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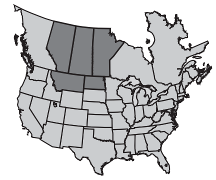

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Grain Protein Content in any One Year Comes from both Fertilizer Nitrogen and Soil Organic Matter

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PRODUCTION of field crops is one of the major activities of agriculture in the Northern Great Plains, and two of the major small grain cereal crops are wheat and barley. Most of the land where these crops are grown has now been farmed for close to 100 years. All grain crops contain protein and a component of protein is N.

During the initial years of crop production on these former grassland soils, crops were grown with no additions of crop nutrients. Crop yields were generally quite good, depending on the amount of moisture received during the growing season. Usually, moisture was and is the main limitation for crop growth. After a couple of decades of crop production, yields of crops began to decline even in years of adequate moisture. It was found in some areas that growing a N-fixing crop such as sweet clover and plowing it under as green-manure resulted in improved wheat growth the following year. The N added to the soil-crop system from the green-manured sweet clover supplied additional N, improving crop yields. This showed that the crops were limited in yield by a decline in plant available N. The initial abundant sources of N had been available through a process called mineralization. Mineralization is defined as a two-step biological process of decomposition where N in soil organic compounds is first converted to ammonium (NH_4^+) and in the second step the NH_4^+ is oxidized to nitrate (NO_3^-) (Henry 2003). Most of the grassland soils naturally had abundant levels of organic matter (OM) that had been built up and reached an equilibrium level since the soils began forming after the last ice age. The average levels of OM in the surface horizons of the major grassland soil zones in the Canadian Prairies are shown in **Table 1**.

Table 1. Average pre-cultivation OM levels in the major Chernozemic soil zones of Western Canada.

Soil zone Canadian (U.S.) taxonomic classes	Average pre-cultivation OM level (% by mass)
Brown (Aridic Boroll)	2
Dark Brown (Typic Boroll)	4
Black (Udic Boroll)	7

Source: Campbell et al., 1990.

Generally, cultivation of original grassland soils results in a loss of OM when the natural vegetation is cultivated under and cropped to annual field crops (Juma, 1999). Declining levels and quality of OM have been identified as one of the major sources of soil degradation (Coote et al., 1981). Nitrogen in the soil at any one time is mostly in the organic form, about 97 to 98%. It is contained in the organic molecules of soil humus, plant residues, soil fauna, soil microbes, or animal wastes.

N Fertilizer Use and N Removal from Fields

The amount of N added as fertilizer can at times equal the amount of N accounted for in the grain, but sometimes it is less than the N removed in the grain. For example, a 30 bu/A wheat crop with 13.5% protein contains approximately 43 lb of N/A: 30 bu/A x 60 lb/bu x 13.5% protein ÷ 5.7 = 42.6 lb N (AACC 2000). A wheat grower in this example may apply 50 lb N/A each year in anticipation of an average wheat crop of 30 bu/A. However, in a year of above average rainfall, the wheat crop may yield higher than normal, e.g. 40 bu/A. The higher than average yield usually results in a lower level of protein due to a greater amount of carbohydrate storage in the more plump kernels. Even so, the amount of N removed in the grain will be increased up to about 53 lb N: 40 bu/A x 60 lb/bu x 12.5% protein ÷ 5.7 = 52.6 lb N. The additional 3 lb N above the fertilizer N comes from mineralization of N from OM in the soil. Organic N mineralization is a biologically accomplished process that microbes do best when they have a warm and moist, but not saturated, environment. A growing season where there is ample, but not excessive, precipitation and warm temperatures results in good crop growth and is fortunately accompanied with more than average mineralization rates of N.

It is important to realize that all fertilizer N applied in any one year is not taken up into that year's crop. In fact, an uptake efficiency of 50% into the aboveground portion of a crop is considered normal, so every year a significant portion of the N used by a crop actually comes from OM mineralization. The other 50% of the applied N becomes part of residual mineral N in the soil (NO_3^- and NH_4^+), or becomes part of OM, or is subject to losses. Losses under the semi-arid conditions of the Northern Great Plains are usually

Abbreviations and notes for this article: N = nitrogen.

