Fertilizer BMPs —

Best Management for Fertilizers on Northeastern Dairy Farms

By Tom W. Bruulsema and Quirine Ketterings

In the past 10 years, many dairy farms in the humid temperate zone of northeastern North America have implemented best management practices (BMPs) for manure and fertilizer to address concerns about nutrient buildup in soils and nutrient losses that can impact water and air quality. This Introductory Guide focuses on fertilizer BMPs: applying the right source at the right rate, at the right time, and in the right place.

On dairy farms, large amounts of nutrients can be removed from the field in the harvest of forages. Nutrients are returned with manure and/or fertilizer applications, and for legumes, also through N fixation. If the amount of nutrients applied exceeds crop nutrient removal, the difference will either be lost to the environment or accumulate in the soil. In the humid temperate zone of northeastern North America, carryover of inorganic N from one year to the next ranges from small to sporadic and risk of harm to the environment increases when surplus inorganic N remains in the soil at the end of the growing season. Surplus P and K most often contribute to an increase in soil test levels.

While dairy farming is associated with increases in soil test P levels over time, not all farm fields test above the agronomic optimum. The proportion of soils deficient in P in northeastern North America ranges from 10 to 20% in Delaware and Pennsylvania to about 50% in Quebec, New York, and Virginia (Ketterings et al., 2005a; PPI, 2006). Soil testing allows a farmer to determine if nutrient additions are needed and is therefore among the most important BMPs for fertilizer management.

Losses of N entail risks to groundwater quality and may also contribute to water quality issues in estuaries where fresh water meets salt water. Losses of P may result in eutrophication of fresh waters, leading to algal blooms and impaired water quality in local water sources.

Fertilizer management influences greenhouse gas emissions as well. Nitrogen fertilizer manufacture emits carbon dioxide, and adding N to soils can increase emissions of nitrous oxide. On the other hand, appropriate N fertilizer use boosts crop absorption of carbon dioxide, and influences soil carbon storage. Applying the right source of nutrient with the right rate, timing and placement is currently the best that can be done to assure the minimum net emission per unit of crop production (Snyder et al., 2007).

Large amounts of nutrients cycle on dairy farms.

For reliable fertilizer management recommendations, extensive research needs to be conducted for multiple years, on local soils, under local management, and under local weather conditions. This type of research is usually done at universities and research institutions. For state-specific fertilizer application rates, we refer to the local land grant university. However, common principles apply for dairy farms across northeastern North America. In the following pages we describe general BMPs that ensure the right source is applied at the right rate, at the right time and in the right place. "Right" is defined as contributing to the cropping system's productivity, profitability, and sustainability while minimizing any harmful impact on the surrounding environment (IPNI, 2008).

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; K = potassium; C = carbon.

This publication is one of a series prepared by cooperators with the staff of the International Plant Nutrition Institute (IPNI). It is part of a project in cooperation with the Foundation for Agronomic Research (FAR) toward fulfilling the goals of a 3-year Conservation Innovation Grant (CIG 68-3A75-5-166) from the USDA-Natural Resources Conservation Service to identify fertilizer best management practices (BMPs). The intent of this publication is to help develop the BMP definition process in such a way that environmental objectives are met without sacrificing current or future production or profit potential and in full consideration of the newer technologies relevant to fertilizer use. The concept of applying the right fertilizer at the "right rate, right time, and right place" is a guiding theme in this series. For additional information, visit the websites: www.farmresearch.com/CIG and www.ipni.net. Item # 30-3220

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A. Right Source

1. Credit nutrients from manure and composts.

In order to calculate the amount of available nutrients, manure should be analyzed for ammonium-N, organic-N, total P and K as well as density and percent solids. Manure P and K tend to become nearly 100% plant available over time. However, not all N in the manure can be credited to crops; the method and timing of manure application influences the amount of available N with the greatest N credit for manure that is spring injected or surface applied and incorporated within one day (CUAFS 4; OMAFRA, 2002; OMAFRA, 2008).

