

Best Management Practices for Fertilizer



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This publication is one of a series on fertilizer best management practices (BMPs), prepared by regional directors of the Potash & Phosphate Institute (PPI)/Potash & Phosphate Institute of Canada (PPIC). This effort is in cooperation with the Foundation for Agronomic Research (FAR) toward fulfilling the goals of a 3-year Conservation Innovation Grant (68-3A75-5-166) from the USDA-Natural Resources Conservation Service (NRCS). The intent of these publications 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.

Fertilizer BMPs for the Northern Great Plains – How Do You Measure Up?

WE ARE HEARING a lot about best (beneficial) management practices (BMPs) these days. Much of this interest in BMPs for agriculture is the increasing awareness that how we manage our soils and landscapes can have a large impact on the surrounding environment. As stewards of the land, farmers in the northern Great Plains have implemented soil conservation practices that exceed any other resource conservation activity in North America. **The resulting reduction in wind and water erosion and moisture conservation have improved soils, and increased crop yields and whole-farm economics.**

Fertilizer nutrients play a major role in meeting the crop yield and quality goals of modern agriculture. With reduced tillage seeding systems, many semiarid regions have been able to extend crop rotations, thus reducing the use of fallow for moisture conservation, and increasing the need to replace the nutrients removed by the increased cropping intensity. How we handle these fertilizer inputs provides the foundation for fertilizer BMPs and positive economic returns from fertilizer use.

BMPs focus on site-specific recommendations, intensive management, improved efficiency, and environmentally sound use of crop production inputs. It is important that these management practices be proven in research and verified through field evaluation. It is also important to remember that BMPs are site-specific; they vary from one region to the next and one farm to the next depending on current and historic soil, climate, crop, and management expertise. Ultimately, it comes down to past research,

farmer experience and the knowledge of the local soil and climatic conditions that dictate the success of a particular BMP in a specific field.

There are three general management practices that foster the effective and responsible use of fertilizer nutrients. These are:

- 1) Matching nutrient supply with crop requirements,
- 2) Fertilizer application, and
- 3) Minimizing nutrient transport off fields.

Within each of these general categories, there are a number of specific practices that we could classify as a BMP.

1. Matching nutrient supply with crop requirements

This involves using all the available information to establish the soil nutrient status and crop requirements prior to making fertilizer application decisions. Specific BMPs include soil testing, setting realistic yield goals, and balancing nutrient inputs with crop removal at optimum soil test levels.

a) Soil Testing

The main science-based tool we have to make estimates of soil nutrient supply on agricultural lands is soil testing. The soil testing process is based on soil samples being taken from representative areas in a field, analyzed using a chemical extraction appropriate for the soils in the region, and either correlated with plant nutrient uptake or calibrated with crop yield (Karamanos, 2003). Resulting fertilizer recommendations would be based on how a particular crop responded to a nutrient, using the average response from a multi-year and multi-site data set. Given that a number of non-fertility factors impact final crop yield (environmental conditions, pest, etc.) it is important to remember that fertilizer recommendations based on correlation with a field response database may account for only 50% of the yield



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variation in the field. It is for this reason that fertilizer recommendations are often made based on yield potential, a reflection of soil water at seeding and past management conditions for a specific field (Jackson, 1998; 2000).

Periodic soil testing of all the fields on a farm acts as an excellent gauge of nutrient sustainability for crop production. These soil test results become part of a record keeping system, including prior soil test data, fertilizer and manure applications, and crop nutrient removal. Together this information acts as an indicator of whether soil fertility is increasing, decreasing, or remaining constant, and leads to responsible nutrient management decisions. If nutrient levels in a soil are allowed to decline to the point of limiting yield potential, substantial economic losses and losses in inherent soil fertility can be expected. Depletion of reserve soil fertility takes years of restoration with fertilizer and/or manure to regain optimum productivity (Roberts, 1991).

