7. Fertilizer Recommendations

Arriving at a correct fertilizer recommendation depends upon several factors related to both crop response to applied nutrients and a producer's objectives. Crop and site-specific fertilizer recommendations are developed using information from:

- soil testing
- tissue analysis
- specific requirements for crop quality
- desired economic and production goals
- production practices
- potential environmental risks

Factors limiting yield response to fertilizer

Many interacting factors affect a crop's yield response to fertilizer applications. Some of these factors are within a producer's control, while others are not. General production practices — how a producer manages water, soil, insects and crop diseases — can improve or reduce yield response to applied fertilizers. These factors are summarized in Table 7–1.

Table 7–1. Factors limiting crop response to applied fertilizers

Category	Factor	How it affects response	Example
soil water management	dry soil	reduces nutrient flow to roots and within plant	boron deficiency in alfalfa
		limits root growth and activity	lack of response to surface-applied fertilizer
		increases salt concentration	risk of fertilizer burn
	wet soil	reduces root growth and ability to absorb nutrients	yellow corn in flooded soil
		changes chemical state of nutrients in low-oxygen soils	denitrification of N; enhanced Mn availability in tire tracks
	cold, wet soils	reduces growth and activity of roots	phosphorus deficiency in corn seedlings
crop rotation	soil structure	affects proportion of soil volume that roots will explore	higher optimum P & K levels in corn in compacted soil
	residual nutrients in the deeper soil profile	deeper rooted crops within a rotation will use nutrients from lower in the soil profile	sugar beets and carrots pull N from deep in the soil profile
	previous crop	affects accumulation and availability of soil nutrients	corn following alfalfa rarely needs N fertilizer
		crops that form mycorrhizal associations	early P uptake of corn (a mycorrhizal crop) may be decreased if the previous crop was non-mycorrhizal (e.g., canola)

Table 7–1. Factors limiting crop response to applied fertilizers

Category	**Factor**	**How it affects response**	**Example**
agronomic factors	choice of tillage system	more tillage leads to less mycorrhizae	greater response to starter P in conventionally tilled than no-till soils
		tillage increases N mineralization	increased N credit where red clover cover crops are tilled
		deep tillage can dilute soil nutrient concentrations	low fertility on eroded knolls where tillage brings subsoil to the surface
		no-till leads to stratification of immobile nutrients	increased corn response to banded K in no-till
pest control	weeds	high soil fertility favours crop and weed growth	banding fertilizer places nutrients where they are less accessible to weeds
	diseases	root diseases affect the root surface area and uptake of nutrients	white beans with root rots require more N
	nematodes	nematodes interfere with root uptake efficiency	soybean cyst nematode increases optimum soil K level
agronomic factors	cultivar/hybrid selection	genetic differences create different rooting habit	potato varieties with smaller root systems tend to respond to higher levels of fertility
		genetic differences create different end uses/quality	N recommendations for wheat and potatoes are specific to cultivar
		genetic differences create different susceptibility to diseases	wheat cultivars susceptible to disease respond more to N when diseases are controlled, with response depending upon timing of fungicide application and growing season conditions
		in corn, genetic differences create different responses to delayed N application	some corn hybrids are less responsive to late-season N applications than other hybrids, although the response may also be related to growing season conditions
	lodging	where crops are susceptible, excess N reduces yield by increasing lodging	optimum N rates are lower for cereals susceptible to lodging
	plant population and spacing	populations with higher yields remove more nutrients	in maximum yield research, high corn populations have sometimes been shown to respond more to fertility

Developing fertilizer recommendations

The need for additional fertilizer is determined through a diagnostic approach. It is essential for managing soil fertility and making recommendations. The tools of the diagnostic approach are:

- soil testing
- plant analysis and tissue testing
- visual nutrient deficiency symptoms

The challenge in making any fertilizer recommendations based on such a diagnostic approach is determining an effective and economical rate of fertilizer. There are two common methods in developing fertilizer recommendations from soil test results: the “sufficiency” approach and the “buildup and maintenance” approach. Both concepts have their own strengths and weaknesses that depend upon the producer’s crop production objectives. Neither system will be effective, however, without soil test calibration.

Soil test calibration

Since its inception, soil testing has been used for most of the major crops produced in Western Europe and North America. Soil testing can index the availability of a wide range of plant nutrients and monitor changes in the levels of soil fertility over time.

No reasonable fertilizer recommendation can be made without assessing the fertility of the soil — directly or indirectly. For annual crops, soil testing is the most common basis or starting point. For perennial horticultural crops, tissue testing is the foundation of fertilizer recommendations.

The soil test provides only an index of availability of a nutrient. This index must be calibrated against actual measurements of crop response in the field.

Different interpretations of soil test calibration are possible. One approach places more emphasis on crop response to applied nutrient. Another considers the yield in relation to the soil test level of a nutrient.

It is not possible to rely solely on the soil test for recommendations. The test does not reflect the external variables such as cool growing temperatures or high rainfall after the soil sample was taken. Nor does the soil test predict whether the crop will be managed to its full yield potential. External factors that affect the yield response to applied fertilizer must be considered in addition to the soil test.

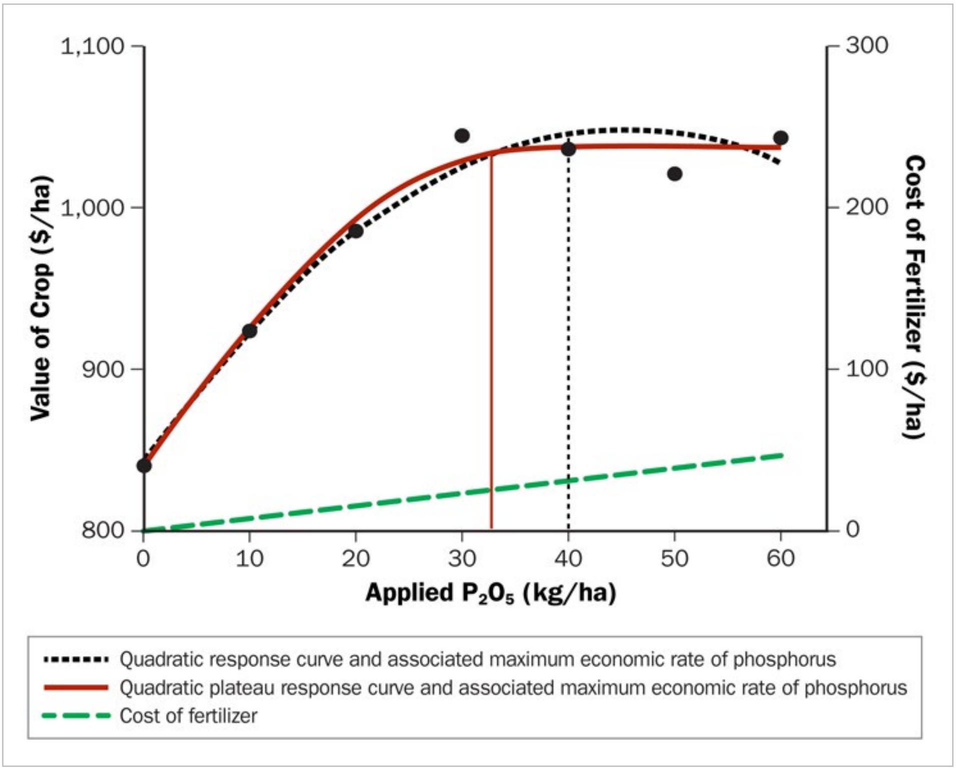

Figure 7–1. Corn yield response to phosphorus fertilization

Yield response to fertilizer applied

Field experiments are used to determine how much nutrient is required for each soil test level. This is determined by applying at least four different rates, including a zero rate, of a nutrient to different plots of a fairly uniform soil and under conditions where only the nutrient of interest is limiting crop production. A graph is developed by plotting the yields against the fertilizer rates applied. The resulting graph is used to define a response curve. Two common response curves are shown in Figure 7–1. A mathematical equation is fitted to the yield data. In this case, the dashed curve represents the data fitted to a quadratic model, while the solid curve represents the data fitted to a quadratic plateau model.

By knowing the response curve, it is possible to use fertilizer price information. As shown in Figure 7–1, this information can be used to calculate the economically optimum fertilizer rate to apply (vertical lines). As the rate of fertilizer applied increases, the slope of the response first increases, then decreases. At the point at which the vertical lines in Figure 7–1 intersect their respective response curve is the maximum economic rate of fertilizer. After this point, the increase in crop yield returns no more value than the increase in fertilizer cost. This is the highest fertilizer rate that can be justified in 1 year.

Choosing a yield response equation

Fertilizer response trials, no matter how extensive, produce data for yield responses at discrete points: either fertilizer additions or soil test levels. These data are fitted to a curve, and the equation for this curve is used to predict fertilizer requirements more precisely. The type of equation used to describe this curve can influence the results.

No one curve is clearly better than any other for describing how crop yields increase with fertilizer additions. The common element of most equations is that the calculated response to fertilizer decreases as the amount of fertilizer added increases, so that at some point, the value of the added yield is less than the cost of additional fertilizer needed to achieve that yield. The point where the incremental increase in yield value equals the added cost of fertilizer to achieve that incremental yield increase is the maximum economic yield.

The quadratic equation, the quadratic-plateau equation (solid curve in Figure 7–1) and the Mitscherlich equation (Figure 7–2) are the most common ones used to fit fertilizer response data. A quadratic equation (Yield = a + bx – cx^2, where x is fertilizer rate and a, b and c are constants used to fit the curve) gives a curve that shows large responses to fertilizer at low rates, gradually decreasing so that eventually there is no more response to added fertilizer, then turning down so that it predicts a decrease in yield with added fertilizer. Such an equation is often adequate for data that show a distinct decrease in yields at higher fertilizer application rates (e.g., cases where excessive lodging or increased disease in a cereal is due to high fertilizer N applications). However, it tends not to fit data very well when yields clearly level off. In this instance, a quadratic plateau model often gives a better fit to the data in the responsive range (see solid regression line in Figure 7–1).