2. Credit N from previous crops.

Previous crops can contribute to the total amount of N available for the next crop, especially legume forages (such as alfalfa, trefoil, or clover), but also perennial grasses managed for hay or pasture can supply large amounts of N when such stands are rotated to other crops (CUAFS 21). Smaller credits are provided by soybeans and winter cover crops. Corn grown for grain and wheat with straw returned to the soil provide the least amount of available N for the next crop, because the high C:N ratio of the crop residues results in temporary immobilization of N in the soil. (Stewart, 2007).

3. Choose a fertilizer nutrient source to suit the crop, soil, and placement.

The choice of source is influenced by the need for nutrient elements that accompany the main nutrient. Common sources of N include anhydrous ammonia, urea, urea-ammonium nitrate, ammonium sulfate, ammonium nitrate, and potassium nitrate. Urea is prone to volatile losses of ammonia when surface-applied, especially when soils are moist, but no precipitation is expected in the days after application. Common sources of P include monoammonium and diammonium phosphate (MAP and DAP), with MAP preferred in starter fertilizers (OMAFRA, 2002). Triple superphosphate is used in blends with potash to fertilize forage legumes. Common sources of K include muriate of potash, sulfate of potash, and sulfate of potash-magnesia. Some crops are sensitive to the chloride in muriate of potash, but the main crops used in dairy farm rotations are not.

Cover crops can help reduce risk of nitrate leaching, improve soil fertility, increase soil organic matter, and minimize surface runoff and erosion.

4. Assess use of enhanced-efficiency N sources.

Many new N products are moving to market: some polymer-coated, some chemically stabilized, some with inhibitors of urease and/or nitrification, and some with combinations of these. Are these products better than split application? Not necessarily everywhere, but for many soils and conditions, split application entails risks and adds extra fuel costs. Examples of risks occur in years when the soil may be too wet at side-dress time to get on to the field, or when soils are so dry that side-dressed N—even in fluid form—does not get to the roots. Controlled-release products have the potential to be more reliable and more convenient in such situations. But weather and many other soil factors can influence the rate of release, so it's important to evaluate these products to find which performs best in your own specific growing conditions. On-farm testing is key (Grant, 2005), especially since little research has been done on these products in northeastern North America.

B. Right Rate

5. Measure soil nutrient supply.

Soils can supply large amounts of nutrients through mineralization of soil organic matter. If this nutrient pool is not taken into account when making fertilizer application decisions, over-application of fertilizer nutrients can occur. Soil sampling for less mobile nutrients such as P and K should be done every 2 to 3 years; preferably at the same point in the rotation each time (CUAFS 1). The depth of sampling should be the same as was done in the research that led to the fertilizer recommendations (usually 6 to 8 in.). Forage harvests remove large amounts of K so it is critical to monitor levels closely, since deficiencies can cut yields but excesses can cause imbalances in the feed ration for dry cows. A Pre-sidedress Soil Nitrate Test (PSNT), taken when corn seedlings are 6 to 12 in. tall, can be a meaningful indicator of organic N supply (soil plus sod and manure N credits) and the probability of a response to extra N (CUAFS 3). Recent research in New York suggests that the Illinois Soil Nitrogen Test (ISNT) is a useful tool for field by field asjustments in N management, but sod and manure N credits need to be taken into account as well (Klapwyk and Ketterings, 2006; CUAFS 36).

6. Maintain soil pH.

Soil pH governs the availability of soil nutrients. For interpretation of soil test pH, see CUAFS 5, and for lime recommendations, CUAFS 6 and 7.

