nitrate-N that has “carried-over” from the previous growing season and is available to crops. Nitrogen fertilizer recommendations in fields where a soil nitrate test has been used can be reduced to reflect the soil’s residual nitrate content. Crediting residual nitrate not only reduces fertilizer costs; it also aids in reducing risks of nitrate movement to groundwater due to N application in excess of crop needs.

The potential for nitrate to remain in a soil profile from the previous growing season is affected by soil texture and precipitation amounts (Table 3). Generally, nitrate is more likely to accumulate on silt loam or heavier textured soils. Nitrate-N carry-over on sandy soils is not expected, and neither the preplant or pre-sidedress nitrate test is recommended on sands. The potential for nitrate carry-over is greatest when:

- precipitation during the previous growing season and over-winter period is normal or below normal
- the amount of previously applied N (including manure and legumes) was greater than the crop's need
- pest problems or climatic conditions limited crop uptake of N during the previous growing season.

Preplant Soil Nitrate Test

A preplant soil nitrate test involves deep soil sampling in the spring prior to both corn planting and any N applications. Soil samples need to be collected in one foot increments to a depth of two feet. Previously, the suggested sampling depth was three feet. The amount of nitrate-N in the third foot is now estimated based on the nitrate content in the top two feet—unless samples are taken to the three foot depth.

Early spring sampling measures only the nitrate form of N in the soil. Preplant soil nitrate test samples are usually collected too early in the growing season to measure N released from fall or spring manure applications, previous legume crops, and soil organic matter. However, if background information on field management is provided with the soil samples, standard N credits for manure, legumes and organic matter are deducted from the N fertilizer recommendation. Because soil sampling occurs too early to measure the N contributions from legumes, the preplant nitrate test is most useful in years of corn following corn in a rotation. If corn follows a forage legume (alfalfa), the test is not needed; however, the standard N credit for the previous legume crop should be taken or the pre-sidedress soil nitrate test could be used.

Sampling procedures for the preplant soil nitrate test and information on sample handling are available from your local UWEX office, as well as in UWEX publication A3512 *Wisconsin's Preplant Soil Profile Nitrate Test*.

Pre-sidedress Soil Nitrate Test

The pre-sidedress soil nitrate test is another method available to corn growers for improving the efficiency of N applications. Unlike preplant soil nitrate test samples, soil samples for the pre-sidedress nitrate test are collected only to a depth of one foot when corn plants are 6 to 12 inches tall, usually four to six weeks after planting. Mineralization of organic N to the plant-available nitrate form has usually occurred by the time pre-sidedress samples are collected. Consequently, this soil test can measure the amount of N released from previous legumes, fall/spring manure applications, and soil organic matter as well as residual nitrate in the top foot of soil. The pre-sidedress soil nitrate test can be a valuable tool for growers wanting to confirm the amount of N credited from manure or previous legume crops.

Table 2. Yield, economic return, and recovery of applied N with 40 lb/a increments of fertilizer N applied to continuous corn. Janesville, Wisconsin, 1983–85.[1]

				N recovery in grain	
N rate	Yield	Value of yield increase	Return	Incremental	Total
(lb/a)	(bu/a)	($/a)	($/a)	(%)	(%)
0	93	—	—	—	—
40	115	44	38	45	45
80	131	32	26	45	40
120	138	14	8	20	37
160	144	12	6	17	32
200	145	2	-4	0	25

[1] *Assumes $0.15/lb for N and $2.00/bu for corn.*

Table 3. Relative effects of soil texture, and previous growing season and over-winter precipitation on nitrate-N carry-over potential.

Soil Texture	Precipitation: Below Normal	Precipitation: Normal	Precipitation: Above Normal
Sand	Low	Low	Low
Loam	High	Medium	Low
Silt loam, & finer	High	High	Low

Pre-sidedress nitrate test results are interpreted using a critical value of 21 ppm nitrate-N. Fields testing above 21 ppm N will most likely ***not*** respond to additional N. Fields testing below 21 ppm N will likely respond to additional N. Recent research showing a relationship between pre-sidedress test results and soil yield potential has improved the usefulness of the test for determining N application rates at soil test levels below the critical value of 21 ppm N. Specific N rate recommendations for corn at various pre-sidedress test results are shown in Table 4.

Growers using the pre-sidedress rather than the pre-plant nitrate test have the advantage of a less labor-intensive sample collection procedure which can reduce the amount of time spent soil sampling. However, use of the pre-sidedress nitrate test may have some disadvantages to corn growers. Obviously, growers using the pre-sidedress test are locked into applying any supplemental N as a sidedress application. This removes some flexibility in the type of N fertilizer and fertilizer application method that can be used. An additional consideration when using the pre-sidedress test is time. Use of this test requires that soil sampling, laboratory analysis, and sidedress N applications all occur during a short period of time (one to two weeks) when a grower may be committed to other farm operations, such as cultivating, haying, etc.

Nitrogen recommendations based on either soil nitrate test are offered by University of Wisconsin labs in Madison and Marshfield and by several commercial soil testing labs. The names of commercial labs performing these tests are available from county UWEX offices.

Table 4. Corn nitrogen recommendations based on the pre-sidedress soil nitrate test (PSNT).

PSNT Result	Soil Yield Potential[1]: Very High/ High	Soil Yield Potential[1]: Medium/ Low
N	N Application Rate	
- - - (ppm) - - -	- - - - - - - - (lb/a) - - - - - - - -	
≥ 21	0	0
20–18	60	40
17–15	100	40
14–13	125	80
12–11	150	80
≤ 10	160[2]	120[2]

[1] *To determine a soil's yield potential, consult UWEX publication A2809, Soil test recommendations for field, vegetable and fruit crops, or contact your agronomist or county agent.*

[2] *Unadjusted nitrogen application rate.*

Phosphorus

Careful management of phosphorus (P) in corn production is essential for preventing nutrient enrichment of surface waters. Contributions of P to surface waters have been shown to increase with increasing rates of applied P. Fertilizer applications at rates higher than crop utilization are unwise from both an environmental and economic viewpoint. Using soil tests to determine crop P needs, setting realistic crop yield goals, and taking appropriate nutrient credits are techniques which will reduce environmental risk and increase economic benefits.

To avoid over-fertilization with P and other nutrients, fertilizer additions should be made according to soil test results. Regular and systematic soil testing is required for determining P application rates. The University of Wisconsin soil testing system recommends soil nutrient applications at levels which in combination with nutrients supplied by the soil result in the best economic return for the grower. This reliance on both soil-supplied and supplemental nutrients reduces threats to water quality by avoiding excessive nutrient applications. At optimum soil test levels, the recommended P and potassium (K) additions are approximately equal to anticipated crop removal and are needed to optimize economic return and maintain soil test levels in the optimum range. Additions of P and K at optimum soil test levels are ***essential*** to prevent reductions in yields and profits.

The soil test recommendation program de-emphasizes the former build-up/maintenance philosophy in favor of a better balance between environmental and economic considerations. As a result, soil fertility levels have the potential to drop below economically productive thresholds in only a few growing seasons. To prevent this, soil test levels need to be monitored closely to detect changes in P and K status. It is recommended that soil tests be taken at least every three years and preferably every other year on sandy and other soils of low buffering capacity. Detailed information on soil test recommendations is available in UW-Extension publication A2809, *Soil Test Recommendations for Field, Vegetable and Fruit Crops*.

Optimum soil test levels for P and other nutrients for corn production in Wisconsin are given in Table 5. Corn fertilizer recommendations for P and K are based on yield goals and soil test results as shown in Table 6. Note that soil test levels for P and K are reported in parts per million (ppm).