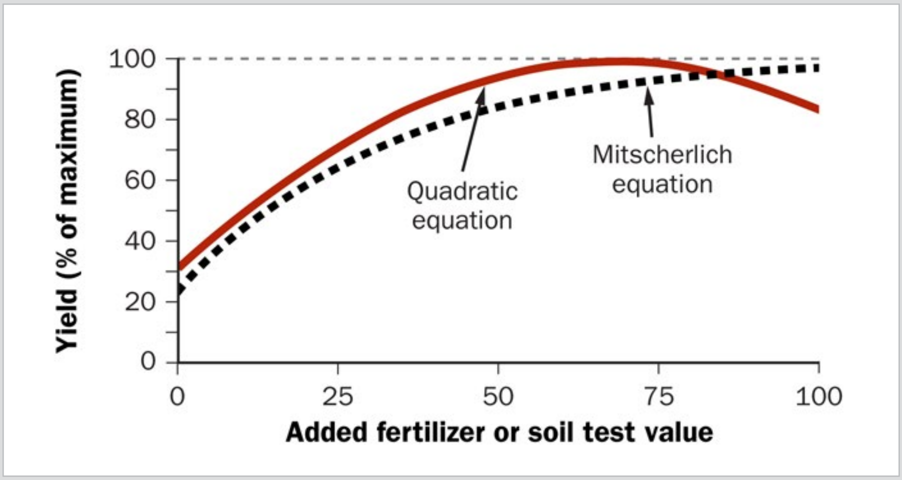

Figure 7–2. Comparison of two different response curves

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Compared to the quadratic models, the Mitscherlich equation has a similar form in the lower parts of the curve, but it never reaches a maximum yield and thus is less suitable for data sets where an obvious maximum crop yield was obtained or yields declined at higher fertilizer application rates. The Mitscherlich equation is RY (relative yield) = 1 – ($10^{(-x+b)*c}$) where x is either fertilizer added or soil test value and b and c are constants relating to the efficiency of fertilizer use.

These equations may give similar maximum economic yield figures at moderate fertilizer and crop values. The differences arise if the value of the crop is high or the cost of the fertilizer is low. In this case, the Mitscherlich equation predicts a significantly higher maximum economic yield than the quadratic models.

Yield response equations are useful tools for predicting maximum economic fertilizer rates, but like any tool, they have limits. Although the Mitscherlich and quadratic equations have similar shapes in the lower parts of the curve, the Mitscherlich equation never reaches the maximum yield, while the quadratic equation reaches the maximum and then begins to drop off, and the quadratic-plateau equation reaches a maximum and levels off. It is extremely important not to extrapolate any curve beyond the data used to generate the curve. The risk of incorrect interpretation is too great.

Response to soil test level

Soil test calibration relates crop responses to soil test levels. This is most important for soil-immobile nutrients like phosphorus and potassium.

To determine this relationship, scientists conduct experiments in which soil test values are adjusted to various levels. At each level, two yields need to be measured: the yield without the applied nutrient and the yield with a non-limiting rate (more than the plant could possibly use) of applied nutrient. Relative yields (the unfertilized yield as a fraction of the non-limited yield) are plotted against soil test level. This determines the critical level above which the crop rarely responds economically to the applied nutrient.

Probability of response versus soil test level

When experiments are conducted over many years, a single response curve accurately represents the average. However, it may not represent actual results in a given year. Recognizing the variability in yield response leads to different approaches to interpreting the soil test results. In this approach, the frequency of positive yield responses is plotted against the soil test level. The soil test rating then becomes an index of the probability of response to the nutrient.

Table 7–2. Probability of response to added nutrients at different soil test levels

Level of soil fertility*	Response rating	Probability of profitable response	Optimum fertilizer rates
low	high response (HR)	most cases	high
medium	medium response (MR)	about half the cases	medium
high	low response (LR)	occasional	low
very high	rare response (RR)	sporadic	very low
excessive	no response (NR)	negligible	nil

* Adding nutrients to soils that already have above-optimum levels of nutrients may reduce crop yields or quality by interfering with the uptake of other nutrients.

Table 7–2 describes the probability of response to added nutrients at different soil test levels. In general, crops grown in soils with low soil tests will respond to added nutrients most of the time, and the optimum rate of fertilizer to apply will be high. On soils with high levels of fertility, profitable responses to fertilizer occur only rarely, and optimum rates of application are lower.

Profitable responses to starter or seed-placed phosphorus in some crops continue to higher soil test levels than those resulting from broadcast applications.

Do high soil nutrient levels harm the environment?

Losses of nutrients from soil can harm water quality. The risk depends on the source of nutrient and pathways of transport. Higher soil nutrient levels increase the source, but do not affect the transport pathways. This is why soil test level is one component of the Phosphorus Index. For phosphorus, on land where risks of erosion and runoff are high, controlling soil test P levels is relatively more important. Phosphorus can also be lost through preferential/macropore flow through to tile drains. In situations where transport pathways are relatively minor, soils with greater soil test P values may pose relatively little risk of harm to water quality. Regardless of soil test level, applying nutrients at the proper rate, time and place will help to minimize nutrient losses to the environment. This is important, as it has been suggested that relatively small losses of phosphorus (i.e., above 2.3–4.6 kg P_2O_5/ha in some instances) could be detrimental to water quality.

Developing fertilizer recommendations: "fertilize the crop" or "fertilize the soil"

There are two approaches to making fertilizer recommendations. One is to "fertilize the crop," often called the *sufficiency approach*. The second is to "fertilize the soil," frequently called the *buildup and maintenance approach*. Table 7–3 summarizes these two approaches to making fertilizer recommendations and Table 7–4 indicates factors that favour one over the other.

Table 7–3. Sufficiency versus buildup approaches to developing fertilizer recommendations

Assumptions, strengths and challenges	Sufficiency approach	Buildup and maintenance approach
assumptions	• cost of the applied nutrient is paid for by the yield increase in the current crop • no economic value is directly assigned to the residual effect of the fertilizer (though residual fertilizer above crop removal will contribute to the soil test value) • the yields obtained at low soil test levels with high added fertilizer are about the same as the yields at high soil test levels with less added fertilizer	• nutrient to be applied is not irreversibly fixed by the soil • nutrient is not subject to losses from the soil by leaching or volatile escape • producer can profit from future returns to investments in soil fertility • application of nutrient at crop removal value will maintain the soil test levels
strengths	• in a single-year analysis, gives the greatest net return to fertilizer, and typically is the most profitable over multiple years as well • can be used for both mobile and immobile nutrients	• accounts for residual benefits of initial fertilizer applications during buildup phase • gives the greatest assurance that crop yields will not be limited by nutrients • in fields with variable soil tests levels in the crop-responsive range to fertilization, higher application rates may provide greater yield response than expected based on the field average soil test value
challenges	• can be difficult to predict precisely the most economic rate for a particular set of circumstances because response can vary with soil, tillage practice, variability in soil, crop variety and the weather • entails a greater risk of under-fertilizing, especially in fields that have extremely variable soil test levels	• applies only to immobile nutrients and therefore is not appropriate for nitrogen • requires amortization of fertilizer costs over several years to obtain full economic return • site-specific conditions or farm practices will affect the profitability of building and maintaining the soil test level at or above the critical level • entails a greater risk of over-fertilizing and nutrient losses from soil and/or nutrient application

Table 7–4. Which system?

Uncertainty exists in dealing with any biological system. We cannot predict exactly how crop yields will react to a specific set of factors or changes in commodity and fertilizer prices. However, there are factors that favour each system.

Factors favouring sufficiency approach	Factors favouring buildup and maintenance approach
• short land tenure, annual rental agreements • desire to not spend any more than necessary • low crop value, high fertilizer prices • alternative uses for capital with higher rate of return • nutrients easily lost from the soil • limitations to yield other than fertility • expectation that crop value and fertilizer prices will remain stable • availability of equipment and ability to directly fertilize each crop each year	• long-term land tenure • desire to ensure fertility is not a limiting factor • high-value, high-yielding crops that are responsive to higher fertility levels • no other use for capital or large investment in equipment • low-cost source of nutrients like manure or biosolids • nutrients held in soils in available forms without appreciable losses or conversion to unavailable forms • expectation that crop value and fertilizer prices will rise • rotational crops that require a high level of soil fertility • desire for flexibility to skip applications in years of high fertilizer prices or when weather conditions make application difficult

The sufficiency approach aims to supply the needs of the current crop. This approach is the basis for Ontario recommendations as well as for those in some adjoining states, including New York. It considers the amount of nutrient available from the soil based on a soil test. Recommendations for applied fertilizer are made that aim to provide an optimum payback in increased value of the current crop. It is the approach of choice for nutrients that are subject to losses from the soil, like nitrogen. It can also be used for other nutrients, including phosphorus and potassium.

Building the soil test level to a specific target is not the goal of this method, as it is the crop response to added nutrient that is deemed important. Higher amounts of fertilizer are recommended at low soil test levels, and lower amounts at high soil test levels. As a result, this method tends to build up low-soil-testing soils and draw down higher-soil-testing soils. How quickly these changes occur depends upon crop yields (i.e., crop removal) and may be field- or site-specific.

The buildup and maintenance approach emphasizes soil fertility levels rather than direct crop response to applied fertilizer. In the buildup phase, fertilizers are applied to build or increase the soil test values to a critical level at which crop growth is not likely to be limited by the nutrient. The maintenance phase involves adding nutrients to replenish nutrients removed by crops based on estimates of crop removal and amount of fertilizer required to change the soil test values. For soils above the targeted range, nutrient recommendations decline to zero.