7. Calculate nutrient removal and field balance.

The Penn State Agronomy Guide discusses how to maintain soil test levels in an optimum range: "The recommendation for an optimum-testing soil is designed to offset crop removal in order to maintain the nutrient in the optimum range" (Penn State, 2007-2008). The amount removed can be determined by measuring the yield of the crop harvested, and analyzing harvest for its nutrient content. Tools that help calculate a field nutrient balance include the NMAN software for Ontario (OMAFRA, 2008) or CUAFS 28.

8. Determine crop yield potential and nutrient demand.

Fertilizer recommendations are often derived taking into account expected yield, or yield potential, of the crop to be grown Ketterings et al., 2003; Stewart, 2007). When these estimates of yield potential are unrealistic, recommendations will be inappropriate as well. The most realistic estimates of yield potential are obtained by using measured yields from past years, projecting forward any trend in yield improvement, or using the best 4 of the past 5 years. Yield potential estimates are provided in relation to soils of New York State (Ketterings et al., 2003).

9. Estimate most economic rates at current prices.

In some states and provinces, response curve data are available that allow for an adjustment to rates depending on the relative prices of fertilizer N and the crop (price ratio). Examples are found in the Ontario Corn N Calculator (Stewart, 2007) and in the Ohio ENRCC (2008). However, in practice fertilizer and crop prices are often tightly linked. In addition, the crop price is not known at the time of fertilizer application unless the crop is pre-sold on the futures market. Rate adjustments are usually relatively small—about 10 to 20% going from the lowest to the highest price ratios encountered—where responses are expected to be large. When input prices are high, it is important to avoid drastic reductions in any one single input that is critical to achieving full yields.

10. End-of-season evaluation for appropriate N rates.

The late-season stalk nitrate test reflects N availability during the growing season, allowing evaluation and future fine-tuning of N management for each specific field (CUAFS 31). A post-harvest soil nitrate test may also provide for such evaluation, but results are more difficult to interpret as low levels could result from substantial losses during the growing season rather than application rates matching crop demand.

C. Right Time

11. Assess split-application to match crop nutrient uptake.

Being vulnerable to losses, N applied too early poses more risk of loss than when applied just before the period of rapid uptake, especially in the humid temperature climate of the Northeast. Corn typically does not begin taking up N rapidly until the plants are 6 to 12 in. tall. However, the development of the seedling requires adequate N availability as well. The starter should include sufficient N to ensure vigorous establishment and growth of the seedling. The remaining N needs can then be applied as a side-dress when the seedlings are up to 12 in. tall. Forages cut several times per season are often best fertilized after each cutting.

12. Crop scouting and plant analysis.

Transient deficiencies of nutrients can impact crop performance, and even crops that look okay maybe suffering from "hidden hunger". Scouting for nutrient deficiencies can most economically be done when scouting for pests. A regular program of monitoring both visual symptoms and nutrient levels in the plant tissue can help diagnose nutrients that either limit crop yield or pose risks of excess in the dairy diet (Mills and Jones, 1996; Cherney et al., 1997). Foliar applications may be required to correct deficiencies.

13. Manage cover crops for optimum nutrient-release timing.

Cover crops can help reduce risk of nitrate leaching, improve soil fertility, increase soil organic matter, and minimize surface runoff and erosion (Penn State, 2007-2008; OMAFRA, 2002). Little information is available on nutrient credits produced by cover crops. Legumes such as hairy vetch and red clover often produce the largest N credits. Ryegrass tends to result in N immobilization in the first 2-3 weeks after termination, possibly increasing the early season N requirements of the following crop (OMAFRA, 2002). Dates of seeding and killing of cover crops have a large influence on their nutrient release to the next crop.

14. Assess optimum timing to suit tillage system.

When soil conservation is practiced, tillage occurs less frequently and thus there are fewer opportunities to distribute fertilizer throughout the rooting zone. Banded applications with planting become more important. Since leaving N on the surface risks ammonia volatilization, and leaving P on the surface increases risk of P runoff, fertilizer applications that either inject or incorporate nutrients into the soil are preferred, especially in no-till or reduced tillage systems. Applying starter N is recommended for all tillage systems, but is particularly important in no-till corn to overcome the slower N mineralization often present early in the season (OMAFRA, 2002). In conservation tillage, K also gains more importance in starter fertilizers for corn (Vyn et al., 2002).

