8. Fertilizer Materials, Blending and Application

Fertilizer materials

No matter what fertilizer you apply, the materials you choose and the way you blend and apply them will have great impact on your fertilizer program. Most of the fertilizer applied in Ontario is in the granular form, but liquids and gases are also used. Each form is listed below and in Table 8–1 with its specific grade (% N-P_2O_5-K_2O by weight), chemical analysis, and handling and use characteristics. All fertilizer materials need to be handled in a safe and effective manner. Material Safety Data Sheets (MSDS) describe the characteristics of each material and are available at every point of sale for customers and employees to obtain.

Granular fertilizers generally have a higher analysis (nutrient content) than liquid fertilizers and are relatively less expensive. Their storage, handling and transport requirements differ from those of liquid or gaseous fertilizers. Granular materials can be blended to meet a wide range of crop requirements.

In general, liquid fertilizers are more expensive per unit of nutrient than granular fertilizers because of the extra weight and volume that must be transported, and, in some cases, the extra processing. This is balanced by the convenience of being able to pump it and the ease and accuracy of metering and placement.

In 2016, ammonium polyphosphate (10-34-0), a liquid, cost 84% more than the same amount of nutrient purchased as (granular) mono-ammonium phosphate. The difference is even greater for complete N-P-K fertilizers, where liquids may cost double the equivalent in granular fertilizer.

Nitrogen (N) sources

Urea (46-0-0)

- $CO(NH_2)_2$
- white
- manufactured from ammonia and carbon dioxide
- most commonly used fertilizer N source worldwide
- may contain small amounts (0.5%–1.5%) of biuret, about 0.3% conditioning agent (formaldehyde or methylene di-urea) and less than 0.5% moisture
- grades for foliar application should contain less biuret
- Urea converts to the ammonium form of N in the soil. The urease enzyme — present in soil, bacteria and crop residues — speeds the process. Surface-applied urea is subject to losses of ammonia gas. Losses increase with higher soil pH, greater crop residue cover and higher temperatures.

Ammonium nitrate (34-0-0)

- NH_4NO_3
- produced by combining ammonia with nitric acid
- may contain about 1% conditioning agent and 0.5% moisture
- more expensive per unit of N than urea
- no longer produced in Canada
- regulations apply to its transport (Transport of Dangerous Goods Class 5.1)
- needs to be kept away from oils and other flammable materials as it can form an explosive mixture
- more hygroscopic than urea and may deteriorate in storage during hot weather as crystal phase changes result in a breakdown of the prills

When applied to the soil, ammonium nitrate dissolves in the soil water and separates into ammonium and nitrate, both of which can be absorbed by plants. At low temperatures, it is available to plants slightly more quickly than urea, but under normal growing conditions there is no practical difference.

Calcium ammonium nitrate (27-0-0)

- uniform mixture of 80% ammonium nitrate and either calcitic or dolomitic limestone
- limestone reduces explosion hazard

When applied at equal weights of N, calcium ammonium nitrate is similar to ammonium nitrate. The lime included in the granules balances part of the acidity released by the N, so that it does not acidify the soil as quickly as ammonium nitrate does.

Urea-ammonium nitrate solution (UAN) (28-0-0 to 32-0-0)

- produced by dissolving urea and ammonium nitrate (50:50) in water
- 28-0-0 can salt out (precipitate out of solution) if the temperature drops below –18°C (0°F)
- more concentrated solution (32-0-0) is available but not often used in Ontario because the salting out temperature is 0°C
- due to its urea content, it is subject to loss as ammonia if applied to the soil surface
- herbicides and other pesticides are commonly added to UAN for broadcast application on the soil
- avoid application onto crop foliage because severe burning will result
- lends itself to side-dress applications

Urea-ammonium nitrate solution is the most commonly used liquid fertilizer in Ontario.

Anhydrous ammonia (82-0-0)

- NH_3
- manufactured by reacting natural gas with atmospheric N under high pressures and temperatures
- colourless, pungent gas at atmospheric pressure
- handled as a pressurized liquid: at –2°C, the pressure is the same as surrounding air; at 16°C, it is 655 kPa (95 psi).
- building block for all manufactured N fertilizers
- similar to urea and ammonium nitrate in its acidifying effect (1.8 lb $CaCO_3$ to neutralize acidity generated per lb of N supplied)

Anhydrous ammonia is applied directly by injecting it into the soil, where it vapourizes and dissolves in the soil moisture. To avoid vapour losses to the air, the anhydrous band must be placed deep enough in the soil that the injection slot closes over.

There is some concern that anhydrous ammonia is harmful to soil life. Within the injection band, high soil pH and hygroscopic conditions are severe enough to kill earthworms and other soil fauna and microflora, but this zone is relatively small and dissipates quickly. The population of soil organisms quickly recovers and is actually increased by the addition of N to the soil ecosystem.

