Nutrient Management to Protect Water Quality
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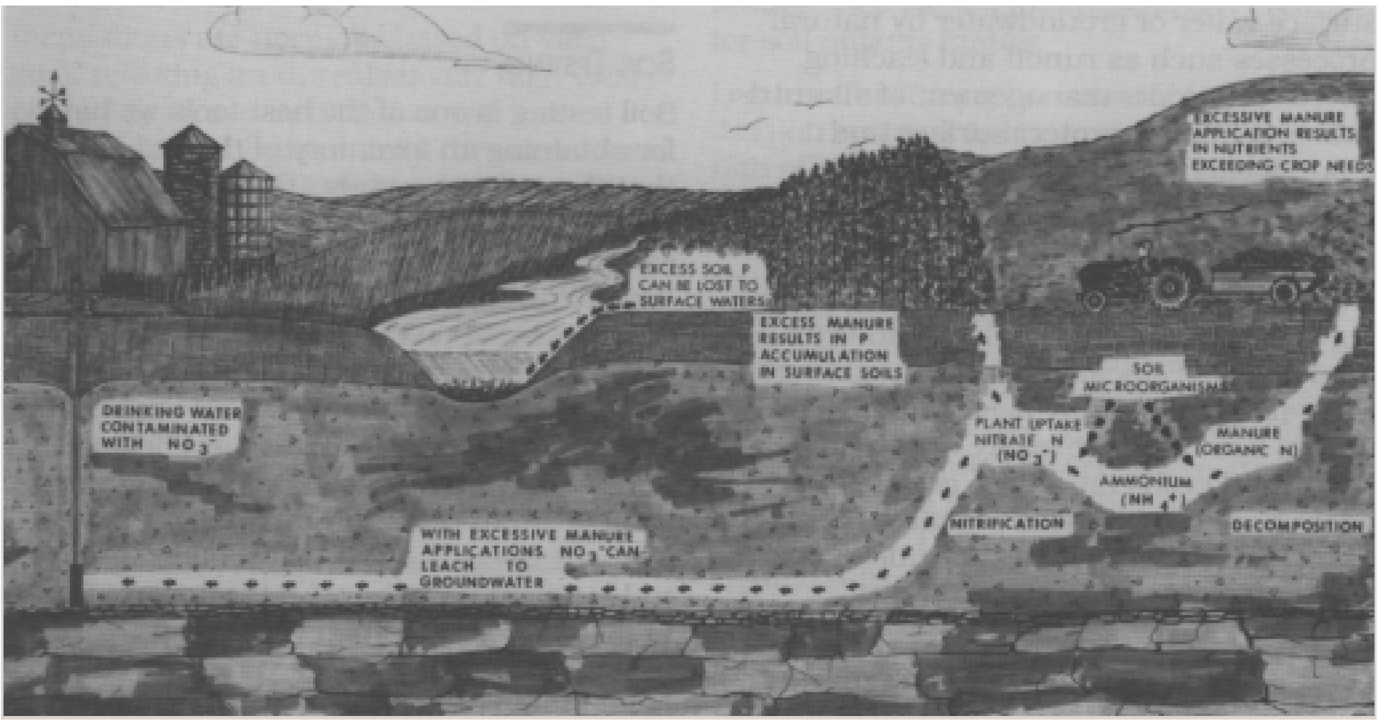
NUTRIENT MANAGEMENT TO PROTECT WATER QUALITY



Considerable national attention is being given to nitrate nitrogen (N) contamination of groundwater and phosphorus (P) contamination of surface water. The source of this contamination is non-point in nature, meaning that it cannot be specifically identified. Agricultural practices, however, have been implicated as causing much of the non-point source contamination.

Water is the most common ingredient in all natural processes and is the medium for movement of nutrients away from the land surface. It is constantly being recycled from water surfaces and through plants to the atmosphere by evapotranspiration and back again to the earth's surface as precipitation to produce stream flow and groundwater flow on and within our land surface. As water moves through this cycle, it dissolves nutrients from soil minerals, crop residues, fertilizers,

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manures and other materials. Thus nutrients, like water, have their own natural cycle.