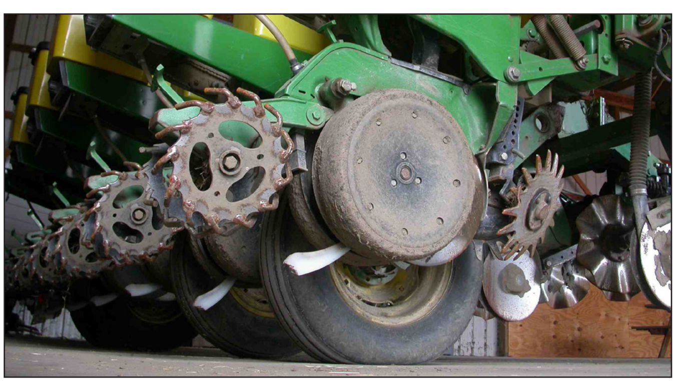
D. Right Place

15. Calibrate equipment for accurate metering and placement.

Maintaining and calibrating the machinery used for applying fertilizers is essential to delivering the right rate. Since fertilizers can be corrosive, cleaning the equipment after use, and adjusting for wear, is necessary. It is also important to ensure that blends are made from materials that are consistently sized to avoid segregation and enable uniform mixing. How is it done? Consult the machinery operator's manual.

16. Assess possibilities for with-seed and band placement.

Corn, cereals and other crops need N, P, and K especially when their seedlings are young. Placement of fertilizer near the seed ensures access to the fertilizer by young seedlings, and placement in a band concentrates the nutrient to minimize fixation by the soil. However, research in New York showed that if soil test P levels are above the agronomic optimum, a yield response to banded P in the starter is not likely (Ketterings et al., 2005b). Small amounts of a P-rich fertilizer placed with the seed of corn were observed to boost grain yields in Ontario, even at soil test levels where no response to broadcast or banded P was expected (Lauzon and Miller, 1997). Such responses may be limited to shorter-season growing environments. Rates placed with the seed should be kept very low and cannot be sufficient to replace crop removal. Recommendations for maximum rates of N plus K, urea or diammonium phosphate in a band are given in section 2.11.3 of Cornell University (2008).



Corn planters for conservation tillage provide the choice of placing fertilizer with or beside the seed, supporting soil-test-based decisions.

Table 7-4 of OMAFRA (2006) provides maximum rate recommendations for Ontario soils, and includes maximum rates for seed-placed fertilizer as well.

17. Management zones for variable rate application.

Soil test levels tend to vary strongly among fields, owing to differences in past fertilizer and manure history, crop rotation and productivity. To avoid over-application on some fields and deficiencies on others, fertilizer management should be specific to the soil test level and crop needs of each field. Within-field variability can also be high. A recent study on 23 farm fields in Ontario, Canada found substantial spatial variability in soil test P, K and pH levels. However, mapping the spatial pattern using soil testing alone would be difficult (Lauzon et al., 2005). Management zones may best be delineated using combinations of measured information on yields, soil testing, and soil map units for each field (Doerge, 1999).

18. Apply soil survey information.

In some states, soil fertility recommendations are directly linked to soil map units. For example, New York N recommendations use soil-specific data on hydrology, N uptake efficiency, soil N supply, and yield potential (as documented in Ketterings et al., 2003), and similarly for K. Soil survey information may also be helpful in identifying management zones within fields. For most reliable recommendations, it is very important to ensure that soil is correctly classified and that human modifications to soil properties are taken into account. For example, if a soil map indicates poor drainage, but the soil seems well-drained, it may be that artificial drainage has modified this characteristic of the original soil. This could impact yield potential, soil N supply, fertilizer uptake efficiency, and overall nutrient needs of the crop.

