9. Soil Fertility and Nutrient Use

Principles for Optimum Management of Nutrients

High yields can be efficiently produced only when fertilizer use is related to the fertility level of the soil and additions of nutrients from manure, crop residues and other organic sources. At one extreme, on very low fertility soils, it may be profitable to add as much, or more, nitrogen, phosphorus or potassium in the fertilizer as a crop removes. At the other extreme, on high fertility soils or following heavy application of manures, adding fertilizer may not be profitable and may occasionally reduce yields.

Proper management of crop nutrition involves choosing the right sources of nutrients, and applying them at the right rate, at the right time and in the right place, to achieve the greatest benefit to the cropping system and the least environmental impact.

For more detailed information regarding management of fertilizer and other nutrients, see OMAFRA Publication 611, *Soil Fertility Handbook.*

Soil Testing

Soil testing is the most accurate tool available to determine supplemental nutrient requirements for a crop. It is actually made up of three separate steps:

1. collecting a representative sample from the field
2. analyzing the sample using OMAFRA-accredited soil tests
3. relating the results of the soil analysis to additional nutrient requirements for optimum crop yields

Other Methods of Assessing Nutrient Needs

Plant analysis is the main tool used for tree fruits and can provide additional information to support the soil test for field and vegetable crops. Symptoms on crop leaves are helpful in evaluating nutrient deficiencies. In some cases, however, they have serious drawbacks, particularly with potassium and phosphorus, because serious yield losses occur before symptoms are visible.

It is sometimes suggested that a producer apply the amounts of nutrients removed by the harvested crop. This approach is discussed in comparison with the sufficiency approach which uses soil fertility measurements and crop response to ensure there are sufficient nutrients to achieve economic maximum yield, and upon which the fertility guidelines are based. Some soils have sufficient phosphorus and/or potassium to last many years, and yearly application on those soils is uneconomical and can cause environmental problems.

The OMAFRA-accredited soil-testing program is the main guide, along with help from plant analysis and nutrient deficiency symptoms, in determining the fertilizer requirements for a specific crop on a specific field. Where manure is applied, soil testing will aid in determining commercial fertilizer needs to balance crop requirements.

The OMAFRA-Accredited Soil-Testing Program

The OMAFRA-accredited soil-testing program provides assurance of appropriate analyses to support guidelines for nitrogen, phosphate, potash, magnesium, zinc and manganese fertilizer, along with parameters for the amount and type of lime to apply. The analytical methods used were chosen to provide accurate results on the range of soils found in Ontario. Table 9–1, *OMAFRA-accredited soil tests*, lists the tests provided on an accredited soil test in Ontario.

Nitrate nitrogen can be measured from a separate, deeper (30 cm or 12 in.) sample. See Chapter 1, *Corn* and Chapter 4, *Cereals* for further information.

Table 9–1. OMAFRA-accredited soil tests

Materials Analyzed	What Is Analyzed[1]
Soils for field crops, commercial turf, etc.	• plant-available phosphorus (sodium bicarbonate extractable) • potassium, magnesium (ammonium acetate extractable), manganese and zinc (index of soil pH and extractable element) • pH • lime requirement (SMP buffer pH)

[1] Soil organic matter provides an overall measure of soil health and is useful for herbicide recommendations, but currently it is not an accredited test.

See Appendix C, *Accredited Soil-Testing Laboratories in Ontario,* for a list of accredited labs in Ontario.

Extractants used for OMAFRA-Accredited Soil Tests

Plant-available phosphorus is measured with a sodium bicarbonate extract, also known as the Olsen extract. Plant-available potassium and magnesium are measured with an ammonium acetate extract. Manganese and zinc are reported as indices that account for both the amount of nutrient extracted from the soil and the soil pH. Soil pH has a huge impact on the amount of these nutrients that is available to plants. Soil test results for phosphorus, potassium and magnesium are reported in units of milligrams per litre of soil (mg/L), or parts per million (ppm), which are approximately equal.

Technology Options for Soil Testing

Equipment for soil sampling includes an auger or sampling probe. Ensure the tube is stainless steel if micronutrients will be analyzed. A screwdriver is handy for removing the soil core from the sampling tube into a container such as a clean plastic pail. Sample depth should be 15 cm (6 in.), with the exception of nitrate nitrogen samples, which should represent 30 cm (12 in.) depth, and pH samples taken in continuous no-till. In continuous no-till fields, with a history of broadcast N, and where lime will be surface applied, collect soil samples for soil pH to a 10 cm (4 in.) sampling depth.

A soil sample is a composite of individual cores mixed together into one, representative of a given area. Take at least 20 cores per sample; one sample should represent no more than 10 ha (25 acres). To collect the individual cores, traverse the area to be represented in a zigzag pattern, see Figure 10–1, *Scouting patterns,* in Chapter 10, *Field Scouting.* Avoid taking cores adjacent to gravel roads or where lime, manure, compost or crop residues have been piled. Sample separately if areas are large enough to manage separately (e.g., site-specific management zones, eroded knolls, etc.) Avoid collecting cores from recent fertilizer bands, or position cores with respect to bands as described in Table 9–2, *Sampling guidelines to account for banded nutrients.*

Soil Tests from Other Laboratories

Each year, a number of producers ask OMAFRA staff to interpret results from laboratories that are not accredited. Provided the laboratory uses the identical test used by the OMAFRA-accredited service and expresses its test results in the same units, the OMAFRA fertilizer requirements for phosphate and potash can be determined, but there is no assurance of the analyses accuracy.

The Olsen extracting solution for P has a pH of 8.5. The Bray 1, Bray 2 and Mehlich 3 extracting solutions all have a pH of 2.5. This can overestimate P availability in alkaline soils due to solubilization of unavailable forms such as some calcium phosphates. The Olsen method is more consistent in predicting P availability for the range of Ontario soils. The Mehlich 3 method extracts comparable amounts of potassium as the ammonium acetate method.

To become OMAFRA-accredited, a laboratory must meet OMAFRA-approved testing procedures to demonstrate acceptable analytical precision and must provide the OMAFRA fertilizer guidelines. **OMAFRA-accredited soil tests will provide the most accurate fertilizer guidelines for Ontario field crops.**

A number of laboratories provide soil tests such as cation exchange capacity, aluminum, boron and copper. These tests are not accredited by OMAFRA because they have not been found to contribute to better fertilizer guidelines. Research has shown that on Ontario soils, use of cation exchange capacity to adjust potash requirements can lead to less reliable guidelines than are currently provided.

Table 9–2. Sampling guidelines to account for banded nutrients

Band Spacing	Placement	Collect
76 cm (30 in.)	planter	1 core within the band for every 20 out of the band
30 cm (12 in.)	planter	1 core within the band for every 8 out of the band
76 cm (30 in.)	strip till, manure injector	1 core in the zone for every 3 out of the zone, where zone of influence is 25 cm (10 in.) wide
band spacing known; location unknown	planter	Paired sampling: 1 random core followed by a second core 50% of the band-spacing distance from the first sample, perpendicular to the band direction
to determine with any spacing	planter	S = 8 [x ÷ 30 cm] (S = 8 [x ÷ 12 in.]) where S = number of cores between bands (outside influence of band is 5 cm for planter placed fertilizer) *x* = band spacing in cm or inches

Sources: Fernandez. 2012. *Assessment of Soil Phosphorus and Potassium following Real Time Kinematic-Guided Broadcast and Deep-Band Placement in Strip-Till and No-Till.* Self-study CEU, Crops & Soils Jul–Aug.
Kitchen, Westfall, Havlin. 1990. *Soil sampling under no-till banded phosphorus.* Soil Sci. Soc. Am. J. 54:1,661–1,665.
Ball Coelho, Roy, Bruin, More, White. 2009. *Zonejection: Conservation tillage manure nutrient delivery system.* Agron. J. 101:215–225

If all of the soil collected for the sample, is sent to the lab for testing, mixing is not necessary; it will be done by the lab. If a subsample is sent to the lab, soil must be mixed thoroughly first — break up lumps, discard stones and crop residue. Heavy-textured soil (clays) may require some drying to allow mixing and subsampling. Place the sample or subsample — about 400 g (1 lb) — into a labelled bag and forward to the lab.

Geo-Referenced and Directed Sampling

Documenting sample locations using global positioning systems (GPS) facilitates re-sampling the same locations in subsequent years, and locating sampling zones that have been identified using other geo-referenced information. It also allows creation of maps for multi-year record keeping and prescription nutrient and/or lime application.

The number of samples required to characterize a field depends on the topography and variability of soils within the field, and number and type of crops grown. To divide up areas larger than 10 hectares (25 acres), use past field boundaries or management differences, such as previous fertilizer, manure or lime applications. Sample the problem areas separately, along with a sample from an adjoining area of normal growth, to diagnose whether nutrient deficiencies are causing reduced crop growth. Grid sampling, where cores are collected within grid cells located systematically across the field, may be suitable to provide a baseline, but generally do not align with variability. Direct the subdivision of fields into sample zones by variability in soil type, texture, topography, drainage, and/or crop characteristics. This is referred to as "Directed" or "Smart Sampling."

There are many parameters that describe variability across a field and therefore many ways to identify sample zones. Defining homogenous zones for sampling is field-specific. A simple approach is to sketch the known variation in texture or topography, field history, or manure history on a map, and sample those areas separately. This does not allow for automated generation of prescription application maps, but may be suitable for some operations.

Directed sampling can be based on yield or elevation maps, or measurements generated by crop or soil sensors mounted on vehicles (usually equipped with GPS). Table 9–3, *Sensors used to define management zones and parameters measured,* details direct sampling options. Figure 9–1, *Infra-red image processed into green difference vegetation index,* is a screen capture showing an image from an infra-red crop canopy optical sensor mounted on an unmanned aerial vehicle (UAV).

Table 9–3. Sensors used to define management zones and parameters measured

Platform	Sensor	Measurement	Soil or Crop Indicator
Ground-based sensors	crop optical	light reflectance from red and near-infrared wavelengths (manufacturers: OPTRX, Greenseeker)	generate normalized differential vegetative index (NDVI), an indicator of aboveground biomass
	soil secondary electromagnetic field sensor	measures electrical conductivity (EC) (manufacturers: EM38, Veris, Dual EM, Soil Doctor)	cation exchange capacity (CEC), clay, soil water, salt concentration — example may be used to create map of soil types in a field
	soil optical	near infra-red (NIR) reflectance 700–900 nm wavelength	organic carbon, CEC (cation exchange capacity), soil water
Remote sensing: · satellite · aircraft · unmanned aerial vehicle (UAV)	optical electromagnetic radiation	how light is absorbed & reflected by soil and plant several wavelength ranges measured: · visible (400–700 nm) · infra-red (700–1,000 nm) · multispectral (>1 wavelength), blue, green, red, near infra-red, bandwidths 50–120 nm · hyperspectral: entire spectrum, narrow bandwidths (1–15 nm)	**visible:** plant structure, health, stresses, volume, soil colour. **multispectral:** green, red & near infra-red often used to create vegetation indices, e.g., NDVI **hyperspectral:** crop health, canopy moisture, nutrient deficiencies
	thermal	thermal radiation — temperature	plant health/stress
	radar (radio detection and ranging)	backscatter (range and magnitude of energy reflected) of microwave radiation, 2 or 3 dimensional images	soil type, mineralogy, moisture, volume, health/stress
	LIDAR (light detection and ranging)	time for laser pulse sent to target (ground) to return to sensor	high resolution topography, vegetation structure, volumetric crop calculations

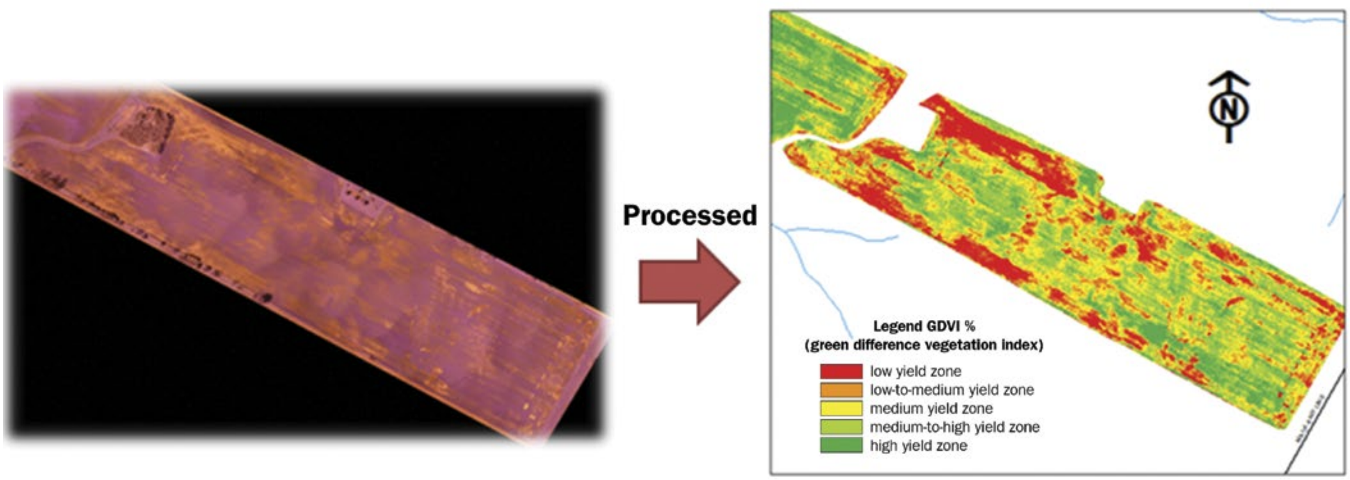

Figure 9–1. Infra-red image processed into green difference vegetation index.

False-colour infra-red image (above left), processed into a green difference vegetation index (above right), to create sample zones that should be verified in the field (ground truth) or supported by other information (e.g., yield maps).

Be aware that some of the correlations between measurements and mapped outputs are not well defined, for example, when sensors that measure one parameter are used to generate maps of other properties for which the correlation may be poor or unknown. In such cases, conduct soil or plant sampling in the field to help verify sensor-derived products that attempt to map specific soil or crop characteristics.

Defining Soil Sampling Zones (i.e., management zones)

Multi-Year Yield Zones

If yield trends are stable over several years, zones may be identified from normalized yields. Normalizing yield means ranking how much yield is above or below field average. Individual years are categorized into low, medium and high yielding zones. Normalizing yield maps can be done across the rotation including all crop types, or by analyzing the same crop over a number of years. Sample zones are based solely on yields in this scenario. Often, yield maps are used in combination with other maps or producer knowledge to assign sampling zones.

Figure 9–2, *Topographic map with sampling zones created from elevation data,* shows an effective sampling strategy where crop productivity correlates well with topography. One way to acquire elevation data is from the guidance system on a farm implement. It is best to use a high-quality GPS signal to collect elevation data. Take advantage of equipment that has the most passes across the field, so that the full extent of the topographic variability is captured. In Figure 9–2, an elevation dataset from a 12 m (40 ft) planter that used Real Time Kinematic (RTK)-GPS guidance was used to create sampling zones and then presented in a 3D view. Composite samples are taken within three distinct topographic zones: well drained (knoll), poorly drained (low depression), imperfectly drained (side slope). Cores are mixed to comprise one sample per elevation class, assuming texture is similar within an elevation class.