Ammonium sulphate (21-0-0)

- $(NH_4)_2SO_4$
- white-to-brown crystalline industrial by-product obtained by neutralizing ammonia from coke ovens with recycled sulphuric acid, or from nylon manufacturing
- may contain about 0.5% moisture and minute amounts of nutrients such as K, calcium, copper, iron, manganese and zinc
- generally more expensive per unit of N than urea

Ammonium sulphate breaks down to ammonium and sulphate when dissolved in the soil water. It is useful for surface broadcast applications as there is less risk of ammonia volatilization. Depending on source, its form is granular or coarse powder.

Calcium nitrate (15-0-0)

- $Ca(NO_3)_2$
- expensive source of N
- used only where both calcium and N are required and soil acidification is undesirable
- contains N in nitrate form and water-soluble calcium
- highly hygroscopic; may liquefy completely when exposed to air with a relative humidity above 47%; store any broken bags in a tightly closed waterproof bag

The highly soluble nitrate-N and calcium are immediately available to the plant.

Potassium nitrate (12-0-44)

- KNO_3
- extracted from dry brine lakes (e.g., Dead Sea) or manufactured by reacting potassium chloride and nitric acid
- expensive source of N and K
- used mainly for horticultural crops, tobacco and hydroponics

Those little puffs

Have you wondered about those little puffs of vapour behind the anhydrous applicator?

Many farmers worry they are losing large quantities of N fertilizer. In fact, most of what they are seeing is a fog created by the cold ammonia gas condensing water vapour. It has been estimated that each millilitre of ammonia can produce over a litre of mist. The average emission loss is only 4% and is less in good conditions.

Table 8–1. Common fertilizer ingredients

LEGEND: – = none N/A = not available

Ingredient	Grade[1] (%)	Other nutrients[2]	Salt index[3]	$CaCO_3$ equivalent[4] (lb/lb)	Bulk density[5] (lb/ft^3)	Bulk density[5] (kg/L)	Relative cost/unit nutrient[6]
Granular							
urea	46-0-0	–	74	1.8	50	0.80	1.00
ammonium nitrate	34-0-0	–	104	1.8	56	0.90	1.42
calcium ammonium nitrate	27-0-0	4%–6% Ca 0%–2% Mg	93	0.9	68	1.10	1.46
ammonium sulphate	21-0-0	24% S	88	3.6	68	1.10	1.41–2.04
calcium nitrate	15-0-0	19% Ca	65	-1.3 (B)	75	1.20	3.72
potassium nitrate	12-0-44	–	70	-1.9 (B)	75	1.20	2.54
sodium nitrate	16-0-0	–	100	-1.8 (B)	78	1.25	N/A
single superphosphate	0-20-0	20% Ca, 12% S	8	neutral	68	1.10	1.77
triple superphosphate	0-46-0	21% Ca	10	neutral	68	1.10	1.00
mono-ammonium phosphate	11-52-0	–	27	5.4	62	1.00	0.82
di-ammonium phosphate	18-46-0	–	29	3.6	62	1.00	0.81
muriate of potash (red)	0-0-60	45% Cl	115	neutral	70	1.10	1.00
muriate of potash (white)	0-0-62	46% Cl	116	neutral	75	1.20	1.00
potassium sulphate	0-0-50	18% S	43	neutral	75	1.20	2.34
sulphate of potash-magnesia	0-0-22	20% S 11% Mg	43	neutral	94	1.50	3.71

[1] Grade: guaranteed minimum percentage by weight of total N, available phosphoric acid (P_2O_5) and soluble potash (K_2O) in each fertilizer material.

[2] Nutrients other than N, P or K.

[3] Salt index: comparison of relative solubilities of fertilizer compounds with sodium nitrate (100) per weight of material. When applied too close to the seed or on the foliage, materials with a higher salt index are more likely to cause injury.

[4] $CaCO_3$ equivalent: pounds of lime required to neutralize the acid formed by 1 lb of the N supplied by the fertilizer material. "B" following the lime index indicates a basic (acid-neutralizing or alkaline) ingredient. **Note:** acid-forming effects can be up to twice as great as indicated, depending on plant uptake processes.

[5] Bulk density: expressed as pounds per cubic foot or kg/L. This is important since fertilizers are metered by volume rather than weight in spreaders or planting equipment.

[6] Relative cost/unit: based on 2006 prices of urea for N, triple superphosphate for P and muriate of potash for K.