The benefits of an investment in building up soil fertility do not all occur in 1 year. While the costs and returns to added fertilizer in a single year may only justify fertilizing to 90%–95% of maximum yield, adding the returns to residual fertility over a much longer term could potentially justify fertilizing for a greater percentage of maximum yield (Reetz and Fixen, 1992), providing the yield increase is of enough value to justify the higher fertilizer cost. Studies conducted that compare the different approaches over multiple years typically find little difference in crop yields between the recommendation systems, with higher fertilizer input costs associated with the buildup and maintenance approach (Olsen et al., 1982; Murdock, 1997).

It is important to consider all the costs of this approach, including amortizing the investment over several years. The cost of investing includes both interest rates and opportunity costs. If other opportunities for investment yield better returns, it would be better not to invest in the additional fertilizer for building soil test levels.

Many commercial, state and university labs, including Pennsylvania, Ohio, Michigan and Indiana, use the buildup and maintenance approach. Major differences between laboratory recommendations can occur when using this approach. Assumptions used for increase in soil test values per unit of fertilizer and the time allowed for the buildup will affect recommendations. Initial soil test levels may also affect the rate of change in soil test values relative to the amount of nutrient added as fertilizer or removed in crop yield from the soil. Regular soil testing remains an important nutrient management tool with the buildup and maintenance approach.

The basis for sufficiency recommendations for corn in Ontario

Table 7–5 compares the current OMAFRA phosphorus recommendations for corn with predicted phosphorus requirements based on 78 different phosphorus fertilizer response trials for corn conducted in Ontario (1969–2010). The data illustrate that current sufficiency recommendations are for the most part providing optimum fertilization of the crop.

Table 7–5. Comparison of sufficiency recommendation to regression-predicted maximum economic rate of phosphorus

Soil test P (Olsen) (ppm)	Sufficiency recommendation (kg P_2O_5 ha^{-1})	Regression-predicted recommendation (kg P_2O_5 ha^{-1})
0–3	110	110
4–5	100	60
6–7	90	40
8–9	70	30
10–12	50	10
13–15	20	10
16–20	20	10
21–30	20	10
31–60	0	10
>60	0	0

(*Source:* Janovicek et al., 2015)

Example of soil test calibration using sufficiency and buildup and maintenance approaches

Examples of corn yield response curves at three levels of soil test phosphorus, each at a different site, are shown in Figure 7–3. The soil test extractant was sodium bicarbonate. The most economic rates were calculated on a corn price of $170 per tonne and a fertilizer price of $1.20 per kilogram of fertilizer phosphorus (P_2O_5).

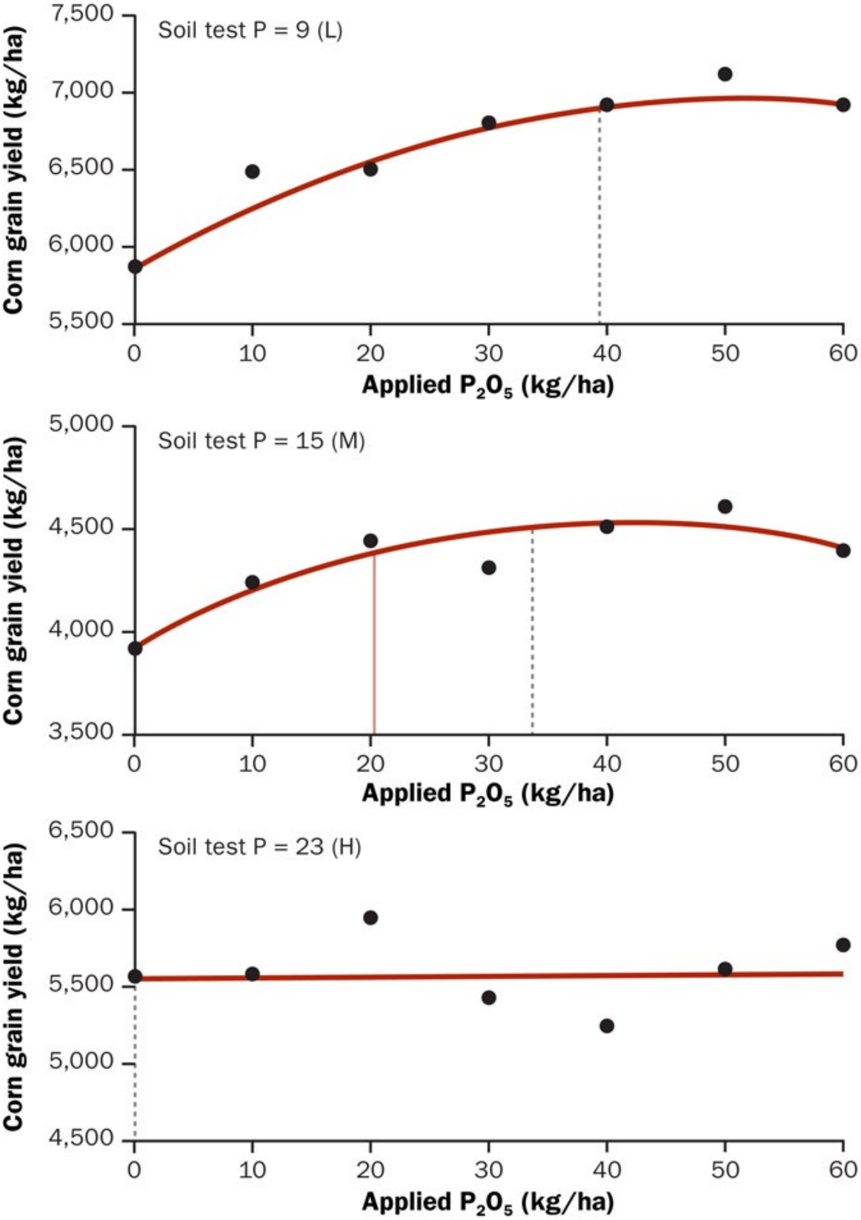

Figure 7–3. Corn yield response curves from experiments at three sites in Ontario with differing levels of soil test phosphorus. Vertical lines indicate the most economic rate using a quadratic (dashed) or quadratic-plateau (solid) regression model.

Table 7–6. Comparison of phosphorus recommendations from different approaches based on Figure 7–3

Soil test P (ppm)	Buildup and maintenance		Maximum economic rate		Current Ontario recommendation (sufficiency)*	
	P_2O_5 (kg/ha)	Yield Response (kg/ha)	P_2O_5 (kg/ha)	Yield Response (kg/ha)	P_2O_5 (kg/ha)	Yield Response (kg/ha)
9	120	1,062	39	1,056	70	1,062
15	64	553	21	528	20	519
23	55	0	0	0	20	0

*OMAFRA Publication 811, *Agronomy Guide for Field Crops* (2017)

Maximum economic rates

Relying strictly on the sufficiency approach, from this one-year set of data, would result in the maximum economic rates of phosphorus fertilizer additions shown in Table 7–6.

This table is only an example. A larger number of experiments are needed to assemble a complete recommendation table. Different soils may show different response curves at the same soil test level. For this reason, the three sites chosen for the example show some difference from the current recommendations.

Current recommendations are based on the sufficiency approach, but allowances have been made for soil variability and for starter responses, particularly for phosphorus. They are derived from a far greater number of experiments than in the example and thus are more appropriate to use as general guidelines.

Critical soil test level

Using the phosphorus response data for corn from the same source as we used for the sufficiency approach example in Figure 7–3, Figure 7–4 shows relative yield of unfertilized corn as a per cent of fertilized corn yield. The horizontal line is set at 95%, and the relative yield chosen as economically attainable. The vertical line is positioned so that the fewest points are in quadrants B and D. This line represents the critical level.

In this case, a critical level of 16 ppm is suggested. With the buildup and maintenance approach, above this level you would recommend maintenance doses only. Below this level, the amount of fertilizer recommended is that required to raise the soil test level plus maintenance (see Figure 7–5). Rates recommended will vary according to length of time allowed for buildup.