19. Use risk indices to protect water quality.

In New York, the Nitrate Leaching Index identifies the relative N leaching risk potential of a field based on soil hydrological group and expected precipitation (at township level) in fall and winter (Czymmek et al., 2003). Similarly in Ontario, an N Index based on soil hydrological group and crop N removal is calculated in the NMAN software (OMAFRA, 2008). Use of these indices ensures that high-risk soils are identified in the nutrient management planning process and receive the greatest attention to minimizing losses of nitrate to groundwater. The use of a P Runoff Index gives a relative ranking of the influence of all major source and transport factors influencing runoff losses of P (Sharpley et al., 2003). In the Ontario NMAN software the P Index determines setback distance requirements for P application from surface water. Specific indices, with software to facilitate calculation, are available for most states and provinces. It should be recognized that implementation of P-Index-based management does not address systematic cropland P imbalances.

20. Incorporate or inject volatile N sources.

When N sources containing urea or ammonium (urea, urea-ammonium nitrate, anhydrous ammonia, ammonium nitrate, and ammonium sulfate) are surface applied without incorporation, ammonia losses can be high, especially when these fertilizers are applied to moist soils and no rain is expected in the days following application. Loss can be minimized by incorporating the fertilizer into the soil as soon as possible (either by rain or mechanically), or by using a controlled-release or stabilized form of urea (Grant, 2005). Loss of N as ammonia is temperature sensitive. When urea is applied as a topdress to an actively growing crop in cool temperatures, as is often the case with winter cereals, losses are small. Based on laboratory research conducted over 40 years ago (Ernst and Massey, 1960) it has been concluded that ammonia losses from applied urea remain reasonably small at temperatures below 60ºF if the soil pH is 6.5 or less (Overdahl et al., 1991). Following first- and second-cut grass forage, however, alternative sources of N should be considered unless urea can be applied directly before irrigation or rain.

Whole-farm nutrient accumulation results when the amount of nutrients coming onto the farm in the form of purchased feed inputs exceeds the amount that leaves the farm in the form of milk, animals, and other products sold. Studies on the nutrient balances of dairy farms show that BMPs that balance inputs and outputs have the potential to increase profitability while reducing nutrient loss to the environment (Rotz et al., 2005; Djodjic et al., 2005). Implementation of the fertilizer BMPs listed above helps improve the whole-farm nutrient balance.

How Does Your Fertilizer Management Rate?

Using the chart, assess your farm's level of BMP adoption. Count two points for each "best" and one for each "making progress" as shown in **Appendix 1**. Not all farms can adopt all BMPs. However, maximizing the adoption of these practices for fertilizer management can contribute to the short- and long-term sustainability of dairy farming systems.

Scorecard

36-40	excellent
31-35	very good
26-30	good
21-25	making progress
16-20	fair
0-15	improvements needed

Author Infornmation

Dr. Tom W. Bruulsema is IPNI Northeast North America Region Director, located at Guelph, Ontario (e-mail: tom.bruulsema@ipni.net). Dr. Ketterings is Associate Professor, Crop and Soil Sciences, at Cornell University; she leads the Nurient Management Spear Program in New York State.

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Brian Boerman, Agricultural Consulting Services, Inc.

Shawn Bossard, Cornell Cooperative Extension

Tibor Horvath, USDA-NRCS-NY (joined USDA-NRCS-SC as Conservation Agronomist in January 2008)

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Appendix 1. Best Management for Fertilizers on Northeastern Dairy Farms.