Table 8–1. Common fertilizer ingredients

LEGEND: – = none N/A = not available

Ingredient	Grade[1] (%)	Other nutrients[2]	Salt index[3]	$CaCO_3$ equivalent[4] (lb/lb)	Bulk density[5] (lb/ft^3)	Bulk density[5] (kg/L)	Relative cost/unit nutrient[6]
Liquid							
anhydrous ammonia	82-0-0	–	47	1.8	37	0.6	0.83
urea-ammonium nitrate (UAN)	28-0-0	–	63	1.8	80	1.28	1.10
	32-0-0	–	71	N/A	82	1.32	N/A
ammonium polyphosphate	10-34-0 11-37-0	–	20	3.6	87	1.40	1.27

1 Grade: guaranteed minimum percentage by weight of total N, available phosphoric acid (P_2O_5) and soluble potash (K_2O) in each fertilizer material.
2 Nutrients other than N, P or K.
3 Salt index: comparison of relative solubilities of fertilizer compounds with sodium nitrate (100) per weight of material. When applied too close to the seed or on the foliage, materials with a higher salt index are more likely to cause injury.
4 $CaCO_3$ equivalent: pounds of lime required to neutralize the acid formed by 1 lb of the N supplied by the fertilizer material. "B" following the lime index indicates a basic (acid-neutralizing or alkaline) ingredient. **Note:** acid-forming effects can be up to twice as great as indicated, depending on plant uptake processes.
5 Bulk density: expressed as pounds per cubic foot or kg/L. This is important since fertilizers are metered by volume rather than weight in spreaders or planting equipment.
6 Relative cost/unit: based on 2006 prices of urea for N, triple superphosphate for P and muriate of potash for K.

Phosphorus (P) sources

Single superphosphate (0-20-0)

- about one-half mono-calcium phosphate and one-half gypsum [$Ca(H_2PO_4)_2 \cdot H_2O + CaSO_4 \cdot 2H_2O$]
- made by reacting phosphate rock with sulphuric acid
- usually contains 20% available phosphate, 12% sulphur and 20% calcium

The oldest commercial fertilizer, single superphosphate has been on the market since 1840 and is no longer handled by major fertilizer suppliers in Ontario. It has been largely replaced by mono-ammonium phosphate (MAP).

Triple superphosphate (0-46-0)

- mostly mono-calcium phosphate [$Ca(H_2PO_4)_2 \cdot H_2O$]
- made by reacting phosphate rock with phosphoric acid
- contains about 83% mono-calcium phosphate, 2% moisture, and a balance of mostly unreacted phosphate rock and other insoluble phosphates

Mono-calcium phosphate is an acidic salt that can break down urea fairly easily. Triple superphosphate should not be blended with urea. It is rarely available in Ontario, and there is only one North American manufacturer producing it, in the western U.S.

Mono-ammonium phosphate (MAP; 11-52-0)

- $NH_4H_2PO_4$
- produced by reacting anhydrous ammonia with phosphoric acid
- off-white-to-grey colour
- usually contains 85% pure chemical compound, 3%–5% di-ammonium phosphate, 1% moisture, and a balance of magnesium and other phosphates and sulphates
- economical source of N (10%–12.5%) and P (48%–52% P_2O_5)

Mono-ammonium phosphate is the P source of choice in Ontario because of its high nutrient concentration and relative crop safety in starter fertilizers. It's well-suited for use in starter bands.

Di-ammonium phosphate (DAP; 18-46-0)

- $(NH_4)_2HPO_4$
- produced by reacting anhydrous ammonia and phosphoric acid
- relatively low cost per unit
- light-to-dark-grey colour
- usually contains about 80% pure chemical compound, 10% mono-ammonium phosphate, 1%–2% moisture, and a balance of magnesium and other phosphates or sulphates
- may also contain a small amount of ammonium nitrate or urea added during manufacturing to bring the N content up to the guaranteed 18%
- nitrogen 100% water soluble; available phosphate usually 90% water soluble

Di-ammonium phosphate had been the main source of P for several decades because of its cost and high nutrient content. However, it is not always the most suitable choice because of the risk of ammonia injury when used in starter fertilizers, particularly in alkaline soils. Availability of DAP in Ontario is very limited, and it has been replaced by mono-ammonium phosphate (MAP).

Ammonium polyphosphate

- $(NH_4)_3HP_2O_7$
- liquid solution, 10-34-0 analysis (can also be 11-37-0)
- about 75% of the P is polyphosphate; 25% is orthophosphate
- made by reacting ammonia with pyrophosphoric acid, which is made by dehydrating orthophosphoric acid
- solution pH of 6, near neutral
- blends well with UAN

A 10-34-0 solution also blends well with micronutrients. For example, it can maintain 2% Zn in solution compared to 0.05% with phosphoric acid (H_3PO_4).