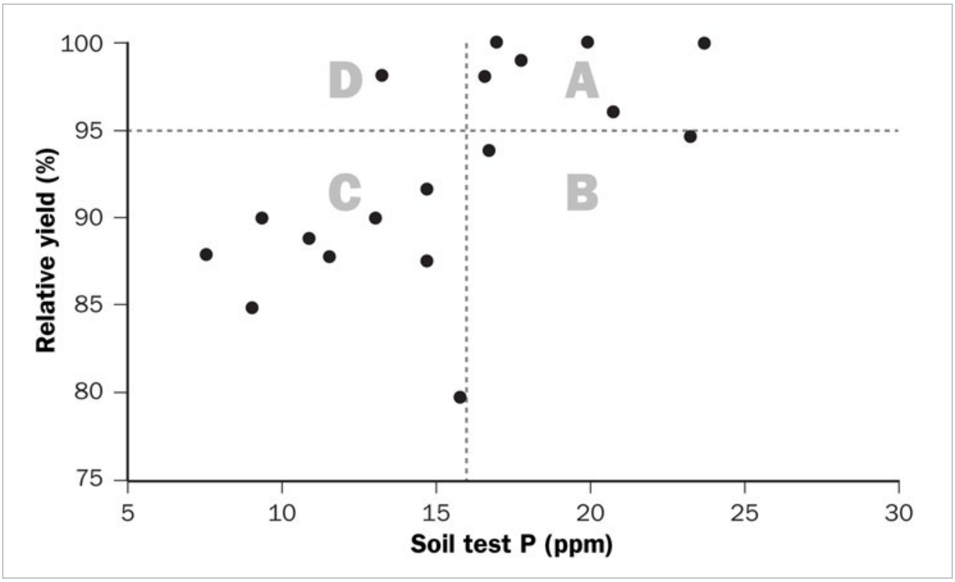

Figure 7–4. Defining the critical soil test level

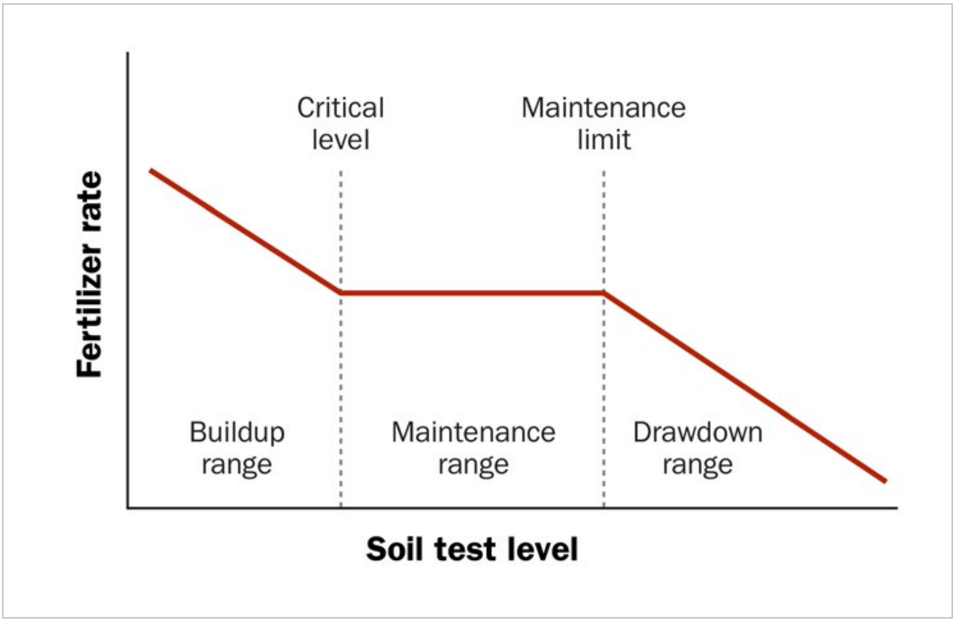

Figure 7–5. Buildup and maintenance approach to calibration

Assumptions and calculations

Recommendations based on the buildup and maintenance approach are shown in Table 7–6. They assume three things:

- It takes 37 kg P_2O_5/ha to increase the soil test by 1 ppm (Richards et al., 1995).
- The target is building the soil test level to the critical level over 4 years.
- The maintenance value is equal to the expected crop removal of 55 kg P_2O_5/ha (based on a ~150 bu/acre or 9.4 tonnes/ha corn crop).

Figure 7–6 illustrates the calculation for the phosphorus recommendation. In this example, the existing soil test level is 9 ppm. The recommended rate is calculated as the target soil test level (16 ppm), less the existing soil test level (9 ppm), multiplied by the amount needed to raise the soil test one unit (37 kg P_2O_5/ha), divided by the number of years (4), plus maintenance (55 kg P_2O_5/ha). The maintenance value should reflect the overall productivity of the site, although research has shown that crop phosphorus removal does not predict changes in soil test P values very well over a wide range of soils (Alvarez and Steinbach, 2017). This may reflect inherent differences between soils with respect to the amounts and forms of soil phosphorus that contribute to plant-available pools over longer periods of time. It may also reflect the fact that plants are utilizing phosphorus from deeper in the soil profile than the soil sampling depth of 15 cm (6 in.).

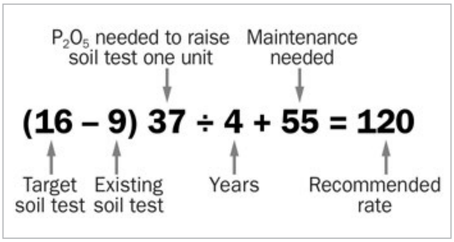

Figure 7–6. Buildup and maintenance requirement calculation

The fertilizer amounts in Table 7-6 for buildup and maintenance are higher than those for the sufficiency approach, even though the same data are used. An economic justification for these rates is quite complex and not universally applicable to all situations. The yield difference between the crop at or above the critical soil level and the yield obtained using the most economical rate at a lower soil test determines the net profitability of the buildup and maintenance approach.

In practice, maintenance applications are recommended over a range of soil test levels. Beyond the maintenance limits, the rates begin to decline.

Maintenance is based on removal by crop and has no direct bearing on crop response. Therefore, the maintenance portion should be based on average crop yield for the field rather than a yield goal.

Table 7–7. Average fertilizer cost and crop yield response value of phosphorus recommendations from different approaches based on Figure 7–3 and for the first 4 years of the program

Soil test P (ppm)	Buildup and maintenance			Maximum economic rate			Current Ontario recommendation*		
	Fertilizer cost (ha/yr)	Yield response (ha/yr)	Profit** (/ha/yr)	Fertilizer cost (ha/yr)	Yield response (ha/yr)	Profit** (/ha/yr)	Fertilizer cost (ha/yr)	Yield response (ha/yr)	Profit** (/ha/yr)
9	$144	$180.50	$36.50	$46.80	$179.50	$132.70	$84	$159.20	$75.20
15	$76.80	$94	$17.2	$25.20	$89.80	$64.60	$24	$77.80	$53.80
23	$66	$0	–$66	$0	$0	$0	$24	$0	–$24

* OMAFRA Publication 811, *Agronomy Guide for Field Crops* (2017)

** Profit is based solely on response to fertilizer and is calculated as the difference between crop value ($170/tonne) and fertilizer cost ($1.20/kg P_2O_5).

Comparison

Table 7–7 presents the average yearly costs and returns of the various programs for the first 4 years (i.e., the buildup phase), illustrating the additional revenue that needs to be generated to cover the initial cost of increasing soil test P levels. Direct comparisons of these two approaches over multiple years often show little difference in yields but higher fertilizer costs with the buildup and maintenance approach recommendations provided by individual laboratories or consultants (Olsen et al., 1982; Murdock, 1997). Recommendations that included micronutrient and secondary nutrient applications also had much higher fertilizer costs, with no observed yield benefit (Olsen et al., 1982).

Figure 7–7 illustrates the long-term potential profitability of these approaches for phosphorus application relative to the current recommendation. Initial profits are higher with the most economical approach method, diminishing with time due to under-fertilization as soil test P levels decrease between soil sampling periods. For the buildup and maintenance approach, profit is less during the buildup phase and remains lower for several decades. This period of time would be greater if credit was given to potential interest earned on capital not invested in fertilizer to build the soil test level.

Using the most economical rate approach, the soil test level is predicted to decrease to a value of approximately 8 ppm. The buildup and maintenance approach would maintain the soil test level at 16 ppm, while the current recommendation would see soil test values fluctuate between 9 and 11 ppm. The reader is cautioned that the above example is based on a limited data set and would surely vary with location. The results do, however, support the published research to date that has found no economic advantage to the buildup and maintenance approach due primarily to higher input costs with no appreciable impact on yields.

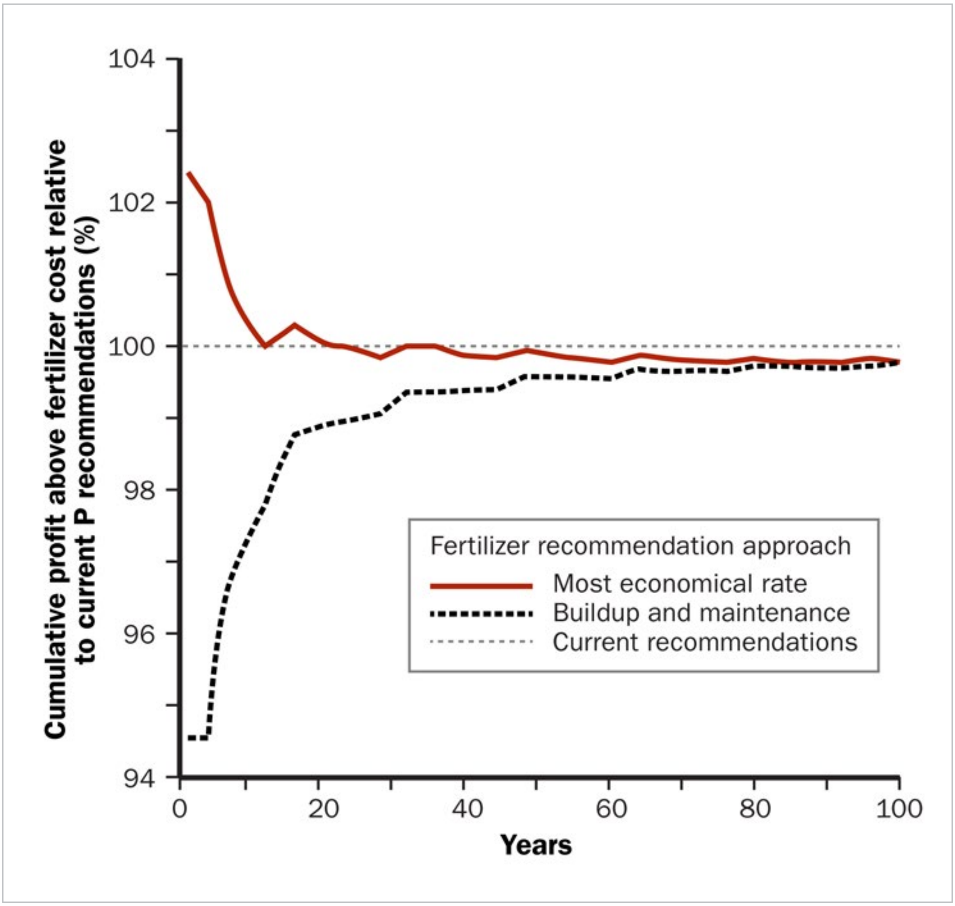

Figure 7–7. Comparison of profit for fertilization approaches relative to Ontario's current recommendations

Yields were assumed to follow the yield response curve observed in Figure 7–3 and relative yield in Figure 7–8. The buildup and maintenance approach was assumed to give the predicted maximum yield in each year, while predicted yields for the other two approaches varied according to changes in soil test level and fertilizer application rate as illustrated in Figure 7–9. Note that in Figure 7–9, the yield response to applied phosphorus diminishes as soil test P increases.