The earth contains an abundant supply of plant nutrients, but not all agricultural soils contain adequate nutrients for intensive crop production, particularly N, P and potassium (K). Fertilizers, manures and other organic materials are required to supplement nutrients supplied by the soil. All nutrients, whether they are synthetic or naturally occurring, can become mixed with surface water or groundwater by natural processes such as runoff and leaching. Therefore, proper management of all nutrients is crucial to protect surface and groundwater quality.

Managing the amount, form, placement and timing of nutrient applications is the only realistic and practical approach to minimizing the risk of surface and groundwater contamination. Education and demonstration programs are urgently needed to help producers become more aware of potential environmental problems and to get them to adopt best management practices. Other less desirable alternatives include legislative action and enforcement.

Crop producers need to develop a “whole-farm” nutrient management plan for their farms. They need to look at the entire farm operation, not just one field at a time. To develop a whole-farm nutrient plan, they should ask a number of questions: What nutrient inputs exist on the farm? Is the farm operation utilizing these inputs to their fullest potential? Where might the operation be overloading the nutrient cycle? What practices need more attention?

Crop producers should also understand how nutrient availability fluctuates from year to year. Nitrogen availability can fluctuate very rapidly and is greatly affected by seasonal weather conditions, whereas phosphorus availability fluctuates very little from year to year because it is largely controlled by soil pH, organic matter and insoluble forms of soil phosphorus. Potassium availability can fluctuate from season to season, depending on crop removal and the ability of the soil to supply potassium. Understanding how nutrient availabilities change with time can help crop producers do a better job of managing fertilizer nutrients.

The following management practices will help protect water quality. Crop producers are encouraged to follow as many of these practices as possible.

Soil Testing

Soil testing is one of the best tools we have for obtaining an inventory of the nutrients that the soil can supply. One of the keys to a good soil testing program is proper soil sampling. MSU Extension bulletins E-498, “Sampling Soils for Fertilizer and Lime Recommendations,” and E-2567, “Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat and Alfalfa,” available from your county Extension office, give instructions for obtaining a good representative soil sample. Fertilizer, manure additions and nutrient removal by crops will alter the soil test, so each field should be tested every two to three years. For high value crops or fields where large amounts of fertilizer are added, retesting every year is desirable. Once we have determined what the soil can supply, we can better determine whether the crop needs supplemental nutrients. Fertilizer recommendations based on soil tests frequently vary between soil testing laboratories. Although some commercial laboratories recommend more fertilizer than Michigan State University does, numerous studies have shown that MSU recommendations are adequate and economical.

Realistic Yield Goals

Recent surveys have shown that many crop producers are overly optimistic in assessing their yield goals. Because fertilizer recom-

Table I. Suggested nitrogen credit for various soil organic matter levels.

Soil organic matter	Nitrogen credit*
0-4% — Mineral soils	None
4-8% — Mineral soils	20-40 lb N/A
>20% — Organic soils	40-80 lb N/A

* Subtract this amount of N from the recommended rate. The amount may be crop and yield dependent.

mendations are normally based on yield goal, selecting an unrealistically high yield goal leads to overfertilization and loss of farm income and potentially threatens water quality. The key is to select a yield goal that is both realistic and achievable, based on soil potential and level of crop management utilized. The farmer should achieve a yield goal at least 50 percent of the time before that yield goal is used to determine the appropriate fertilizer recommendations. If the desired goal is seldom achieved, factors other than soil fertility may be limiting yield.

Table II. Nitrogen credits for corn based on the previous crop.

Previous crop	Nitrogen credit[1]
	-lb N/A-
Corn and most other crops	0
Soybeans	30
Grass sod/pastures	40
Established forage legume[2] 40 + 20 x (plants/sq. ft.) to a maximum of 140	40-140
Annual legume cover crop[3]	40

[1]Subtract this amount of N from the recommended rate.