Rock phosphate

- sedimentary rock made up primarily of calcium fluorophosphate with impurities of iron, aluminum and magnesium
- raw material for production of P fertilizers
- sometimes promoted as a "natural" source of P
- none of the P is water-soluble

- citrate solubility of the P ranges from 5%–17%
- finely ground, it can supply sufficient plant-available P in low pH (acidic) soils when applied at 2 to 3 times the rates of superphosphates
- availability to plants is low-to-nil in neutral or alkaline soils

Potassium (K) sources

Muriate of potash (0-0-60 or 0-0-62)

- KCl (potassium chloride)
- most common and least expensive source of K
- contains chloride (47%), an essential plant nutrient needed for cell division, photosynthesis and disease suppression
- a small amount (less than 100 g/t) of an amine/oil anti-caking agent is often included in the shipped product
- red and white forms offer equal availability of the K to plants

Red muriate of potash (0-0-60)

- mined primarily in Saskatchewan, and some in New Brunswick
- contains about 97% potassium chloride (KCl)
- iron impurities are responsible for the colour; they do not affect solubility

White muriate of potash (0-0-62)

- obtained by crystallizing potassium chloride out of the solution mining liquor
- almost pure potassium chloride

Potassium sulphate (0-0-50-17S)

- K_2SO_4
- extracted from the brines of Great Salt Lake in Utah
- also contains 17% sulphur in the water-soluble form

Potassium sulphate, or sulphate of potash, has a lower salt index and is more expensive than muriate of potash. It is used mainly on crops sensitive to chloride, such as tobacco, potatoes, tree fruits and some vegetables.

Sulphate of potash-magnesia (0-0-22-10.5Mg-22S)

- potassium-magnesium sulphate $K_2SO_4 \bullet 2MgSO_4$
- mined from deposits in New Mexico
- commonly referred to as K-Mag and Sul-Po-Mag

Potassium-magnesium sulphate, or sulphate of potash-magnesia, has a higher cost per unit of K than the muriate form. It also contains 10.5% magnesium and 22% sulphur in water-soluble form and therefore readily available to plants. It is useful as a source of soluble magnesium in fields where lime is not required.

Table 8–2. Blended liquid fertilizers

Analyses	Weight/ US Gal (lb)	Weight/ Imp. Gal (lb)	Weight/ Litre (lb)	Imp. Gal/ Tonne	US Gal/ Tonne	Litre/ Tonne
8-25-3	11.11	13.35	2.94	165.1	198.4	749.9
6-18-6	10.69	12.85	2.83	171.6	206.2	779.0
3-11-11	10.45	12.55	2.76	175.7	211.0	798.8
9-9-9	10.49	12.60	2.77	175.0	210.2	795.9
7-7-7	10.41	12.5	2.75	176.4	211.8	801.7
6-24-6	11.07	13.30	2.93	165.8	199.2	752.4
9-18-9	11.07	13.30	2.92	165.8	199.2	755
5-10-15	10.7	12.85	2.83	171.6	206.0	799
2-10-15	10.62	12.75	2.81	172.9	207.6	784.6
10-34-0	11.6	14.0	3.09	157.0	188.5	715.8

1 Imperial gallon = 1.201 US gallons; 1 US gallon = 3.785 litres

1 US gallon = 0.8326 Imperial gallons; 1 Imperial gallon = 4.546 litres

Clear solutions

- wide range available of N-P and N-P-K fertilizers with neutral pH (see Table 8–2)
- based on ammonium polyphosphate (10-34-0)
- made by adding urea, aqua ammonia, phosphoric acid, potassium chloride or potassium hydroxide to the ammonium polyphosphate
- micronutrients can be added but must be in the chelated form
- all ingredients must be high quality, since impurities can lead to salting out or gelling of the fertilizer solution
- generally of high agronomic quality, although salt injury to seeds and roots becomes a concern with higher amounts of N and K
- most commonly used as starter fertilizer applied in the seed furrow
- reduces time and labour at planting because of low use rates and the ability to pump the material from nurse tanks into the planter
- equipment cost for planters can be reduced because separate fertilizer opener not required

Acid solutions

- combinations of phosphoric acid, sulphuric acid and urea
- micronutrients do not have to be added in chelated form

Acid solutions are not commonly used in Ontario because they are corrosive and expensive compared to granular fertilizers. These solutions are promoted on the basis that nutrients are more available at the low pH created in the fertilizer band, particularly in alkaline soils. Most soils are well enough buffered, however, that the acid addition has no effect on soil pH. These materials are equal to, but not better than, other fertilizer materials in nutrient availability.

Suspensions

- produced by mixing finely ground dry ingredients with water and a suspending agent such as clay
- can produce a complete fertilizer with a higher analysis than dissolved fertilizer
- mix needs agitation to keep it suspended and special handling and application equipment

Suspensions form an almost insignificant part of the Ontario fertilizer market. Although they were once popular in western Canada, they are in decline.