Realistic Yield Goals

As shown in Table 6, an important criteria in the recommendation of appropriate P and K application rates for corn is the determination of realistic yield goals. Yield goal estimates that are too low will underestimate P and K needs and could inhibit corn yield. Yield goal estimates that are too high will overestimate corn needs and will result in soil nutrient levels beyond those needed by the crop which could increase the likelihood for nutrient contributions to surface waters.

Table 5. Optimum Wisconsin test levels for corn.

Soil test	Medium & fine textured soils				
	Southern & Western	Eastern Red	Northern	Sandy soils	Organic soils
	(ppm)				
Available Phosphorus	11–20	16–20	13–18	23–32	23–32
Exchangeable Potassium	81–110	81–110	101–130	66–90	66–90
Calcium	600–1,000	600–1,000	600–1,000	400–600	600–1,000
Magnesium	100–500	100–500	100–500	50–250	100–500
Sulfur	30–40	30–40	30–40	30–40	30–40
Manganese	10–20	10–20	10–20	10–20	10–20
Zinc	3–20	3–20	3–20	3–20	3–20
Boron	0.9–1.5	0.9–1.5	0.9–1.5	0.5–1.0	1.1–2.0

Yield goals must be realistic and achievable based on recent yield experience. Estimates used to determine corn P and K requirements should be cautiously optimistic but not more than 10 to 20% above the recent average corn yield from a particular field. Yield goals 10 to 20% higher than a 3-to 5-year average yield are suggested because annual yield variations due to factors other than nutrient application rates (primarily climatic factors) are often large.

Critical to successful estimation of corn yield goals is the keeping of ***accurate records*** containing corn yields from specific fields. Absence of crop yield records can result in other, less reliable, estimates being used in the determination of corn P and K requirements. It is strongly recommended that growers develop or maintain accurate corn yield records. The information gathered from such records can increase production efficiency and minimize threats to water quality.

Table 6. Corn fertilization recommendations for phosphate and potash at various soil test interpretation levels.

	Soil test interpretation[1]				
Yield goal	Very Low[2]	Low[2]	Optimum	High	Excessively High[3]
(bu/a)			P_2O_5, (lb/a)		
71–90	60–90	50–70	30	15	0
91–110	70–100	60–80	40	20	0
111–130	75–105	65–85	45	25	0
131–150	85–115	75–95	55	25	0
151–170	90–120	80–100	60	30	0
171–190	100–130	90–110	70	35	0
191–220	105–135	95–115	75	40	0
			K_2O, (lb/a)		
71–90	50–80	40–65	25	15	0
91–110	55–85	45–70	30	15	0
111–130	60–90	50–75	35	15	0
131–150	65–95	55–80	40	20	0
151–170	70–100	60–85	45	20	0
171–190	75–105	65–90	50	20	0
191–220	80–110	70–95	55	25	0

[1] *Where corn is harvested for silage, an additional 30 lb P_2O_5/a and 90 lb K_2O/a should be applied to the subsequent crop if soil tests are optimum or below.*

[2] *For phosphate, use the higher values on sandy or organic soils and lower values for other soils. For potash, use the lower values on sandy or organic soils and higher values for other soils.*

[3] *Use a small amount of starter fertilizer on soils that warm slowly in spring (a minimum addition is considered 5, 10, 10 lb/a of N, P_2O_5, and K_2O, respectively).*

Nutrient Crediting

The best integration of economic return and environmental quality protection is provided by considering nutrients from all sources. In the determination of supplemental fertilizer application rates, it is critical that nutrient contributions from manure, previous crops grown in the rotation, and land-applied organic wastes are credited. Both economic and environmental benefits can result if the nutrient supplying capacity of these nutrient sources is correctly estimated. Economically, commercial fertilizer application rates can often be reduced or eliminated entirely when nutrient credits are properly assessed. Environmentally, the prevention of over-fertilization reduces potential threats to water quality. The use of appropriate nutrient credits is of particular importance in Wisconsin where manure applications to cropland and legume crop production are common.

Manure

Manure can supply crop nutrients as effectively as commercial fertilizers in amounts that can meet the total N and P requirements of corn. In order to utilize manure efficiently, the application rate and nutrient supplying capacity need to be estimated. Guidelines for determining rates of application can be found in UWEX publication A3537, *Nitrogen Credits for Manure Applications*. The most effective method for gauging the nutrient content of manure is to have samples analyzed by a commercial or university laboratory. Large farm-to-farm variation can occur in nutrient content due to manure storage, handling, livestock feed, or other farm management differences. Unfortunately, laboratory analysis is not always convenient or available; in such instances, estimates of crop nutrients supplied by animal manures should be made. Table 7 summarizes the University of Wisconsin recommendations for average nutrient values of livestock manures common to the state.

As indicated in Table 7, not all the nutrients in manure are available in the first year following application. For example with N, manure contains both organic and inorganic N—only the inorganic form is immediately available for crop uptake. The available N contribution to corn from dairy manure is approximately 30-35% of the total N content of the manure in the first crop year. Additional amounts of nutrients are added to the soil in the second and third year following manure applications. Detailed information on the second and third year manure nutrient credits can be found in USDA-Natural Resources Conservation Service *Wisconsin Field Office Technical Guide–Sec. IV, Spec. 590.*

Table 7. Average nutrient content from various manures.[1]

	Animal Type[2]			
	Dairy	Beef	Swine[3]	Poultry
Total Nutrient Content				
Nitrogen (N)				
Solid (lbs/ton)	10	14	14	40
Liquid (lbs/1000 gal)	24	20	25	16
Phosphate (P_2O_5)				
Solid (lbs/ton)	5	9	10	50[4]
Liquid (lbs/1000 gal)	9	9	23	10
Potash (K_2O)				
Solid (lbs/ton)	9	11	9	30
Liquid (lbs/1000 gal)	20	20	22	12
First Year Availability				
Nitrogen (N)				
Solid (lbs/ton)				
surface applied	3	4	7	20
incorporated	4	5	9	24
Liquid (lbs/1000 gal)				
surface applied	7	5	13	8
incorporated	10	7	16	10
Phosphate (P_2O_5)				
Solid (lbs/ton)	3	5	6	30[4]
Liquid (lbs/1000 gal)	5	5	14	6
Potash (K_2O)				
Solid (lbs/ton)	7	9	7	24
Liquid (lbs/1000 gal)	16	16	18	10

1 *Values are rounded to the nearest pound.*

2 *Assumes 24, 35, 20 and 60% dry matter for solid dairy, beef, swine and poultry manure, respectively. Assumes 6, 5, 3, and 3% dry matter for liquid dairy, beef, swine, and poultry manure respectively.*

3 *Assumes a farrow-nursery indoor pit operation for swine liquid manure nutrient values.*

4 *For turkey, use 40 lb/ton for total nutrient content and 24 lb/ton for first-year available nutrient content.*

The Wisconsin soil test recommendations account for manure (and legume) nutrient credits when the appropriate field history information is provided with soil samples. The soil test report utilizes the standard nutrient credits from Table 7 unless specific manure analyses have been performed. For analyzed manure, 35 to 60% of the total N (depending on manure type), 55% of the total P_2O_5, and 75% of the total K_2O should be credited in the first year. The fertilizer adjustment for analyzed manure needs to be made by the individual farmer, consultant, etc. For more information on the nutrient value of manure, see UWEX fact sheet A3411, *Manure Nutrient Credit Worksheet* or A3537, *Nitrogen Credits for Manure Applications*.