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

[3]Any legume or legume-grass mixture that has been established for less than one year. Nitrogen credit may be quite variable, depending on plant species, stand, growing conditions and date of destruction. Where legume growth is heavy following a small grain harvest, N credit may be considerably higher.

Soil Organic Matter, Legume and Manure Credits

The contribution of soil organic matter to plant nutrition should be taken into account to make accurate N recommendations. High organic matter soils will need less fertilizer N to obtain the same crop yield because they are capable of mineralizing more N than low organic matter soils. Michigan State University N fertilizer recommendations are based on soils with 0 to 4 percent organic matter. See Table I for suggested N credits for soil organic matter.

Legumes have long been used in crop production systems to improve the fertility and tilth of soils. The N supplied by legumes, which is due to a nitrogen fixation process in root nodules, needs to be credited to subsequent crops as a part of the nutrient management plan. A good stand of alfalfa will release more than 100 pounds of N per acre in the first year after being plowed or renovated. Other legumes, such as soybeans, red clover and sweet clover, also contribute to the available N supply, but the amount is usually less. The amount of credit given for legume N fixation depends on how long the legume has been growing and the density of the legume when killed by herbicide or tillage. See Table II for suggested N credits for previous crops.

Manure has long been recognized as a source of plant nutrients. All of the crop nutrient requirements can be met by manure if sufficient amounts are applied, but frequent applications of manure often result in a buildup of residual N and P. Extremely high soil P levels should be avoided, because runoff or erosion from this land can increase the risk of non-point source losses of P to lakes and streams. This leads to growth of unsightly weeds and aquatic plants in the water, increases the biological oxygen demand, and reduces both its recreational value and its ability to support fish and other desirable animals.

When manure or other biological (organic) materials are applied to cropland as nutrient sources, crop producers should follow the Michigan Right-to-Farm generally accepted agricultural and management practices (GAAMP). One set of GAAMP addresses manure management and utilization and a second set discusses nutrient utilization. Recommended practices include analyzing manure (or other organic material) to determine its nutrient content, knowing the rate of application, following fertilizer recommendations, implementing good soil and water conservation practices, and recordkeeping. Application of manure to frozen or snow-covered soils should be avoided or appropriate provisions must be made to ensure that manure is not lost to surface waters by runoff and erosion.

Fertilizer Placement

Band-applied starter fertilizer to the side and below the seed is considered the most efficient placement for P, K and most micronutrients. When soil test levels are low, broadcast applications are less efficient and will normally result in lower yields than band applications. When soil test levels are high, broadcast applications are not likely to improve yields but will build or maintain soil test levels. Broadcast applications of P should be incorporated to improve nutrient recovery by plants, minimize economic losses and prevent excessive runoff. Surface applications of fertilizer on snow-covered or frozen sloping land should be avoided because of the high risk of loss to surface waters in the spring.

Soil Nitrate Testing

Nitrate is the form of nitrogen that is most available to plants and supplies to crops most of their N needs. Soil type, rainfall and temperature greatly affect the seasonal availability of N to plants. Under wet conditions, N losses can occur by leaching from the rooting zone and/or by denitrification from the soil. Denitrification is a microbial process that occurs rapidly when soils become water saturated and temperatures are warm (>50 degrees F). Nitrate leaching can occur at any soil temperature. Denitrification losses are greatest on fine-textured soils with poor internal drainage; leaching losses are greatest on coarse-textured sandy soils with good internal drainage. The seasonal availability of nitrate N should be assessed each year and matched to crop needs.

Soil nitrate testing is an excellent and inexpensive way of evaluating the available N status of your soil. Michigan State University research and demonstration studies have shown that many crop producers can reduce their N fertilizer application rate on corn without risk of reducing yields if they use the soil nitrate test. Nitrate testing can also help to prevent overuse of N fertilizers.

The soil nitrate test measures only nitrate N — it does not measure ammonium N or organic N. If samples are taken in June, much of the ammonium and some of the organic N will have been converted to nitrate and will show up in the test.