Secondary nutrient sources

Secondary nutrients are needed occasionally in Ontario soils. If required, they may be applied as part of a fertilizer blend or added as part of a lime application to correct soil acidity. Common sources for secondary and micronutrients are shown in Table 8–3.

Table 8–3. Common secondary and micronutrient sources

Nutrient	Source	Percentage nutrient	Other nutrients	Application	
				soil	foliar
calcium (Ca)	calcitic limestone	22%–40%		yes	no
	dolomitic limestone	16%–22%	6%–13% Mg	yes	no
	gypsum ($CaSO_4 \cdot 2H_2O$)	23%	19% S	yes	no
	calcium chloride ($CaCl_2$)	36%	64% Cl	yes	yes
	calcium nitrate ($Ca(NO_3)_2$)	19%	15.5% N	yes	yes
	pelletized lime	16%–40%	0%–13% Mg	yes	no
	cement kiln dust	26%–32%	2%–9% K_2O	yes	no
magnesium (Mg)	dolomitic limestone	6%–13%	16%–22% Ca	yes	no
	Epsom salts ($MgSO_4$)	9%	13% S	yes	yes
	sulphate of potash magnesia	11%	22% K_2O; 20% S	yes	no
sulphur (S)	ammonium sulphate	24%	34% N	yes	no
	potassium sulphate	18%	50% K_2O	yes	no
	sulphate of potash magnesia	22%	22% K_2O; 11% Mg	yes	no
	calcium sulphate	19%	23% Ca	yes	no
	granular sulphur	90%	–	yes	no
boron (B)	various granular materials	12%–15%	–	yes	no
	Solubor™	20%	–	no	yes
copper (Cu)	copper sulphate	25%	–	yes	no
	copper chelates	5%–13%	–	no	no
manganese (Mn)	manganese sulphate	28%–32%	–	no	yes
	manganese chelates	5%–12%	–	no	yes
molybdenum (Mo)	sodium molybdate	39%	–	no	yes
zinc (Zn)	zinc sulphate	36%	–	yes	yes
	zinc oxysulphate	8%–36%	–	yes	no
	zinc chelates	9%–14%	–	no	yes

Calcium

Limestone (either calcitic or dolomitic) is the most common source of calcium. There are some quarries and cement manufacturers that offer limestone-based by-products that carry significant quantities of potassium (e.g., 3%– 9%), magnesium and sulphate-sulphur. Care must be taken to account for the differences in Agricultural Index and the additional nutrient content, which may or may not be required for a given field.

Limestone is used to increase the pH of acidic soils. To be effective, it must be finely ground. Limestone is available in powder form or in pellets made from finely ground limestone. The solubility of limestone drops quickly as soil pH increases.

In soils with neutral or alkaline pH, gypsum (calcium sulphate) is the preferred form of calcium because it is more soluble than lime. Gypsum has no effect on soil pH.

Calcium chloride or calcium nitrate are occasionally used as foliar sources of calcium.

Magnesium

Magnesium deficiency is most common in acidic soils. If dolomitic limestone is added to correct the acidity, it will also supply enough magnesium to correct the deficiency. The solubility of dolomitic limestone decreases as the soil pH increases, and it is therefore not appropriate for alkaline soils.

In neutral or alkaline soils, Epsom salts (magnesium sulphate) or sulphate of potash magnesia can be used for supplemental magnesium.

Sulphur

Sulphate-sulphur is present in a number of common fertilizer materials and can be included in a fertilizer blend in these ingredients. Most common are ammonium sulphate, potassium sulphate and sulphate of potash magnesia. Gypsum (calcium sulphate) can also be used as a sulphur source. Product availability, transportation costs and crop requirements for other nutrients will dictate which source of sulphur is most economical.

Granular elemental sulphur (90% S) can be another source. It will also acidify the soil. The sulphur must be oxidized to sulphate before it is available to the crop, which can take several months. Some of the intermediate products in the oxidation process can be toxic to crops; therefore, if high rates are required, they should be broadcast rather than banded.

Micronutrient sources

Since micronutrients are required and applied in relatively small quantities, even distribution during application is important. The main classes of micronutrient products are granules intended for mixing with granular fertilizers and liquids or soluble powders for foliar application. The most appropriate form for application will depend on the specific nutrient as well as the crop species and soil conditions.

Granular micronutrient products are blended with other fertilizer ingredients for broadcast application or use as a starter fertilizer. Compatibility with the other ingredients is important, both chemically and in granule size. Since many micronutrients are toxic to plants if over-applied, segregation of the fertilizer blends must be avoided.