b) Plant Analysis

The term plant analysis refers to the total or quantitative analysis of nutrients in plant tissue. Unlike tissue testing, a qualitative measure of nutrient content, plant analysis works with soil sampling to evaluate soil fertility and overall nutrient availability. Plant analysis is used in-crop to help evaluate nutrient deficiencies and take corrective action on the current crop or future crops. It can be a powerful tool in adding accuracy to the monitoring process as nutrient management plans are implemented. While a range of nutrient concentrations is often provided to help guide the plant analysis process, concentrations can vary with crop, variety, plant part sampled, growth stage when sampled, environment, geographic area, and other factors. Collecting samples from both 'poor' and 'good' areas of a field growing the same crop can be a useful means of establishing the role of a deficient nutrient in crop production, especially when soil samples are taken from the same area.

c) Establishing Realistic Yield Goals

A realistic yield goal is one developed from past performance in a field and use of the most current information on those factors which most influence yield. In semiarid agriculture, water is one of the major driving variables in crop yields. Nutrients also play an important role in improving the use of water by crops by increasing the amount of yield per unit of water used (Zentner et al., 2002). As a result, a field-specific yield goal is determined based on available soil moisture at seeding, precipitation probabilities for the region, crop water use, and soil residual nutrient levels. For nitrogen (N) specifically, the result is a minimum fertilizer recommendation followed by in-season crop monitoring at critical growth stages based on plant density, tiller formation, and spikelets per head. If

| | | |
|----------------|----------------------------------|-----------------------------|
| 1997 – 46 bu/A | | |
| 1998 – 42 bu/A | Average = 41 (46 not using 2001) | Realistic yield goal |
| 1999 – 51 bu/A | Highest yield recorded = 58 bu/A | 46 x 110% = 51 bu/A |
| 2000 – 44 bu/A | | |
| 2001 – 24 bu/A | | |

yield estimates indicate a larger yield than fertilized for originally, additional N can be top-dressed before the crop becomes too advanced.

A common approach to setting realistic yield goals is selecting a value somewhere between an above average yield and a past maximum yield obtained by you on that specific field, or one of similar production and management history (Rourke et al., 1993). Setting a target of 10% above the 3- to 5-year average of crops not suffering a severe yield loss due to drought or pests is also a commonly suggested method. This requires that individual field records be maintained, and that only those fields of similar production potential be considered in making estimates. An example for a wheat yield is shown below and considers the best 4 of the previous 5 years, scaled up by 10%. While short of the maximum yield grown, it does provide a means of striving for yield increases. It is important to remember that, over time, yield goals will increase as long as the average yield continues to increase.

d) Nutrient Budgets

There are a number of situations where crop advisers and farmers find that they can make fairly good estimates of crop nutrient requirements based on what was grown and what was applied in a specific field. Information such as crop yield, grain protein concentration, and straw management can all be used to establish the status of a nutrient such as N. For phosphorus (P) and potassium (K), the year-to-year variation in plant-available supply is minor, and annual application based on a balance between soil test levels and crop requirements can avoid depletion or over application. In no way is the determination of a balanced nutrient budget an appropriate replacement for soil testing, given the absolute need to use soil testing to establish a nutrient supply starting point. Often this type of input/removal assessment is carried out in the years between which comprehensive soil sampling is conducted.

There are nutrient removal information sources available on the internet. Check out the PPI/PPIC website >www.ppi-ppic.org/nutrientremoval<.

While the values in these tables represent averages from field sampled crops, using your own information is always the best source whenever possible.

2. Fertilizer Application

The way we handle fertilizers can have a major impact on the efficiency of nutrient use by crops and potential impact on the surrounding environment. In all instances, we are striving to improve fertilizer-use efficiency by increasing the bushels per acre for each unit of nutrient applied without sacrificing yield potential. This is especially true

for N, the major nutrient removed from the soil by most of our annual grain crops and perennial forages. Efficient fertilizer management means paying close attention to the "Four Rights" of fertilizer application.

a) Right Balance of Nutrients

Most crop advisers have heard about Liebig's Law of the Minimum, which states that the yield of a crop will be determined by the element present in most limiting quantity. In other words, the deficiency of one nutrient cannot be overcome by the excess of another. Soil testing and use of crop nutrient uptake and removal information are important guides to ensuring that balance among soil available nutrients plus applied fertilizer prevents nutrient deficiencies from limiting crop yields or some nutrients from being used inefficiently.