Management recommendations for minimizing the threat of manure nutrient losses to surface and groundwater are described in the manure management section of this publication.

Legumes

Legume crops, such as alfalfa, clover, soybeans, and leguminous vegetables, have the ability to fix atmospheric N and convert it to a plant-available form. When grown in a rotation, some legumes can supply substantial amounts of N to a subsequent corn crop. For example, a good stand of alfalfa can often provide all of the N needed for a corn crop following it in a rotation. An efficient nutrient management program needs to consider the N contribution of a legume to the next crop.

Table 8 lists the N credits currently recommended in Wisconsin for various legume crops. With forage legumes, stand density, soil texture, and cutting schedule affect the value of the N credit. Detailed information on legume-N crediting can be found in UWEX Publication A3517 *Using Legumes as a Nitrogen Source*.

Similar to the nutrient credits for manure applications, the Wisconsin soil test recommendations account for the nutrient contributions from legumes, provided that rotation information is included with the soil samples submitted for testing.

Whey and Sewage Sludge

Application of organic wastes such as whey and sewage sludge is common in certain areas of the state; however, the overall percentage of corn acres treated with organic wastes is relatively small. Nonetheless, the nutrient contributions from sludge and whey applications are often significant and need to be credited. Special management and regulatory considerations pertain to the land application of these and other organic waste materials. Detailed information on the nutrient values and management practices associated with sludge and whey applications to agricultural lands is available in UWEX publications R2779, *Sewage Sludge Wastes that can be Resources*, and A3098, *Using Whey on Agricultural Land–A Disposal Alternative*.

Starter Fertilizer

A minimal amount of starter fertilizer is recommended for corn planted in soils slow to warm in the spring. For corn grown on medium and fine textured soils, a minimum application of 10 lb N, 20 lb P_2O_5, and 20 lb K_2O per acre is recommended as a starter fertilizer at planting. In most corn fields, all the recommended P_2O_5 and K_2O can be applied as starter fertilizer. On soils with test levels in the excessively high range, starter fertilizer applications in excess of 10 lb N, 20 lb P_2O_5, and 20 lb K_2O per acre should be avoided. Any amount of N applied as starter fertilizer that exceeds 20 lb N/acre should be credited against the overall N recommendation.

Table 8. Nitrogen credits for legume crops.

Legume Crop	N Credit	Exceptions
Forages		
First Year Credit		
Alfalfa	190 lb N/acre for a good stand[1] 160 lb N/acre for a fair stand[1] 130 lb N/acre for a poor stand[1]	Reduce credit by 50 lb N/a on sandy soils[2] Reduce credit by 40 lb N/acre if less than 8 inches of regrowth at time of kill
Red clover	80% of alfalfa credit	Same as alfalfa
Birdsfoot trefoil	80% of alfalfa credit	Same as alfalfa
Second Year Credit		
Fair or good stand	50 lb N/acre	No credit on sandy soils[2]
Green manure crops		
Sweet clover	80–120 lb N/acre	Use 20 lb N/acre credit if field has less than 6 inches of growth before tillage, killing frost, or herbicide application
Alfalfa	60–100 lb N/acre	
Red clover	50–80 lb N/acre	
Soybeans	credit of 40 lb N/acre	No credit on sandy soils[2]
Leguminous vegetable crops		
Peas, snap beans and lima beans	20 lb N/acre	No credit on sandy soils[2]

[1] *A good stand of alfalfa (70–100% alfalfa) has more than 4 plants/ft²; a fair stand (30–70% alfalfa) has 1.5 to 4 plants/ft²; and a poor stand (< 30% alfalfa) has less than 1.5 plants/ft².*

[2] *Sandy soils are sands and loamy sands.*

Timing of Applications

Timing of application is a major consideration in N fertilizer management. The period between N application and corn uptake is an important factor affecting the efficient utilization of N by the crop and the amount of nitrate-N lost through leaching or other processes. Obviously, loss of N can be minimized by supplying it just prior to the period of greatest uptake by corn. In Wisconsin this typically occurs in mid-June throughout July when corn is in a rapid growth and dry matter accumulation period. Applications at such times reduce the potential for N to leach from the root zone before plant uptake can occur. On sandy soils, this kind of timely application is essential. On medium and finer textured soils, N leaching losses during the growing season are significantly less. Other factors including soil, equipment, and labor, are involved in determining the most convenient, economical, and environmentally safe N fertilizer application period for corn.

In regards to P fertilizer management, application timing is not a major factor affecting water quality protection. However, applications of P on frozen sloping soils or applications just prior to likely runoff events should be avoided to prevent P contributions to surface waters.

Fall Versus Spring N Applications

The advantages and disadvantages of fall N fertilizer applications have been discussed for many years. An increased risk of N loss during the fall and early spring needs to be weighed against the price and convenience advantages often associated with fall-applied N. The agronomic concern with fall N applications is that losses between application and uptake the following growing season will lower crop recovery of N and reduce corn yield. The environmental concern with fall application is that the N lost prior to crop uptake will leach into groundwater.

Fall to spring precipitation, soil texture, and soil moisture conditions influence the potential for fall-applied N losses. As a result, the relative effectiveness of fall N applications varies widely from one year to the next depending on climatic conditions. If a soil is wet in the fall, rainfall may cause either leaching of nitrate in coarse soils or denitrification of nitrate in heavy, poorly drained soils. Long-term studies indicate that fall applications are usually less effective than spring applications. Wisconsin research has shown fall applications on medium textured soils to be 10 to 15% less effective than the same amount of N applied spring preplant.

For both agronomic and environmental reasons, fall applications of N fertilizers are not recommended on coarse textured soils or on shallow soils over fractured bedrock. If fall applications are to be made on other soils, they should be limited to the application of only the ammonium forms of N (anhydrous ammonia, urea, and ammonium sulfate) on medium textured, well-drained soils where N losses through leaching or denitrification are usually low. Fall applications of N should also be delayed until soil temperatures are less than 50° F in order to slow the conversion of ammonium to nitrate by soil organisms. If fall applications must be made when soil temperatures are higher than 50° F, a nitrification inhibitor should be used. Studies have shown that nitrification inhibitors are effective in delaying the conversion of ammonium to nitrate when N is fall-applied. However, fall applications of N with an inhibitor are still not likely to be as effective as spring-applied N.

Table 9. Probability of corn yield response with sidedress versus preplant N application.

Soil	Relative Probability
Sands & loamy sands	Good
Sandy loams & loams	Fair
Silt loams & clay loams:	
– well-drained	Poor
– poorly drained	Fair

Preplant N Applications

Spring preplant applications of N are usually agronomically and environmentally efficient on medium-textured, well drained soils. The potential for N loss prior to corn uptake on these soils is relatively low with spring applications. If spring preplant applications of N are to be made on sandy soils, ammonium forms of N treated with a nitrification inhibitor should be used. Likewise, nitrification inhibitors should be used if spring preplant N is applied to poorly drained soils. Use of nitrification inhibitors reduces the potential for N loss compared to preplant applications without them; however, sidedress or split applications are usually more effective than preplant applications with nitrification inhibitors.

Sidedress N Applications

Sidedress applications of N during the growing season are effective on all soils with the greatest benefit on sandy or heavy textured-poorly drained soils (Table 9). The efficiency of sidedress N applications can be attributed to the application of N just prior to the period of rapid N uptake by corn and a much shorter period of exposure to leaching or denitrification risks. Table 10 illustrates the higher yield

Table 10. Effect of rate and time of N application on corn yield and recovery of applied N on sandy, irrigated soil. Hancock, Wisconsin, 1981–84.