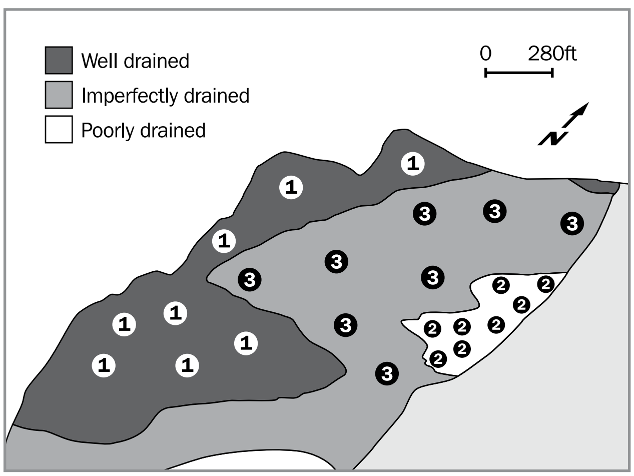

Figure 9–2. Topographic map with sampling zones created from elevation data.

Using the Soil Test Results

Data from the soil tests can be used to define Soil Management Zones (SMZ) for nutrient and lime application. If input needs are the same, or very similar across sampling zones, combine them into larger management zones. SMZs must be large enough to be effectively covered by farm-scale equipment, and have similar nutrient requirements. Use Geographic Information System (GIS) software to create nutrient or lime prescription maps for variable rate application. Copy the prescription map into the tractor or applicator software and vary the rate accordingly as the machine travels through the field. Application rate decisions may also be influenced by other factors. For example, low yielding areas having the same soil test as high yielding areas might be prescribed less nutrients to account for lower nutrient removal. If water is the yield-limiting factor rather than fertility, it may be more profitable to apply less fertilizer on coarse-textured areas of the field, even if nutrient recommendations from soil tests are the same.

How Often to Sample

Sample fields frequently enough to detect changes in the soil test before they become large enough to significantly affect crop yields or fertilizer requirements. For most farms, once every 3 years is adequate for this purpose. This often works out to once in the rotation, at the same point in the rotation. Where large amounts of K are removed (e.g., high yielding alfalfa, corn silage) levels can change quickly. Under these conditions, take samples more frequently.

Time of Year

To allow time for transport and analysis, take soil samples the previous fall, from fields to be fertilized for spring-seeded crops. Harvest rush and the frequency of poor weather in late fall may make summer a more convenient time. Sampling at the same time each year allows better precision if trends are tracked over time.

Sample Boxes and Information Sheets

Soil sample boxes, information sheets and details on the cost of various tests are available from any of the accredited labs, or from many fertilizer and farm supply outlets.

Management practices such as manure application or legume sod plowed down can affect soil test results and impact fertilizer requirements. Management information is essential to balance nutrient inventories with crop needs and should be recorded on the field information sheet that accompanies soil samples sent in for analysis.

Micronutrient Tests

OMAFRA-accredited tests are available for manganese and zinc. In the case of zinc on corn, the soil test is best used in conjunction with visual deficiency symptoms. With manganese, plant analysis, visual symptoms and the soil test are all useful. OMAFRA-accredited tests are not available for boron, copper, iron or molybdenum. Current tests for these nutrients have not provided good estimates of the availability of these nutrients to plants. Plant analysis is generally a better indicator of deficiencies of these nutrients.

Contamination

Great care is required to prevent contamination of soil samples with micronutrients, particularly zinc. Do not use galvanized (zinc-plated) soil sampling tubes to take soil samples for micronutrient tests. Do not use metal containers to collect and mix samples. Use clean plastic containers.

Sampling the soil

Micronutrient deficiencies frequently occur in small patches in fields. In these cases, soil or plant analysis taken from the entire field is unlikely to identify the problem. Collect separate samples of problem and adjacent good areas, to allow for diagnostic comparison.

Plant Analysis

Plant analysis measures the nutrient content of plant tissue. Comparing the results against the "normal" and "critical" values for the crop can indicate whether nutrient supply is adequate for optimum growth.

Plant analysis is the basis of fertilizer recommendations for tree fruits and grapes, and is a useful supplement to soil testing for evaluation of the fertility status of other crops. It is independent of soil testing and can provide a valuable "second opinion," especially for phosphorus, potassium, magnesium and manganese. It is less reliable for nitrogen and zinc. For boron and copper there is no reliable soil test, so plant analysis and visual symptoms are the methods used for diagnosing deficiencies.

Plant analysis has limitations. Interpreting the results is often difficult since plant-tissue analysis does not usually indicate the cause of a deficiency or the amount of fertilizer required to correct it. Plant analysis is most useful if combined with visual inspection of the crop and soil conditions, knowledge of past management in the field and a current soil test to provide information about soil nutrient levels and soil pH.

There is no formal accreditation process in Ontario for plant tissue analysis. However, accredited labs that perform plant analysis are monitored and provide quality analysis and interpretation of plant tissue samples.

Sampling

The time of sampling has a major effect on the results, since nutrient levels vary considerably with the age of the plant. Suggested growth stages are given in each crop chapter. Results are difficult to interpret if samples are taken at times other than those recommended. Nevertheless, sample plants suspected of being nutrient deficient as soon as a problem appears. Samples are best taken from a problem area rather than from the entire field, and it is often helpful to sample an adjacent area of healthy plants at the same time, for comparison.

Take samples for plant analysis from at least 20 plants distributed throughout the area chosen for sampling. Each sample should consist of at least 100 g (3.5 oz) of fresh material. Avoid contaminating plant tissue samples with soil. Even a small amount of soil will cause the results to be invalid, especially for micronutrients. Soil samples from "deficient" and "good" areas should also be collected at the same time for diagnostic purposes.

Sample Preparation

Deliver samples of fresh plant material directly to the laboratory. If samples are not delivered immediately, dry them to prevent spoilage. Samples may be dried in an oven at 65°C or less, or dried in the sun provided precautions are taken to prevent contamination from dust or soil. Avoid contact of samples with galvanized (zinc-coated) metal, brass or copper.

Fertilizer Guidelines

Soil Acidity and Liming

The pH scale ranging from 0–14 is used to indicate acidity and alkalinity. A pH value of 7.0 is neutral. Values below 7.0 are acidic, and those above 7.0 are alkaline. Most field crops grow well in a soil pH range from 6.0–8.0.

To correct soil acidity, broadcast ground limestone and work it into the soil at rates determined by a soil test. Table 9–4, *Guidelines for lime application to Ontario crops*, shows the pH values below which liming is recommended, and the target soil pH to which soils should be limed for different crops. In Ontario, most crops grow quite well at pH values higher than the target pH to which liming is recommended. The soil pH measures the amount of acidity in the soil solution and indicates whether liming is necessary for crop production. It does not measure the amount of reserve acidity.

The Buffer pH

Buffer pH measures the amount of reserve acidity held on the clay and organic matter particles in the soil, which will dictate how much lime is needed. Different amounts of reserve acidity will mean that two soils at the same pH value will need different amounts of lime to raise the pH to the desired level. The greater the amount of reserve acidity, the lower the buffer pH and the more lime is required to raise the pH. For soils needing lime, Table 9–4, *Guidelines for lime application to Ontario crops,* may be used to determine the amount of lime required to reach different "target" soil pH values.

Limestone Quality

Calcitic limestone consists largely of calcium carbonate, and dolomitic limestone is a mixture of both calcium and magnesium carbonates. Use dolomitic limestone on soils with a magnesium soil test of 100 or less, as it is an excellent and inexpensive source of magnesium for acidic soils. On soils with magnesium tests greater than 100, use calcitic or dolomitic limestone.

The two main factors that affect the value of limestone for soil application are the neutralizing value and particle size. Neutralizing value is the amount of acid a given quantity of limestone will neutralize when it is totally dissolved. It is expressed as a percentage of the neutralizing value of pure calcium carbonate. A limestone that will neutralize 90% is said to have a neutralizing value of 90. In general, the higher the calcium and magnesium content of a limestone, the higher the neutralizing value. See Table 9–5, *Lime requirements to correct soil acidity based on soil and buffer pH.*

Table 9–4. Guidelines for lime application to Ontario crops

Soil Type	Crops	Soil pH Below Which Lime Is Beneficial	Target Soil pH[1]
Coarse- and medium-textured mineral soils (sand, sandy loams, loams and silt loams)	perennial legumes, oats, barley, wheat, triticale, beans, peas, canola, flax, tomatoes, raspberries, strawberries, all other crops not listed below	6.1	6.5
	corn, soybeans, rye, grass, hay, pasture, tobacco	5.6	6.0
	potatoes	5.1	5.5
Fine-textured mineral soils (clays and clay loams)	alfalfa, cole crops, rutabagas	6.1	6.5
	other perennial legumes, oats, barley, wheat, triticale, soybeans, beans, peas, canola, flax, tomatoes, raspberries, all other crops not listed above or below	5.6	6.0
	corn, rye, grass hay, pasture	5.1	5.5
Organic soils (peats/mucks)	all field crops, all vegetable crops	5.1	5.5

[1] Where a crop is grown in rotation with other crops requiring a higher pH (e.g., corn in rotation with wheat or alfalfa), lime the soil to the higher pH.

Table 9–5. Lime requirements to correct soil acidity based on soil and buffer pH

Ground limestone required – t/ha (ton/acre)
(based on Agricultural Index of 75)

Buffer pH[1]	Target Soil pH			
	7.0	6.5[2]	6.0[3]	5.5[4]
7.0	2 (0.9)	2 (0.9)	1 (0.5)	1 (0.5)
6.9	3 (1.3)	2 (0.9)	1 (0.5)	1 (0.5)
6.8	3 (1.3)	2 (0.9)	1 (0.5)	1 (0.5)
6.7	4 (1.8)	2 (0.9)	2 (0.9)	1 (0.5)
6.6	5 (2.2)	3 (1.3)	2 (0.9)	1 (0.5)
6.5	6 (2.7)	3 (1.3)	2 (0.9)	1 (0.5)
6.4	7 (3.1)	4 (1.8)	3 (1.3)	2 (0.9)
6.3	8 (3.6)	5 (2.2)	3 (1.3)	2 (0.9)
6.2	10 (4.5)	6 (2.7)	4 (1.8)	2 (0.9)
6.1	11 (4.9)	7 (3.1)	5 (2.2)	2 (0.9)
6.0	13 (5.8)	9 (4.0)	6 (2.7)	3 (1.3)
5.9	14 (6.2)	10 (4.5)	7 (3.1)	4 (1.8)
5.8	16 (7.1)	12 (5.4)	8 (3.6)	4 (1.8)
5.7	18 (8.0)	13 (5.8)	9 (4.0)	5 (2.2)
5.6	20 (8.9)	15 (6.7)	11 (4.9)	6 (2.7)
5.5	20 (8.9)	17 (7.6)	12 (5.4)	8 (3.6)
5.4	20 (8.9)	19 (8.5)	14 (6.2)	9 (4.0)
5.3	20 (8.9)	20 (8.9)	15 (6.7)	10 (4.5)
5.2	20 (8.9)	20 (8.9)	17 (7.6)	11 (4.9)
5.1	20 (8.9)	20 (8.9)	19 (8.5)	13 (5.8)
5.0	20 (8.9)	20 (8.9)	20 (8.9)	15 (6.7)
4.9	20 (8.9)	20 (8.9)	20 (8.9)	16 (7.1)
4.8	20 (8.9)	20 (8.9)	20 (8.9)	18 (8.0)
4.7	20 (8.9)	20 (8.9)	20 (8.9)	20 (8.9)
4.6	20 (8.9)	20 (8.9)	20 (8.9)	20 (8.9)

[1] Buffer pH in Ontario is measured using the Shoemaker, MacLean and Pratt (SMP) buffer. Other jurisdictions may use different buffers, which will give similar but not identical results.
[2] Lime if soil pH is below 6.1.
[3] Lime if soil pH is below 5.6.
[4] Lime if soil pH is below 5.1.

The second factor that affects the value of limestone as a neutralizer of acidity is the particle size. Limestone rock has much less surface area to react with acid soil than finely powdered limestone and, therefore, it neutralizes acidity much more slowly — so much slower that it is of little value. The calculation of a fineness rating for ground limestone is illustrated in Table 9–6, *Example calculation of the fineness rating of a limestone.*

Table 9–6. Example calculation of the fineness rating of a limestone

Particle Size	% of Sample	x	Fineness Factor	=	Rating
Coarser than No. 10 sieve[1]	10%	x	0	=	0
No. 10 to No. 60 sieve[2]	40%	x	0.4	=	16
Passing through No. 60 sieve	50%	x	1.0	=	50
			Fineness Rating	=	**66**

[1] A #10 Tyler sieve has wires spaced 2.0 mm apart.
[2] A #60 Tyler sieve has wires spaced 0.25 mm apart.

The Agricultural Index

This index has been developed in Ontario as a means of combining the neutralizing value and the fineness rating to compare various limestones that are available.

$$\text{The Agricultural Index} = \frac{\text{neutralizing value x fineness rating}}{100}$$

The Agricultural Index can be used to compare the relative value of different limestones for neutralization of soil acidity. Lime with a high Agricultural Index is worth proportionately more than lime with a low index because it may be applied at a lower rate.

For example, if two ground limestones — A and B — have Agricultural Indices of 50 and 80 respectively, the rate of application of limestone A required for a particular soil will be 80/50 x the rate required for limestone B. Limestone A spread on your farm is worth 50/80 x the price of limestone B per tonne.

Guidelines from the OMAFRA-accredited pH and buffer pH soil tests are based on limestone with an Agricultural Index of 75. If the Agricultural Index is known, a rate of application specifically for limestone of that quality can be calculated using the following equation:

$$\text{Limestone application rate from soil test} \times \frac{75}{\text{Agricultural Index of Limestone}} = \text{Rate of Application of Limestone}$$

For example, if there is a limestone requirement by soil test of 9 t/ha (4 ton/acre), and the most suitable source of limestone from a quality and price standpoint has an Agricultural Index of 90, then apply 7.5 t/ha (3.3 ton/acre) (75/90 x 9).

The Agricultural Index does not provide information about magnesium content. Use dolomitic limestone on soils low in magnesium.

Tillage Depth

Lime amounts presented in Table 9–5, *Lime requirements to correct soil acidity based on soil and buffer pH,* should raise the pH of the top 15 cm (6 in.) of a soil to the listed target pH. If the soil is plowed to a lesser or greater depth than 15 cm (6 in.), proportionately more or less lime is required to reach the same target pH. Where reduced tillage depths are used, reduce rates of application proportionately. More frequent liming will be needed. For no-till with surface applied fertilizer, soil sample the top 10 cm (4 in.) to determine pH and apply two-thirds the rate prescribed in Table 9–5.

Lowering Soil pH

On soils with pH values below 6.5, it is possible to lower the pH (make the soil more acidic) by adding sulphur or ammonium sulphate. This may be desirable for some crops, for example, potatoes for scab control, but usually will not be suitable for rotation crops. Soil pH cannot be adjusted from a low pH to a more moderate pH year to year. If the soil pH is above 6.5, it is not advisable and also usually quite impractical to lower the soil pH, due to the very large amounts of sulphur or ammonium sulphate required.

Nitrogen

Nitrogen fertilizer guidelines for field crops are presented in Tables in the *Fertility Management* section for each crop chapter. Rates are adjusted downward if manure is applied, or if the previous crop contains perennial legumes such as alfalfa.

To protect crop quality and avoid movement of nitrogen into groundwater, the combined application of fertilizer, manure, biosolids and residuals and other sources of nitrogen should not supply plant-available nitrogen in excess of the crop's requirement.

Phosphate and Potash

Phosphate and potash guidelines are based on OMAFRA-accredited soil tests. The requirements of these nutrients are presented in the *Fertility Management* section for each crop chapter. Only use these tables with OMAFRA-accredited soil tests. Non-accredited tests may use extractants that pull out different amounts of nutrient so they will not give correct values if used with the published OMAFRA tables.