An example of proper nutrient balance is illustrated in a winter wheat study conducted in Manitoba (**Table 1**). Soil testing indicated a deficiency of both N and P at this site. The P fertilizer was seed row-applied at planting, and the N spring broadcast as ammonium nitrate (NH_4NO_3) immediately prior to crop growth and N uptake. While application of N alone increased yields more than P alone, it was the balance of N + P that optimized the crop response. To maximize yields using the highest rate of N, the highest rate of P was also required. Similar examples can be shown with N and sulfur (S) on canola.

Table 1. Winter wheat response to fertilizer N and P application in Manitoba.

| P ₂ O ₅ rate, lb/A | N rate, lb/A | | N efficiency lb grain/lb N |
|--|-------------------------|-----|-------------------------------|
| | 0 | 110 | |
| | -- Grain yield, bu/A -- | | |
| 0 | 15 | 48 | 26.2 |
| 20 | 17 | 55 | 30.0 |
| 40 | 20 | 65 | 35.5 |

Grant et al., 1985

b) Right Fertilizer Form

Plants take up the bulk of their nutrients from the soil in forms which are best suited to their use in the crop. Nitrogen is taken up as nitrate (NO_3^-) and ammonium (NH_4^+), P as primary (H_2PO_4^-) or secondary (HPO_4^{2-}) orthophosphate, K in its elemental form (K^+) and S as sulfate (SO_4^{2-}). Fertilizers are formulated to be either in these plant-available forms, or converted to these forms after application to the soil. In some instances, this conversion limits immediate use by the plant, requiring specific application management for efficient use. An example of this is elemental S, which must first be converted to SO_4 to be plant-available, a process that requires surface application of the fertilizer and up to 12 months for the conversion to be completed. In other instances, a fertilizer form may be selected to delay conversion to a plant-available form, minimizing potential losses from the soil. An example of this would be fall applied N in the NH_4 form, which in cool soils is slow to convert to the NO_3 form where it is subject to potential losses by leaching in coarse textured soils, or denitrification in saturated soils.

c) Right Placement

An important part of optimizing crop response to a fertilizer nutrient is ensuring that the nutrient is placed in such a way that it provides rapid uptake by the crop, and reduces potential losses. The mobility of a nutrient in the soil plays the biggest role in how important placement is. For example, low mobility of P in calcareous soils means that short-term crop utilization of the P is improved considerably when it is placed close to the germinating seed. When broadcast-applied on low P soils, optimum P rates are generally twice that which is required when seed placed or side banded, and incorporation with tillage is sometimes required to improve exposure to plant roots.

Placement can be a powerful management tool to minimize N losses. Under ideal conditions, the goal is to apply the N so that it is in the plant-available form and close proximity to the plant roots. Deep banding of fertilizer N is a very important BMP, widely used on the northern Great Plains. It has been shown to reduce per-unit production costs by increasing fertilizer efficiency (Harapiak et al, 1986). Seeding system also plays an important role on the impact of fertilizer placement. When incorporated with tillage, barley showed a similar response to broadcast and in-soil band application (**Table 2**). However, when the broadcast urea is applied onto the residue-covered surface of a zero tillage field and not incorporated, grain yield was reduced by 31% relative to an in-soil band. When incorporation is not an option with surface applied fertilizer N, selecting a less volatile form such as NH_4NO_3 , or timing application of urea to avoid warm and wet conditions, can help minimize N losses.

Table 2. Barley yield response to tillage and fertilizer urea placement.

| | Conventional tillage | Zero tillage |
|----------------------|---------------------------|--------------|
| | --- Grain yield, bu/A --- | |
| Broadcast, 65 lb N/A | 62 | 45 |
| Band, 65 lb N/A | 64 | 65 |

Source: Malhi and Nyborg, 1992

d) Right Timing

The demand for a nutrient by a growing crop generally varies through the growing season, with the highest uptake associated with the period of most rapid growth. Timing fertilizer applications so that they provide a plant-available supply of nutrients when the crop needs them is the desired goal. Plants subject to a deficiency during specific periods of growth may not recover to achieve full yield potential. An example of this is the impact of an early season P deficiency on wheat, where an absence of adequate P during the first 4 to 6 weeks of growth limited tiller and root formation by the crop (**Table 3**). Even when the P deficiency was corrected after 4 to 6 weeks, the negative impact on the crop had already occurred, illustrating the critical early season response.