quite low. For example, in a fertilizer N study near Carmangay, Alberta (Jensen 1985), N-15 enriched fertilizer recovery in soil and above-ground crop biomass showed that 43% of applied N was in the grain and straw, and 48% in the soil down to a 4 ft. depth (1.2 m) for a total recovery of 91%. Of the 9% of N not accounted for, a portion was in root tissues, not sampled or analyzed. It is estimated that actual losses were not more and probably less than 9%. The OM is made up of different pools, such as stabilized soil organic humus that is slow to decompose, active or easily mineralized soil organic residues in various stages of decomposition, soil microbial biomass, and recent crop residues (e.g. roots, chaff, and straw). Losses of N occur through leaching of NO_3^-, denitrification of NO_3^-, and some volatile losses of gaseous ammonia (NH_3) from NH_4^+-based fertilizers under alkaline pH conditions, urea fertilizer hydrolyzation, or from decomposing crop residues on the soil surface. The pool of OM both consumes mineral fertilizer N and releases mineral N into the soil solution on a continuing basis. In any one growing season, the net amount taken into OM may be a positive or negative amount.

Table 2. The effect of fertilizer application on organic C and total N in continuous wheat, Lethbridge 1912-1975. (Adapted from Freyman et al., 1982.)

Crop rotation	Fertilizer treatment	Organic C, %	Total N, %	Approximate OM content, %
Continuous wheat	None	1.62	0.149	2.98[1]
Continuous wheat	N + P according to soil test needs	1.88	0.171	3.42

[1]Total soil OM calculated assuming total soil N is 5% of soil OM.

In the previously noted example of an above average rainfall year, more N was released from OM…which helps explain why N removal in grain is greater than N applied as fertilizer. In a drier than average year, e.g. 20 bu/A of 15% N protein wheat, only about 32 lb N (20 bu/A x 60 lb/bu x 15% protein ÷ 5.7 = 31.6 lb N) is removed in the grain from an acre of land. If the typical rate of 50 lb N/A was applied as fertilizer before planting, a net addition of about 18 lb N may result. This extra 18 lb N will be portioned between mineral N and OM in the soil.

If N removal is consistently more than N fertilizer additions, OM levels will gradually decline. There are some natural N additions to the soil-plant system from aerial and precipitation deposition, N fixation by free-living soil microbes, and possibly some input of N from deep within the soil from movement upward of groundwater with some soluble N in the form of NO_3^-. In a long-term rotational study at Lethbridge, Alberta, the level of total soil N was seen to stabilize at slightly less than 0.15% after 70 years of cropping to wheat with no addition of N or any other fertilizers (Freyman et al., 1982). When fertilizers were regularly added to the soil, the amount and quality of organic carbon (C) and total N were stabilized at higher levels (**Table 2**).

Predicting the Amount of N Mineralization

The natural cycling of N between the pool of OM and plant available mineral N (NH_4^+ and NO_3^-) has been studied and there have been measurements of the amount of N mineralized. Campbell et al. (1988) observed that the amount of N mineralized was affected by the amount of precipitation received in a growing season. In a Brown loam soil at Swift Current, Saskatchewan, the net amount of N mineralized was represented by the following equation:

$N_{min} = 23 + 0.29$ precipitation, ($r=0.75$ at $p<0.05$).

Soil samples can be incubated in a laboratory at a constant moisture content and temperature to estimate the amount of mineral N generated over a certain time. Another way is to extract mineral N using a hot potassium chloride (KCl) solution. Yet another way is to use a formula similar to the one noted above, but to include the OM content as well as an estimation of precipitation to calculate net N mineralized. This is used in the fertilizer test prediction program Virtual Soil Test (VST) developed by Rigas Karamanos of Westco Fertilizers (Karamanos, 2004). For example, in a Thick Black soil with an average OM of 5.5%, the following are estimates of net N mineralized for a dry, average, and above average precipitation year…respectively, 34, 62 and, 74 lb N/A. The amount of additional N that could be mineralized in a wet year compared to a dry year is 40 lb N/A.

Conclusion

The amount of N removed from a field in the grain of a crop of wheat or other Northern crop can be less than, equal to, or greater than the amount of N applied as fertilizer in that specific year. In a favorable moisture year, the additional N supplied to a crop comes from the mineralization of N from the OM present in a soil. This OM has been a source of N for crops in the Northern Great Plains, but studies have shown the source can be depleted. **Addition of N and other required nutrients as fertilizer can help increase crop yields and maintain the levels of OM in soils.** ■

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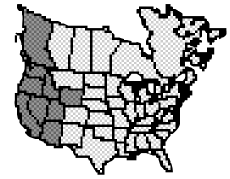
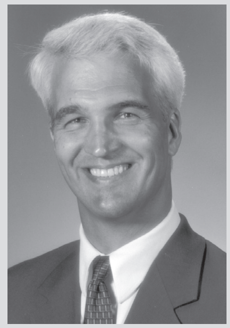