Phosphorus Soil Test

Be sure to read the results from the sodium bicarbonate (Olsen) method for phosphorus. Other methods, such as Brays or Mehlich 3, cannot be used to determine crop fertilizer recommendations from the *Fertility Management* sections in this publication.

A 2015 review of phosphate and potash recommendations in Ontario, which assessed 368 Ontario crop response trials on P and/or K fertilizer application conducted from 1969–2013, found that economic yield responses for corn, soybeans, wheat and alfalfa were typically small when soil test levels were above 12 ppm for phosphorus (Olsen P) or above 100 ppm for potassium (*An Ontario P + K Database to Affirm and Update BMPs in Field Crop Production Systems.* Janovicek et al., 2015). In such instances, application rates of 20 kg/ha (18 lb/acre) P_2O_5 and 20–30 kg/ha (18-27 lb/acre) K_2O generally provided the greatest economic response. The authors suggested, based on the data, that soil test values of 12–18 ppm for phosphorus and 100–130 ppm for potassium represent optimal target ranges. A comprehensive economic analysis of the long-term profitability of maintaining soil test levels above the noted ranges for P and K has not, to date, been performed in Ontario.

> **Phosphorus Pools in Soil**
>
> Phosphorus in soil exists in three main "pools":
>
> Solution P pool: the phosphorus found in soil water. It represents a very small portion of total soil P — usually less than 1.12 kg/ha (1 lb/acre).
>
> Active P pool: the solid phase phosphorus that replenishes solution P. It is the main source of available P for crops and comes from minerals (e.g., calcium phosphate), inorganic P attached to soil, and P mineralized from organic matter.
>
> Fixed P pool: inorganic phosphate that is unavailable and organic phosphorus that is resistant to mineralization. It can remain in soil for years without becoming available to plants.
>
> Source: *The Nature of Phosphorus in Soils.* Busman et al., 2009. www.extension.umn.edu

Regular monitoring through soil testing and ensuring that soil test levels remain within a reasonable range is an important part of managing risk on your farm. It is also important to note that a soil test result is an estimate of nutrient availability. In the case of both phosphorus and potassium, the value reported on a soil test report reflects the portion of that soil nutrient that is available for crop uptake; it represents a small percentage of the total amount of nutrient in the soil. For example, for phosphorus, the soil test value represents the amount of phosphate that is immediately and moderately available for plant uptake — it is the phosphorus present in the "solution P pool" and some of the "active P pool" (see side bar). Applied phosphate fertilizers are highly soluble and initially enter the solution pool; however, a portion of applied fertilizer phosphate will react in soil and become part of the unavailable, or fixed, P pool. Due to the reactive and immobile nature of phosphate, it is most efficiently applied in a band close to crop roots for maximum uptake benefit in the application year.

Good soil structure is a critical component of soil fertility. An extensive root system allows a crop to access nutrients from a greater volume of soil, which is particularly important for immobile nutrients such as phosphate. A healthy, well-structured soil will also have improved nutrient cycling, which can result in an enhanced supply of nutrients such as phosphorus and potassium from the breakdown of residue, soil organic matter, and soil minerals.

Where a soil test is not available, a rough estimate of requirements can be obtained from the phosphate and potash guidelines tables using the following guidelines:

- Where the field has been fertilized regularly for a number of years, or heavily in recent years, use one of the rates of phosphate and potash recommended for the moderately responsive (MR) soil test rating.
- If the field has received little fertilizer in the past, use one of the rates recommended for a highly responsive (HR) soil test rating.
- When the soil test response rating for phosphorus is NR (no profitable response), the soil contains much more plant-available phosphorus than is required by most crops. Application of phosphorus in fertilizer, manure or biosolids may reduce crop yield or quality and is not advised. For example, phosphate applications may induce zinc deficiency on soils low in zinc and may increase the risk of water pollution.

The risk of surface water contamination by phosphorus may be increased at higher soil test phosphorus levels. Since phosphorus binds tightly to soil particles, the movement of soil off the field through erosion is a major factor in determining the risk of surface water contamination. It is for this reason that the risk of surface water contamination by phosphorus cannot be based solely on a soil test phosphorus level. Wherever soil tests show a very low or no probability of response to added phosphorus, application of any source of phosphorus should be guided by a phosphorus index. See the OMAFRA nutrient management planning (NMAN) software, or the OMAFRA Factsheet, *Determining the Phosphorus Index for a Field,* available at ontario.ca/omafra. A phosphorus index ranks the relative risk of surface water contamination for applications made to a particular area of land. It will also determine maximum application rates, if manure is applied, and suggested setbacks from watercourses.

Magnesium

Magnesium is a nutrient that is naturally plentiful in many Ontario soils. Although rare, when magnesium soil tests are below 20 ppm, according to an OMAFRA soil test, magnesium application will be required for production of most crops. If the soil pH is below 6.0

and magnesium is below 100 ppm, the most effective and inexpensive means of supplying magnesium is by application of dolomitic lime. On soils with a higher magnesium test, use either dolomitic or calcitic lime to correct soil pH. If the pH is above 6.0 and the soil test is 20 ppm or less, supply magnesium by either magnesium sulfate or sulfate of potash magnesia (a mixture of sulfate of potash and magnesium sulfate). Apply 30 kg/ha (27 lb/acre) of actual soluble magnesium. These latter sources of magnesium are usually more expensive compared to supplying magnesium from dolomitic limestone.

Potassium competes with magnesium for uptake by crops, and potash applications can therefore induce or increase magnesium deficiency. For this reason, it is important to monitor soil potassium levels and carefully control potash fertilizer applications on low magnesium soils.

Crops grown on a number of Ontario soils are low in magnesium to the extent that livestock health is affected, although the crops themselves do not suffer from magnesium deficiency. In these situations, it is usually much more economical to add magnesium to the animal's diet than to add it to the soil. Closely monitor soil potassium and restrict potash applications to requirements as measured by soil test.

Calcium

Calcium deficiency has not been a problem in Ontario soils with soil pH adequate for field crop growth.

Sulphur

Sulphur is often provided in adequate amounts for crop growth in acid precipitation, livestock manure and organic matter breakdown. Sulphur deficiencies are increasing due to less atmospheric deposition. Deposition from rainfall has decreased by over 5 kg S/ha over the past 20 years. There has been increasing response to sulphur application in numerous trials, especially in canola, alfalfa forages and wheat crops. Where sulphur is required, apply it as ammonium sulphate, calcium sulphate (gypsum), ammonium thiosulphate, potassium sulphate or elemental sulphur. Elemental sulphur must be oxidized to the sulphate form before the plants can absorb it. Apply elemental sulphur a few months before a crop requiring sulphur is planted, or in fall for established alfalfa.

Micronutrient Fertilizers

Apply micronutrient elements only on competent advice or where experience has proven their application to be necessary. Generally, it is best to make soil applications during soil preparation and foliar applications during the growing season. Include a spreader sticker in micronutrient sprays applied directly to crop foliage.

Do not combine micronutrient elements with insecticide or fungicide sprays unless the manufacturer's directions indicate that this may be done.

Manganese

Preventing and Correcting Manganese Deficiency

The general symptom of manganese deficiency is interveinal chlorosis of leaves, which begins on the younger foliage. Later, the whole plant may be affected. Cereals show manganese deficiency as a general yellowing and stunting, occasionally with grey specks on the leaves. The crops most susceptible to manganese deficiency are soybeans, dry edible beans and cereals.

Manganese is less available at high soil pH, so it is important not to add more lime than is needed to correct soil acidity. The oxidized form of Mn is less available than the reduced form, which is why sometimes symptoms appear in areas with greater aeration and less compaction. For materials and rates to correct a deficiency, consult the individual crop chapters under *Micronutrients*. Interpretation of the manganese soil test is found in Table 9–7, *Manganese soil test interpretation.*

Table 9–7. Manganese soil test interpretation

Manganese Index[1]	Suggested Treatments
greater than 30	Soil manganese availability is adequate for field-grown crops.
16–30	Soil manganese availability is adequate for many crops but is approaching deficiency levels for oats, barley, wheat and soybeans. If deficiency symptoms appear, spray with manganese. Consider a re-check for deficiency using plant analysis.
below 16	Soil manganese availability is believed to be insufficient for oats, barley, wheat and soybeans. Spray with manganese at the 4-leaf stage of cereals and again 3 weeks later if required.

[1] These values are indices of manganese availability based on phosphoric acid extractable soil manganese and soil pH.
Where soil pH ≤ 7.1: Mn Index = 498 + 0.248(phosphoric acid extractable Mn in mg/L) - 137(soil pH) + 9.64(soil pH)^2
Where soil pH > 7.1: Mn Index = 11.25 + 0.248(phosphoric acid extractable Mn in mg/L)

Zinc

Preventing and Correcting Zinc Deficiency

Corn is the main crop that shows zinc deficiency in Ontario. Zinc deficiency has been reported in dry edible beans in other areas but only occasionally in Ontario. Deficiencies tend to occur on low organic matter soils, compacted soils, sandy soils, very high pH soils, and eroded soils. Deficiency symptoms may also appear when early growing season conditions are cool and wet. Zinc deficiency generally appears on new growth and symptoms appear as pale green area between veins and yellowing of leaf tips and outer margin. High phosphorus in the soil and/or in the fertilizer can cause or increase the severity of zinc deficiency. **Apply only the suggested amount of phosphorus.** Use of animal manures or biosolids can prevent or reduce zinc deficiency. Erosion control can prevent deficiency of zinc by limiting movement of topsoil.

Prevent zinc deficiency by applying zinc fertilizer to the soil at a rate of 4 kg/ha (3.6 lb/acre). Broadcasting up to 14 kg/ha (12.5 lb/acre) will correct a deficiency for 3 years, but do not band more than 4 kg/ha (3.6 lb/acre). Foliar sprays can be useful to correct a deficiency after the symptoms have appeared, provided this is done early in the growing season. Interpretation of the zinc soil test is found in Table 9–8, *Zinc soil test interpretation*.

Table 9–8. Zinc soil test interpretation

Zinc Index[1]	Suggested Treatments
greater than 200	Suspect contamination of the sample or of the field.
25–200	Soil zinc availability is adequate for most field-grown crops.
15–25	Zinc availability is adequate for most field crops but is bordering on deficiency for corn. If the field sampled is uneven in soil texture, pH or erosion, some areas may respond to zinc applications. Deficiency symptoms at the 4–6-leaf stage of corn are a reliable indication of zinc deficiency.
less than 15	Zinc is likely to be deficient for corn and should be applied in the fertilizer.

[1] These values are indices of zinc availability based on DTPA extractable soil zinc and soil pH.
Zinc index = 203 + 4.5(DTPA extractable zinc in mg/L soil) – 50.7(soil pH) + 3.33(soil pH)^2.

Copper

Copper soil tests are quite unreliable on Ontario soils, but plant analysis is useful. Copper is unlikely to be deficient on mineral soil, except perhaps on very sandy soils. Copper deficiency does occur on organic (muck) soils and is best diagnosed by plant analysis. When organic soils are first brought into cultivation, apply copper to the soil at 14 kg/ha (12.5 lb/acre) for each of the first 3 years.

Boron

Boron is required for alfalfa, particularly on sandy or gravelly soils with low water-holding capacity. Deficiencies are more common in central Ontario than in the rest of the province. Boron deficiency occurs most frequently during dry weather, and the response to boron may be inconsistent. It has not been possible to develop a reliable soil test. Plant analysis is useful as a predictor of boron requirements as are visual symptoms on the plants. For rates of boron to correct a deficiency, see Chapter 3, Forages, *Micronutrients*.

Boron is needed only in very small quantities, and since an overdose is toxic, take extreme care in its use. Boron deficiency has not been diagnosed in cereals, peas or beans in Ontario, and boron applications to these crops — or applied to other crops in the year preceding them — can be toxic. **Boron should be broadcast; not banded at seeding.**

Iron and Molybdenum

Iron and molybdenum have not been found to be deficient in field crops in Ontario.

Changes in Crop or Management

Fertilizer requirements on the OMAFRA soil test report are specific to the selected crop and management. Adjustments in fertilizer requirements may be needed if changes are made in manure application or if legumes are going to be incorporated. For fertilizer adjustments, see Table 9–9, *Adjustment of nitrogen requirement, where crops containing legumes are plowed down*. Changing the crop from the original soil test guideline will require a new fertilizer prescription. Obtain this by looking up the appropriate table under the specific commodity chapter in this publication.

Adjustments to Fertilizer Guidelines

The general fertilizer guidelines in this book apply to situations where no organic sources of nutrients have been applied to the field. If manure or biosolids are applied to the land, or if legumes are plowed down, reduce the fertilizer rates to adjust for the nutrients applied in the organic form.

Adjustment for Legumes Plowed Down

When sod containing perennial legumes such as alfalfa, birdsfoot trefoil and clover are plowed under, they supply an appreciable amount of nitrogen to the following crop. Table 9–9, *Adjustment of nitrogen requirement, where crops containing legumes are plowed down*, shows reductions that should be made in nitrogen fertilizer applications to crops following sod containing legumes.

The use of organic amendments beyond just livestock manure is increasing. Organic amendments include manure, and non-agricultural sourced materials (NASM) such as biosolids, compost, anaerobic digestate, as well as some Canadian Food Inspection Agency (CFIA) registered products that also contain organics (e.g., processed biosolids).

In this publication, "manure" and "other organic amendments" can be interchanged when discussing nutrient availability and risk.

Table 9–9. Adjustment of nitrogen requirement, where crops containing legumes are plowed down

Type of Crop	For All Crops, Deduct From N Requirement
Less than one-third legume	0
One-third to half legume	55 kg/ha (49 lb/acre)
Half or more legume	110 kg/ha (100 lb/acre)
Perennial legumes seeded and plowed in the same year[1]	45 kg/ha (40 lb/acre)
Soybean and field bean residue[2]	0

[1] Applies where the legume stand is thick and over 40 cm (16 in.) high.
[2] For all crops other than corn. For adjustments to corn fertilizer requirements, see **Corn Nitrogen Rate Worksheet, Chapter 1, Corn (metric version or Appendix B for imperial version).**

Adjustments for Manure Application

A large number of Ontario farms produce livestock, generating over 25 million tonnes of manure annually. Proper management of the nutrients from manure is essential for optimum economic benefit to the producer, with minimal impacts on the environment.

Estimating Nutrients Available to the Crop from Average Values

The best way of determining the amount of each nutrient from manure is to analyze a sample. Unfortunately, this is not always possible, as in the case of a new barn. In this case, average values will provide an estimate of the nutrients available to the crop.

Table 9–10, *Typical amounts of total and available nitrogen, phosphate and potash from various organic nutrient sources*, provides estimates of available nutrients from various types of manure. It is based on the average results from manure analyses from the accredited labs in Ontario. Nitrogen is reported as available N under various application systems. Phosphate and potash values are reported as nutrients available to replace fertilizer nutrients. Use these values as the starting point in crediting nutrients from manure application.