Oxy-sulphates

- combinations of the oxide and sulphate forms of the micronutrient
- sulphates are much more soluble and available than the oxides
- oxides are much more stable in a blended product
- oxides are only slowly available to the crop

These products have been declining in popularity because of the inconsistency in plant availability and crop response.

Sulphates

- quite soluble
- tend to be hygroscopic and can cause problems with caking or clumping when mixed with other fertilizer ingredients

Despite these concerns, their consistent plant availability has made them popular in fertilizer blends.

Liquid and soluble micronutrients

These materials may be mixed with water and sprayed on crop foliage or mixed with liquid fertilizers for use as starters.

Chelates

- complex organic molecules that bind metallic ions held in soluble forms, which prevents them from reacting with other minerals to form insoluble compounds
- allows many of these nutrients to be mixed with liquid fertilizers without forming insoluble precipitates
- may increase the availability of the nutrients in soil
- most commonly used chelating agents are EDTA and DTPA
- other organic materials (humic acids, lignosulphonates, glucoheptonates) will form complexes with metallic ions but do not hold them as tightly as a true chelate

Chelates are considerably more expensive than other soluble forms of micronutrients. They should be used with care, since they can bind with minerals already in the soil and make the deficiency worse.

Water-soluble powders

- the least expensive form of micronutrients for foliar application and the most consistently reliable
- most require a sprayer with good agitation to keep material in solution
- sticker-spreader needed to get the nutrient through the cuticle and into the leaf

Dry dispersible powders

- powdered materials that are made for use in dry granular blend applications and are applied by the fertilizer retail blender

- the inclusion rate per tonne is set by the manufacturer to assure the correct application rate and reduce dust off
- excess dust can be created by exceeding the manufacturer's recommendations and over-mixing the blend
- the material clings by static forces to the granular fertilizer, which results in each individual granule receiving the micronutrient
- much more expensive on a nutrient basis than other dry granular material; however, improved performance at lower inclusion rates may justify use
- each granule in the blend is coated with the micronutrient for better application distribution

Liquid micronutrient coatings

- similar in concept to dry dispersible powders, some manufacturers have liquid materials in either a latex or oil-based formulation designed to be sprayed onto granular fertilizer
- these coatings are professionally applied by retail blenders and usually require a heating blanket on liquid totes during cool weather and specialized metering equipment for proper application
- since they are liquid there is no dust-off potential, but there are restrictions to inclusion rates applied per tonne
- on-farm trials are a good way to compare or confirm product performances

Materials to enhance fertilizer efficiency

Nitrogen

Most products designed to enhance the efficiency of N uptake delay the release of its mineral forms, ammonium and nitrate. A 2016 fertilizer use survey conducted by Stratus Ag Research found that 22% of Eastern Canadian corn producers used a nitrogen stabilizer of some form (Stratus Ag Research, 2016). The products fall into one or more of the following categories:

- **Slow or controlled-release fertilizers.** These are materials that contain N in a form that delays its availability for plant uptake and thus makes it available over a longer period of time, in comparison to the regular ammonium, nitrate or urea fertilizers. The delay in release can be attained by a variety of mechanisms, including polymer or sulphur coatings, occlusions, or incorporation into compounds that are either insoluble or require mineralization to release the N. Some products are available in a range of grades varying in release profiles. Note that each material is designed for a specific application and specific crop.
- **Urease inhibitors.** These are substances that inhibit the hydrolytic action on urea by the urease enzyme. An example is Agrotain which contains N-(n-butyl) thiophosphoric triamide (NBPT).
- **Nitrification inhibitors.** These are substances that inhibit the biological oxidation of ammonium to nitrate. Examples include

N-Serve (nitrapyrin) and DCD (dicyandiamide). Ammonium thiosulphate also inhibits nitrification to some extent.
- **Stabilized fertilizers.** A nitrogen stabilizer is a substance added to a fertilizer that extends the time the fertilizer remains in the urea or ammoniacal form. An example is SuperU, a urea fertilizer containing both NBPT (a urease inhibitor) and DCD (a nitrification inhibitor).

Research by Dr. Craig Drury of Agriculture and Agri-Food Canada (AAFC) at the Woodslee Research Farm in Essex County in 2013 and 2014 has demonstrated the efficacy of some of the products above. He has shown that the combined use of a urease and nitrification inhibitor with corn N fertilization reduces losses from both volatilization and nitrous oxide production (Drury et al, 2017). The benefit depends on the specific combination of management, soil and weather conditions. Generally, urease and nitrification inhibitors can help to:

- minimize the concentration of inorganic soil N that is susceptible to loss
- substitute for capital investment in specialized machinery for placement
- increase flexibility in timing of application
- reduce potential for losses due to volatilization
- capture more yield potential by reducing the risk of N loss
- reduce environmental loss through pathways such as leaching and denitrification

Controlling the release of nitrogen can have disadvantages if the use of these materials is not carefully planned. Most fertilizer materials are supplied in a soluble form to maximize plant availability. It is only in specific situations — when the amount applied exceeds what plants can take up within a reasonable time frame — that the above materials will enhance efficiency.