Although soil samples may be taken anytime for this test, the best time to take samples is in June after the soil has warmed up, when it usually contains the greatest amount of nitrate N. The June presidedress nitrate test (PSNT) measures both residual nitrate N from the previous year and recently mineralized N from organic matter. Soil samples taken in early spring (April or May) will contain only residual nitrate. Although testing in early spring may still be helpful in assessing how much additional N is needed, samples taken just prior to sidedress time provide the greatest advantage in determining the appropriate rate of sidedress N.

Manured fields and legume fields will likely contain the most nitrate. Early sampling of these fields will not result in the maximum N credit because ammonium N and easily decomposed organic N will not yet have been converted to nitrate and will not be measured by the test. Therefore, only the PSNT is recommended for these fields.

Other fields that show high nitrate N levels are fields with medium- and fine-textured soils (loam, clay loam and clay) that have been heavily fertilized in previous years. Sandy soils, even though heavily fertilized the previous year, may not show much N carryover because nitrate N can be easily lost by leaching.

Soil sample boxes and information on taking soil samples for the PSNT are available from your county Extension office or the MSU Soil and Plant Nutrient Laboratory, East Lansing, MI 48824-1325.

Forms of Nitrogen Fertilizer

Nitrate forms of N fertilizer are more subject to loss than other forms. For example, calcium nitrate and ammonium nitrate are readily available sources of N for plants, but this N is also subject to immediate leaching when added to soil. Therefore, nitrate forms of N should not be used where leaching is a serious problem. Ammonium forms of N, such as urea or anhydrous ammonia, are preferred sources of N for most crops because they are not subject to immediate leaching when added to soil. Ammonium N must be converted to nitrate N before it can be leached or denitrified. This conversion to nitrate occurs rapidly under warm, moist conditions.

Nitrogen can also be lost by volatilization of gaseous ammonia if urea or N solutions containing urea are surface applied and not incorporated. Because the volatilization loss is difficult to assess and represents an economic loss to the farmer, all urea-containing fertilizers should be incorporated.

Timing of Nitrogen Fertilizer and Split Applications

Spring applications of N in the semi-humid regions of the United States, including Michigan, have clearly been shown to be superior to fall applications. Climatic conditions from fall to spring significantly affect the amount of N lost. Estimates of N losses from fall applications vary from 10 to 20 percent on fine- to medium-textured soils (clay, clay loams and loams) and from 30 to more than 50 percent on coarse-textured soils (sandy loams, loamy sands and sands). Though applying N in the fall on fine-textured soils may have certain economic benefits, the environmental risks of this practice generally outweigh the economic benefits. Fall applications of N are not warranted in Michigan and should be discontinued except for small applications on fall-seeded wheat.

Yield benefits of split or sidedress N applications for corn have frequently been observed on coarse-textured soils. Although the benefits of sidedress N on fine-textured soils are rarely seen, there is no question that sidedress N applications on fine-textured soils can improve N recovery. For these reasons, crop producers should seriously look at sidedress N applications on all soil types to improve N efficiency.

Waiting until the corn is well established before applying large amounts of N has two major advantages: nitrate N losses between preplant and sidedress are eliminated, and yield potential can be more accurately determined at sidedress time. Poor stand, poor weed control and/or dry weather at sidedress time are good reasons for adjusting the yield goal downward and reducing the total amount of N to be applied. The risk of being unable to sidedress N because of wet weather can be greatly reduced if corn is sidedressed when it is 3 to 4 inches tall instead of 1 foot tall. The benefits of sidedressing N when the corn is 1 foot tall or higher, rather than 3 to 4 inches tall, are minimal.

Applying nitrogen fertilizer through an irrigation system, often referred to as nitrogation, offers several advantages for irrigators:

- N can be applied when the crop's demand is greatest.
- The technique requires little additional energy for application.
- The practice is well suited to sandy soils where irrigation is needed and leaching is a problem.