Table 9–10. Typical amounts of total and available nitrogen, phosphate and potash from various organic nutrient sources

Type	Sub-Type	DM	Available Nutrients				Lab Analysis			
			Nitrogen[1]		P_2O_5[2]	K_2O	% N	% NH_4-N	% P	% K
			Fall Applied	Spring Applied						
Solid Manure										
Hogs	composite	31%	3.7 kg/t (7.4 lb/ton)	3.6 kg/t (7.1 lb/ton)	4.5 kg/t (9.0 lb/ton)	6.2 kg/t (12 lb/ton)	0.93	0.29	0.49	0.57
Dairy	light bedding	21%	2.1 kg/t (4.1 lb/ton)	3.1 kg/t (6.1 lb/ton)	1.9 kg/t (3.7 lb/ton)	6.5 kg/t (13 lb/ton)	0.69	0.16	0.20	0.60
	heavy bedding	41%	2.5 kg/t (4.9 lb/ton)	1.3 kg/t (2.5 lb/ton)	2.0 kg/t (3.9 lb/ton)	7.2 kg/t (14 lb/ton)	0.82	0.11	0.21	0.66
Beef	light bedding	24%	2.1 kg/t (4.2 lb/ton)	2.8 kg/t (5.5 lb/ton)	2.0 kg/t (4.0 lb/ton)	6.0 kg/t (12 lb/ton)	0.70	0.14	0.22	0.55
	medium bedding	35%	3.1 kg/t (6.2 lb/ton)	4.2 kg/t (8.4 lb/ton)	3.4 kg/t (6.8 lb/ton)	8.0 kg/t (16 lb/ton)	1.03	0.20	0.37	0.74
	heavy bedding	46%	4.0 kg/t (8.0 lb/ton)	5.4 kg/t (10.7 lb/ton)	5.0 kg/t (9.9 lb/ton)	9.4 kg/t (19 lb/ton)	1.34	0.25	0.54	0.87
Sheep	composite	32%	2.6 kg/t (5.2 lb/ton)	2.8 kg/t (5.5 lb/ton)	3.2 kg/t (6.3 lb/ton)	8.2 kg/t (16 lb/ton)	0.87	0.28	0.34	0.76
Dairy goats	composite	36%	3.1 kg/t (6.2 lb/ton)	3.6 kg/t (7.8 lb/ton)	2.6 kg/t (5.2 lb/ton)	11.1 kg/t (22 lb/ton)	1.04	0.28	0.28	1.03
Compost	cured	46%	3.4 kg/t (6.7 lb/ton)	1.0 kg/t (1.9 lb/ton)	2.4 kg/t (4.8 lb/ton)	4.9 kg/t (9.7 lb/ton)	0.84	0.00	0.26	0.45
	immature	47%	5.4 kg/t (11 lb/ton)	5.2 kg/t (10 lb/ton)	3.8 kg/t (7.5 lb/ton)	11.4 kg/t (23 lb/ton)	1.32	0.12	0.41	1.05
Veal (grain fed)	composite	31%	2.4 kg/t (4.7 lb/ton)	2.6 kg/t (5.2 lb/ton)	1.8 kg/t (3.5 lb/ton)	6.5 kg/t (11 lb/ton)	0.79	0.14	0.19	0.51
Horses	composite	37%	1.5 kg/t (3.0 lb/ton)	-1.3 kg/t (-2.5 lb/ton)	1.4 kg/t (2.8 lb/ton)	4.7 kg/t (9.3 lb/ton)	0.50	0.07	0.15	0.43
Mink	composite	46%	16.4 kg/t (33 lb/ton)	21.8 kg/t (44 lb/ton)	16.8 kg/t (33 lb/ton)	8.6 kg/t (17 lb/ton)	3.28	1.42	1.82	0.79
Chickens	layers	37%	10.4 kg/t (21 lb/ton)	12.6 kg/t (25 lb/ton)	9.2 kg/t (18 lb/ton)	10.6 kg/t (21 lb/ton)	2.07	0.81	1.00	0.98
	pullets	43%	16.0 kg/t (32 lb/ton)	23.2 kg/t (46 lb/ton)	12.7 kg/t (25 lb/ton)	15.0 kg/t (30 lb/ton)	3.19	0.70	1.38	1.39
	broilers	66%	15.6 kg/t (31 lb/ton)	18.8 kg/t (38 lb/ton)	13.0 kg/t (26 lb/ton)	19.4 kg/t (39 lb/ton)	3.12	0.66	1.41	1.79
	BB growers	63%	9.4 kg/t (19 lb/ton)	7.9 kg/t (16 lb/ton)	13.1 kg/t (26 lb/ton)	14.0 kg/t (28 lb/ton)	1.88	0.29	1.42	1.29
	BB layers	65%	11.1 kg/t (22 lb/ton)	10.7 kg/t (21 lb/ton)	14.6 kg/t (29 lb/ton)	16.9 kg/t (34 lb/ton)	2.21	0.32	1.58	1.56
Turkeys	toms	52%	13.1 kg/t (26 lb/ton)	15.5 kg/t (31 lb/ton)	12.7 kg/t (25 lb/ton)	17.4 kg/t (34 lb/ton)	2.62	0.87	1.38	1.59
	poults	71%	16.6 kg/t (33 lb/ton)	20.0 kg/t (40 lb/ton)	8.3 kg/t (17 lb/ton)	13.2 kg/t (26 lb/ton)	3.31	0.66	0.90	1.22
	breeders	55%	10.8 kg/t (22 lb/ton)	10.6 kg/t (21 lb/ton)	12.0 kg/t (24 lb/ton)	14.6 kg/t (29 lb/ton)	2.16	0.86	1.30	1.35
	broilers	62%	16.8 kg/t (33 lb/ton)	22.0 kg/t (44 lb/ton)	11.2 kg/t (22 lb/ton)	15.4 kg/t (31 lb/ton)	3.35	0.60	1.21	1.42
Biosolids	composite	32%	15.1 kg/t (30 lb/ton)	30.8 kg/t (61 lb/ton)	12.1 kg/t (24 lb/ton)	1.2 kg/t (2.4 lb/ton)	3.76	0.64	1.31	0.11

[1] Useable N = amount of nitrogen available assuming material incorporated within 24 hr.

[2] The available P_2O_5 represents half of the phosphorus contribution that is available shortly after application. The remaining P_2O_5 becomes available by the following year.

The actual immediate value for crop production will be less if all the nutrients applied are not required for growing the crop.

The micronutrient and organic matter values are not reflected in these tables.

Table 9–10. Typical amounts of total and available nitrogen, phosphate and potash from various organic nutrient sources

Type	Sub-Type	DM	Available Nutrients				Lab Analysis			
			Nitrogen[1]		P_2O_5[2]	K_2O	%	%	%	%
			Fall Applied	Spring Applied			N	NH_4-N	P	K
Liquid Manure										
Hogs	sows (SEW)	1.7%	0.8 kg/m³ (8.4 lb/ 1,000 gal)	1.6 kg/m³ (16 lb/ 1,000 gal)	0.6 kg/m³ (5.5 lb/ 1,000 gal)	1.2 kg/m³ (12 lb/ 1,000 gal)	0.24	0.18	0.06	0.11
	weaners	2.3%	1.0 kg/m³ (9.8 lb/ 1,000 gal)	1.9 kg/m³ (19 lb/ 1,000 gal)	0.8 kg/m³ (8.3 lb/ 1,000 gal)	1.6 kg/m³ (16 lb/ 1,000 gal)	0.28	0.19	0.09	0.15
	finishers	4.9%	1.8 kg/m³ (18 lb/ 1,000 gal)	3.3 kg/m³ (33 lb/1,000 gal)	1.4 kg/m³ (14 lb/ 1,000 gal)	2.9 kg/m³ (29 lb/ 1,000 gal)	0.52	0.36	0.15	0.27
	farrow to finish	3.8%	1.5 kg/m³ (15 lb/1,000 gal)	2.8 kg/m³ (28 lb/1,000 gal)	0.9 kg/m³ (9.2 lb/ 1,000 gal)	2.3 kg/m³ (23 lb/1,000 gal)	0.43	0.29	0.10	0.21
Dairy	composite	8.6%	1.2 kg/m³ (12 lb/1,000 gal)	1.8 kg/m³ (18 lb/1,000 gal)	0.8 kg/m³ (8.3 lb/ 1,000 gal)	2.7 kg/m³ (27 lb/1,000 gal)	0.39	0.16	0.09	0.25
	thick	14.1%	1.6 kg/m³ (16 lb/1,000 gal)	2.1 kg/m³ (21 lb/1,000 gal)	1.3 kg/m³ (13 lb/ 1,000 gal)	3.4 kg/m³ (33 lb/ 1,000 gal)	0.53	0.18	0.14	0.31
	fluid	4.4%	0.8 kg/m³ (7.5 lb/ 1,000 gal)	1.3 kg/m³ (13 lb/1,000 gal)	0.4 kg/m³ (3.7 lb/ 1,000 gal)	2.1 kg/m³ (20 lb/ 1,000 gal)	0.25	0.12	0.04	0.19
	watery	1.1%	0.4 kg/m³ (3.6 lb/ 1,000 gal)	0.8 kg/m³ (8.4 lb/ 1,000 gal)	0.2 kg/m³ (1.8 lb/ 1,000 gal)	1.2 kg/m³ (12 lb/ 1,000 gal)	0.12	0.06	0.02	0.11
Beef	composite	8.6%	1.1 kg/m³ (11 lb/ 1,000 gal)	1.6 kg/m³ (16 lb/ 1,000 gal)	0.7 kg/m³ (7.4 lb/ 1,000 gal)	2.5 kg/m³ (25 lb/ 1,000 gal)	0.37	0.15	0.08	0.23
Runoff	composite	0.7%	0.15 kg/m³ (1.5 lb/ 1,000 gal)	0.3 kg/m³ (2.9 lb/ 1,000 gal)	0.1 kg/m³ (0.9 lb/ 1,000 gal)	1.0 kg/m³ (9.7 lb/ 1,000 gal)	0.05	0.03	0.01	0.09
Mink	composite	3.6%	1.6 kg/m³ (16 lb/ 1,000 gal)	3.1 kg/m³ (31 lb/ 1,000 gal)	0.9 kg/m³ (9.2 lb/ 1,000 gal)	1.0 kg/m³ (9.7 lb/ 1,000 gal)	0.45	0.26	0.10	0.09
Veal (milk-fed)	composite	1.5%	0.2 kg/m³ (2.4 lb/ 1,000 gal)	0.4 kg/m³ (3.7 lb/ 1,000 gal)	0.2 kg/m³ (1.8 lb/ 1,000 gal)	1.9 kg/m³ (19 lb/ 1,000 gal)	0.08	0.05	0.02	0.18
Chickens	layers	9.9	2.8 kg/m³ (28 lb/ 1,000 gal)	4.8 kg/m³ (48 lb/ 1,000 gal)	2.5 kg/m³ (25 lb/ 1,000 gal)	3.1 kg/m³ (31 lb/ 1,000 gal)	0.81	0.56	0.27	0.29
	pullets	15.3%	3.6 kg/m³ (36 lb/ 1,000 gal)	5.9 kg/m³ (58 lb/ 1,000 gal)	3.7 kg/m³ (37 lb/ 1,000 gal)	3.7 kg/m³ (38 lb/ 1,000 gal)	1.04	0.62	0.40	0.34
Biosolids	aerobic	2.0%	0.4 kg/m³ (4.2 lb/ 1,000 gal)	0.8 kg/m³ (7.8 lb/ 1,000 gal)	0.6 kg/m³ (5.5 lb/ 1,000 gal)	0.0	0.12	0.01	0.06	0.00
	anaerobic	4.4%	1.0 kg/m³ (9.8 lb/ 1,000 gal)	1.7 kg/m³ (17 lb/ 1,000 gal)	1.3 kg/m³ (13 lb/ 1,000 gal)	0.0	0.28	0.08	0.14	0.00

[1] Useable N = amount of nitrogen available assuming material incorporated within 24 hr.
[2] The available P_2O_5 represents half of the phosphorus contribution that is available shortly after application. The remaining P_2O_5 becomes available by the following year.
The actual immediate value for crop production will be less if all the nutrients applied are not required for growing the crop.
The micronutrient and organic matter values are not reflected in these tables.

The availability of manure N to the crop depends on the proportion of ammonium and organic N in the manure, as well as the timings of application and incorporation. The ammonium nitrogen in manure is chemically the same form of nitrogen as in many mineral fertilizers and is immediately available to the crop. Unfortunately, the ammonium form is also subject to loss by volatilization if not incorporated immediately. The balance of the nitrogen in manure is in the organic form, which becomes available to crops gradually as the organic compounds break down.

More precise estimates of available nutrients can be made by accounting for the actual timing and conditions for manure application, and the lag time before incorporation. See the OMAFRA worksheet, *Calculating Available Nutrients from Spring-Applied Manure Using a Manure Analysis.* OMAFRA's NMAN software can also help with this process. NMAN3 software is available to download at ontario.ca/omafra.

Manure Management

The Value of Manure

The value of manure in crop production is often underestimated. Manure contains all of the nutrients needed by crops but not necessarily in the proportions needed for specific soil and crop conditions. In addition to nitrogen, phosphorus and potassium, manure contains many secondary nutrients and micronutrients, as well as organic matter that help build and maintain soil structure.

Nutrient Management Plans

A nutrient management plan matches the nutrients from the soil and those available from manure, cover crops, and commercial fertilizer, to the nutrients required by the crop. Analysis of nutrients contained in the manure, along with soil test results and crop requirements, helps determine the manure application rate and additional commercial fertilizer requirements.

A nutrient management plan may limit the rate of manure or fertilizer applied if that application creates certain risks, as shown below:

Criteria	Risk
Nitrogen	nitrate leaching into groundwater
Phosphorus	phosphate movement into surface water
Volume of liquid	direct runoff, carrying ammonia, phosphate and pathogens

An Example

A producer spreads 45 m³ (45,000 L) of liquid finisher swine manure per hectare (4,000 gal per acre) in the spring, working the manure into the soil within 24 hours.

Fertilizer	Equivalent Amount		Price/kg[1]		Value/ha
Nitrogen	153 kg/ha	x	1.30	=	$199
P_2O_5	126 kg/ha	x	1.45	=	$183
K_2O	96 kg/ha	x	0.97	=	$93
Total value per hectare				=	$475
Total value per acre				=	$215

Calculate the equivalent amount of commercial fertilizer using Table 9–10, *Typical amounts of total and available nitrogen, phosphate and potash from various organic nutrient sources.* At the sample prices for commercial fertilizer shown in this chart, the approximate value of the manure is $475/ha ($215/acre), assuming that all nutrients are needed by the crop.

[1] Price based on average commercial fertilizer costs in 2016.

Availability of Manure Nitrogen to Crops

The amount of nitrogen contained in manure that is available to crops will depend on the composition of the manure, the time that it is applied and how soon following application the manure is incorporated into the soil. The relevant manure characteristics are the total N content, the proportion that is in the mineral (ammonium) and organic forms, and the rate of breakdown of the organic material to release mineral N.

There are many variables that will influence how much nitrogen will be available to a subsequent crop from manure applications. These variables include:

- manure type
- amount and type of bedding
- time of application to incorporation
- subsequent crop
- site-specific soil and weather conditions

A recent review of manure N response data has revealed a number of areas where the nitrogen credits from manure could be fine-tuned. In particular, the estimates on N availability from ruminants (e.g., bedded cattle manure) are higher when manure is fall applied, and decreased for spring pre-plant applications. The nitrogen credits from hog and poultry manure have remained relatively unchanged from previous estimates.