BMPs for Fertilizer Management in the Northern Great Plains

| Practice | Best Practice | Making Progress | Improvements Required |
|--|--|---|---|
| Diagnostic | | | |
| Soil testing | Annually test for N where it is applied. Less than every 3 years for P and K. | Less than one-fourth to one-third of fields tested each year. | Never test, or last soil test more than 10 years old. |
| Plant tissue analysis | Routinely use tissue sampling to evaluate effectiveness of fertility program. | Occasionally use tissue sampling for diagnostic purposes. | No tissue samples collected. |
| Yield goals set | Develop crop- and field-specific yield goals based on measured yield history and crop sequence. | Develop yield goals for each crop on the farm, regardless of field. | No yield goals considered in planning, or arbitrary or unrealistic yield goals are used. |
| Nutrient budgets | Consider last year's crop removal and this year's yield goal, in matching fertilizer applied with current soil test results. | Consider crop nutrient removal based on a desired yield goal, or replace last year's removal regardless of soil test level. | No consideration for crop nutrient removal or past production. |
| Fertilizer Application | | | |
| Right balance | Meet the specific needs of other nutrients when N rates are set. | Fertilizers applied as a fixed blend based on N needs. | N rates set with no consideration to other nutrient needs. |
| Right form | Consider N form when selecting fertilizer types and application timing. | Incorporate broadcast urea or UAN within 24 hours, unless on soils with low pH or low soil temperatures. | Unaware of any form effects. Surface broadcast urea or UAN with no incorporation in warm weather. |
| Right placement | Use band placement of most N, and place at least some of the less mobile nutrients near seed. | Broadcast and incorporate all fertilizer throughout surface soil. | Broadcast application. |
| Right timing | Consider timing of crop uptake and plant source availability when considering time of application. | Apply all N before seeding. | All nutrients applied well in advance of seeding. |
| Site-specific management | Evaluating field variation when making fertilizer application decisions. | Fields are grouped based on the dominant soil-landscape formation. | No consideration to field variability in fertilizer application. |
| Minimizing Nutrient Losses | | | |
| Leaching avoidance on sensitive soils and landscapes | Full use of N BMPs: soil NO ₃ testing, split N application, fall cover crops, groundwater monitoring. | Use of half the BMPs at left. | No consideration of potential leaching losses or use of BMPs. |
| Conservation tillage | Seed using a low disturbance one-pass or two-pass direct seeding system. | Minimum tillage used to maintain reasonable (30%) residue cover. | Conventional tillage with the majority of the residue buried or burned. |
| Buffer strips | Have buffer strips next to surface waters and reduce tillage near the area to minimize soil transport. | No buffer maintained, but use no-till adjacent to surface water edge. | Surface water not considered in management of fertilizers. |

Table 3. Impact of P deficiency during a 10-week growth period on the development of tillers and secondary (tiller) roots of wheat.

| Weeks without P in 10-week growth period | Tillers/6 plants at week 10 | Secondary roots/6 plants at week 10 |
|--|-----------------------------|-------------------------------------|
| Control – no deficiency | 27.7 | 120.0 |
| First 2 weeks | 22.3 | 76.2 |
| First 4 weeks | 10.3 | 21.6 |
| First 6 weeks | 9.4 | 19.8 |

Adapted from Boatwright and Viets, 1966

Where fertilizers are subject to transformation in the soil, application timing can play a critical role in optimizing crop nutrient response. Nitrogen is likely the nutrient which is influenced most by the soil moisture and temperature conditions, which demands management attention. A project on heavy clay soils in Manitoba found that fall N application timing had less of an impact on crop yield response in upland landscape positions than lowland areas (Table 4). Even though all of the urea N treatments were banded in this study, delaying the N application timing improved the crop response with the wetter soil conditions in the lowland areas of the field.