Stretching Your Fertilizer Dollar



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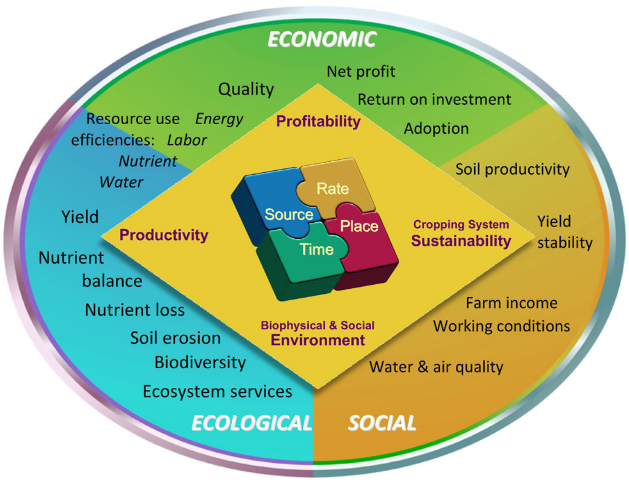
AS WE FACE an uncertain future relative to fertilizer prices, it is good to review the decision-making process we go through when making purchasing decisions. A farmer's immediate concern is how much of each nutrient to buy and whether each purchased pound of nutrient will provide short-term, long-term, or minimal value in return. Additional decisions then have to be considered based on whether the fertilizer should be purchased with credit or immediately paid in cash and the economic risks associated with either option.

The economically optimal rate (EOR) is simply the amount of fertilizer needed to maximize net returns from the nutrients. While the EOR for fertilization is easy to explain, it is very difficult to achieve in the field. Since there is considerable variability experienced in many fields and during the growing season, predicting the correct EOR each year is not easy. Achieving the EOR is made more difficult because much of the fertilizer is applied before the plants begin to grow and crop yields are influenced by unpredictable weather and environmental factors. Microeconomic models are frequently used to help eliminate some of the uncertainty, but they can have significant bias depending on the accuracy of the underlying assumptions. This short review of some important concepts will help with the decision-making process and help clear up confusion regarding some common economic terms.



Fertilizer should be managed with appropriate management practices to get the maximum benefit. This includes applying nutrients in the right source at the right rate, the right time, and the right place. The success of these management practices can have significant impact on the larger economic, ecological, and social surroundings.

Net Return

One of the easiest things to measure is the amount of money left after the crops are sold and the bills are paid. But calculating how to maximize this net return is not always so easy. In theory, the net return is greatest when the value of the additional crop yield from additional fertilizer is greater or equal to the cost of that additional fertilizer.

In practice, it is difficult to precisely predict this point since changing prices, unpredictable weather, and other fluctuating market conditions bring a degree of uncertainty each year. The closer a grower can get to the maximum net return, the lower the cost per unit of production (lower cost per bushel for example), even though the cost of the inputs may increase. This is because the fixed costs associated with growing a crop, such as land costs, irrigation expenses, and taxes, are spread out over more production and greater yield.

Value/Cost Ratio

The ratio of the crop value compared with the cost of the inputs (V/C) is often calculated to predict potential profitability. This number represents the value of the increased crop compared with the additional fertilizer required to produce it.

This number can sometimes be misleading when viewed alone. For example, the V/C ratio is generally highest when the first increment of fertilizer is applied (at the lower part of the yield response curve), even though this is not an economic range of production. Looking only at the V/C ratio also ignores the long-term benefits of building soil fertility in the field.

Fertilizer/Crop Price Ratio

The price of fertilizer needs to be compared with the likely price of the crop to determine if it is a wise invest-

Abbreviations and notes: P = phosphorus; K = potassium.