Mineral Nitrogen from Manure

Manure from different farming systems contains varying proportions of organic- and ammonium-N. Liquid manure contains a higher proportion of the nitrogen in the ammonium form than solid manure. The proportion of ammonium-N (NH_4-N) and organic-N can be determined from a manure analysis, or estimated from the values in Table 9–11, *Approximate ammonium-nitrogen as a percentage of total nitrogen in various manure types.*

NH_4-N is immediately available to a growing crop, similar to nitrogen from mineral fertilizers, but it is also subject to volatilization loss to the air. The volatilization process continues until the manure is moved into the soil by incorporation or rainfall. Manures that are incorporated quickly will provide more nitrogen to the crop. The rate of NH_4-N loss will depend on the soil moisture and weather conditions at the time of application. Moist soils increase the opportunity for ammonium to be absorbed in the soil water. Warm temperatures increase the rate of ammonium loss to the air. These losses are highest on sunny, warm days, when soils are dry; losses are lowest when conditions are overcast and cold (<10°C), when soils are moist or during rainy periods. The balance of ammonium-N that remains in the soil is available for crop uptake. The estimated retention of ammonium under various conditions is listed in Table 9–12, *Estimated proportion (factor) of ammonium nitrogen from manure retained in year of application.* Average values are used for planning purposes, however, the impact of temperature on nitrogen retention is illustrated.

Table 9–11. Approximate ammonium-nitrogen as a percentage of total nitrogen in various manure types

Type	Source	Ammonium-N2
Liquid manure[1]	Liquid hog	66%
	Liquid dairy	42%
	Liquid beef	43%
	Liquid poultry	67%
Solid manure[2]	Solid hog	26%
	Solid dairy	21%
	Solid beef (high bedding)	12%
	Solid horse	15%
	Solid poultry (broilers)	6%
	Solid poultry (layers)	46%
	Composted cattle	0.6%
Municipal sources	Aerobic sewage biosolids	1.6%
	Anaerobic sewage biosolids	35%
	Dewatered sewage biosolids	12%
	Lime-stabilized sewage biosolids	trace
	Paper-mill biosolids	trace
	Spent-mushroom compost	5%

[1] Ammonium content increases as moisture content increases (or dry matter decreases).
[2] Balance of nitrogen is in organic form.

With manure applied in late fall (<10°C), ammonium losses are lower since cooler temperatures slow down microbial action in soil, which minimizes conversion. Losses can be high due to runoff from late fall applications, especially when not incorporated. Denitrification and leaching losses of nitrogen are dealt with in *Nitrogen Risk Mitigation.*

Organic Nitrogen from Manure

Organic nitrogen is not available to the crop until it has been mineralized to the ammonium form by microbial action. The amount of mineralization will vary with

Table 9–12. Estimated proportion (factor) of ammonium nitrogen from manure retained in year of application

Incorporation Details	Injected (covered)	Incorporated					Not Incorporated		
		1 day	2 days	3 days	4 days	5 days	Bare Soil	Residue	Standing Crop (below canopy)
Average (factor)	1.00	0.75	0.60	0.50	0.45	0.40	0.35	0.50	0.66
Cool (<10°C)[1]	1.00	0.85	0.70	0.60	0.55	0.50	0.45	0.66	0.75
Warm (>25°C)[1]	1.00	0.65	0.50	0.40	0.35	0.30	0.20	0.35	0.55

Adapted (K. Reid) from Dr J. Lauzon, K. Janovicek, University of Guelph 2013. The table is based on an evaluation of data from 180 field sites which measured crop yield response to manure, of which 165 recorded grain corn yields.

[1] Shows a trend for ammonia loss under cooler or warmer than average temperatures. Other factors such as soil moisture and amount of cover will affect ammonium retention.

the type of manure, as the organic material in some manure is more resistant to breakdown than in others. As a general rule, the organic-N will become available more quickly from manure from animals receiving a concentrate-based diet vs. a forage-based diet.

The speed of mineralization increases with warm temperatures and adequate moisture, which promote microbial growth, and will almost stop when soil temperatures approach freezing. Nitrogen from solid manure applied just before planting may not be available in time to meet the requirements of the crop. The influence of soil microbial populations in mineralizing the organic N is important. Carbon-to-nitrogen ratios (C:N) help predict how much nitrogen will be released to a crop. A solid beef manure with high carbon (wood chip bedding) and low nitrogen (low-quality forage) will have a high C:N ratio (e.g., 50:1). A solid poultry manure with straw bedding and high protein ration would have a low C:N ratio (e.g., 9:1)

To calculate available organic N, a combination of manure nutrient analysis, organic carbon and C:N ratio is used. See equation in this section, Estimated percentage of organic nitrogen available in year of application, which estimates the amount of nitrogen that will be available for crop uptake from the organic N portion of manure. Availability can be estimated by determining how much nitrogen the soil life would require to mineralize all the nitrogen in manure. If the manure contains more N than is required by soil life, then the surplus is released. If there is less N in the organic material than is required by the organisms, the additional N required will be immobilized (borrowed) from the soil, which results in decreased plant-available N.

Based on a University of Guelph evaluation in 2013 of data from 180 field studies that measured crop yield response to manure by Dr. Lauzon, K Janovicek, the estimate of organic N available from spring applied manure was updated to the equations shown below. The equation assumes the average carbon content of manure is 42% of manure dry matter and that the retained carbon is 37.4% for liquid manure and 31% for solid manure and the C:N ratio of soil life is 8:1.

The equation: Available manure Organic N = Organic N x (carbon content of manure x carbon retained by soil life x C:N ratio of soil life) x Conversion factor (% to lb per ton or per 1000 gallons) has been condensed to those shown below.

NH_4-N, whether applied directly or from the mineralization of organic-N, is further converted to nitrate-N by microbial action in the soil. Unlike NH_4-N, which will adhere to soil particles, the nitrate ion can move freely with soil water.

Equation: Estimated Percentage of Organic Nitrogen Available in Year of Application (spring applied)

% Organic N = % Total N - % NH_4-N

Liquid (as applied)
[% organic N – (% DM ÷ 50.93)]
x 100 = lb/1000 gal
x 10 = kg/1000 L or kg/m^3

Example: Liquid Dairy Manure
(4.5% DM, 0.25 % Total N; 0.12% NH4-N; 0.04% P; 0.19% K)

Available Organic N
= [(0.25 - 0.12) - (4.5 ÷ 50.93)]
= (0.13 - 0.09)
= 0.04 %

0.04 % x 100 = 4 lb/1000 gallons
0.04 % x 10 = 0.4 kg/ m^3

Solid (as applied)
[% organic N – (% DM ÷ 61.44)]
x 20 = lb/ton
x 10 = kg/tonne

Example: Solid Broiler Manure
(70% DM, 3.12 % Total N; 0.6% NH4-N; 1.4% P; 1.8% K)

Available Organic N
= [(3.12 - 0.6) - (70 ÷ 61.44)]
= (2.52 - 1.14)
= 1.38 %

1.38% x 20 = 27.6 lb/ton
1.38% x 10 = 13.8 kg/T)

Loss of nitrate-nitrogen (NO_3-N) through leaching or denitrification will occur if manure (especially liquid manure — high in NH_4-N) is applied to bare soil in the summer or early fall. The amount of loss will depend on how much NO_3-N is produced, which in turn depends on the time required for NH_4-N and organic-N to be converted to NO_3-N. Late-summer applications of manure have a greater chance of NO_3-N losses than manure applied just before freeze-up or in the spring.

Cover crops can help retain the nitrogen from manure applied in the summer or early fall. Nitrogen scavengers, such as brassicas (radish), cereals (oats) and legumes (red clover) will take up nitrogen and hold it in the roots and biomass. Refer to cover crops in Chapter 8, *Managing for Healthy Soils*.

Field trials with specific livestock manure types, to determine how much nitrogen would be available to crops the following year has resulted in Table 9–13, *Estimate of available nitrogen from late summer- and fall-applied manure, as a proportion (factor) of total N applied*. To estimate the amount of nitrogen available to the crop, multiply the amount of manure total nitrogen (from analysis) applied to the field by the availability factor (Table 9–13) appropriate for the manure type and application timing.

For example, 45,000 L/ha (4,000 gal/acre) of liquid hog finishing manure is applied in early fall to bare soil (total N content in manure analysis is 0.52% translates to 5.2 kg/m^3 or 52 lb/1,000 gal total N). Losses due to early fall application result in a total nitrogen credit from manure of 82 kg/ha (73 lb/acre). [45 L/ha x 5.2 kg/L x 0.35 = 82 kg/ha]

Table 9–13 accounts for the volatilization of ammonium-N into the air, the mineralization of organic-N and the loss of nitrate through denitrification and/or leaching. A large part of the ammonium-N will be lost to the air if manure is left un-incorporated on the soil surface, so the proportion of nitrogen available to the crop is greater with incorporated manure.

Manure Analysis

Manure analysis is necessary because the quantities of nutrients contained in manure, especially the phosphorus and potash components, will vary from farm to farm. Type of livestock, ration, bedding, added liquids and storage system all affect the final nutrient analysis. Phosphorus tends to be concentrated in the solids, while potassium levels tend to be higher in the liquid portion, therefore the level of agitation will affect nutrient levels being applied to a field. Fertilizer adjustments based on a manure analysis will be more accurate than those based on average values, however average values can be fine-tuned for future fertilizer application where analysis results are available after application. Table 9–14, *Interpreting manure analysis results,* summarizes the significance of analysis results, the potential availability and potential risks (e.g., total salts).

Table 9–13. Estimate of available nitrogen from late summer- and fall-applied manure, as a proportion (factor) of total N applied

Available N in manure = Total N (from analysis) x available N (factor from Table)

Assumes a spring-planted full season crop (e.g., corn).

Accounts for ammonia loss to atmosphere and mineralization of organic N.

Manure Type	Application Time	Incorporated (<24 hr)			Not Incorporated[1]	
		Late Summer	Early Fall	Late Fall	Early Fall	Late Fall
Solid	Solid cattle/sheep/horse	0.20	0.30	0.35	0.30	0.35
	Solid swine/compost[1]	0.30	0.40	0.45	0.40	0.45
	Solid poultry/mink	0.40	0.50	0.60	0.50	0.60
Liquid	Liquid cattle	0.30	0.30	0.35	0.30	0.35
	Liquid swine	0.25	0.35	0.45	0.35	0.45
	Liquid poultry/mink[1]	0.25	0.35	0.50	0.35	0.50
	Liquid biosolids	0.25	0.35	0.45	0.35	0.45

[1] These coefficients are based on assumed N availability given the characteristics of each manure type, since there are no direct measurements of N availability for these materials.

Adapted (K. Reid) from Dr. J. Lauzon, K. Janovicek. University of Guelph. 2013. The table is based on an evaluation of data from 180 field sites that measured crop yield response to manure, of which 165 recorded grain corn yields.

Table 9–14. Interpreting manure analysis results

An electronic version of calculating nutrients from an analysis is available with NMAN3 software at ontario.ca/omafra or as a spreadsheet at www.gocorn.net.

LEGEND: – = no data available

Components	Liquid and solid manure example: Example Analysis – Solid	Example Analysis – Liquid	~Available Nutrients solid (liquid)	Comments
Dry Matter	41%	8.6%	410 kg/t (86 kg/m^3)	Dry matter can be converted to volume of solids applied from manure.
Total Nitrogen (N)	0.82%	0.38%	Available Organic N + Available NH_4-N = total available N	Total N – NH_4-N = Organic N Organic N is slow release with microbial activity ranging from 5%–30%, depending on: • timing of application • C:N ratio • soil/weather conditions
NH_4-N (ammonium-nitrogen)	1,100 ppm	1,600 ppm	2.6 kg/t (1.8 kg/m^3)	NH_4-N is readily available, but easily lost through volatilization. Same day incorporation provides ~ 75% of NH_4-N
Phosphorus (P)	0.21%	0.09%	3.7 kg/t (1.7 kg/m^3) P_2O_5	Assumption that P in manure is ~80% as available over time as commercial sources; where 20% is tightly tied to soil or lost in runoff or erosion. Total P% x 1.84 x 100 = lb/1,000 gal available P_2O_5 (over long term) Total P% x 1.84 x 20 = lb/ton available P_2O_5. Where soil fertility is low, the full amount of P may not be available immediately after application and additional P_2O_5 may be needed (commercial sources).
Potassium (K)	0.66%	0.10%	7.1 kg/t (1.1 kg/m^3) K_2O	Assumptions that K in manure is ~90% as available over time as commercial sources. Total K% x 1.08 x 100 = lb/1,000 gal available K_2O. Total K% x 1.08 x 20 = lb/ton available K_2O.
Organic Matter (OM)	42%	18.5%	463 kg/t (185 kg/m^3)	Available OM is reported as dry material returned to the soil. Existing soil organic matter levels will impact nutrient uptake/cycling/loss and water-holding capacity. Where manure is applied regularly, soil organic matter levels are usually higher.
C:N ratio	25 : 1	11:1	–	Carbon to Nitrogen ratio indicates how quickly carbon breakdown may occur. Nitrogen is the food source for microorganism breaking down carbon. C:N ratio ~ 10:1 is similar to soil conditions. C:N ratio over 25:1 (i.e., high bedding manure) could result in nitrogen from the soil being tied up to break down carbon and cause N deficiency.
Carbon	–	–	~ 178 kg/t (~ 24 kg/m^3)	Organic N x Carbon value from C:N ratio – gives a rough estimate. Organic carbon measurement can also be requested from a lab analysis.
pH	8.0	7.0	–	Ammonia volatilization occurs because NH_4-N in manure or solution is converted to dissolved NH3 gas. More N is volatilized as pH and/or temperature increases. Some digestate materials and processed biosolids have high pH and high ammonium-N and are subject to high N loss from volatilization when not immediately incorporated.
Bulk Density	455 kg/m^3 (28.4 lb/ft^3)	1,062 kg/m^3 (66.3 lb/ft^3)	–	Bulk density is an important consideration when planning for amendments that are being transported and applied. Bulk density of broiler manure/compost materials is generally 25 lb/ft3, where solid cattle manure with high bedding will often be greater than 50 lb/ft^3. To convert: kg/m^3 x 2.2 ÷ 35.31 = lb/ft^3
Sulphur (S)	627 ppm	320 ppm	0.63 kg/t (3.2 kg/m^3)	Significant portion as organic or elemental S – slow release with soil microbial activity. Regular application of manure will generally provide adequate S for crop requirements. Infrequent application may not provide enough S for canola or alfalfa crops especially in cool–wet soil conditions.

kg/t x 2 = ~ lb/ton kg/m^3 x 10 = ~ lb/1000 gal

Table 9–14. Interpreting manure analysis results

An electronic version of calculating nutrients from an analysis is available with NMAN3 software at ontario.ca/omafra or as a spreadsheet at www.gocorn.net.

LEGEND: – = no data available

	Liquid and solid manure example			
	Example Analysis		~Available Nutrients	
Components	**Solid**	**Liquid**	**solid (liquid)**	**Comments**
EC (conductivity)	10 ms/cm	14 ms/cm	6.4 kg/t (9 kg/m³)	All salts – K, NH4, Mg, Ca, Al and including sodium (Na). EC and Sodium (Na) both measure salt content. Both materials have a high salt content and would cause potential injury (seedling/germination) if planting occurred too quickly after application or if material was surface applied (no-till) and conditions were very dry.
Sodium (Na)	0.86%	0.06%	8.6 kg/t (0.6 kg/m³)	Sodium is a component of total salts and contributes to EC. Sodium is the form of salt used in food/feed. Sodium levels are high in food waste compost and in some types of manure.
Aluminum (Al)	1200 ppm	154 ppm	1.2 kg/t (0.15 kg/m³)	Micronutrients are reported as they exist in the organic amendment. Availability for crop uptake varies with soil conditions, soil microbial activity, organic matter levels and existing fertility. Generally in the year of application, about half of the sulfur, calcium and magnesium is available. About two-thirds of the boron, copper, iron, manganese and zinc is available for crop uptake.
Boron (B)	6 ppm	4 ppm	0.006 kg/t (0.004 kg/m³)	
Calcium (Ca)	1.3%	0.35%	13 kg/t (3.5 kg/m³)	
Copper (Cu)	24 ppm	15 ppm	0.02 kg/t (0.02 kg/m³)	
Iron (Fe)	990 ppm	210 ppm	1.0 kg/t (0.21 kg/m³)	
Magnesium (Mg)	0.31%	0.11%	3.1 kg/t (1.1 kg/m³)	
Manganese (Mn)	88 ppm	30 ppm	0.09 kg/t (0.03 kg/m³)	
Zinc (Zn)	78 ppm	36 ppm	0.08 kg/t (0.04 kg/m³)	

kg/t x 2 = ~ lb/ton   kg/m³ x 10 = ~ lb/1000 gal

Above-average levels of nitrogen, phosphorus or trace elements in manure may be an indication that dietary levels are higher than required. Amino acid-balancing for nitrogen, reducing the amount of phosphorus in the mineral supplements or adding phytase (an enzyme that increases phosphorus efficiency in the animal) may help reduce these nutrients in manure. Consult a livestock nutritionist before making ration changes.