Phosphorus

Products designed to enhance efficiency of P uptake prevent the fixation of P by the soil. These may include organic or humic materials, and polymer coatings that reduce the rate of diffusion from the granule to the fixation sites in the soil. As an example, a grade of 11-52-0 mono-ammonium phosphate coated with maleic itaconic copolymer (AVAIL) has been marketed for more than 25 years in North America.

In certain soil conditions, slowing the release of phosphate could potentially reduce fixation reactions that make applied P unavailable. For instance, Garcia et al. (1997) found that urea phosphate or lignin-coated triple superphosphate increased soil P availability in a highly calcareous P-fixing soil, while uncoated superphosphate or di-ammonium phosphate did not. However, the timing of release is a critical factor for most starter fertilizers. Most field crops require available P release to the seedling within a few weeks from planting.

There are some products that inoculate the soil with micro-organisms that claim to make phosphorus and other nutrients more available. Recent introductions of *Penicillium bilaii, Bacillus amyloliquefaciens* and *Trichoderma virens* seed treatments are part of an emerging industry of biologicals. On-farm trials that determine how effective these products might be on your own farm are the best way to validate their performance.

Materials for organic production systems

Many of the materials listed above are not approved for use in organic production systems. According to the Canadian General Standards Board, substances used to improve the fertility of soils in organic production systems must be of plant, animal, microbial or mineral origin and may undergo the following processes: physical, enzymatic or microbial. Since most N, P and K fertilizers undergo some degree of chemical processing, they are considered not to be naturally occurring elements. Exceptions include some grades of rock phosphate, muriate of potash, potassium sulphate and sulphate of potash magnesia. For a detailed list of permitted substances, contact the Canadian General Standards Board.

Fertilizer blending

Blended fertilizers were available for much of 20th century, but the early forms left much to be desired. For many years, fertilizers were shipped to the farm as fine powders in paper bags. These powders tended to bridge in the drill boxes or cake if they got damp.

In the 1950s, mixed granulated fertilizers were introduced in Ontario. These materials incorporated the same raw materials into a multi-nutrient granule. The equipment to produce these mixed granules, however, was cumbersome and expensive, and mixed granulated fertilizers were soon supplanted by bulk blends.

Bulk blending is the act of mixing granular fertilizer ingredients to produce the desired ratio. In Ontario, these operations are generally carried out at retail blenders.

These operators make custom blends based on unique agronomic needs of individual fields. Custom blends, or customer formula fertilizers, are obtained by mixing granular fertilizer materials according to a formula calculated to suit the fertilization recommendation for a given field and crop.

Custom blends are efficient because they:

- provide the exact amount of nutrients required to grow the crop
- are less likely to absorb moisture and cake in storage
- minimize the cost of fertilization with high-analysis, filler-free materials

Limitations to blends

Bulk blends, and custom blends in particular, are subject to a few limitations. Applying low rates of high-analysis fertilizers requires the use of appropriate metering systems. Often air distribution systems are used to precisely apply the required rates.

For some applications, there are advantages to fertilizers that combine several nutrients in the same granule. Examples include starter fertilizers incorporating small amounts of micronutrients and home lawn fertilizers. These homogenized fertilizers spread all nutrients uniformly and are convenient to use. Their main limitation, however, is that their nutrient ratios are fixed, and thus it is difficult to match specific soil requirements.

Physical and chemical compatibility of blending materials

Fertilizer materials are generally compatible with each other as long as they remain dry.

There are some exceptions:

- Do not blend ammonium nitrate with urea. When these two are brought together, the mix is so hygroscopic that it turns into a soaking mess in minutes. Take precautions to avoid cross-contamination during storage and handling. Before mixing two blended fertilizers, check the ingredients to ensure you are not bringing ammonium nitrate and urea together.
- Do not blend single or triple superphosphate with urea. Superphosphates (0-20-0 or 0-46-0) may react with urea, especially if they are not dry and hard. When this reaction takes place, the urea is broken down and the mix becomes sticky.
- Spread blends containing a superphosphate and di-ammonium phosphate as soon as possible. Single or triple superphosphates may react with di-ammonium phosphate in the presence of moisture. The mix becomes sticky and eventually cakes.

DO NOT BLEND

- AMMONIUM NITRATE with UREA
- SUPERPHOSPHATE with UREA

Spread mixes containing micronutrients as soon as possible

Some micronutrient ingredients (particularly sulphates) may absorb moisture from the air.