	Yield		N Recovery	
N Rate	Preplant	Sidedress[1]	Preplant	Sidedress
- - - (lb/a) - - -	- - - - - - - - - - (bu/a) - - - - - - - - - -		- - - - - - - - - - (%) - - - - - - - - - -	
0	38	38	—	—
70	88	105	50	73
140	120	136	44	64
210	132	143	40	49
Average	113	128	45	62

[1] *Sidedress treatments applied six weeks after planting.*

and crop recovery of N on sandy soils with sidedress applications. In these trials, use of sidedress N applications improved average N recovery over preplant applications by 17%. The use of sidedress or delayed N applications on sandy soils is essential for minimizing N loss to groundwater since unrecovered N on these soils will be lost through leaching. Sidedress N applications may also be of benefit on shallow soils over fractured bedrock.

Sidedressing N requires more management than preplant N applications. In order to maximize efficiency, sidedress N applications must be properly timed to provide available N during the maximum N-uptake period for corn which begins at about 6 weeks after planting and continues for an additional 4 to 6 weeks. Applications too late may result in lower yield and plant injury from root pruning and other physical damage.

Split or Multiple N Applications

Application of N fertilizer in several increments during the growing season can be an effective method for reducing N losses on sandy soils. However, a single well-timed sidedress application is often as effective as multiple applications. Ideally, split applications supply N when needed by the corn and allow for N application adjustments based on early growing season weather or plant and soil tests. Where split or multiple applications are used, any preplant N additions should be minimized and most of the N should be applied just prior to expected crop use.

To be successful, the timing of application and placement of fertilizer materials are critical. Climatic factors, such as untimely rainfalls, may interfere with application schedules and could result in nutrient deficiencies. Split applications, as well as sidedress applications, also tend to be more time, labor, energy and equipment intensive than preplant N applications.

Fertigation

A common method for split or multiple N applications is via irrigation systems. Multiple applications of fertilizer N at relatively low rates (30-50 lb N/a) can be injected into the irrigation water and applied to correspond with periods of maximum plant uptake. Theoretically, this should make less N available for loss through leaching. The most common fertilizer applied in irrigation systems is 28% N solution because it is readily available and causes little or no equipment problems during injection to irrigation water. Anhydrous ammonia should not be used in sprinkler irrigation systems because it can cause precipitation of calcium in the water and loss of free ammonia to the atmosphere.

The success of fertigation systems is dependent on climatic factors and proper management. Fertigation should not be relied upon as a sole method of applying N in a cropping season for the following reasons:

- Adequate rainfall during the early growing season could delay or eliminate the need for irrigation water. A delay in fertilizer application could reduce yields dramatically.
- Leaching can result if N is applied through an irrigation system at a time when the crop does not need additional water.
- All N applications need to be made prior to the crop's period of major N uptake. If applied later, little of the applied N will be used and leaching potential will be increased.

It also needs to be noted that the potential for back-siphoning of N into the well exists with fertigation. Wisconsin law requires anti-siphoning check valves to be in place on irrigation systems; however, if the guards are not properly installed, maintained, or not in place at all, fertigation systems could directly contribute to groundwater contamination.

Nitrification Inhibitors

Nitrification inhibitors are used with ammonium or ammonium-forming N fertilizers to improve N efficiency and limit losses of fertilizer N on soils where the potential for nitrate leaching or denitrification is high. Nitrification inhibitors function by slowing the conversion of ammonium to nitrate, thereby reducing the potential for losses of N that occur in the nitrate form. At this time nitrapyrin (N-Serve) is the only nitrification inhibitor registered for use in Wisconsin.

Table 11. Relative probability of increasing corn yield by using nitrification inhibitors.

Soil	Time of N Application: Fall	Time of N Application: Spring Preplant
Sands & loamy sands	—[1]	Good
Sandy loams & loams	Fair	Good
Silt loams & clay loams		
– well-drained	Fair	Poor
– somewhat poorly drained	Good	Fair
– poorly drained	Good	Good

1 *Fall applications not recommended on these soils.*

Note: Likelihood of response to inhibitor with spring sidedress N applications is poor.

Table 12. Effects of nitrification inhibitor on corn yield and recovery of applied N, Hancock, Wisconsin, 1982–84.

N-Serve Rate	Yield[1]	N Recovery
(lb/a)	(bu/a)	(%)
0	87	29
0.5	99	43

1 *Average of three N rates (70, 140, 210 lb/N/a).*

The effectiveness of a nitrification inhibitor depends greatly on soil type, time of the year applied, N application rate and soil moisture conditions that exist between the time of application and the time of N uptake by plants. Table 11 gives relative probabilities for obtaining a corn yield increase when using a nitrification inhibitor in Wisconsin based on soil type and time of application.

Research has shown that the application of nitrification inhibitors on coarse textured, irrigated soils has the potential to increase corn yield and total crop recovery of N (Table 12). It should be noted that responses to inhibitor use on coarse-textured soils usually occur with spring preplant N applications. However, fall applications of N with an inhibitor on coarse textured soils are not recommended because the present inhibitors do not adequately control nitrification on these soils over such an extended period of time. As indicated previously, sidedress N applications are likely to be more effective on these soils. It is unlikely that sidedress applications of N will benefit from the use of a nitrification inhibitor due to the short period between application and uptake. Nitrification inhibitors have been shown to give a positive response on corn yield when used with fall or spring preplant N applications on heavy textured, poorly drained soils.

Careful management of N fertilizers even with the use of a nitrification inhibitor is required. Nitrapyrin is volatile and requires immediate incorporation. Also, fall applications of N when soil temperatures are above 50° F may result in accelerated degradation of the inhibitor which will reduce the potential for improved N recoveries.

Soil Nutrient Placement

Placement of soil nutrients on agricultural fields can be a factor in determining their potential to affect water quality. Nutrient placement is a more important consideration with respect to P management and surface water quality protection than with N and groundwater quality.

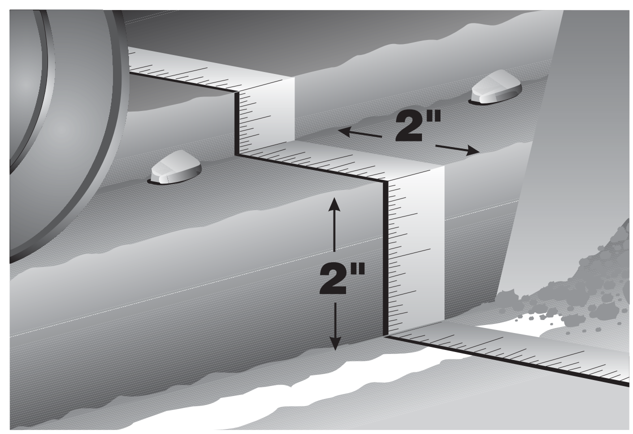
Nitrogen

The concern with N placement focuses more on preventing N loss through ammonia volatilization than movement to groundwater. Applications of N in the form of urea or N solutions need to be incorporated by rainfall, irrigation, injection or tillage. The amount of volatilization that occurs with surface N applications depends on factors such as soil pH, temperature, moisture, and crop residue cover. Minimal volatilization losses of N can be expected if spring surface applications are incorporated within 3 to 4 days—provided temperatures are low (<50˚F) and the soil is moist. However, a late spring or summer application should be incorporated within a day or two because higher temperatures and the chance of longer periods without rainfall could lead to significant N volatilization losses. Recent research shows that losses may be as high as 20% under these conditions.