To simplify the example, there was no accounting for additional revenue from potential interest on the capital used to purchase the fertilizer for the buildup and maintenance approach. Other assumptions included: soil testing performed once every 5 years; soil test P values changed based on amounts of P removed by crop (55 kg P_2O_5/ha/year) or added as fertilizer; and a fertilizer cost of \$1.20/kg P_2O_5 and corn value of \$170/tonne.

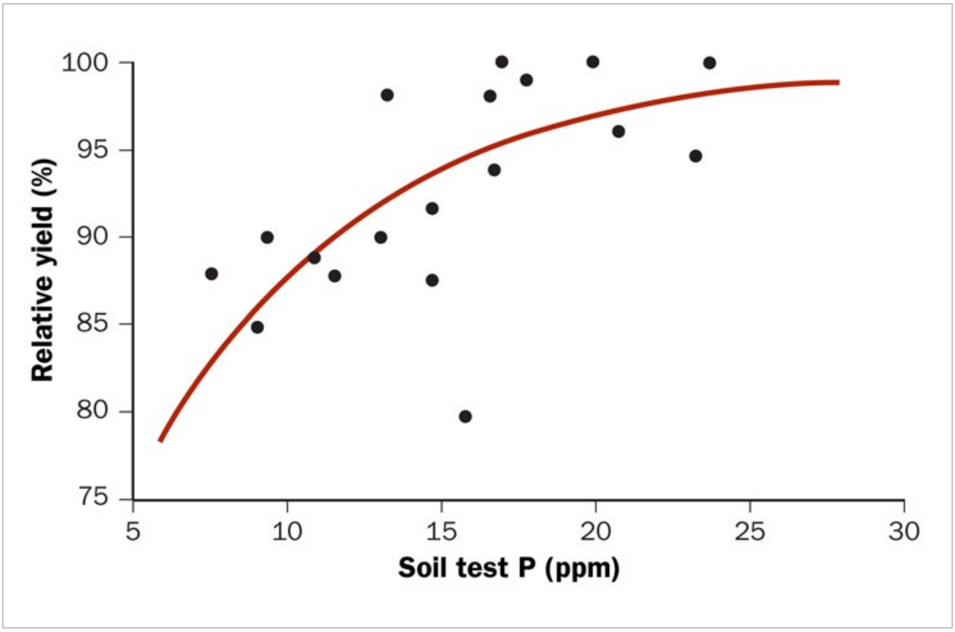

Figure 7–8. Relative yield at different soil test levels

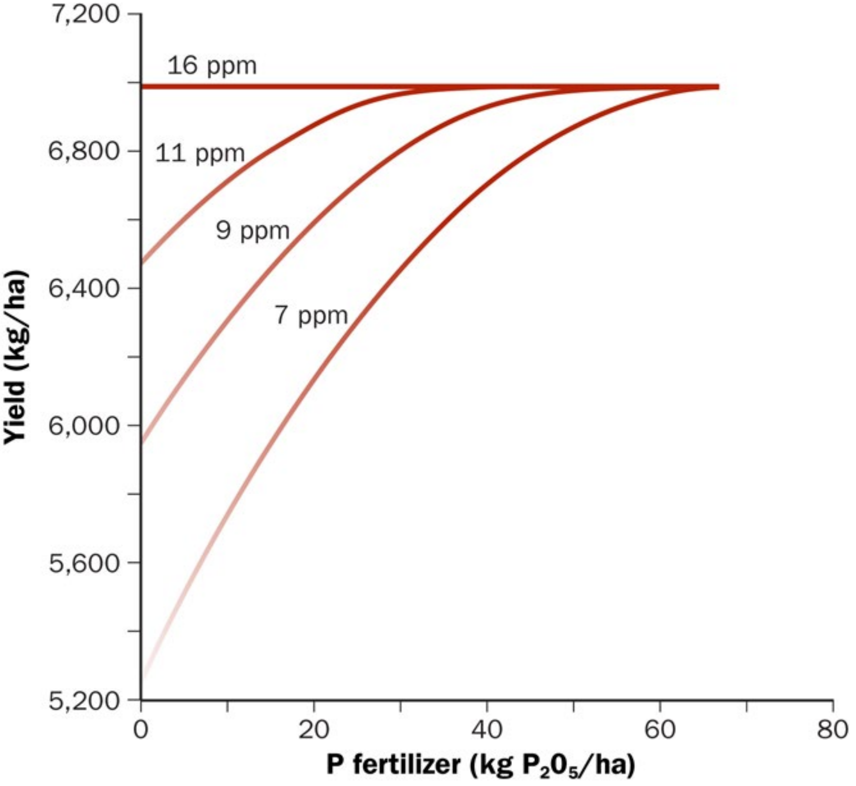

Figure 7–9. Predicted effect of changes in soil test P on crop response to applied fertilizer P. **Note:** Numbers on the curves indicate soil test P level.

Other things to consider

Yield goal

Expected yields have often been used in making fertilizer rate decisions. Obviously, the final yield is what pays for the input costs, so that higher-value crops tend to receive more fertilizer because it takes less of a crop response to cover the fertilizer expense. Basing fertilizer application rates on crop removal will clearly result in higher application rates as yields increase but does not necessarily mean a higher fertilizer requirement for the crop. There is little scientific evidence to support the direct relationship between yield goal and fertilizer requirement. However, one must remember newer varieties/hybrids/cultivars are potentially more efficient at using all resources available to them (i.e., water, light and nutrients, whether from soil or fertilizer) to produce yield (Mueller and Vyn, 2016). In terms of nitrogen fertilization, yield response to applied N is much better correlated to fertilizer N requirement than the absolute yield or yield goal of the crop (Lory and Scharf, 2013; Kachanoski et al., 1996).

In the long term, higher yields remove more nutrients from soil and require more to be added if the desire is to maintain the soil test levels. Regular soil testing will monitor changes in soil test levels in the plow layer. Soils with high yield potential have deep topsoil and excellent structure. This allows roots to explore larger volumes of soil for nutrients and moisture. Given that plant roots will take nutrients from below the top 15 cm where the soil test is taken, one might expect applications based on crop removal to slightly increase soil test levels.

Response to fertility is only one component of crop yield. For example, research at the Ridgetown Campus recorded a corn yield of 18.4 tonnes/ha (293 bu/acre) in 1985 on research plots near Chatham (Stevenson, 1983). Many factors contributed to the high yield, including soil properties, irrigation and high inputs of fertilizer and manure nutrients. The most important factors, however, were considered to be hybrid selection and population.

Basic cation saturation ratios and percentages

The ratios or percentages of the basic cation nutrients — calcium (Ca), magnesium (Mg) and potassium (K) — are sometimes used as indicators of their availability. The aim is to recognize interactions among the cations.

These basic cations are known to have antagonistic effects on each other. This means a very high soil test level of one cation may reduce the availability to plants of one of the others. For practical purposes, these interactions are only important when one of the nutrients is approaching deficiency.

The basic cation saturation concept originated in New Jersey in the 1940s (Bear et al., 1945). In a series of greenhouse experiments over 8 years, infertile, acid soils were limed and fertilized to grow alfalfa, and the cation saturation of the soils was measured. The investigators suggested the cation exchange complex should be occupied by 65% calcium, 10% magnesium, 5% potassium and 20% hydrogen. It is important to note that the crop grew well with these levels of nutrients in the soil, but this does not imply that these exact proportions are required for crop growth.

In many trials since the original study, crop growth has not been adversely affected over a wide range of Ca:Mg:K ratios or percentages, as long as one of the nutrients was not clearly deficient. A study on alfalfa and trefoil in New York State found that Ca:Mg ratios ranging from 267:1 to 1:1 had no significant influence on yields (Reid, 1996).

There are two main drawbacks to the use of basic cation saturation ratios or percentages in making fertilizer recommendations:

- No economic analysis is included in the recommendations, particularly on soils high in calcium and magnesium. The cost of these fertilizer programs can be extremely high.

- Many alkaline Ontario soils have high levels of carbonate minerals. These minerals can be dissolved by the soil test extractant, releasing calcium and magnesium into the extract. This will inflate the calculated CEC and the calcium and magnesium percentages, leading to unrealistically high potassium recommendations.

The basic cation saturation ratio concept does have merit in recognizing extremes in the ratios between cations, especially in soils with very low CEC and fertility. In particular, potassium can interfere with magnesium uptake. Extra care must be taken to ensure adequate magnesium supplies where soils test high in potassium and low in magnesium. This interaction is particularly important in the management of ruminant nutritional problems such as grass tetany.

Adjusting potassium recommendations for cation exchange capacity (CEC)

Some states adjust potassium recommendations for CEC. In Michigan, Ohio and Indiana, the potassium recommendations increase with increasing CEC. This recommendation is based on trials in southern Ohio. Clay soils in this area can fix significant amounts of potassium. This leads to a greater requirement for potassium on the heavier textured soils, both for optimum crop yield and to build the potassium soil test levels. The younger soils of northern Ohio contain more native potassium in the clays and do not fix potassium as readily. In these soils, the clay content or CEC has only a very minor effect on the amount of potassium required.

In New York, for a given level of soil test potassium, potassium recommendations are higher on sandier, low-CEC soils. Research there has shown that soils higher in clay release more potassium through weathering, so that less potassium fertilizer is required for optimum crop yields.

Ontario research has not found any significant effect of CEC on the amount of potassium required.