Approximately two-thirds of the total N requirements of corn may be supplied by this method. For example, some irrigators choose to apply one-third of their N at planting, one-third at sidedress time and one-third through the irrigation system. Depending too much on the irrigation system to "spoon feed" a crop in Michigan can have its drawbacks, however. Rain during the early growing season may prevent crop producers from using their irrigation systems. If no previous N was applied, this could result in an N shortage early in the season. To eliminate this problem, some crop producers have modified their center pivot systems so they can apply only a very small amount of water in one application. This allows them to apply N through irrigation regardless of rainfall patterns. It is important not to overirrigate during the early part of the growing period in June and July because nitrate concentrations, which are most subject to leaching loss, are highest during this time.

Plant Analysis

Plant analysis during the season offers the grower an opportunity to assess the status of nutrients in the growing plant. High or excessive levels of a nutrient in the plant tissue are an indication that more nutrients may have been applied than were necessary for optimum growth. Once the fertilizer or manure has been applied, little can be done, but N rates can be reduced in future years to bring the nutrient levels back into the normal or sufficiency range.

Research on corn is being conducted to determine if tissue chlorophyll meter readings or plant analysis for N during the growing season can be used to help determine the amount of N to apply. Once the corn plant is past the sidedress stage, however, growers may encounter other difficulties in applying N fertilizer. The only equipment available for non-irrigators is high-clearance equipment and aerial applicators. In addition, N applied at later stages may not be beneficial. Research indicates that N applied to corn after silking is not efficiently utilized.

Nitrification Inhibitors

Crop producers in many states have successfully used nitrification inhibitors to delay the conversion of ammonium N to nitrate N. Preventing rapid conversion of ammonium to nitrate can reduce the amount of nitrate N that is available for denitrification or leaching early in the season. Table III gives the potential for economic response to the use of nitrification inhibitors on corn for various times of the year and for various soil types.

Crop producers should consider using nitrification inhibitors when it is not feasible to use delayed N applications, such as by sidedressing or applying through an irrigation system. Nitrification inhibitors can be beneficial if N applications are made early and leaching or denitrification conditions exist. The amount of N used is very critical to the successful use of a nitrification inhibitor. Nitrification inhibitors will work best when the amount of N applied is slightly deficient. If the rate of N fertilizer applied is adequate or excessive, no benefits can be expected. In summary, nitrification inhibitors can improve N recovery when used appropriately, but they should not be used as a substitute for following other recommended management practices.

Calibration of Equipment

Evidence of uneven fertilizer distribution due to improperly adjusted fertilizer spreaders can be seen almost every year, particularly on winter wheat. The uneven distribution of fertilizer results in overfertilization in some areas of the field and underfertilization in others. The result is less than optimum yields and potential loss of excess nutrients to surface water and groundwater.

All fertilizer applicators need to be accurately calibrated. If crop producers are unsure whether the equipment they are using is properly calibrated, they should recalibrate the equipment to avoid crop yield loss and potential risk to the environment. Improving the calibration of fertilizer applicators will result in more uniform distribution of the fertilizer at the proper rate.

Crop Rotations, Forages and Cover Crops

Crop rotations can be very beneficial in a successful crop production system. For example, a corn-soybean rotation is preferable to a continuous corn rotation because continuous corn requires more N fertilizer to obtain the optimum yield. Some of the noted yield improvement may be due to the rotational effect — better disease, insect and weed control, and improved soil tilth — and some to N fixation by soybeans. Other non-legume rotations also have been shown to produce better yields of corn with less N fertilizer.

Forage crops such as Sudangrass and alfalfa are well suited to recovering nitrate N from soils and thereby preventing excessive nitrate leaching. Although alfalfa fixes its own N, it does so only when all of the nitrate N in the soil is gone. Alfalfa's deep rooting system makes it ideal for taking up N that has moved deep in the soil profile. The disadvantage of alfalfa is that it is slow to establish, so a longer growing period is needed before it can prevent nitrate leaching.

Cover crops such as rye can be very beneficial in preventing wind and water erosion. They protect the soil surface from erosion and thereby reduce the risk of nutrient losses by runoff as soluble nutrients or erosion as sediment. Cover crops may also be used as green manure crops to take up nitrate and prevent it from being leached to ground water. This practice is well suited to many

Table III. Potential for an economic response to the use of nitrification inhibitors with anhydrous ammonia on corn for different application times and soil management groups.