Manure analysis is available from several laboratories in Ontario. Sample after complete agitation or thorough mixing, each time the storage is emptied (e.g., spring and fall), and send the sample for analysis. After several analyses, a trend in results should become evident. As well, sampling should occur when there are changes in ration or other management factors.

When sending a sample to the lab, fill a plastic jar about half-full, secure the top, place in a plastic bag and store in a cool place until shipping. Analysis should include total nitrogen, ammonium-nitrogen (NH_4-N), phosphorus, potassium and dry matter. Micronutrients, including sulphur, pH, organic matter and C:N ratio (for solid manure) analysis can provide valuable data for fertilizer application. Labs accredited for OMAFRA soil test return analysis results with "as-applied" percentages for nitrogen, phosphorus, potassium and dry matter, as well as mg/kg (or ppm) of ammonium nitrogen and micronutrients. On most reports, percentages of phosphorus, potassium and significant micronutrients from manure are converted to commercial fertilizer equivalents and potential commercial fertilizer reductions are often reported.

Details for interpreting a manure analysis are shown in the OMAFRA worksheet *Calculating Available Nutrients from Spring-Applied Manure Using a Manure Analysis* and Table 9-14, *Interpreting manure analysis results*. Information from a manure analysis, fine-tuned with specific application details can be used to provide a more precise estimate of the available nutrients in the manure applied to fields.

Calculating Available Nutrients from Spring-Applied Manure Using a Manure Analysis

Keep the same units throughout the calculation. Some reports will provide ammonium-N contents in ppm (mg/kg, mg/L), while the other numbers are in percentages. To convert ppm to percentage, divide by 10,000.

Available Nitrogen[1]

A. Total Nitrogen __________
B. Ammonium-N __________
C. Organic N[3] (A – B) __________
D. Ammonium Retained
(B x factor from Table 9–13) __________
E. Available Organic N, formula from Table 9–14,
Liquid: C – (Dry Matter ÷ 51)
Solid: C – (Dry Matter ÷ 61.4) __________
F. Total Available Nitrogen (D + E)[4] __________

Available Phosphate[2]

G. Total Phosphorus __________
H. Available Phosphorus
(G x 0.4) __________
I. Available Phosphate
(H x 2.29) __________

Available Potash[2]

J. Total Potassium __________
K. Available Potassium
(J x 0.9) __________
L. Available Potash
(K x 1.2) __________

Notes

[1] Available nitrogen is determined by subtracting the ammonia losses to the air from the ammonium-N applied and adding the mineralization from the organic N portion of the manure.

[2] Calculate reductions in fertilizer phosphate and potash by determining the available portion of the total P and K in the manure (40% for phosphorus and 90% for potassium) and multiplying by a factor to convert from the elemental form to the oxide form (fertilizer nutrients are expressed in the oxide form). In the year of application, 40% is available; another 40% is available in the following year.

[3] Organic N will also give an N credit for several years after application: 10% in the second year, 5% in the third year, 2% in the fourth year.

[4] To estimate the available N from summer or fall applications of manure, multiply the Total N content by the appropriate factor in Table 9–13, Estimate of Available Nitrogen From Late Summer- and Fall-Applied Manure.

Example: Dairy manure is spring applied at 55 m^3/ha (5,000 gal/acre) ahead of planting corn (incorporated within 3 days); DM content is 7%; total N is 0.65%; ammonium N is 0.35%; total P is 0.2%, total K is 0.3% (as-is basis).

Available Nitrogen

A. Total Nitrogen	0.65
B. Ammonium-N	0.35
C. Organic N (0.65 – 0.35)	0.30
D. Ammonium Retained (0.35 x 0.50)	0.175
E. Available Organic N Liquid: 0.3 – (7 ÷ 51)	0.16
F. Total Available N (0.175 + 0.16)	0.34

Nutrients kg/m^3 (lb/1,000 gal) = 3.4 (34)

Available Phosphate

G. Total Phosphorus	0.2
H. Available Phosphorus (0.2 x 0.4)	0.08
I. Available Phosphate (0.08 x 2.29)	0.18

Nutrients kg/m^3 (lb/1,000 gal) = 1.8 (18)

Available Potash

J. Total Potassium	0.3
K. Available Potassium (0.3 x 0.9)	0.27
L. Available Potash (0.27 x 1.2)	0.32

Nutrients kg/m^3 (lb/1,000 gal) = 3.2 (32)

An electronic version of this worksheet can be found in the OMAFRA NMAN software or as a spreadsheet at www.gocorn.net.

to convert percent to volumes,
i.e., 0.32 x 20 = 6.4 lb/ton available potash

To get:	multiply by:
kg/m^3 (kg/1,000 L)	10
lb/1,000 gal	100
kg/tonne	10
lb/ton	20

Value of manure is based on purchase price of an equivalent amount of mineral fertilizer (Jan 2016).

($N – P_2O_5 – K_2O$ = 1.30 – 1.35 – 0.95 $/kg) or
($N – P_2O_5 – K_2O$ = 0.60 – 0.61 – 0.43 $/lb).

Long-Term Value of Manure

The long-term availability of phosphorus (P), potassium (K), magnesium, zinc or manganese from previous manure applications is best estimated by soil testing. Application of large quantities of manure over time can result in high levels of available P and K in soils. Manure also provides organic matter and other plant nutrients to the soil that will contribute to improved soil physical structure and buffering.

Most of the available N in manure is used by the crop or is lost during the first growing season following application. The remaining organic nitrogen becomes available in small, diminishing quantities in the succeeding years. Many variables affect availability, however for planning purposes an estimated 10% of the organic nitrogen is assumed available in the year after application, with 5% and 2% assumed available in the subsequent 2 years. Generally, the amount of residual nitrogen from one application of liquid manure is too small to make a practical difference in nitrogen guidelines for a crop. However, where solid manure is applied regularly to the same field, there can be significant residual nitrogen available for a crop.

Crop Requirements

Soil test results and yield goals will determine the maximum economic manure application rate and/or additional fertilizer requirements. Often soil test levels from livestock farms indicate that soil fertility levels are high enough that no response would be expected from additional nutrient applications.

An alternative to determining application rates from soil test values is to apply manure based on the amount of nutrients removed by a crop and then match phosphorus and/or nitrogen from manure to determine an application rate. In theory, this method should keep soil fertility levels constant. Table 9–15, *Average nutrient (N, P_2O_5, K_2O) removal by common field crops*, will help determine the average nutrient removal for various crops.

If manure is applied to meet the entire nitrogen requirements of a corn crop, there will usually be more P and K applied than the crop will remove, and soil test levels will increase. For liquid manure, an application goal of two-thirds to three-quarters of the nitrogen requirements for a corn crop is a reasonable compromise. The high carbon content in the bedding materials of solid manure makes the release of nitrogen much less predictable. Due to difficulty in uniform application for both solid and liquid manure, starter fertilizer is often still suggested, unless soil test results indicate that there will be no economic response to additional fertilizer.

Table 9–15. Average nutrient (N, P_2O_5, K_2O) removal by common field crops

Crop	Removal		
	N[1]	P_2O_5	K_2O
Grains, oilseeds			
Grain corn	11.5–18 kg/t (0.65–1.0 lb/bu)	6.6–7.9 kg/t (0.37–0.44 lb/bu)	4.6–5.2 kg/t (0.26–0.30 lb/bu)
Corn stover	8 kg/t (16 lb/ton)	2.9 kg/t (5.8 lb/ton)	20 kg/t (40 lb/ton)
Soybeans	62–67 kg/t (3.7–4.0 lb/bu)	13–15 kg/t (0.80–0.88 lb/bu)	23 kg/t (1.4 lb/bu)
Soybean stover	20 kg/t (40 lb/ton)	4.4 kg/t (8.8 lb/ton)	19 kg/t (38 lb/ton)

Source: Based on Ontario data where possible and general North American data (IPNI) where local data was insufficient. Forage crop data from Agri-Food Laboratories, Guelph. (1990–95).

[1] Soybeans, dry beans and forage legumes receive most of their nitrogen from the air.
[2] The range of P_2O_5 and K_2O in cereal straw and dry hay will be reduced (leached) if heavy or frequent rainfall occurs while the material is in windrows in the field.
[3] To convert from "as harvested" to "dry matter yield," multiply the as-harvested yield by the dry matter content of the crop (e.g., 25T corn silage x 40% DM (60% moisture) = DM yield of 10T)
[4] The range of N removal is large, because hay is harvested at a wide range of protein levels. Generally, higher protein means lower yield.
[5] Second cut generally has a higher legume content.

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Table 9–15. Average nutrient (N, P_2O_5, K_2O) removal by common field crops

Crop	Removal		
	N[1]	P_2O_5	K_2O
Winter wheat (grain only)	19–21 kg/t (1.15–1.25 lb/bu)	9.1–10.4 kg/t (0.55–0.63 lb/bu)	6.0 kg/t (0.36 lb/bu)
Winter wheat (straw)[2]	7 kg/t (14 lb/ton)	1.7 kg/t (3.4 lb/ton)	12 kg/t (24 lb/ton)
Barley (grain only)	18–23 kg/t (0.87–1.1 lb/bu)	8.0 kg/t (0.40 lb/bu)	5.3–7.2 kg/t (0.25–0.35 lb/bu)
Barley (straw)	6.5 kg/t (13 lb/ton)	2.6 kg/t (5.2 lb/ton)	20 kg/t (40 lb/ton)
Oats (grain only)	18–24 kg/t (0.63–0.80 lb/bu)	7.5 kg/t (0.25 lb/bu)	5.8 kg/t (0.19 lb/bu)
Oats (straw)	6 kg/t (12 lb/ton)	3.2 kg/t (6.4 lb/ton)	19 kg/t (38 lb/ton)
Winter rye (grain only)	19–22 kg/t (1.1–1.2 lb/bu)	6.1–8.2 kg/t (0.3–0.5 lb/ton)	6.25 kg/t (0.35 lb/ton)
Winter rye (straw)	6 kg/t (12 lb/ton)	1.5 kg/t (3 lb/ton)	11 kg/t (22 lb/ton)
Dry beans	42 kg/t (2.5 lb/bu)	14 kg/t (0.83 lb/bu)	14 kg/t (0.83 lb/bu)
Canola	40–44 kg/t (2.0–2.2 lb/bu)	22–27 kg/t (1.1–1.3 lb/bu)	11–13 kg/t (0.55–0.67 lb/bu)
Silage/Forage Crops (removal in dry matter)[3, 4]			
Corn silage	11–15 kg/t (22–30 lb/ton)	4.6–6.8 kg/t (9.2–13.6 lb/ton)	8.3–15 kg/t (16.6–30 lb/ton)
Legume haylage	27–37 kg/t (54–74 lb/ton)	5.3–7.9 kg/t (10.6–15.8 lb/ton)	22–35 kg/t (44–70 lb/ton)
Mixed haylage	23–34 kg/t (46–68 lb/ton)	5.2–7.8 kg/t (10–16 lb/ton)	22–35 kg/t (45–71 lb/ton)
Grass haylage	16–27 kg/t (32–54 lb/ton)	4.9–7.8 kg/t (9.8–15.6 lb/ton)	20–36 kg/t (40–72 lb/ton)
Legume hay	22–33 kg/t (44–66 lb/ton)	5.2–8.0 kg/t (10.4–16 lb/ton)	21–35 kg/t (42–70 lb/ton)
Mixed hay	17–27 kg/t (34–54 lb/ton)	5.0–7.2 kg/t (10–14.4 lb/ton)	17–30 kg/t (34–60 lb/ton)
Grass hay (first cut)	13–23 kg/t (26–46 lb/ton)	4.4–7.0 kg/t (8.8–14 lb/ton)	14–28 kg/t (28–56 lb/ton)
Mixed hay (second cut)[5]	25–36 kg/t (50–72 lb/ton)	5.7–7.8 kg/t (11.4–15.6 lb/ton)	20–32 kg/t (40–64 lb/ton)

Source: Based on Ontario data where possible and general North American data (IPNI) where local data was insufficient. Forage crop data from Agri-Food Laboratories, Guelph. (1990–95).

[1] Soybeans, dry beans and forage legumes receive most of their nitrogen from the air.
[2] The range of P_2O_5 and K_2O in cereal straw and dry hay will be reduced (leached) if heavy or frequent rainfall occurs while the material is in windrows in the field.
[3] To convert from "as harvested" to "dry matter yield," multiply the as-harvested yield by the dry matter content of the crop (e.g., 25T corn silage x 40% DM (60% moisture) = DM yield of 10T)
[4] The range of N removal is large, because hay is harvested at a wide range of protein levels. Generally, higher protein means lower yield.
[5] Second cut generally has a higher legume content.

Take into account residual nitrogen from legume crops when determining additional nitrogen needs from manure or fertilizer. See Table 9–9, *Adjustment of nitrogen requirement, where crops containing legumes are plowed down*. Apply manure to cereal crops, soybeans or canola with caution, since too high a rate will increase the potential for lodging.

Equipment technology is increasing the opportunities for manure application into growing crops such as corn, forages, and cover crops planted after wheat harvest. For summer application to established forages, keep rates below 45m^3/ha (4,000 gal/acre) or 55–65 kg/ha (50–60 lb/acre) NH_4-N. Complete application to forages as soon as possible after harvest to avoid wheel track damage to new growth and potential nitrogen burn to new leaf tissue. Do not apply concentrated manures with high ammonium-nitrogen levels (e.g., liquid layer poultry or concentrated finisher hog manure) onto leaf tissue of standing crops. Older forage stands with higher grass content will benefit most from the manure nitrogen.

Soil compaction is a problem for many producers and is a main reason that application into growing crops, late summer or early fall manure application is popular. Compaction leads to poor drainage and decreased aeration. The best way to reduce or avoid soil compaction from manure application is to spread manure when the soil is dry. Drag-hose systems can help reduce compaction, as do radial tires and on-the-go-tire inflation options on manure application equipment. Loads should stay below 4.5 tonnes (5 tons) per axle. Spring spreading is often carried out on fields where soils are too wet, and it is not unusual for strips of stunted crops to reveal the location of wheel traffic from application equipment.

Environmental Concerns With Manure

To minimize environmental concerns with manure, the 4-R approach commonly used for fertilizer can also apply to manure application:

- right product
- right place
- right time
- right rate

Manure has unique aspects that are different from fertilizer — its blend of nutrients (i.e., N-P-K ratios) are not adjustable therefore commercial fertilizer may be used along with manure to meet nutrient requirements. Conversely, some nutrients may be applied over requirements, but within the ability of the crop (or a rotation of crops) to uptake the nutrients over a period of time. A nutrient management plan will address this.