Spatial variability

Most fertilizer calibrations have been done on small plots where soil fertility is relatively uniform. Most fields, however, show large variations in soil test levels. Ontario fields that have been intensively sampled show a coefficient of variation of 18%–54% for nitrate, 20%–140% for phosphorus, 12%–70% for potassium and 50%–60% for micronutrients.

This variation in soil test values means that part of the field has above-average fertility and a lower-than-average response to applied fertilizer. Another part of the field has below-average fertility and shows a larger-than-average response to fertilizer.

The yield gain from extra fertilizer on the low-testing areas generally is larger than the cost of the extra fertilizer on the high-testing areas.

As the field becomes more variable, the part that is highly responsive becomes larger in relation to the low- or no-response part of the field. The net result is that, in variable fields, the most profitable single rate of fertilizer to apply to the whole field is higher than the requirement for a uniform field.

An example of the effect of variability in soil test values on optimum fertilizer rate is shown in Table 7–8. Note how spatial variability increases the optimum constant rate of potassium, particularly in high-testing soils.

If the spatial variability within a field can be mapped accurately, the same yields could be attained with less increase in fertilizer use than shown in the table. This could be done by using variable rate application of fertilizer on the most responsive areas. However, sampling fields on the scale of one sample per hectare or acre can miss some of this variability. The variable-rate technology for such applications is available, but the development of accurate application maps is still very challenging.

In fields with highly variable soil test values, you can improve profitability of fertilizer use with variable rate application, providing that significant areas of the field are in the responsive soil test range.

Table 7–8. Influence of variability in soil test K values on optimum K fertilizer rate in Ontario

Average soil test K ppm	**Optimum K_2O rate (kg/ha) at differing levels of variability in soil test values**		
	Low	**Moderate**	**High**
45	100	101	106
90	50	58	77
135	0	30	58

Source: Kachanoski and Fairchild, 1994. Coefficient of variation for low variability site = 0%, moderate = 53% and high = 131%.

Cost of under- versus over-fertilizing

In yield response curves (e.g., Figure 7–3), the slope decreases as applied fertilizer increases. Therefore, the change in yield for a given percentage of under-fertilization is greater than the change in yield for the same amount of over-fertilization (see Table 7–9).

If you are unsure whether a recommendation is accurate, erring on the side of over-fertilization entails smaller profit losses than those arising from under-fertilizing. The actual difference depends on the shape of the response curve. This is most likely to be apparent for nutrients such as nitrogen, where yield increases are relatively linear until a plateau is reached.

For nutrients that can have a negative environmental impact, such as nitrogen and phosphorus, over-fertilization is a concern. It’s important to make every attempt to be accurate in determining recommendations and to use every means possible to get information on the particular recommendation.

Table 7–9. Effect of under-fertilizing versus over-fertilizing on net return for grain corn

LEGEND: MERN = maximum economic rate of nitrogen

Fertilizer rate kg N/ha (lb N/acre)	Yield t/ha (bu/acre)	Crop value	Nitrogen cost	Net return	Difference
		$/ha ($/acre)			
90 (81) ⅓ less	9.3 (148)	1,466 (594)	119 (48)	1,347 (545)	- 84 (34)
135 (121) recommended	10.2 (163)	1,610 (652)	179 (73)	1,431 (579)	–
181 (161) ⅓ more	10.7 (171)	1,687 (683)	239 (97)	1,448 (586)	+17 (7)
148 (132) MERN	10.7 (171)	1,686 (682)	196 (79)	1,490 (603)	+59 (24)

Price assumptions: Corn @ $4.00/bushel; N @ $0.60/lb.

Recommended nitrogen rate based on Ontario Corn Nitrogen Calculator. Previous crops included grain corn, soybeans, edible beans and cereals. Sites with forage grasses, forage legumes or cover crops as previous crop were excluded.

Source: mean of 96 fertilizer N rate trials from the Ontario corn nitrogen database, 2005–2017.

Agronomic and environmental impacts of fertilizer application

Under the humid conditions of eastern North America, the amount of mineral nitrogen left in the soil post-harvest is a reliable indicator of the risk of loss through either leaching or denitrification. Post-harvest residual nitrate levels increase greatly when application rates exceed the amount required for optimum yield. This is clearly shown in Figure 7–10, where the crop yield plateaus while the level of residual soil N continues to increase.

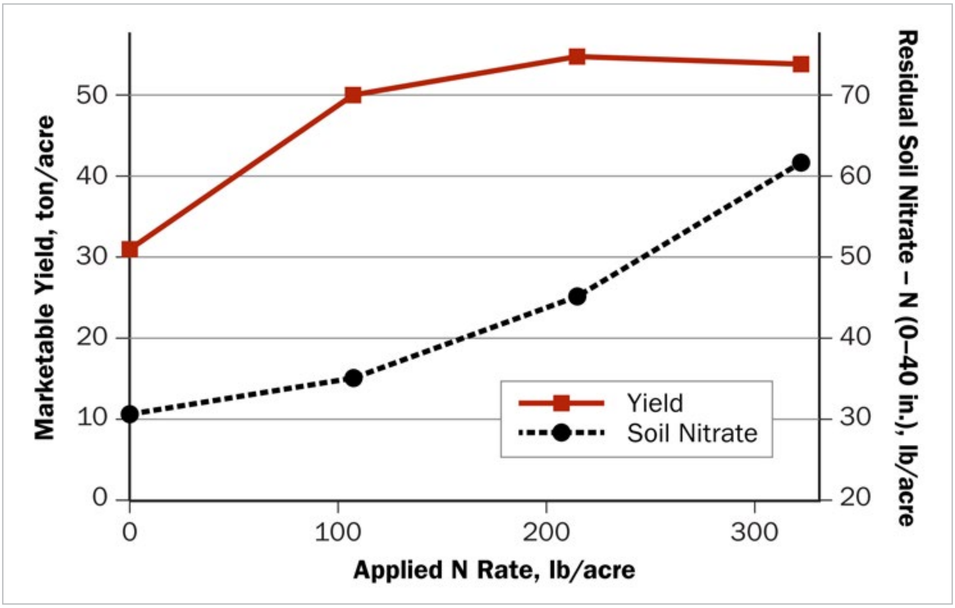

Figure 7–10. Tomato response to nitrogen. (The use of imperial measurement reflects the standards used in the industry.) *Source:* T.Q. Zhang, Agriculture and Agri-Food Canada, 2005.

Nitrogen fertilization: rate, timing, weather and planting dates

Given that weather affects the rate at which fertilizer nitrogen is lost from the soil, a crop's demand for nitrogen and the rate at which organic nitrogen in the soil is mineralized and made plant-available, it is little wonder that we see yearly variations in crop fertilizer requirements and responses to applied nitrogen. Recent studies (Tremblay et al., 2012; Xie et al., 2013; Kablan et al., 2017) and evaluations of corn nitrogen response datasets in neighbouring states and Quebec suggest that response to nitrogen fertilizer is greater in fine-textured versus medium-textured soils, and yield responses to in-season (side-dressed) nitrogen applications are greater with increased rainfall.

The series of studies demonstrate that the year-to-year variability in optimal nitrogen rate is more dependent on the distribution of rainfall than the overall amount of rainfall or crop heat units (CHUs), although CHUs are still important. In growing seasons with low CHUs and increased variability of rainfall patterns, responses to in-season nitrogen applications decrease. Well-distributed rainfall and higher CHUs lead to higher optimal in-season nitrogen application rates. Precipitation prior to side-dressing appears to be more strongly correlated to fertilizer nitrogen yield responses than rainfall after side-dressing. Late planting results in greater variability in the optimal nitrogen rates than planting on optimal planting dates.

Side-dressing and possibly further splitting the application of nitrogen on corn might be one way to minimize losses while allowing for fertilizer rate adjustments based on growing season conditions and planting dates. With later nitrogen applications after side-dressing, the additional cost of the application is an important consideration in determining the overall economic benefit.

Developing fertilizer recommendations: the Ontario Corn Nitrogen Calculator

Ontario's nitrogen recommendations for corn were updated in 2006. Data was collected from 41 years of N trials, and response curves were re-calculated to fit a quadratic-plateau model. Optimum rates of N for each site-year were determined, and the factors with the greatest impact on optimum N rates were used to develop a model to predict N requirements for individual fields.

The factors included in the model were the yield potential for the field (average yield for the past 5 years), soil texture, previous crop, crop heat unit rating, application timing and the relative price of corn and nitrogen fertilizer.

More information on the Ontario Corn Nitrogen Calculator can be found at www.gocorn.net.

Crop nutrient uptake and removal per unit of yield

Nutrient uptake refers to the maximum quantity of nutrient taken up into the above-ground portion of the crop. Nutrient removal is the amount of nutrient removed in the harvested portion of the crop. The two are nearly equal in crops harvested as whole plants like silage corn, alfalfa and cabbage.

The amounts shown in Tables 7–10 and 7–11 are based on Ontario field data where possible and general North American crops where local data were insufficient. To do precise nutrient budgeting, it is necessary to have the particular crop analyzed for nutrient content.

The forage crop figures are specific to Ontario and are ranges observed in samples submitted for analysis to Agri-Food Laboratories, Guelph, over 5 years in the early 1990s.