Phosphorus

The placement of P-containing materials directly influences the amount of P transported to lakes and streams by surface runoff. If P inputs are broadcast on the soil surface and not incorporated, P levels of runoff waters can rise sharply. Phosphorus is strongly bound to soil particles; however, adequate soil-P contact must occur to allow for adsorption. Incorporation by tillage or subsurface band placement is a very effective means of achieving this contact. Wisconsin studies have shown that eroded sediment and runoff from soil surfaces where P fertilizer was not incorporated will contribute significantly higher amounts of P to runoff and have a greater potential for impact on surface water quality than from soil surfaces where P was incorporated.

To avoid enriching surface waters with soil nutrients, it is recommended that annual fertilizer applications for corn be band-applied near the row as starter fertilizer at planting. Annual starter applications of P can usually supply all of the P required for corn. This practice reduces the chance for P enrichment of the soil surface and reduces P loads in runoff from cropland. In addition, research has shown row applications of starter fertilizer can increase corn yields on most soils. Band fertilizer placement should be 2 inches to the side and 2 inches below the seed. Rates of application should be monitored closely if placement is closer to the seed.



When large broadcast P fertilizer applications are needed to increase low soil P levels, these applications should always be followed by incorporation as soon as possible.

Manure Management

Manure is a valuable resource. Manure applications to cropland provide nutrients essential for crop growth, add organic matter to soil, and improve soil structure, tilth, and water holding capacity. As with other nutrient sources, improper use of manure can result in environmental damage. The major concerns associated with manure applications are related to its effects on surface and groundwater quality. In regards to groundwater, the nitrate-N contribution of manure is of greatest concern. The likelihood of nitrate reaching groundwater is increased if manure applications exceed crop N needs, N contributions to soil from manure applications are not credited in fertilizer recommendations, or manure is improperly stored or handled. With surface waters, P is the manure nutrient of importance. Runoff from manured fields can carry readily available soil nutrients to surface waters. The high soluble P content of manure can have immediate adverse effects on surface water quality by enhancing production of algae and aquatic plants, and decreasing dissolved oxygen levels.

Application Methods

Proper manure application techniques are very important for reducing contributions of P to surface waters. Agronomically, proper application of manure is important in preventing losses of N through the volatilization of ammonia. Both nutrients can be conserved by incorporating or injecting manure. To protect surface water quality and reduce volatilization losses, it is recommended that surface-spread manure be incorporated within three days of application. Incorporation should reduce nutrient loss provided the tillage is sufficiently deep and does not accelerate soil loss. If a reduction in soil erosion protection appears likely from the incorporation of manure on sloping lands, a form of reduced tillage should be used. All incorporation or injection should follow the land contour when possible. When the incorporation or injection of manure is not practical, manure spreading should be directed to fields that have run-off control practices in place and which do not discharge unfiltered runoff to streams and lakes.

Application Rates

Two common strategies for manure application to cropland exist:

- a P management strategy, and
- a N management strategy.

If maximum nutrient efficiency is the goal, rates of manure application need to be based on the nutrient present at the highest level relative to crop needs. For corn, the nu-

trient is P. With this strategy, manure should be applied at a rate which will meet corn's requirement for P; additional N and potassium (K) are supplied from other nutrient sources as needed. A management strategy based on P dictates the lowest manure application rates but it is the least likely to result in degradation of water quality. It has the disadvantages of being inefficient with respect to labor, energy, and time, more costly, and may have limited practicality. This system is only possible where the farmer has adequate land to spread manure at the lower rates required for this strategy.

An alternative strategy for utilizing manure is to determine a rate of application which will fulfill the corn requirement for N. This strategy maximizes the rate of application but results in the addition of P and K in excess of corn nutrient needs. The N strategy is most commonly used since the amount of land available for application is often limited. While other environmental considerations may restrict the timing, location, and methods of application, corn N requirements are the major rationale for limiting rates with this method of utilization. The amount of available N in manure and soil can be determined by manure and soil analysis. In lieu of specific manure analysis, estimates of the amount of available nutrients from manure are given in Table 7.

A manure application strategy based on crop N requirement will lead to an accumulation of P with repeated applications. Excessive soil test levels of P can result in surface water quality problems in the event of runoff and soil erosion. When soil test levels for P reach **75 ppm**, manure applications should be reduced and P-demanding crops such as alfalfa planted. At P soil test levels of **150 ppm**, manure and other sources of P should be discontinued until soil test levels decrease. Soil runoff and erosion control practices such as residue management, conservation tillage, contour farming and filter strips are strongly recommended on soils where P levels significantly exceed crop needs.

From strictly a water quality viewpoint, P soil test levels of 75 to 150 ppm may be too high for some agricultural sites. Soil test P levels lower than 75 ppm would significantly reduce threats to surface water quality and be adequate for most crop needs. However, with the average P soil test level of Wisconsin soils at approximately 46 ppm and P soil test levels from dairy operations approximately twice that level, a P soil test limit of 75 ppm is not realistic for livestock operations needing to dispose of animal waste. Additionally, a statewide recommendation limiting soil test levels at 75 ppm would fail to consider the diversity of the state's soils. For example, areas of sandy soils where the potential for runoff and water erosion is low, higher P soil test levels would most likely not pose a threat to surface water quality. A general recommendation for P soil test levels would be that in the absence of adequate runoff control and soil conservation practices on soils susceptible to runoff and erosion, P soil test levels of 75 ppm should not be exceeded.

For surface water quality protection, it is recommended that on fields where manure cannot be incorporated, no more than 25 tons/acre of solid dairy manure or its equivalent based on P content be applied annually. In long term cropping situations that preclude manure incorporation (i.e. continuous no-till corn) it is recommended that a cumulative total of not more than 25 tons/acre of solid dairy manure (or its equivalent in P-content) be applied over a 5-year period unless previously applied manure has been incorporated.

Application Timing

Manure application timing is of greater concern in controlling P contributions to surface waters than nitrate movement to groundwater. Manure should not be spread on sloping lands any time a runoff producing event is likely. Unfortunately, runoff producing events are impossible to predict and the elimination of manure applications to sloping lands is seldom a practical consideration for landowners. The period of major concern is the late fall, winter, and early spring months. Manure applied on frozen ground has an increased likelihood for contributing nutrients to surface waters due to spring thaws and rains causing runoff.

If winter applications of manure must be made, the risk should be minimized to the greatest extent possible. Manure applications to frozen soils should be limited to slopes of less than 6%. Preferably these soils are cornstalk covered, roughly tilled, or protected from up-slope runoff.

If applications of manure to frozen soils with slopes of 6 to 12% must be made, conservation measures need to be in place in order to protect surface waters. Grassed waterways must be well-established and maintained. Terraces should be in place, if appropriate, or fields contoured and strip-cropped with alternate strips in sod. If fields are farmed on the contour, they should be protected with an adequate residue cover from the previous year's crop.

Manure should not be applied to frozen soils on slopes greater than 12%.

Site Considerations

Most soils have a high capacity for assimilating nutrients from waste materials such as manure. Unfortunately, areas of the state exist where the soil is highly permeable or shallow over fractured bedrock. In such areas, groundwater problems from the application of manure can result. For shallow soils, manure should not be applied to soils less than 10 inches thick over fractured bedrock. Where soil cover is 10 to 20 inches thick, manure needs to be incorporated within three days of application to allow for maximum soil adsorption of nutrients. Manure should not be applied when these soils are frozen. The 10 to 20 inch recommendation is intended for livestock operations in limited areas of the state where such unique soil conditions exist.