The timing of application may be driven by the production of the manure and the available manure storage. Application timing should avoid nutrients (especially inorganic nitrogen) being on the soil for long periods of time before utilization by a crop. The use of cover crops may be considered if manure is to be applied in late summer or early fall.

Application to fields with steep slopes or impermeable soils can cause manure runoff when application rates are too high. For some soil types, several applications at lower rates may be necessary. Spreading manure in the winter and early spring creates the potential for runoff to surface water and nutrient accumulations in water-ponded areas. Never apply manure on snow-covered or frozen soil due to risk of nutrient movement. The soil has no capacity for infiltration, which results in phosphorus movement with melt-water and soil. Although winter application should not be part of a nutrient management plan, there are some mild spells where field application accompanied by immediate incorporation is possible. When winter spreading is essential (i.e., part of contingency plan), take care to select fields with the lowest risk of runoff to surface water.

Contamination of the environment is prohibited under the *Environmental Protection Act, 1990,* the *Ontario Water Resources Act, 1990* and the federal *Fisheries Act , 1985*. In addition, there are specific requirements for manure application under the *Nutrient Management Act, 2002* and Regulation 267/03. Refer to the most recent updates of the regulation and protocols at ontario.ca/laws.

Rain can cause organic nitrogen to wash into streams if manure has been applied to unprotected cropland. Phosphorus attached to soil particles can be carried to streams by soil erosion. Conservation practices can reduce the chances of nutrients polluting waterways.

A vegetated buffer along watercourses protects against contamination from manure applied in adjacent fields and protects the watercourse from streambank erosion. Runoff potential is influenced by field slope and soil texture. Flow in tile drains can become contaminated, if manure enters a catchbasin or travels through soil cracks or earthworm/root channels to the tiles. To minimize the risk of contaminated tile flow, apply at low rates when the tiles are not running, or lightly till the field before manure application to break any macropores.

Application of nutrients contained in manure or fertilizer in excess of crop requirements can result in contamination of groundwater, particularly on shallow soils over bedrock, soils with a water table close to the surface or very sandy soils where leaching is a concern. Groundwater contamination can occur by mass flow through cracks and holes to groundwater or through leaching of nitrates through the soil. Contamination can also occur if manure seeps directly into inadequately protected water wells. Manure should not be applied within 15 m (50 ft) of drilled wells, 30 m (100 ft) of dug wells or 100 m (330 ft) of a municipal well. See the *Nutrient Management Act, 2002* and Regulation 267/03, section 43.

Large livestock operations on small land bases pose special challenges. To avoid over-application of nutrients, complete a nutrient management plan. It may be necessary to sign agreements with neighbouring farms to ensure the availability of fields for proper manure spreading.

Detailed information about maximum application rates and setbacks from surface water or water wells can be found in the NMAN3 software at ontario.ca/omafra.

Nitrogen Risk Mitigation

The nitrogen cycle, with its many forms of nitrogen, is a complicated process that is influenced by many factors, including weather, soil, physical, chemical and biological processes. Use the optimum amount of nitrogen required for crop production, keeping in perspective that any nitrogen not used by the crop has the potential to leach below the root zone, volatilize into the atmosphere or denitrify (potentially to nitrous oxide).

Nitrate that could potentially leach out of the rooting zone includes nitrogen that is applied in excess of crop removal and nitrogen from manure or biosolids applied during the non-growing season (late summer or fall). In Ontario, most of the drainage to groundwater occurs during the late fall to early spring period, when precipitation exceeds evaporation. On sandy, well-drained soils, much of the nitrate present in the fall could be leached into groundwater when drainage occurs. On heavier soils, more of the loss will be through denitrification. Minimizing the amount of soil nitrate present in the fall will reduce both types of loss.

Management practices to reduce the risk of nitrate losses include:

- growing cover crops whenever manure is applied in late summer or early fall
- timing nitrogen applications close to crop nitrogen uptake (right time)
- matching total nitrogen applications to crop requirements (right rate)

Phosphorus Risk Assessment

The risk of surface water contamination by phosphorus may be increased at higher soil test phosphorus levels. However, since phosphorus binds tightly to soil particles, the movement of soil from a field by erosion is also a major factor in determining the risk of surface-water contamination. Because of this, the risk of surface-water contamination by phosphorus cannot be based on a soil-test phosphorus level alone.

The risk of phosphorus contamination to surface water increases when soil test results indicate that no additional phosphorus is required to achieve maximum economic yield, but manure nutrients are still applied. Phosphorus in surface-water sources increases eutrophication or aquatic plant growth (algae blooms), which leads to oxygen fluctuations and decreased ability for the water source to support aquatic life. To address the environmental risk of additional phosphorus application when soil test levels are adequate, a phosphorus index has been developed. The phosphorus index results in lower phosphorus application rates and wider phosphorus-free buffers adjacent to water courses when there is a significant risk of nutrient/soil runoff and when phosphorus fertility levels are high.

The phosphorus index considers:

- soil erosion potential
- water runoff potential
- phosphorus soil fertility levels
- fertilizer and manure application method (right place) and rate (right rate)

OMAFRA is developing an updated phosphorus index, which will also consider the impact of tile drainage, as well as the solubility of various types of manure and risk of loss in the non-growing season. For more information on phosphorus risk assessment, see the OMAFRA factsheet, *Determining the Phosphorus Index for a Field* or visit the website at ontario.ca/crops.

Manure and No-Till

The goal with no-till is to minimize disturbance of the soil and seedbed. The goal with manure application in a no-till system is a combination of nutrients to feed crops and soil microorganisms as well as to provide organic matter contributions that help improve soil health. Manure application is most effective when nutrients are incorporated. When manure is utilized in a no-till system, there has to be a compromise. Some tillage will be required or some loss of nutrients will occur. Advances in application technology and in-crop application opportunities (including dribble bar application of manure under a crop canopy or slurry-seeding cover crops after cereal harvest) allow manure application to occur in no-till systems with minimal nutrient loss.

A few points to consider when applying manure in a no-till system:

- Plan manure application to consider crop rotation and in-crop applications, especially in a true no-till system where nutrients are not incorporated through tillage.
- Manure applied after wheat or spring cereal harvest is the best option. Shallow tillage using vertical tillage or discing when soils are dry will help incorporate cereal straw and manure and could also incorporate cover crop seed. During warm, dry conditions earthworms reside deep in the soil where minimal tillage will not destroy their channels, and nitrogen will help with straw breakdown.
- Apply manure to corn when soils are dry to avoid rutting and compaction. Consider side-dress applications to standing corn. If nutrients, especially nitrogen, are the important feature, decide which is more important: limited pre-planned tillage or some nitrogen loss. Manure type will influence how much nitrogen is potentially lost. Solid manure has a smaller portion as ammonium-N, therefore less total nitrogen will be lost. The higher the organic-N component is the less available N is but it results in the release of nitrogen over a longer period of time. Where manure is surface applied to bare soil, a majority of the ammonium portion of the manure will be lost. Rain (10–15 mm (~1/2 in.) gentle, infiltrating) shortly after application will incorporate some of the ammonium.
- Although white mould is less problematic in no-till systems, manure applied ahead of soybean planting often results in a denser canopy where risk of white mould is higher. Choose a variety with some resistance to white mould.
- Liquid manure applied to forages is a good option. Apply manure as soon as possible after harvest, before re-growth. Application to older grass-alfalfa stands will give the largest nutrient benefit.
- Surface applied phosphorus from manure in no-till scenarios will increase risk of movement (runoff) to water courses, especially when application occurs outside the growing season. Increased residue cover or cover crops will limit movement, however where manure is applied on sloping land, it is best to have a buffer (vegetated or separation distance) from a water courses or in-field area of concentrated flow.
- Never plan to apply manure to frozen or snow covered land since nutrient (especially phosphorus) runoff is a high risk. Avoid applying liquid manure to snow-covered perennial forages, since ice can form under the manure, resulting in increased winterkill and runoff.
- A nutrient analysis is important, regardless of which crop the manure is applied to, so that commercial fertilizer application can be balanced with what was provided in the manure.
- High volumes of surface applied manure can lead to slower soil warm-up in spring or sealing of soil. Calibrate application equipment to ensure an accurate rate.

Calibrating Application Equipment

Calibrating manure application equipment is essential. Several methods can be used to measure spreading rates. Weighing a load of manure and measuring the area that load covers is one method of estimating the rate of application. Another method is to weigh solid manure by placing plastic sheets on the ground and liquid manure by using straight-walled pails for measuring depth of application. Consider overlap, especially in irrigation systems. Table 9–16, *Calibrating manure application equipment*, gives an estimate of application rates, while Table 9–17, *Densities of different types of manure*, distinguishes between the densities of different types of manure. For further details, visit the OMAFRA website at ontario.ca/crops.

Table 9–16. Calibrating manure application equipment

Solid Manure Calibration[1]		Liquid Manure Calibration[2]	
Manure per sheet	**Application Rate[3]**	**Depth of Manure in Pail**	**Application Rate**
0.5 kg	3.6 t/ha	2.5 mm (1⁄10 in.)	25 m^3/ha (2,225 imp. gal/acre) (2,675 U.S. gal/acre)
0.9 kg	7.2 t/ha	3.2 mm (1⁄8 in.)	32 m^3/ha (2,850 imp. gal/acre) (3,420 U.S. gal/acre)
1.4 kg	10.8 t/ha	6.4 mm (1⁄4 in.)	64 m^3/ha (5,520 imp. gal/acre) (6,845 U.S. gal/acre)
1.8 kg	14.3 t/ha	10 mm (4⁄10 in.)	100 m^3/ha (8,900 imp. gal/acre) (10,690 U.S. gal/acre)
2.3 kg	17.9 t/ha	12.7 mm (1⁄2 in.)	127 m^3/ha (11,305 imp. gal/acre) (13,580 U.S. gal/acre)
3.2 kg	25.1 t/ha	15.0 mm (6⁄10 in.)	150 m^3/ha (13,355 imp. gal/acre) (16,040 U.S. gal/acre)
4.5 kg	35.8 t/ha	19.1 mm (3⁄4 in.)	191 m^3/ha (17,000 imp. gal/acre) (20,420 U.S. gal/acre)
6.8 kg	53.8 t/ha	25.4 mm (1 in.)	254 m^3/ha (22,610 imp. gal/acre) (27,160 U.S. gal/acre)
1 m^3 = 1,000 L			

[1] Using a 122-cm-x-102-cm sheet (40-in.-x-48-in. plastic feedbag).
[2] Using a straight-walled pail.
[3] tons/acre = t/ha x 0.45.

Table 9–17. Densities of different types of manure

Manure Type	Density			
Liquid	1,000 kg/m^3	62 lb/ft^3	1.0 kg/L	80 lb/bu
Semi-solid	960 kg/m^3	60 lb/ft^3	0.9 kg/L	76 lb/bu
Thick solid	800 kg/m^3	50 lb/ft^3	0.8 kg/L	64 lb/bu
Light solid	560 kg/m^3	35 lb/ft^3	0.6 kg/L	45 lb/bu
Dry poultry litter/ compost	400 kg/m^3	25 lb/ft^3	0.4 kg/L	30 lb/bu
1 bu = 1.25 ft^3				

Use of Non-Agricultural Sourced Materials on Agricultural Land

Non-agricultural sourced waste (e.g., sewage biosolids) are nutrient-rich, processed organic materials derived from municipal wastewater treatment processes. They usually contain mineral and organic nitrogen, phosphorus, potash, organic matter and micronutrients such as zinc, magnesium and copper. The use of biosolids as part of a farm nutrient management package can provide the same benefits as manure. These non-agricultural sourced materials (NASM) are ideal for field crops.

NASM are regulated under the *Nutrient Management Act* and Regulation 267/03. They include pulp-and-paper mill fibre residuals, grain processing by-products, and many other organic-based waste. Each type of waste has unique characteristics that have potential to benefit soil quality or crop production. It is important to be informed about the nutrient content or precautions associated with each material. For example, sewage biosolids are very low in potassium.

NASM materials are classified under one of three categories. Each category can be applied to agricultural land, however, application standards vary based on the category and quality of the material.

- Category 1: Unprocessed plant material (e.g., vegetable culls)
- Category 2: Processed plant material (e.g., organic waste materials from a bakery)
- Category 3: Animal-based NASM (e.g., organic residual material from meat-processing plant, pulp and paper biosolids and municipal sewage biosolids)

The Regulation introduced an NASM Plan to replace the need for an Organic Soil Conditioning Site Certificate of Approval (C of A) for agricultural land. An NASM Plan is similar to a Nutrient Management Plan (NMP), but deals only with the field(s) where an NASM is applied and not the whole farm. NASM Plans must be prepared by a certified NASM Plan Developer.

Some NASM products, (sewage biosolids) are further processed to stable products and treated as commercial fertilizers with an organic matter benefit. They are registered through the Canadian Food Inspection Agency (CFIA) and currently do not require an NASM Plan. Examples of these products include:

- N-Viro – biosolids processed with kiln dust to provide a liming benefit
- Biosolid pellets – processed pelleted and heat treated biosolids
- Lystek – patented process that combines biosolids with potassium hydroxide, heat and a lysing process

Fertilizer Materials

Nitrogen fertilizer materials are available in dry or liquid forms. There are some limitations to the use of these materials (see *Toxicity of Fertilizer Materials*). Urea and ammonium forms are susceptible to volatilization loss if placed on the surface and not incorporated. The choice of material should depend on availability, equipment for handling, cost per kilogram of nitrogen, cost of application and susceptibility to loss. The greater the proportion of nitrate, the more susceptible to loss by leaching or denitrification.

Calculate the cost per kilogram of nitrogen for various sources delivered to your farm. Using the rate of application, determine the cost per hectare. Add to this the cost of application per hectare before deciding which nitrogen source to use.

Where separate additions of nitrogen are referred to in the fertilizer guidelines, kilograms of elemental nitrogen, not kilograms of fertilizer materials, are used. Table 9–18, *Fertilizer materials — primary and secondary nutrients,* and Table 9–19, *Fertilizer materials — secondary and micronutrients*, show the percentage of fertilizer nutrient contained in different materials.

Various fertilizer companies have pre-mixes available, containing one or more micronutrients in addition to the micronutrient sources listed in Table 9–18, *Fertilizer materials — primary and secondary nutrients.*

Plant availability of zinc is greater from sulphate than oxide forms. Zinc chelates are more expensive on weight basis than other forms, but are about two times more effective than sulphates with equivalent zinc amount. Zinc chelates/lignosulfonates are used in liquid fertilizer solutions or for foliar applications. Other sources listed in Table 9–19, *Fertilizer materials — secondary and micronutrients*, are for dry formulations and the most important thing to consider with these is the percentage that is soluble.

A wide range of liquid fertilizers are used in Ontario. While these are generally more expensive per unit of nutrient than dry granular fertilizers, liquid fertilizers can be easier to handle. Characteristics of the most commonly used liquid fertilizers are included in Table 9–20, *Densities of common liquid fertilizers*.