Soil management group	Time of nitrogen application: Late fall <50ºF	Early spring <50ºF	Late spring >50ºF	Sidedress
Clays (0,1)	Good	Good-fair	Poor-fair	Poor
Clay loams (1.5)	Good-fair	Fair-good	Poor-fair	Poor
Loams (2.5)	Fair-good	Fair	Fair	Poor
Sandy loams (3)	Fair	Fair	Fair	Poor
Loamy sand (4)	Fair-poor	Fair	Fair	Poor
Sands (5)	Poor-fair	Fair-poor	Fair	Poor

KEY:
Good = Economic response expected at least 60% of the time.
Fair = Economic response expected 40 to 50% of the time.
Poor = Economic response expected less than 30% of the time.

soils in Michigan and could be used more effectively than it is now. One of the keys to utilizing cover crops successfully is to get them established in early fall so that they have a chance to take up excess nitrate N before winter dormancy and excessive precipitation occur.

RECORDKEEPING

Recordkeeping is an important management practice for developing a productive cropping system that makes efficient use of available plant nutrients. Good recordkeeping demonstrates good management and will be beneficial for the producer, particularly if the producer's management practices are challenged. The Michigan Right-to-Farm GAAMP recommends that annual records include the following for individual fields:

- Most recent soil fertility test(s) and/or plant tissue analysis reports.
- Previous crop grown and yields of past harvested crops.
- Date(s) of nutrient application(s).
- The nutrient composition of fertilizer or other nutrient-supplying material used. (If the nutrient composition, availability or solubility is not provided with the purchase of the nutrient-supplying material, then representative samples of this material should be analyzed to provide nutrient composition information. Non-legume crop residues grown in the field and left to recycle nutrients are not considered nutrient additions.)
- Amount of nutrient-supplying material applied per acre.
- Method of application and placement of applied nutrients (e.g., broadcast and incorporated, broadcast and not incorporated, subsurface banded, surface banded, soil injected or applied through an irrigation system, etc.).
- The name of the individual responsible for calibrating fertilizer application equipment (e.g., fertilizer, manure spreaders, etc.) and the dates of the last calibrations. (If the equipment is owned by a fertilizer dealer or someone else who is responsible for the adjustment, then the name of the individual and/or business responsible for the equipment adjustment should be retained.)
- Vegetative growth and cropping history of perennial crops.

Records such as these will help the producer determine whether a balanced nutrient program is being followed. Changes in soil P test levels with time due to nutrient additions can be determined from good records. The records should help to determine if nutrients are accumulating or being depleted in the soil. A paper recordkeeping system, such as that described in MSU Extension bulletin E-2340, may be helpful in accomplishing this goal. In addition, MSU offers two microcomputer programs — MSUFR (CP001) and MSUNM (CP036) — for managing fertilizer and manure nutrient sources for field and vegetable crops. MSUFR is a fertilizer recommendation program that can be used to generate fertilizer recommendations using soil test laboratory data from all Michigan ACP-approved laboratories. MSUNM is an entry-level microcomputer recordkeeping program that can assist crop and livestock producers in taking a whole-farm nutrient management approach. Fertilizer recommendations and manure application rates that follow Right-to-Farm GAAMP can be generated for individual fields.

IRRIGATION MANAGEMENT

When crops are irrigated, conscientious management of irrigation water is necessary for good N management. Because nitrate N is readily soluble in water, excess water from irrigation or precipitation can cause nitrates to move below the root zone. Precise scheduling of irrigation water during the growing season can minimize these percolation losses.

Several methods are available to schedule irrigation water accurately. All methods require knowledge of the soil's water-holding capacity and ability to determine or estimate the available soil moisture at any time during the growing season.

The soil moisture procedure requires an estimate of soil moisture. Irrigation begins when 50 percent of the available soil moisture is depleted. Tensiometers, which measure the tension with which soil holds water, are excellent tools for use on sandy soils. Their use on fine-textured soils, however, is usually unsatisfactory. Soil moisture blocks, which measure water conductivity, are better instruments to use.