Movement of mobile nutrients to groundwater is more likely on excessively drained (sandy) soils. Manure applications in early fall to fields where no actively growing crop is present to utilize the N, may allow for the conversion of organic N to nitrate which is then subject to movement by leaching. Whenever possible, manure should not be applied to sands or loamy sands in the fall when soil temperatures are greater than 50° F (conversion of ammonium-N to nitrate-N is significantly reduced at soil temperatures below 50° F) unless there is an over-wintering cover crop present to utilize the N. In the absence of a cover crop, apply manure when soil temperatures are below 50° F.

The main site characteristics affecting nutrient contributions to surface waters are those that affect soil runoff and erosion. These include slope, soil erodibility and infiltration characteristics, rainfall, cropping system and the presence of soil conservation practices. Site related management practices dealing specifically with manure placement to protect surface water include:

- ❑ Do not apply manure within a 10-year floodplain or within 200 feet of lakes and streams unless incorporation follows as soon as possible—no later than 72 hours after application. Do not apply manure to frozen soils in these areas. The 200 foot set-back allows for buffer strips to slow runoff velocity and deposit nutrient and sediment loads. Do not apply manure to the soils associated with these land areas when they are saturated.

- ❑ Do not apply manure to grassed waterways, terrace channels, open surface drains or other areas where surface flow may concentrate.

Manure Storage

During periods when suitable sites for land application of manure are not available (i.e., soils are frozen or seasonally saturated), the use of manure storage facilities is recommended. Storage facilities allow manure to be stored until conditions permit land application and incorporation. In addition, storage facilities can minimize nutrient losses resulting from volatilization of ammonia and be more convenient for calibrated land applications. With the exception of those systems designed to filter leachate, storage systems should retain liquid manure and prevent runoff from precipitation on stored waste. It is imperative that manure storage facilities be located and constructed such that the risk of direct seepage to groundwater is minimized. With regards to maximum nutrient efficiency and water quality protection, it is critical that appropriate application techniques and accurate nutrient credits of the manure resource are utilized when the storage facility is emptied.

Irrigation Management

Irrigation has become a standard agricultural practice in the sandy regions of Wisconsin and in other areas where shallow groundwater is available. As a result corn production on these often droughty soils has been successful; however, water quality problems may be increasing. Over-irrigation or rainfall on recently irrigated soils can leach nitrate and other contaminants below the root zone and into groundwater. Irrigation systems management is an important practice to consider in protecting the quality of groundwater.

The N management practices previously described will not, by themselves, effectively reduce leaching on soils that are regularly over-irrigated. Excess water from irrigation or precipitation can cause nitrate movement below the root zone. Accurate irrigation scheduling during the growing season can reduce the risk of leaching losses. A good irrigation scheduling program that considers soil water holding capacity, crop growth stage, evapotranspiration, rainfall and previous irrigation in order to determine the timing and amount of irrigation water to be applied is essential. Irrigation amounts adequate to meet crop needs but less than the amount needed to saturate the soil profile will allow for rainfall to occur without causing leaching or runoff.

To promote irrigation efficiency, the University of Wisconsin-Extension has implemented the Wisconsin Irrigation Scheduling Program (WISP). WISP uses a water budget approach to advise growers on appropriate irrigation frequencies and amounts. Parameters included in the program include those mentioned above. The program allows flexibility in irrigation scheduling due to variations in weather. Further information on WISP can be found in UWEX publication *A3600, Irrigation Management in Wisconsin–the Wisconsin Irrigation Scheduling Program (WISP).*

Soil Conservation

Land-use activities associated with modern agriculture can increase the susceptibility for runoff and sediment transport from cropland fields to surface waters. Consequences of cropland erosion include loss of fertile topsoil, accelerated eutrophication and sedimentation of surface waters, destruction of fish and wildlife habitat, and decreased recreational and aesthetic value of surface waters.

The key to minimizing nutrient contributions to surface waters is to reduce the amount of runoff and eroded sediment reaching them. Numerous management practices for the control of runoff and soil erosion have been researched, developed, and implemented. Runoff and erosion control practices range from changes in agricultural land management (cover crops, diverse rotations, conservation tillage, contour farming, contour strip cropping, etc.) to the installation of structural devices (diversions, grade stabilization structures, grassed waterways, terraces, etc.). These practices are effective in reducing contaminant transport to surface waters.

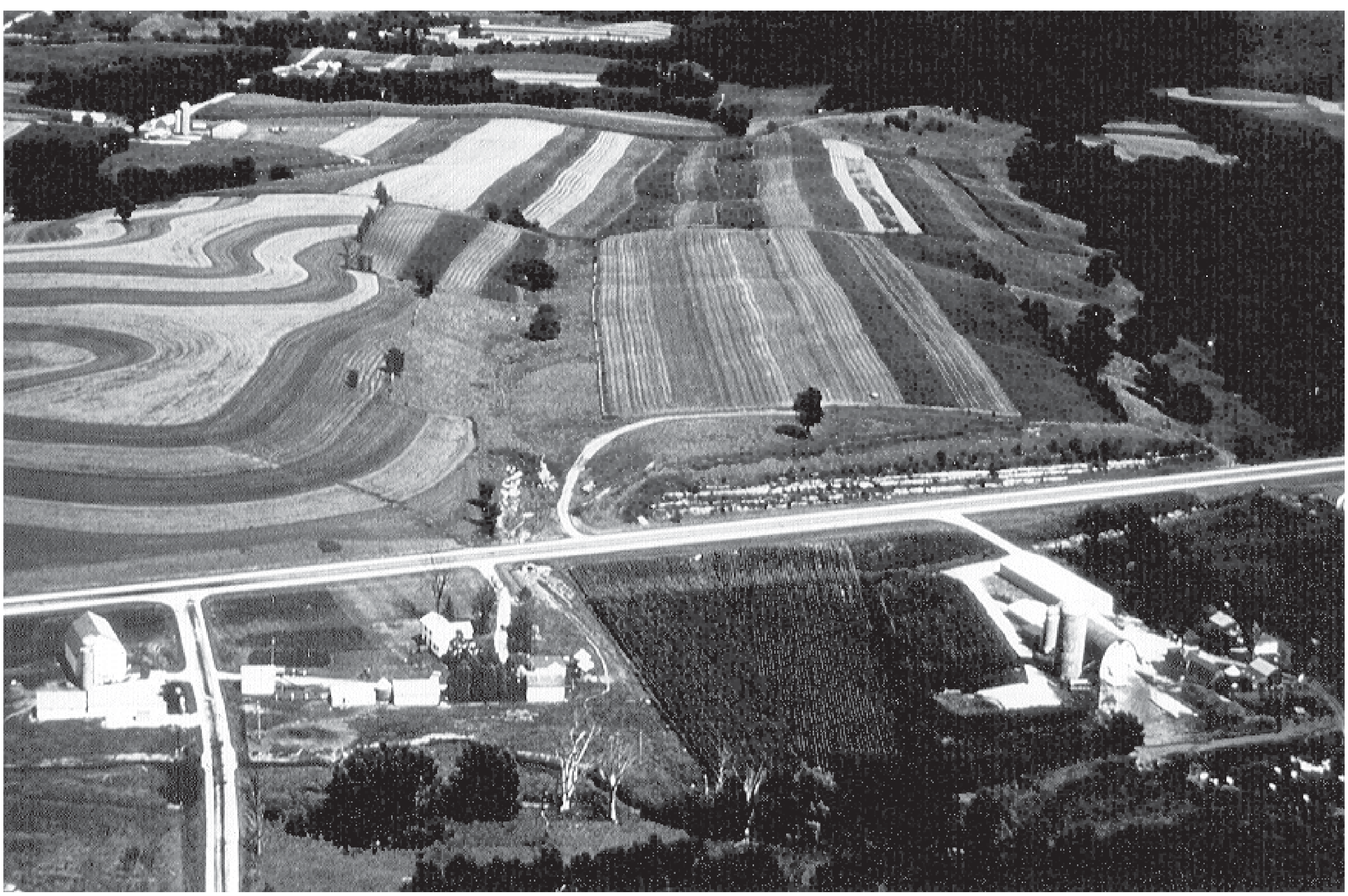
Despite the proven effectiveness of soil conservation practices in reducing nutrient loadings to surface waters, their effect on groundwater quality is unknown. Practices that reduce surface runoff by increasing soil infiltration may, in turn, enhance the movement of soluble agricultural chemicals through the soil profile to groundwater. Trade-offs between reducing runoff and protecting groundwater quality may exist. If such is the case, decisions weighing the impact of one resource versus another will need to be made. Research on the effects of soil conservation management practices on groundwater quality is limited and often contradictory. It is clear that these relationships require further investigation.