Table 4. Effect of landscape position on wheat grain yield response to time of N band application in Manitoba.

| | Upland area, 33 lb N/A ¹ | Lowland area, 28 lb N/A ¹ |
|-------------------------------|-------------------------------------|--------------------------------------|
| - - - Grain yield, bu/A - - - | | |
| Early fall (mid-Sept) | 37.9 a ² | 29.1 c |
| Mid fall (early Oct) | 38.0 a | 28.7 c |
| Late fall (Mid-Oct) | 37.2 a | 32.4 ab |
| Spring (at seeding) | 36.7 a | 32.5 a |
| Early fall + inhibitors | 36.7 a | 29.4 bc |
| Check (no N) | 28.8 b | 18.5 d |

Source: Tiessen et al., 2003.

¹ Value represents the average soil residual NO₃-N, 0 to 12 in. depth, at the four trial locations (33 lb/A upland, 28 lb/A lowland).

² Yields followed by the same letter within columns are not significantly different.

e) Site-Specific Nutrient Management

Fertilizing soils rather than fields is an emerging BMP that continues to gain in popularity with technology development. Using some form of field diagnostic, such as intensive soil sampling, soil sensing, yield mapping, or scouting records, whole fields are divided into management units where the fertilizer application used is independent of the rest of the field. This form of site-specific fertility management assures that nutrient needs are properly identified and appropriate corrective fertilizer applications are made only where required. This management practice can take into account the natural variation in soil fertility and nutrient supply.

Optical plant sensors have also been developed that use the crop biomass as an indication of N sufficiency. These

sensors use a reference biomass for the specific crop to assess the need for added N at a specific growth stage. The sensor is mounted on a field applicator capable of varying the N rate on-the-go. This technology uses the plant as an indicator of N sufficiency, integrating the variety with soil and fertilizer N supply. In instances where field variability of N is large, this type of application prevents the over-application characteristic of fixed field rates in those areas where the soil N supply is sufficient.

3. Minimizing Nutrient Transport Off Fields

From an environmental impact perspective, the goal of land managers should be to retain soil and associated nutrients within the boundaries of a field and the rooting zone of the crops grown. Fertilizer application based on soil testing and realistic yield goals helps to ensure that proper rates are recommended and applied. This improves plant nutrient use efficiency, and lessens the potential for residual nutrients to accumulate to excessive levels in a field and pose an environmental threat.

a) Nutrient Leaching

Retention of soluble nutrients in the rooting zone of crops ensures efficient recovery and efficient use in food production systems. Leaching occurs when excessive residual nutrients are left in the soil profile and moved below the rooting zone (48 in.) by precipitation. While leaching is not a common problem in most semiarid regions, historic use of fallow has been shown to leave NO₃-N accumulated below the rooting zone of crops. While there are no reported incidences of P leaching through fertilizer use at soil test recommended rates, leached P has been reported with the application of livestock manure at rates grossly in excess of crop requirements.

While excess nutrients can result in leaching, withholding needed fertilizer may be more damaging to the environment than applying fertilizer. When N is applied alone, and not in balance with required P, more leached N has been found below the crop rooting zone (Campbell et al., 1993; Schlegel et al., 1996). The balance of applied fertilizer N with P improved the recovery of N by the crop and removal in the grain, reducing the residual N left in the soil for leaching below the rooting zone (Figure 1). The same situation of NO₃ leaching has been observed with the use of livestock manure, where the timing of N release from this organic source is often out of synchrony with crop nutrient uptake, leaving residual nutrients in the soil and subject to potential leaching loss (Johnston and Janzen, 1992).

b) Conservation Tillage, Soil Erosion, and Carbon Sequestration

Farmers on the northern Great Plains are leaders in North America for conservation tillage practices with the adoption of no-till seeding systems. The retention of crop residues on the soil surface has significantly reduced the loss of soil by wind and water erosion, while at the same time improving moisture conservation and crop yields.

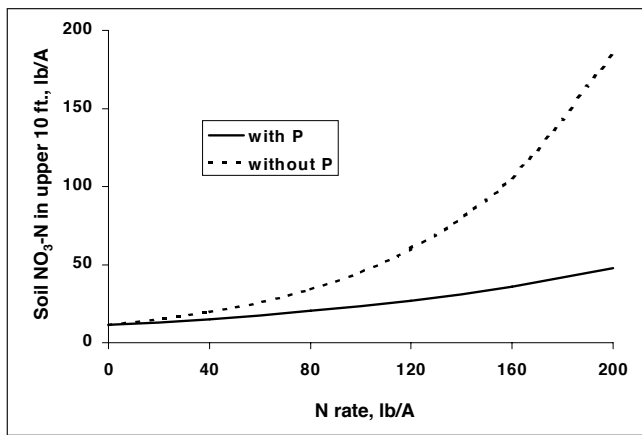


Figure 1. Effect of N and P fertilization on residual NO₃-N in the upper 10 ft. after 30 years of irrigated corn production (Kansas, Schlegel).