The water balance approach requires an estimate of crop water use (i.e., evapotranspiration). Computerized programs do an excellent job of estimating crop water use and keeping track of soil moisture. Additional information on irrigation scheduling can be found in the Michigan Irrigation Guide, which is available from county MSU Extension offices or the Department of Agricultural Engineering at MSU.

SUMMARY

Many management strategies exist for achieving effective and efficient use of nutrients without risk of reducing yield or contaminating water resources. Here are several important management practices that crop producers should follow:

1. Soil test every two to three years and follow MSU fertilizer recommendations.
2. Choose a realistic yield goal that can be achieved 50 percent of the time.
3. Take credit for nutrients supplied by organic matter, legumes and manure or other biological wastes containing nutrients. Manures and other wastes should be tested to determine the amounts of nutrients they can supply.
4. Where leaching is a serious problem, use ammonium forms of fertilizer to reduce nitrate N losses.
5. Avoid fall applications of N on all soils where winter and spring precipitation can cause runoff or leaching.
6. Use delayed or split applications of N to prevent excessive leaching of nitrates on sandy soil.
7. Use soil nitrate tests to determine residual nitrate and recently mineralized nitrate to estimate N credits for reducing N fertilizer recommendations for corn.
8. Consider using nitrification inhibitors when it is not feasible to use delayed or split N applications.
9. Consider using plant analysis to determine how well you have done in supplying crop nutrients.
10. Consider using crop rotations rather than monocultures to reduce the need for N and assist with pest control.
11. Use cover crops and forages to prevent wind and water erosion and excessive loss of N to groundwater.

12. Check nutrient application equipment for proper calibration.
13. Keep good records of soil test results and plant nutrients applied to demonstrate that good management practices are being followed.
14. Use modern irrigation scheduling techniques to avoid applying excessive amounts of water that could leach nitrate N below the rooting zone.
15. Develop a whole farm nutrient management plan, particularly for livestock operations that generate manure nutrients. Planning for best utilization of all available nutrients — whether from manure, soil organic matter, legumes or fertilizers — will return economic benefits as well as reduce risks to water quality.

References

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MacKellar, B.A., L.W. Jacobs and S.U. Böhm. 1994. Michigan State University Nutrient Management (MSUNM). CP-036, Version 1.1. MSU Bulletin Office, 10-B Agriculture Hall, Michigan State University, East Lansing, MI 48824-1039. Cost: $75.

Vitosh, M.L. 1995. Michigan State University Fertilizer Recommendations (MSUFR). CP-001, Version 3.0. MSU Bulletin Office, 10-B Agriculture Hall, Michigan State University, East Lansing, MI 48824-1039. Cost: $25.

For more information on water quality, consult the following publications, available from your county MSU Extension office or the MSU Bulletin Office, 10-B Agriculture Hall, MSU, East Lansing, MI 48824-1039. (All orders totaling less than $100 must be prepaid.)

E-498, “Sampling Soils for Fertilizer and Lime Recommendations” (free).

E-550A, “Fertilizer Recommendations for Field Crops in Michigan” ($1.50).

E-550B, “Fertilizer Recommendations for Vegetable Crops in Michigan” ($1.50).

E-2340, “Recordkeeping System for Crop Production” ($2).

E-2567, “Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat and Alfalfa” ($1).

WQ03, “Managing Organic Soils to Reduce Non-Point Pollution” (free).

WQ05, “Phosphorus: Pollutant and Essential Plant Food Element” (free).

WQ06, “Nitrogen Management Strategies for Corn Producers” (free).

WQ07, “Nitrogen Fertilizer Management for Efficient Crop Production and Water Quality Preservation” (free).

WQ08, “Understanding Sediments: Problems and Solutions” (free).

WQ19, “Nitrate — A Drinking Water Concern” (free).

WQ20, “Agriculture and Water Quality in Michigan” (free).

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