Crop Rotation and Selection

The selection of crops to include in a rotation with corn has been shown to influence the movement of N through soil profiles and the transport of P to surface waters. Legumes and other crops that do not require supplemental N inputs can effectively “scavenge” N remaining in the soil from previous crops. Also, crops with low N fertilizer requirements used in sequence with crops that require high N inputs or inefficiently recover N can reduce the amount of N inputs applied over a number of years. On soils with excessively high P levels, including a P-demanding crop such as alfalfa in the rotation would help to draw down P levels, as well as reduce soil and runoff losses and P losses to nearby surface waters.

Legumes used in cropping rotations fix atmospheric N and serve as an organic source of N. However, legumes will utilize residual inorganic N from the soil in preference to fixing N. Deeply rooted legumes such as alfalfa often utilize soil N located below the rooting depths of other crops such as corn. Alfalfa has the potential to root to depths greater than 18 feet and research has shown that nitrate is utilized by alfalfa from any depth where soil solution is extracted by its roots. The use of alfalfa in rotations appears to be a viable management alternative for removing nitrate from soils below the rooting depth of most crops.

The removal of subsoil nitrates by deeply rooted legumes such as alfalfa would most likely be of more significance on medium and heavy textured soils than on sands. Research has shown that N applied to sandy soils that is not utilized by the crop is often leached below rooting depths in less than one year. Thus, alfalfa following corn in a rotation on sandy soils will not be able to recover nitrate which has previously passed through the profile.



Filter Strips

Maintaining or establishing strips of close-growing vegetation adjacent to water bodies is a practice that can reduce the sediment and nutrient content of runoff waters reaching them. The velocity of runoff is reduced when passing through a buffer strip as is its capacity for transporting sediment and nutrients. Sediment is deposited and runoff infiltrates or passes through the buffer strip with a substantially reduced nutrient content.

The width of an effective buffer strip varies with land slope, type of vegetative cover, watershed area, etc. Buffer strip dimensions need to be specifically designed for given field and cropping conditions. Local Land Conservation Department or Soil Conservation Service staff can assist landowners in establishing buffer strips.

Although proven effective in improving surface water quality, buffer strips may potentially have an adverse effect on groundwater quality. Increased infiltration in an area of sediment deposition may promote the leaching of soluble contaminants such as nitrate. The extent to which this may occur needs to be investigated and evaluated against the benefits to surface water quality.

Conservation Tillage

Conservation Tillage and Fertilizers

Conservation or reduced tillage systems, while being very effective in reducing runoff and soil erosion, require some degree of specialized nutrient management. This is particularly true for no-till systems of corn production. Research evaluating the effect of conservation tillage systems on nitrate movement to groundwater is limited. However, from a corn production standpoint, it is recommended that in addition to the standard N recommendation, an additional 30 lbs/acre of N be applied to continuous no-till and ridge-till corn production systems where residue cover after planting is at least 50%. This is needed to offset N that may be immobilized in surface residues and the lower annual amount of N mineralized from soil organic matter in high residue systems.

A great deal of research has investigated the effects of conservation tillage systems on P losses to surface waters. Recommended production practices for conservation tillage in Wisconsin fit well with surface water quality objectives. It has always been recommended that required fertilizer and lime be broadcast and incorporated prior to the implementation of a conservation tillage system. Annual fertilizer additions should be band-applied once the conservation tillage system is established.

Conservation Tillage and Manure

Effective handling of manure is very important in protecting water quality. As mentioned earlier, nutrient additions to surface waters can be significantly reduced if land applied manure is incorporated. This is possible with most forms of reduced tillage but obviously not in no-till systems.

For both water quality and crop production purposes, manure applications to no-till cropland are not recommended. Research has shown that the P loadings to surface waters from manured no-till cropland can be extremely high. In addition, serious production problems can result from the application of manure to no-till fields. A colder and wetter soil environment is created which can delay seed germination and the early growth of crops. Weed problems may also increase due to manure reducing herbicide activity and contributing weed seeds to the soil. Manure and the associated higher soil moisture content can also produce mechanical problems for planting equipment. Any or all of these conditions can cause serious production problems and reduce yields.

The problems presented with manure applications to no-till fields can be alleviated with light incorporation. After applications to no-till fields, manure should be lightly disked into the first two inches of soil. This will allow P to interact with soil particles and should reduce P contributions to runoff. In addition, the disking distributes manure more evenly and reduces the mechanical and soil temperature problems. This practice should not sacrifice erosion control because sufficient surface residues should still remain. While no longer strictly no-till, this modified practice is necessary to integrate the benefits of no-till and manure application.

Regardless of tillage, the practice of injecting manure at recommended rates with proper techniques can remove potential threats to surface water quality. Injection places soluble P in manure below the soil surface and maintains sufficient surface residue for runoff and soil erosion control in conservation tillage systems.

Conclusion

This publication provides a brief summary of general nutrient management practices for Wisconsin corn production. It is not a complete inventory but rather an overview of soil fertility management options available to corn growers for improving farm profitability and protecting water quality. The selection of appropriate nutrient management practices for individual farms needs to be tailored to the specific conditions existing at a site.

Additional information on the topics discussed in this publication is available. Consult the following reference list for other publications on soil nutrient management practices. Advice on the applicability of these practices to individual farming situations can be gained from local University of Wisconsin–Cooperative Extension Service staff.

References

Bundy, L.G. 1985. Corn fertilization. Univ. Wis. Coop. Extn. Ser. Bull. No. A3340.

Bundy, L.G. 1985. Understanding plant nutrients: soil and applied nitrogen. Univ. Wis. Coop. Extn. Serv. Bull. No. A2519.

Bundy, L.G. 1987. Nitrogen management for groundwater protection and efficient crop use. Proceedings of 1987 Wis. Fert., Aglime & Pest Mgmt. Conf. 26:254-262.

Bundy, L.G. 1988. Estimating nitrogen availability from soil and plant tests. Proc. 1988 Wis. Fert., Aglime & Pest Mgmt. Conf. 27:319-325.

Bundy, L.G. 1989. Nitrogen management to protect groundwater resources. Ag Chem. Mgmt. Univ. Wis. Coop. Extn. Ser. Inservice Handbook.