Practice	Best	Making Progress	Improvements Needed
RIGHT SOURCE			
1. Credit nutrients from manure and composts	Analyze for total and available nutrients	Occasional or partial analysis	No nutrient credits considered
2. Credit N from previous crops	Adjust N rates based on research data for credits from previous crops, particularly legume hay or sod	Reduce corn N rates when following alfalfa	No consideration of N credits from previous crops
3. Choose a fertilizer nutrient source to suit the crop, soil, and placement	Source chosen to suit application method , blend compatibility, crop needs and sensitivities, and price	Compare anhydrous ammonia, urea, urea-ammonium nitrate, ammonium sulfate, and ammonium nitrate for price	No consideration of sources
4. Assess use of enhanced-efficiency N sources	Use controlled-release N or inhibitors to match N release to crop N needs where split application is impractical	Partial use of controlled-release sources or inhibitors	Not considered
RIGHT RATE			
5. Measure soil nutrient supply	Soil analysis for pH, P, K, and other nutrients every 2 to 3 years	Most soils analyzed within past 5 years	Soils not sampled in last 10 years
6. Maintain soil pH	Lime applied in fall whenever required	Lime applied occasionally	No testing for soil pH
7. Calculate nutrient removal and balance	Calculated from measured yield and nutrient content	Based on estimated yields and nutrient content	Not considered
8. Determine crop yield potential and nutrient demand	Measured yields from at least 5 past years	Measured yields from at least 3 past years	Desired yield level, or not considered
9. Estimate most economic rates at current prices	Use a calculator based on regional crop response data	Use a generalized calculator based on price ratios	No consideration of relative prices of crop and fertilizer
10. End-of-season evaluation for appropriate N rates	Use late season cornstalk nitrate test or soil nitrate test	Monitored occasionally	Not monitored
RIGHT TIME			
11. Assess split application to match crop nutrient uptake	Split applications used wherever practical	Partial use of split applications	Not considered
12. Crop scouting and plant analysis	Done regularly and systematically for each field	Occasionally done to diagnose problem areas	Rarely or never
13. Manage cover crop for optimum nutrient-release timing	Cover crop killed at optimum time for yield of following crop	Cover crop killed in fall	No cover crop
14. Assess optimum timing to suit tillage system	Fertilizer applications with conservation tillage or planting	Fertilizers applied before conservation tillage or planting	Not considered
RIGHT PLACE			
15. Calibrate equipment for accurate metering and placement	Maintain and test application equipment annually	Equipment well maintained	Equipment functioning poorly; rate adjustment "seized"
16. Assess possibilities for with-seed and band placement	Banded or with-seed starter use based on soil test	Banding or with-seed starter for some crops	No equipment for directed placement
17. Management zones for variable rate application	Management zones based on multiple-year yield data	Zones delineated by expected productivity	Not considered
18. Apply soil survey information	Detailed soil survey maps available and in use for each field	Soil survey maps used for some fields	Soil survey information not used for any fields
19. Use risk indices to protect water quality	Use Nitrate Leaching Index and Phosphorus Index	Maintain unfertilized buffer of set width from watercourses	Full field practice to stream bank
20. Incorporate or inject volatile sources	Manure injected; urea banded or soil-incorporated	Manure incorporated within one day after application	Manure or urea surface-applied

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CUAFS 1. Soil Sampling for Field Crops.

CUAFS 3. Pre-sidedress Nitrate Test.

CUAFS 4. Nitrogen credits from manure.

CUAFS 5. Soil pH for Field Crops.

CUAFS 6. Lime Recommendations for Field Crops.

CUAFS 7. Liming Materials.

CUAFS 21. Nitrogen Needs of 1st Year Corn.

CUAFS 28. Removal of Phosphorus by Field Crops.

CUAFS 31. Late Season Stalk Nitrate Test

CUAFS 36. Illinois Soil Nitrogen Test (ISNT)

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FOUNDATION FOR AGRONOMIC RESEARCH

International Plant Nutrition Institute (IPNI)
3500 Parkway Lane, Suite 550 • Norcross, GA 30092-2806 U.S.A.

Phone: 770-447-0335 • Fax: 770-448-0439 • E-mail: info@ipni.net • Website: www.ipni.net

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