Table 7–10. Field crop nutrient removal in Ontario

LEGEND: — = Data not available

Crop	Unit	N*	P_2O_5	K_2O	Ca	Mg	S
Grains and oilseeds (at marketing moisture content)							
grain corn	kg/t	11.5–17.7	6.6–7.9	4.6–5.2	0.12	1.55	1.2–1.3
	lb/bu	0.7–1.0	0.37–0.44	0.26–0.29	0.007	0.087	0.07
soybean	kg/t	62.3–66.7	13.3–14.7	23.0–23.3	3.0–3.7	2.3–3.0	0.67
	lb/bu	3.7–4.0	0.80–0.88	1.38–1.40	0.18–0.22	0.14–0.18	0.033
winter wheat	kg/t	19.1–20.9	9.1–10.4	5.78–6.22	0.44	2.67	1.33
	lb/bu	1.15–1.25	0.55–0.63	0.35–0.37	0.027	0.16	0.08
barley	kg/t	18.1–23.1	7.78–8.33	5.28–7.22	0.56	1.11	1.67
	lb/bu	0.87–1.11	0.37–0.40	0.25–0.35	0.027	0.053	0.08
oat	kg/t	19.6–25.0	7.92	5.83–6.25	0.833	1.25	2.08
	lb/bu	0.63–0.80	0.253	0.19–0.20	0.027	0.04	0.067
winter rye	kg/t	19.3–21.8	6.07–8.21	6.07–6.43	1.07	1.43	1.79–3.57
	lb/bu	1.08–1.22	0.34–0.46	0.34–0.36	0.06	0.08	0.10
dry beans	kg/t	83.3	27.8	27.8	2.22	2.22	5.56
	lb/bu	2.50	0.83	0.83	0.067	0.067	0.167
canola	kg/t	40.0–44.4	22.2–26.7	11.1–13.3	4.0–5.3	5.33–6.67	6.67
	lb/bu	2.0–2.2	1.11–1.33	0.56–0.67	0.20–0.27	0.27–0.33	0.33

* Soybeans, dry beans, forage legumes get most of their nitrogen from the air.

** Nutrient contents in harvested stover or straw are extremely variable due to variations in harvesting methods (cutting height, method of collection, timing of harvest, etc.). It is highly recommended that nutrient analyses of a representative subsample of the harvested material be conducted for more reliable estimates of nutrient removal.

Ranges of nutrient uptake and removal for yield levels typical of good growing conditions for field crops. Figures are based on Ontario field data where possible and are estimates. Actual uptake and removal will vary with yield, and nutrient concentrations will also vary with year, level of soil fertility and crop variety. Precise nutrient management planning would require analysis of each crop each year. Actual changes to soil fertility may differ from the amount removed by the crop. In some instances, weathering of soil materials and organic matter may compensate for part of the nutrient removal by crops. In other instances, nutrients may be chemically fixed by the soil or lost to leaching, and the loss of nutrients will exceed crop removal.

Table 7–10. Field crop nutrient removal in Ontario

LEGEND: — = Data not available

Crop	Unit	N*	P_2O_5	K_2O	Ca	Mg	S
Grains and oilseeds — stover or straw (based on dry weight) **							
corn stover	kg/t	8.0–10.6	2.1–6.4	17.4–20.0	3.5–13.4	2.5–8.6	1.3–1.7
	lb/ton	16.0–21.2	4.1–12.8	34.8–39.9	7.0–11.4	5.0–17.2	2.6–3.4
soybean stover	kg/t	8.0–23.0	1.0–4.4	8.7–19.0	15.0–17.3	4.1–8.6	3.1–6.5
	lb/ton	4.0–46.0	2.0–8.8	17.4–37.9	30.0–34.6	8.1–17.2	6.2–13.0
winter wheat straw	kg/t	4.4–9.6	1.0–4.9	12.0–23.2	1.6–10.4	0.4–7.1	2.7
	lb/ton	8.8–19.2	2.0–9.8	24.0–46.4	3.2–20.8	0.7	5.4
oat straw	kg/t	6.0	3.2	19.0	2.4	0.7	2.3
	lb/ton	12.0	6.4	37.9	4.8	1.3	4.5
winter rye straw	kg/t	6	6.1–8.2	6.3	—	0.3	1.0
	lb/ton	12.0	12.2–16.4	12.5	—	0.6	2.0
Forages (based on dry weight)							
corn silage	kg/t	10.8–15.0	4.6–6.8	8.3–15.2	1.6–3.1	1.1–1.9	0.8–1.0
	lb/ton	21.6–29.9	9.3–13.6	16.6–30.4	3.3–6.1	2.3–3.8	1.6–2.0
legume haylage	kg/t	26.6–36.8	5.3–7.9	22.4–35.5	11.3–17.7	1.9–3.6	1.9–2.0
	lb/ton	53.2–73.4	10.6–15.8	44.8–70.8	22.6–35.4	3.8–7.2	3.8–4.0
mixed haylage	kg/t	22.8–33.9	5.2–7.8	22.4–35.6	9.5–16.4	1.6–3.4	1.5–2.9
	lb/ton	45.6–67.6	10.4–15.6	44.8–71.0	19.0–32.8	3.2–6.8	3.0–5.8
grass haylage	kg/t	16.2–27.4	4.9–7.8	20.4–35.9	5.3–11.3	1.3–2.6	0.8
	lb/ton	32.3–54.8	9.8–15.5	40.8–71.8	10.5–22.5	2.5–5.3	1.6
legume hay, 1st cut	kg/t	22.3–33.1	5.2–8.0	20.6–35.1	10.1–15.4	2.1–3.4	1.9–2.7
	lb/ton	44.6–66.2	10.4–16.0	41.2–70.0	20.2–30.8	4.2–6.8	3.8–5.4
mixed hay, 1st cut	kg/t	17.2–27.4	5.0–7.2	17.0–29.8	8.2–13.5	1.8–3.0	1.3–2.1
	lb/ton	34.4–54.6	10.0–14.4	34.0–59.4	16.4–27.0	3.6–6.0	2.6–4.2
grass, 1st cut	kg/t	12.9–22.7	4.4–7.0	13.9–28.1	5.3–10.6	1.4–2.6	1.4–2.0
	lb/ton	25.8–45.3	8.8–14.0	27.8–56.0	10.5–21.3	2.8–5.3	2.8–4.0
mixed hay, 2nd cut	kg/t	25.4–35.9	5.7–7.8	19.7–31.9	11.4–17.0	2.3–3.8	1.8–2.8
	lb/ton	50.7–71.7	11.3–15.7	39.7–63.7	22.7–34.0	4.7–7.7	3.7–5.7

* Soybeans, dry beans, forage legumes get most of their nitrogen from the air.

** Nutrient contents in harvested stover or straw are extremely variable due to variations in harvesting methods (cutting height, method of collection, timing of harvest, etc.). It is highly recommended that nutrient analyses of a representative subsample of the harvested material be conducted for more reliable estimates of nutrient removal.

Ranges of nutrient uptake and removal for yield levels typical of good growing conditions for field crops. Figures are based on Ontario field data where possible and are estimates. Actual uptake and removal will vary with yield, and nutrient concentrations will also vary with year, level of soil fertility and crop variety. Precise nutrient management planning would require analysis of each crop each year. Actual changes to soil fertility may differ from the amount removed by the crop. In some instances, weathering of soil materials and organic matter may compensate for part of the nutrient removal by crops. In other instances, nutrients may be chemically fixed by the soil or lost to leaching, and the loss of nutrients will exceed crop removal.

Table 7–11. Horticultural crop nutrient uptake and removal Ontario

Ranges of nutrient uptake and removal for yield levels typical of good growing conditions for horticultural crops

LEGEND: — = Data not available

Crop	Uptake/ removal	N*	P_2O_5	K_2O	Ca	Mg	S
		kg/tonne (lb/ton)					
beans, green	uptake	17 (34)	5–12 (10–24)	10–20.4 (20–40.7)	— —	2.2 (4.3)	— —
	removal	2.9 (5.7)	0.5 (1)	5.7 (11.3)	— —	— —	— —
broccoli	uptake	16.6 (33.3)	1 (2)	20.6 (41.2)	— —	— —	— —
	removal	6 (12)	0.6 (1.3)	4.5 (9)	— —	— —	— —
cabbage	uptake	3–4.8 (6–9.6)	0.8–1.8 (1.6–3.6)	3.3–5.4 (6.5–10.8)	1.1–3.3 (2.2–6.6)	1.1 (2.2)	0.9–1.1 (1.8–2.2)
	removal	2.0–3.3 (4.0–6.6)	0.6–1.1 (1.2–2.2)	2.1–3.4 (4.2–6.8)	1.0–3.1 (2.0–6.2)	0.7 (1.4)	0.6–0.7 (1.2–1.4)
carrot	uptake	2.9 (5.8)	0.5 (1.0)	6.9 (13.8)	— —	— —	— —
	removal	1.6 (3.2)	0.4 (0.8)	4.0 (8.0)	— —	— —	— —
corn, sweet	uptake	12.9–15.6 (25.8–31.2)	1.7–5.3 (3.3–10.5)	8.8–15.1 (17.5–30.2)	— —	2.3 (4.5)	1.3 (2.5)
	removal	4.2 (8.3)	0.3 (0.7)	2.5 (5.0)	— —	— —	— —
onion	uptake	3–3.6 (6–7.3)	0.6–1.3 (1.3–2.7)	2.6–3.9 (5.3–7.8)	0.8 (1.5)	0.3 (0.5)	0.5–0.9 (1.0–1.8)
	removal	1.9 (3.8)	0.4 (0.8)	2.0–2.1 (4.0–4.3)	0.6 (1.2)	0.1–0.3 (0.2–0.5)	0.5–0.9 (1.0–1.8)
peas, green	uptake	43–65 (85–130)	5.5–14.0 (11–28)	20–42 (40–84)	— —	7.3 (14.5)	4 (8)
	removal	10 (20)	0.5 (1)	7.5 (15)	— —	— —	— —
potato	uptake	5.3–5.7 (10.7–11.3)	1.7–1.8 (3.3–3.7)	7.3–11.0 (14.7–22.0)	— —	1 (2)	0.5 (1)
	removal	2.1 (4.2)	0.4 (0.8)	3.6–4.2 (7.2–8.3)	0.08 (0.16)	0.17 (0.33)	0.17–0.20 (0.33–0.40)
sugar beets	uptake	4.2–4.8 (8.5–9.6)	0.7–1.5 (1.3–3.0)	8.8–9.2 (17.5–18.3)	— —	1.3 (2.7)	0.7–0.8 (1.4–1.6)
	removal	2.0–2.1 (4.0–4.2)	0.3–0.9 (0.5–1.8)	3.3–4.2 (6.5–8.3)	— —	— —	0.3 (0.6)

* Legumes such as beans and peas get much of their nitrogen from the air.