Bundy, L.G. 1989. The new Wisconsin nitrogen recommendations. Proc. Wis. Area Fert. and Aglime Dealer Meetings, Nov. 28 - Dec. 14, 1989.

Bundy, L.G., T.W. Andraski, and P.C. Widen. Soil nitrate test results and corn N responses in 1989. Dept. of Soil Sci., Univ. Wis.-Madison. Mimeo.

Bundy, L.G., K.A. Kelling, and L. Ward Good. 1990. Using legumes as a nitrogen source. Univ. Wis. Coop. Extn. Ser. Bull. No. A3517.

Bundy, L.G., and E.S. Malone. 1988. Effect of residual profile nitrate on corn response to applied nitrogen. Soil Sci. Soc. Am. J. 52:1377-1383.

Bundy, L.G., S.J. Sturgul, and K.A. Binning. 1994. Soil nitrate tests for Wisconsin cropping systems: A guide for using the preplant and pre-sidedress soil nitrate tests. Univ. Wis. Coop. Extn. Serv. Bull. No. A3624.

Bundy, L.G., S.J. Sturgul, and R.W. Schmidt. 1990. Wisconsin's preplant soil profile nitrate test. Univ. Wis. Coop. Extn. Ser. Bull. No. A3512.

Combs, S.M., E.E. Schulte, and L.G. Bundy. 1989. Summary of 1989 soil nitrate test results and outlook for 1990. Proc. 1989 Wis. Fert., Aglime, and Pest Mgmt. Conf.

Council for Agricutural Science and Technology (CAST). 1985. Agricultute and groundwater quality. CAST Report No. 103. May, 1985.

Curwin, D., and L.R. Massie. 1994. Irrigation management in Wisconsin-the Wisconsin irrigation scheduling program (WISP). Univ. Wis. Coop. Extn. Serv. Bull. No. A3600.

Daniel, T.C., D.H. Mueller, B.J. Andraski, and R.E. Springman. 1989. Effect of tillage on erosion and runoff water quality. Univ. Wis. Coop. Extn. Serv. Bull. No. G3432.

Daniel, T.C., R.C. Wendt, and F.W. Madison. 1979. Nonpoint pollution: sediment and phosphorus in agricultural runoff. Univ. Wis. Coop. Extn. Serv. Bull. No. G2966.

Keeney, D.R., T.C. Daniel, and B. Shaw. 1986. Nitrate in Wisconsin groundwater: sources and concerns. Univ. Wis. Coop. Extn. Serv. Bull. No. G3054.

Kelling, K.A., and A.E. Peterson. 1981. Using whey on agricultural land - a disposal alterrnative. Univ. Wis. Coop. Extn. Serv. Bull. No. A3098.

Kelling, K.A., E.E. Schulte, L.G. Bundy, S.M. Combs, and J.B. Peters. The new Wisconsin soil test recommendation program: Vegetables. Proc. Processing Crops Conf. 20-22 Feb, 1990. LaCrosse, WI.

Kelling, K.A., E.E. Schulte, L.G. Bundy, S.M. Combs, and J.B. Peters. The new Wisconsin soil test recommendation program: Forages. Proc. WI Forage Council Symp. 1990.

Kelling, K.A., E.E. Schulte, L.G. Bundy, S.M. Combs, and J.B. Peters. 1991. Soil test recommendations for field, vegetable, and fruit crops. Univ. Wis. Coop. Extn. Ser. Bull. No. A2809.

Hendrickson, L.L., D.R. Keeney, and L.M. Walsh. 1978 Evaluation of nitrapyrin as a means of improving nitrogen efficiency in irrigated sands. Agron. J. 70:689-703.

Hendrickson, L.L., L.M. Walsh, and D.R. Keeney. 1978. Effectiveness of nitrapyrin in controlling nitrification of fall and spring applied anhydrous ammonia. Agron. J. 70:704-708.

Jackson, G., D. Keeney, D. Curwen, and B. Webendorfer. 1987. Agricultural practices to minimize groundwater contaimination. Univ. Wis. Coop. Extn Serv. 115p.

Leclerc, S. 1987. Effects of residual profile nitrate accumulation on corn response to applied N. M.S. Thesis. Dept. of Soil Sci., Univ. Wis.-Madison.

Madison, F., K.A. Kelling, J. Peterson, T.C. Daniel, G. Jackson, and L. Massie. 1986. Managing manure and waste: guidelines for appplying manure to pasture and cropland in Wisconsin. Univ. Wis. Coop. Extn. Serv. Bull. No. A3392.

Magdoff, F.R., D. Ross, and J. Amadon. 1984. A soil test for nitrogen availability to corn. Soil Sci. Soc. Am. J. 48:1301-1304.

Mathers, A.C., B.A. Stewart, and B. Blair. 1975. Nitrate-N from soil profiles by alfalfa. J. Environ. Qual. 4:403-405.

Mueller, D.H., T.C. Daniel, and R.C. Wendt. 1981. Conservation tillage: best management practice for nonpoint runoff. Environ. Mgmt. 5(1):33-53.

Mueller, D.H., R.C. Wendt, and T.C. Daniel. 1984. Phosphorus losses as affected by tillage and manure application. Soil Sci. Soc. Am. J. 48:901-905.

Olsen, R.J., R.F. Hensler, O.J. Attoe, S.A. Witzel, and L.A. Peterson. 1970. Fertilizer nitrogen and crop rotation in relation to movement of nitrate-N through soil profiles. Soil Sci. Soc. Am. Proc. 34:448-452.

Schulte, E.E., and A.E. Peterson. 1988. Using cover crops in sustainable agriculture. Dept. of Soil Sci., Univ. Wis.-Madison.

Schulte, E.E., and L.M. Walsh. 1993. Management of Wisconsin soils. 4th ed. Univ. Wis. Coop. Extn. Ser. Bull. No. A3588

Stewart, B.A., F.G. Viets, and G.L. Hutchinson. 1968. Agriculture's efffect on nitrate pollution of groundwater. J. Soil Water Cons. 23:13-15.

USDA-Soil Conservation Service. 1991. Wisconsin field office technical guide, Sec. IV-Spec. 590.

Ward Good, L., F.W. Madison, K. Cates, and K.A. Kelling. 1991. Nitrogen credits for manure applications. Univ. Wis. Coop. Extn. Ser. Bull. No. A3537.

Wis. Dept. Ag., Trade & Cons. Protection. 1989. Nutrient and pesticide best management practices for Wisconsin farms. WDATCP Tech. Bull. 1 - Univ. Wis. Coop. Extn. Ser. Bull. No. A3466.

Authors: Larry G. Bundy, Keith A. Kelling and Emmett E. Schulte are professors of soil science, University of Wisconsin-Madison and extension soil scientists, University of Wisconsin-Extension. Sherry Combs is director of the Soil and Plant Analysis Laboratory, University of Wisconsin-Extension. Richard P. Wolkowski is an outreach program manager in the Department of Soil Science, University of Wisconsin-Extension. Scott J. Sturgul is a senior outreach specialist with the Nutrient and Pest Management Program, University of Wisconsin-Madison. Desktop publishing: Kimberly Binning is an editor and Roger Schmidt is an information processing consultant with the Nutrient and Pest Management Program, University of Wisconsin-Madison.

Partial funding provided by the Wisconsin Department of Natural Resources - Nonpoint Source Priority Watershed Program.

This Publication is available from your Wisconsin County Extension office or from: Extension Publications, Cooperative Extension Publications , 45 N. Charter Street, Madison WI 53715. Phone (608) 262-3346 or (877) 947-7827 Contact Extension Publications to determine availability before publicizing.