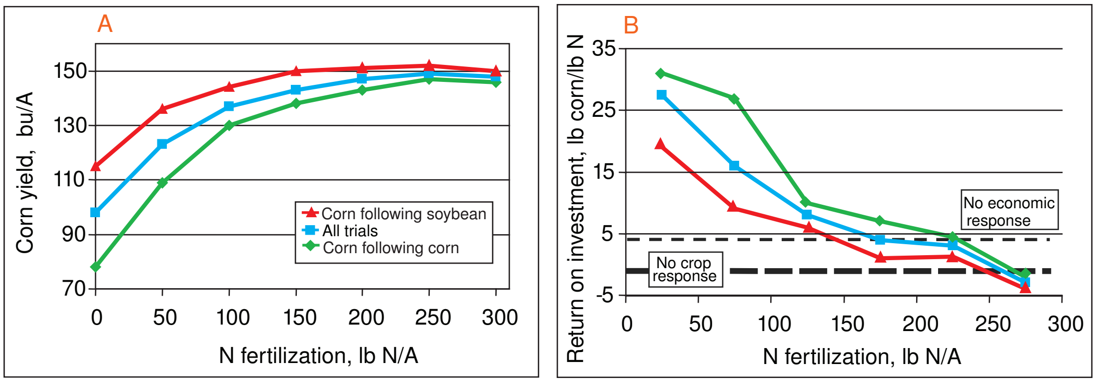


Figure 1. The graph at left (A) shows results of 54 separate experiments measuring the response of corn to added N fertilizer following corn or following soybean in rotation. These types of response data allow the economics of fertilization to be calculated as the return on investment (or the discrete marginal product) where additional fertilization is no longer profitable (B, right). These relationships change each year depending on crop prices and fertilizer costs.

Data from P.M. Kyveryga et al. 2007. Alternative benchmarks for economically optimal rates of nitrogen fertilization for corn. Agron. J. 99:1057-1065.

ment. Higher fertilizer prices or lower crop prices can cause growers to decide to cut nutrient purchases. It is tempting for some farmers to rush to make large reductions in nutrient use as fertilizer prices increase, but the price of the crop has a much larger influence on overall profitability than the price of fertilizer. A large yield reduction from inadequate fertilization is generally a poor economic trade off.

Return on Investment

Whenever money or resources are invested in the farming operation, the return on investment (ROI) is a measure of how much profit or savings are realized from the activity. The overall ROI is used to evaluate how well a decision benefits the overall operation. The ROI may be used to measure progress towards long-term goals as well as immediate profits or cost savings. The ROI of many individual purchased inputs is often measured after a single growing season. Economists often refer to this as the marginal product. The return for each pound of added fertilizer is called the discrete marginal product (**Figure 1**).

Time Value of Money

It is well known that money available at the present time is worth more than the same amount in the future, due to its potential earning capacity. This common principle states that if an asset will appreciate, any amount of money is worth more the sooner it is received. For example, since money in the bank will earn interest, $100 invested today would be worth $105 in one year (at 5% interest). Therefore it is preferable to receive $100 today than $100 in the future.

Another way to look at the time value of money is when a grower predicts whether the investment of today's dollars is better spent on needed nutrients today or to delay the purchase in hopes that the invested money will appreciate more quickly than the future price of fertilizer. Some nutrients (like P and K) remain in the soil for many years, continuing to provide crop nutrition long after the initial application is made, serving as a long-term reservoir.

Applying fertilizer at the most economic rate does not guarantee a profitable crop. Profit is determined by the differences between total income and total expenses. Rising fertilizer prices will have the greatest impact on the profitability of the crops with the highest fertilizer demand, all other factors remaining constant. The relative profitability of various crops needs to be compared when crop selection decisions are made. Uncontrolled events, such as weather and global market conditions also add to uncertainty. Every farm manager should consider input from agronomy and financial experts before making decisions about the investment of available capital. It may be wise in some circumstances to place orders for fertilizer with an eye on taxes, too.

Some producers are inclined to try short cuts to the well-established principles of plant nutrition. Essential plant nutrients are called "essential" because there is an absolute requirement for them in order for plants to survive. There are many techniques that can help growers get the maximum benefit from fertilizers, but these must be done thoughtfully and deliberately. If the soil has been analyzed and found to already contain adequate concentrations of nutrients, no additional fertilizer may be required for a period of time. The careful monitoring of soil nutrient concentrations allows this to be done without reducing crop yields.

As fertilizer prices increase, there seems to be a proliferation of new "wonder products" that claim to reduce or virtually eliminate the need for added nutrients. Many of these products are not field tested or independently evaluated. Often where there is inadequate field testing, there is a potential for dishonesty and misrepresentation. Where dishonest practices occur, there is the possibility for the reputation of the honest dealer to be damaged, too.

George Akerloff won the Nobel Prize in economics by explaining how the lack of solid information in the marketplace and the presence of ineffective products reduce the reputation and viability of even the good companies. It does not take an economist to know that you should find a trusted agronomist or consultant with whom you can establish a long-term relationship… someone who will tell you the truth in both the good and the lean years.

Use sound financial and scientific principles in making future decisions on how to nourish your crops. Use fertilizers as an essential input to improve your bottom line and maintain your financial security. ■

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