Table 7–11. Horticultural crop nutrient uptake and removal Ontario
Ranges of nutrient uptake and removal for yield levels typical of good growing conditions for horticultural crops

LEGEND: — = Data not available

Crop	Uptake/ removal	N*	P_2O_5	K_2O	Ca	Mg	S
		kg/tonne (lb/ton)					
tobacco	uptake	42–55 (84–110)	8.5–15 (17–30)	85.0–85.5 (170–171)	— —	9 (18)	7 (14)
	removal	28.0–37.5 (56–75)	2–3 (4–6)	52–60 (104–120)	37.5 (75)	8 (16)	6.5 (13)
tomato	uptake	2.9 (5.8)	1.1 (2.2)	5.8 (11.6)	— —	0.45 (0.9)	0.7 (1.4)
	removal	1.8–2.0 (3.6–4.0)	0.3 (0.6)	3.5–3.6 (7.0–7.2)	0.18–0.30 (0.35–0.60)	0.28–0.30 (0.55–0.60)	0.35 (0.7)
apple	uptake	4.2 (8.3)	1.9 (3.8)	7.5 (15)	— —	1 (2)	— —
grapes	uptake	4.3 (8.5)	1.5 (3)	6.7 (13.3)	— —	0.8 (1.5)	— —
peaches	uptake	1.7 (3.3)	0.7 (1.3)	2 (4)	0.36 (0.7)	— —	— —

* Legumes such as beans and peas get much of their nitrogen from the air.

Nutrient recommendations based on plant tissue analysis

Tissue, leaf or plant analysis can be used to:

- determine the nutrient needs of established perennial crops such as cane berries, tree fruit and grapes
- confirm the diagnosis of visual symptoms of unusual plant growth, so that remedies can be used immediately

In perennial crops, it is often preferable to use tissue analysis in conjunction with soil testing. Tissue analysis also helps show what nutrients are being taken up by the crop, as opposed to what is available in the soil. Occasional soil analysis from orchards and vineyards is often useful when done along with tissue analysis, particularly for monitoring pH levels. A tissue analysis may indicate a nutrient could be deficient or limiting, but it is not easy to make a fertilizer recommendation rate from a tissue analysis. Thus, tissue analyses can be used to adjust fertilizer application for the following growing season.

Used along with a soil test, tissue analysis can identify possible nutrient limitations or deficiencies. A tissue analysis may indicate that nutrients could be deficient or limiting but may not provide information in time for correction for annual crops in the current growing season.

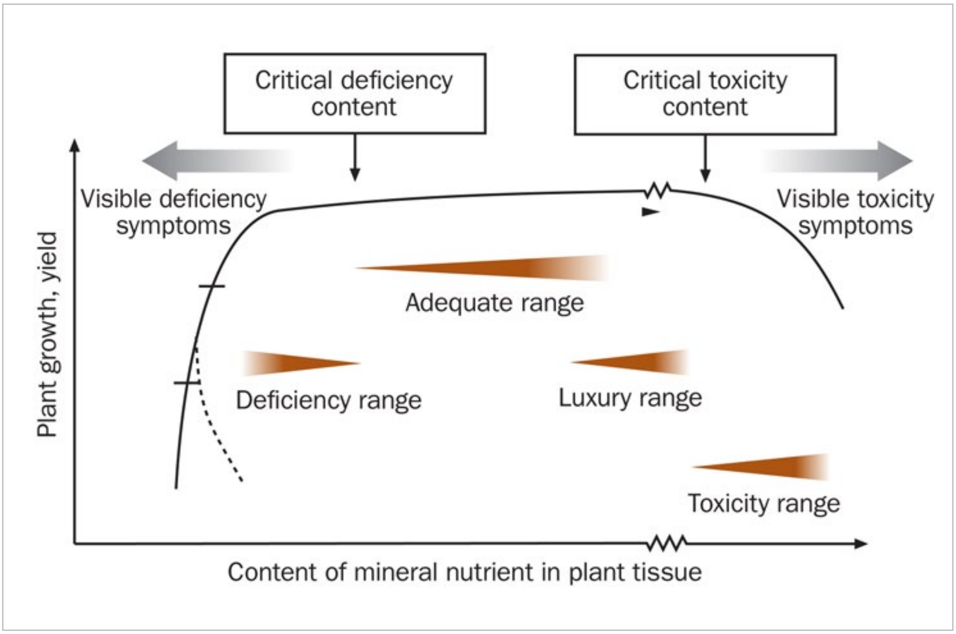

Figure 7–11. Relationship between plant nutrient content and growth yield of plants

Deficient, critical and sufficient concentrations

Plant analysis identifies a nutrient as being deficient when its concentration falls below a critical level for a given plant part for a given crop at a given stage of plant development. The concept of the critical level separating deficient and adequate ranges is illustrated in Figure 7–11.

In order to interpret the tissue analysis, the timing or stage of plant growth and the plant part being sampled are very important. For more details on sampling plant tissue, refer to Chapter 4.

OMAFRA crop recommendation and production guides list critical nutrient ranges for most crops grown in Ontario. Many publications on field and horticultural crops list critical values. Most labs that do tissue analysis have their own set of critical values, developed from their own experience. It is important to closely follow the laboratory's instructions regarding plant part sampled, stage of plant development and sample handling.

When investigating crop growth peculiarities, if the time of sampling does not correspond to the stage of plant development for which there are established critical values, separately sample affected and unaffected areas for comparison.

Table 7–12 shows the probable causes for excessive or deficient levels of nutrients in plant tissue samples. Interpretations of these results are not as simple as simply looking at the numbers on the analytical report.

Table 7–12. Possible causes for variation in plant tissue nutrient levels

Nutrient	Excessive	Deficient
all nutrients	soil or dust contamination of the plant material can give rise to elevated values for many nutrients; similarly, recent foliar application of fertilizers will give elevated plant tissue values	inadequate supply of any nutrient from the soil will tend to produce low plant tissue levels
nitrogen	over-application of nitrogen, from commercial sources and or manure; high levels of soil organic matter; high rates of mineralization	low organic matter, soil compaction, dry soil conditions, water-logged conditions causing denitrification
phosphorus	high soil test value, low or deficient zinc, high rates of phosphorus nutrient application	low or high soil pH, soil compaction, drought, cold soils, root disease
potassium	high rates of application, high soil test level	excessive nitrogen, soil compaction, cold soils
magnesium	mature plant parts, over-application of magnesium fertilizer	low pH, high potassium availability, high ammonium-N levels
calcium	mature plant parts, diseased leaf, contamination of sample with soil **Note:** High calcium levels are rare.	leached sandy soil, high rates of potassium in low-CEC soils, high ammonium-N availability, low pH, inadequate rates of limestone
zinc	naturally high soil zinc, heavy application of swine manures, high levels of organic matter	high soil pH, high phosphorus application rates, eroded soil areas, low levels of soil organic matter
manganese	high nitrogen and phosphorus applications, low-pH, soil compaction, low oxygen root environment, contamination from sprays and dust	high soil pH, highly aerated soil, high organic matter
copper	high soil copper levels, spray materials (fungicides), soil splash up on leaves	high levels of soil organic matter, leached soil, high levels of zinc and manganese
iron	wet soil conditions, soil on leaves, zinc deficiency	excessive phosphorus, zinc, copper and manganese
boron	improper application rates, lowered soil pH	sandy leached soils, low levels of organic matter, dry sandy soils
sulphur	high application rates of sulphate-sulphur, foliar spray residues on leaves	excessive rates of nitrogen application or high mineralization rates from soil organic matter, leaching losses
molybdenum	high soil pH, foliar application residues	low soil pH, high levels of phosphorus, sulphur applications (ion antagonism at root)

Diagnosis and recommendation integrated system (DRIS)

The DRIS was initially designed to apply to both soil and plant analysis. In North America it has been used more frequently for plant analysis.

The system relates complete sets of nutrient concentrations and ratios for a particular crop to those of crops grown under optimum conditions at the highest attainable yield levels. The values and ratios obtained from these crops are referred to as DRIS norms.

The DRIS approach applied to plant analysis places a relative ranking of the essential elements from the most to the least deficient. In some cases, this analysis has been found to be more sensitive than the critical, or sufficiency, level in identifying the need for higher levels of one or more nutrients. Because DRIS uses ratios of nutrients, dry matter dilution due to the maturing of the crop is minimized and the time of sampling has less influence on the test results.

Initially it was thought DRIS norms were applicable across wide areas. However, studies on major agronomic crops show that locally or regionally developed norms are more accurate in diagnosing deficiencies. While the DRIS has not yet become a completely reliable system for fertilizer recommendations, it provides the possibility of bringing together all the elements of plant nutrition and evaluating them simultaneously with yield level as part of the process. Providing that adequate calibration data become available, the DRIS approach may be used more often in the future.

Fertilizer recommendations: not a production prescription

No one table of recommendations can cover all situations. A recommendation is not a production prescription. The amounts recommended by any source may be adjusted using local experience and knowledge of the particular soils and financial conditions of the producer. It is more valid to make such an adjustment than to use the general recommendations.

The fertilizer retailer is often in a good position to know the peculiarities of the soils, owing to the geographic limitations of distribution from a fertilizer blending plant. For this reason, each retail outlet should have at least one experienced agronomist or Certified Crop Adviser qualified to make sound recommendations.

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