When fertilized according to soil test recommended rates, increased crop yields lead to higher levels of crop residues returned to the surface of no-till fields for erosion protection.

Crops grown with proper nutrition are also playing a major role in building soil organic matter. Increased crop residue production leads to increased residue incorporation to build soil organic matter levels. In long-term rotation studies across the semiarid region of western Canada, moderate applications of N and P fertilizer have been shown to increase surface soil organic matter content (Table 5). In these studies fertilizer N application not only increased the quantity of organic matter, but also improved the supply of organic N and the ability of the soil to replace plant available N (Biederbeck et al. 1984; Janzen, 1987; Campbell et al., 1990). The positive effects of fertilization can be directly attributed to the amount of crop residues returned to the soil. The application of fertilizer increases grain yields, and straw and root production, both of which support the formation of soil organic matter. This increase in soil organic matter also represents an increase in soil carbon (C) storage, or sequestration. By reducing tillage, the rate of soil C decomposition is decreased, and a new, increased equilibrium level of soil C is achieved. This sequestration of atmospheric C as stable soil organic matter has been shown to be one of the few means of producing a net reduction in atmospheric carbon dioxide (CO₂), a greenhouse gas.

c) Field Buffer Strips

The movement of N and P into surface waters with eroded soil poses a serious threat to aquatic ecosystems. While some nutrients are required for ecosystem function, too much can lead to a decline in productivity. Stopping soil erosion from agricultural lands has been a high priority for all farmers. Any eroded soil means loss of nutrients, organic matter, and future crop productivity. The adoption of conservation practices such as no-till and buffer strips

Table 5. Influence of fertilization on the average organic C and total N concentration in surface soils from long-term continuous wheat rotations on the Canadian Prairies.

| Location | Fertilizer | Organic C, % | Total N, % |
|----------------------------------|------------|--------------|------------|
| Swift Current (Brown soils) | P | 1.78 | 0.197 |
| | N + P | 2.15 | 0.226 |
| Lethbridge (Dark Brown soils) | None | 1.62 | 0.149 |
| | N + P | 1.88 | 0.171 |
| Indian Head (Black soils) | None | 2.48 | 0.198 |
| | N + P | 2.59 | 0.223 |

Sources: Biederbeck et al., 1984; Janzen, 1987; Campbell et al., 1990.

adjacent to surface water have been shown to reduce this unwanted movement of nutrients. In many instances where no-till field management has been adopted, soil erosion and water runoff have been significantly reduced. In Quebec, an on-farm program using forage buffer strips adjacent to surface water bodies found that total runoff of water was reduced by 48%, soil particles in the water were reduced by 90%, and nutrient losses were reduced by 69% for total N and 86% for total P. These results indicate the powerful filtering ability of a 3-meter (approximately 10 ft.) buffer strip in reducing nutrient losses from agricultural lands in a high precipitation region.

Taking Stock of Your Fertilizer Management

It is time to take stock of how you measure up in the use of fertilizer BMPs. Using the reference chart on pages 4 and 5, evaluate the number of categories under which you rank in the top two categories. If you cannot demonstrate a suitable fit in these top two categories you may want to re-evaluate some of your current management practices. Ensuring that we have either achieved, or are working towards, fertilizer BMPs is a measure of our production system success.

Many farmers in the northern Great Plains region have demonstrated a rapid adoption of these fertilizer BMPs. Soil testing, realistic yield goals based on available water, balanced fertilizer application, in-soil banding of fertilizer at seeding, and use of no-till seeding systems all demonstrate excellent progress to date. While continued adoption of these BMPs is critical, those BMPs which have positive economic impact have been and continue to be, rapidly adopted on farms. ■

Reference list is on back page.

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