Table 9–18. Fertilizer materials — primary and secondary nutrients

Materials	Form	Primary Nutrient	Sulphur	Salt Index[1]	Salt Index[2]
Nitrogen (N)					
Ammonium nitrate (34-0-0)	dry	30%–34%		104	14.5
Calcium ammonium nitrate (27-0-0)	dry	27%		93	15.3
Urea (46-0-0)	dry	45%–46%		73	8.1
Ammonium sulphate (21-0-0)	dry	21%	24%	88	16.3
Urea-ammonium nitrate (28-0-0)	liquid	28%		63	11.3
Anhydrous ammonia (0-0-82)	liquid[3]	82%		47	2.9
Phosphate (P_2O_5)					
Monoammonium phosphate (11-52-0)	dry	48%–52%		27	2.0
Diammonium phosphate (18-46-0)	dry	46%		29	2.3
Ammonium polyphosphate (10-34-0)	liquid	34%		20	2.3
Potash (K_2O)					
Muriate of potash (0-0-60)	dry	60%–62%		115	9.7
Potassium sulphate (0-0-50)	dry	50%	18%	46	4.3
Sulphate of potash magnesia (0-0-22)	dry	22%	20%	43	9.9
Potassium nitrate (13-0-44)	dry	44%		74	6.1

[1] Osmotic pressure increase from dissolution of the fertilizer relative to the same weight of sodium nitrate (100).
[2] Expressed per unit (100 lb) of nutrient (N + P_2O_5 + K_2O).
[3] Liquid under pressure.

Table 9–19. Fertilizer materials — secondary and micronutrients

Nutrient	Amount
Magnesium (Mg)	
Dolomitic limestone	6%–13% Mg
Magnesium sulphate (Epsom salts)	10.5% Mg 14% S
Sulphate of potash magnesia	11% Mg 20% S
Sulphur (S)	
Calcium sulphate (gypsum)	19% S
Elemental sulphur	90% S
Ammonium thiosulphate	12% N 26% S
Boron (B)	
Sodium borate	12%–21% B
Solubor	20.5% B
Copper (Cu)	
Copper sulphate	13%–25% Cu
Copper chelates	5%–13% Cu
Manganese (Mn)	
Manganese sulphate	26%–28% Mn
Manganese chelate	5%–12% Mn
Molybdenum (Mo)	
Sodium molybdate	39% Mo
Zinc (Zn)	
Zinc sulphate	36% Zn
Zinc chelates	7%–14% Zn
Zinc oxysulphate	18%–36% Zn

Soluble Salts in Farm Soils

High concentrations of water-soluble salts in soils can prevent or delay the germination of seeds, and can kill established plants or seriously retard their growth.

Ontario soils are naturally low in soluble salts. Soluble salts therefore rarely cause a problem in crop production and are not routinely measured in soil tests.

Soluble salts in soils can result from excessive applications of fertilizers and manures, some composts, runoff of salts applied to roads and chemical spills on farmland. High concentrations of soluble salts in or near a fertilizer band can cause serious reductions in early plant growth without seriously affecting the salt concentrations in the remainder of the soil. A given amount of salt in a soil provides a higher salt concentration in soil water, if the amount of water is small.

Soluble salts also interfere with the uptake of water by plants. For these reasons, plant growth is most affected by soluble salts in periods of dry conditions at planting.

Soluble salts can be measured readily in the laboratory or in the field by measuring the electrical conductivity (EC) of soil water slurry. The higher the concentration of water soluble salts, the higher the conductivity. Table 9–21, *Soil conductivity reading interpretation*, provides an interpretation of soil conductivity readings;

Table 9–20. Densities of common liquid fertilizers

Analyses	kg/L	L/t	imp. gal/t	lb/L	lb/imp. gal
8-25-3	1.33	749.9	165.1	2.94	13.35
6-18-6	1.28	779.0	171.6	2.83	12.85
3-11-11	1.25	798.8	175.7	2.76	12.55
6-24-6	1.33	752.4	165.8	2.93	13.30
9-18-9	1.33	755.0	165.8	2.92	13.30
5-10-15	1.25	799.0	171.6	2.83	12.85
2-10-15	1.28	784.6	172.9	2.81	12.75
10-34-0	1.40–1.41	715.8–711.2	157.5–156.4	3.08–3.10	14.0–14.1
28%	1.28	781.8	172.2	2.82	12.8
54% phos. acid	1.58	633.5	139.5	3.48	15.8

1 imp. gal = 1.201 U.S. gal = 4.546 L
lb/imp. gallon x 0.832 = lb/U.S. gal

1 U.S. gal = 0.8326 imp gal = 3.785 L
imp. gallon/t x 0.832 = U.S. gal/t

where "L" is low, "M" is medium, "H" is high and "E" is excessive. Some dissolved solutes are more detrimental to plants (e.g., Na^+, Cl^-) than others (Ca^{2+}, Mg^{2+}, SO_4^{2-}, HCO_3^-) and so where salts are a problem, determination of ion concentrations is more diagnostic than EC.

Table 9–21. Soil conductivity reading interpretation

Using 2:1 water-to-soil ratio. For saturated paste equivalent, multiply by 5.

Conductivity "salt" reading (millisiemens/cm)	Rating	Plant Response
0–0.25	L	Suitable for most plants with recommended amounts of fertilizer.
0.26–0.45	M	Suitable for most plants with recommended amounts of fertilizer.
0.46–0.70	H	May reduce emergence and cause slight-to-severe damage to salt-sensitive plants.
0.71–1.00	E	May prevent emergence and cause slight-to-severe damage to most plants.
1.00	E	Expected to cause severe damage to most plants.

Toxicity of Fertilizer Materials

All fertilizer salts are toxic to germinating seeds and plant roots if applied in sufficient concentration near the seed. Fertilizers vary in toxicity per unit of nutrient due to:

- differences in the amount of salts contained in the fertilizer per unit of nutrient
- differences in the solubility of the salts in the soil
- the presence of specific materials or elements that are particularly toxic (e.g., ammonia and boron)

Many nitrogen fertilizers, despite relatively low salt index, release free ammonia into the soil.

Fertilizer Calculations — An Example

Based on soil test results and N calculator, a producer requires 120 lb of N, 18 lb P_2O_5 and 30 lb K_2O to grow a crop of corn. A liquid starter fertilizer (5 gal/acre 6–24–6) will be included.

Step 1: Determine starter contribution

Liquid fertilizer with a blend of 6–24–6 and a density of 13.3 lb/gal is applied at 5 gal/acre.

The fertilizer contains 6% N, 24% P_2O_5 and 6% K_2O. The application rate is 5 gal/acre x 13.3 lb/gal = 66.5 lb/acre.

N 66.5 lb/acre x 6/100 = 4 lb/acre

P_2O_5 66.5 lb/acre x 24/100 = 16 lb/acre

K_2O 66.5 lb/acre x 6/100% = 4 lb/acre

Step 2: Determine balance required

120–4 = 116 lb N/acre still required

18–16 = 2 lb P_2O_5/acre (small enough difference to ignore)

30–4 = 26 lb K_2O/acre still required

Step 3: Determine supplemental fertilizer to meet balance of crop requirements

Fertilizer rates are determined by dividing the nutrient requirement by the percent nutrient in the fertilizer. If the supplemental fertilizer is to be a blend of urea plus potash, the calculations will be:

116 lb N/acre ÷ 0.46 (or 46%) = 252 lb/acre urea (46–0–0)

26 lb K_2O/acre ÷ 0.62 (or 62%) = 42 lb/acre muriate of potash (0–0–60)

Total application rate = 252 + 42 = 294 lb/acre of blended fertilizer

For more details on calculating nutrient requirements and fertilizer blends, see OMAFRA Publication 611, *Soil Fertility Handbook*.

Nitrogen Fertilizers

Ammonium nitrate, monoammonium phosphate and ammonium sulphate are similar in toxicity and much safer than anhydrous ammonia, aqua ammonia or urea. Diammonium phosphate is more toxic than monoammonium phosphate but less toxic than urea. Use lower rates of urea, or increase the distance between the seed and fertilizer band, particularly with sensitive seeds such as beans or peas, and on coarse-textured soil (sand and sandy loam).

Because anhydrous ammonia and aqua ammonia release free ammonia, they should not be placed near seeds. It is preferable to make pre-plant applications crossways to the direction in which the crop will be planted. Stand reductions may still occur over the band, in very dry soils or if planting takes place too soon after application.

Urea is toxic when banded with or near the seed, but is safe when broadcast at rates normally used. Blends containing more than half as much nitrogen as phosphate frequently contain urea.

Phosphate Fertilizers

Phosphate fertilizers are usually low in toxicity due to a large portion of the phosphate being precipitated in the soil before it can reach the plant roots. The concentration of phosphorus in soil solution at any one time is very low. No limit is normally set for the safe rate at which phosphates may be applied with, or near, the seed of field-grown crops.

Diammonium phosphate is more injurious than other phosphate fertilizers. See *Nitrogen Fertilizers.*

Potash Fertilizers

Muriate of potash (KCl) is the most common source of potassium in fertilizers and is less injurious per unit of plant nutrients than most nitrogen fertilizers.

Sulphate of potash (K_2SO_4) has a lower salt index than muriate of potash. Sulphate of potash-magnesia has approximately the same toxicity per unit of potassium as muriate of potash. Potassium nitrate is one of the safer sources of potassium.

Table 9–22, *Maximum safe rates of nutrients in fertilizer,* provides the maximum safe rates of nutrients for various crop scenarios. The safe rates listed in this table are for single applications. If two or more fertilizer applications are combined, the additive effect may cause damage to the crop even though the individual applications are below the threshold for injury.

Guidelines for Safe Rates of Nutrients Applied at Seeding

Fertilizer toxicity varies widely, depending on the amount of soil moisture. Injury will occur most frequently on course-textured (sandy or gravelly) soils low in organic matter and with dry weather. To ensure completely safe rates of banded fertilizer for all seeding conditions they would require extremely low rates of application. The maximum safe rates suggested here will most likely reduce or delay germination, or retard growth in up to 10% of the cases where they are used. It is generally advisable to use lower rates of fertilizer at seeding than those listed in Table 9–22, *Maximum safe rates of nutrients in fertilizer*.

Excess fertilizer can harm seedlings because of effects from ammonia and salt. These effects are related to fertilizer N and K content. It is generally advisable to use lower rates of fertilizer at seeding than those listed.

If fertilizer requirements are high, it may be better to broadcast most of the fertilizer required and to band only a small portion at seeding. Fertilizers containing the micronutrients boron, copper, iron, manganese and zinc are more injurious than the same grades without micronutrients, and the safe rates recommended will be lower than those shown in this table. Boron is particularly toxic and should not be banded.

Some producers use much higher rates of banded fertilizer than are listed here, with no apparent problem. Crops are able to tolerate much higher rates of fertilizer with adequate moisture, but it is impossible to predict before planting when adverse conditions for germination will occur. Keeping below the maximum safe rates is the surest way to ensure a good start for the crop.

Table 9–22. Maximum safe rates of nutrients in fertilizer

LEGEND: – = no data NR = not recommended

		Nitrogen			Nitrogen + Potash + Sulphur		
Crop	**Fertilizer**	75 cm row (30 in. row)	38 cm row (15 in. row)	18 cm row (7 in. row)	75 cm row (30 in. row)	38 cm row (15 in. row)	18 cm row (7 in. row)
Banded 5 cm to the side x 5 cm (2 in. x 2 in.) below seed							
Corn[1]	urea	40 kg/ha	–	–	79 kg/ha	–	–
	other fertilizers	52 kg/ha	–	–	117 kg/ha	–	–
Soybean,[2] pea, dry beans	ammonium sulphate	30 kg/ha	60 kg/ha	–	NR	NR	–
	other fertilizers	NR	NR	–	90 kg/ha	180 kg/ha	–
With the seed[3]							
Corn	other fertilizers	NR	NR	–	10 kg/ha	20 kg/ha	–
Winter wheat, triticale, barley	other fertilizers	–	–	15 kg/ha	–	–	40 kg/ha
Spring oats, barley, wheat	urea	–	NR	10 kg/ha	–	–	30 kg/ha
	other fertilizer — sand	–	NR	35 kg/ha	–	–	55 kg/ha
	other fertilizer — clay	–	–	45 kg/ha	–	–	70 kg/ha
Canola	ammonium sulphate — sand	–	–	22 kg/ha	–	–	11 kg/ha
	ammonium sulphate — clay	–	–	22 kg/ha	–	–	33 kg/ha
Broadcast, Strip Till							
Corn	urea	200 kg/ha	–	–	250 kg/ha	–	–

100 kg/ha = 90 lb/acre

[1] At higher rates, band at least 15 cm (6 in.) from seed. At row widths other than 75 cm, the rate may be adjusted to provide the same maximum concentration in the row (e.g., in a 50 cm (20 in.) row, the safe rate = 75/50 x 52 = 78 kg/ha (70 lb/acre) N).
[2] Significant amounts of nitrogen inhibit nodulation and are not recommended.
[3] Urea with the seed is not recommended for corn, soybean or winter wheat.

Excess fertilizer can harm seedlings because of effects from ammonia and salt. These effects are related to fertilizer nitrogen (N) and potassium (K) content. Toxicity varies widely depending on soil texture, moisture conditions, crop, fertilizer source and placement. Table 9–22, *Maximum safe rates of nutrients,* provides guidelines that will most likely limit injury to less than 10% of the cases where they are used. Injurious effects include reduced or delayed germination or retarded growth. Weather, stress and other conditions that affect growth may increase the chances of injury.

Foliar Fertilizers

Micronutrients can be supplied to crops through foliar fertilization, particularly in instances where a deficiency is due to a tie-up of these nutrients in the soil (e.g., manganese). Quantities of nutrient that can be applied in this manner are limited, because of the danger of leaf burn. When combining nutrients, take care that the resulting solution is not too concentrated. Check pesticide labels before mixing foliar nutrients with any pesticide spray.

It is not practical to supply macronutrients through foliage, due to limitations in the concentration and amount of nutrients that can be applied per spray. The potential for significant nutrient supply via foliage varies among nutrients.

Calculating Fertilizer Requirements

Calculate the mineral fertilizer required for optimum crop production by deducting the nutrients in manure and legumes from the total nutrients required. It is often beneficial to separate the starter component of the fertilizer, which is generally high in phosphorus, from the balance of the nitrogen and potassium.

The choice of starter fertilizer will depend on the crop to be grown, the mineral fertilizer requirements and the equipment available. It is often equally efficient to apply part of the fertilizer as a starter and broadcast the rest, as it is to apply all the fertilizer through the planter or drill. The advantage to this program is savings in time and labour, and less risk of fertilizer injury to the seedling. Broadcasting phosphate fertilizers on the soil surface without incorporation, however, increases risks of harming water quality. Consider alternatives wherever possible.

Deduct applications of starter fertilizer and side-dressed fertilizer from the total mineral fertilizer requirement. Broadcast any balance remaining. If only very small numbers remain, consider adjusting the rates of one of the other nutrient sources, ignoring the small residuals or planning a fertilizer application that will meet multi-year requirements (P and K only).

Citations

Table 9–3. *Sensors used to define management zones and parameters measured.*

Adapted from:
Sensors - Precision Farming and Variable Rate Technology: A Resource Guide. 2010. Agricultural Research and Extension Council of Alberta.

Table 9–15. *Average nutrient (N, P_20_5, K_20) removal by common field crops*

Adapted from:
Murrell, T.S., 2005. Average nutrient removal rates for crops in the northcentral region. Available at www.ipni.net/article/IPNI-3258

Table 9–18. *Fertilizer materials - primary and secondary nutrients*

Adapted from:
Follett, R.H., Murphy L.S., Donahue, R.L., 1981. *Fertilizers and soil amendments. (Fertilizer materials: salt index)* Prentice-Hall, Inc., Englewood Cliffs, N.J.

Joseph Jez (ed.), 2008. *Sulfur: A Missing Link between Soils, Crops, and Nutrition,* Agronomy Monographs 50. Chapter: *Sulfur forms and cycling processes in soil and their relationship to sulfur fertility.* pg 1-10. Schoenau, J., Malhi S.S., ASA, ISBN: 978-0-89118-186-6