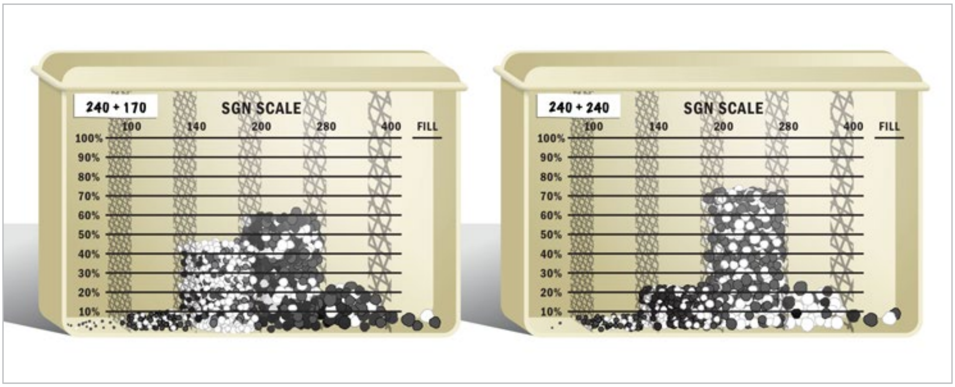

Figure 8–1. Testing for segregation

Consistent particle size critical

Consistent particle size is critical in mixing and applying bulk blends. If particle sizes of ingredients differ, the ingredients will segregate when they are dropped into a bin, with the largest particles at the outside of the pile and the finer materials in the centre. This can result in a large variation in the makeup of the fertilizer from one part of the pile to another.

Particle size also influences the spreading pattern of the fertilizer. Tests conducted by the Tennessee Valley Authority showed a range of spreading widths from 10.5 m (35 ft) for material with a 1.7 mm diameter, to 19.5 m (65 ft) for materials with a 3 mm diameter. If the materials in the blend are different sizes, the application of the different ingredients is not uniform.

The fertilizer blender should use materials with similar sizes. The Canadian Fertilizer Institute published the SGN System of Materials Identification in 1986.

SGN, or size guide number, is the average dimension of the fertilizer particles, measured in millimetres times 100. For example, SGN 280 means that half the fertilizer sample is retained on a testing sieve of 2.80 mm opening. SGN and the uniformity index, a measure of size uniformity, are the two characteristics used to simplify the selection of size-compatible materials.

Figure 8–1 shows the impact of mixing two materials of different sizes. A fertilizer blend made with the materials in the box labelled “SGN 240 + 170” will show significant segregation in the bin or fertilizer box, resulting in uneven application of the nutrients across the field.

There is no segregation in the box tagged 240 + 240. The box tagged 240 + 170, however, shows segregation between the white material SGN 170 and the grey material SGN 240.

Formula calculations

A custom blend is one formulated to meet the fertilization recommendation exactly. The formula is nothing more than a recipe calculated to use available materials to supply the desired plant nutrients.

The same calculations work with any combination of ingredients, but most fertilizer blenders have a limited range of ingredients. This normally includes an N source (46-0-0, 27-0-0, etc.), a P source (11-52-0, etc.) and a K source (0-0-60, 0-0-62, etc.).

The exact analyses of the ingredients may vary, depending on the source, making it important to know what ingredients are available. Some blenders also stock specialty ingredients for crops like tobacco.

The most important calculation is determining the amount of fertilizer required to provide each nutrient. Do this by using the proportion of each nutrient in the ingredient. (The proportion is the percentage divided by 100 — the decimal parts in 1 rather than the parts in 100. For example, 46% becomes 0.46.) Calculate the amount of ingredient required by dividing the amount of nutrient required by the proportion of nutrient in the ingredient. An example is shown in Worksheet A. A blank worksheet is found in Appendix A.

Calculating fertilizer blends that contain N and P is similar to calculating N-K or P-K blends, except you will want to take advantage of the savings possible with MAP or DAP. This adds a couple of steps to the process, because you will have to calculate the amount of ingredient to meet one requirement and then deduct the contribution of that ingredient from the other requirement (see Worksheet B and Appendix B).

Which requirement you calculate first depends on the ratio of N:P required and the choice of ammonium phosphate (MAP or DAP).

In general, fill the P requirement first in high-N fertilizers (fertilizers with an N:P ratio of 1:2 and higher). Fill the N requirement first in fertilizers with an N:P ratio of 1:4 and lower.

Computer software and smartphone apps are available that help facilitate blend calculations. Nutrient Management Planning software (go to ontario.ca/crops and search for AgriSuite Planning Tools) can be used to create crop nutrient plans using commonly available fertilizer blends and/or manure sources.

Worksheet A.
Example for N-K or P-K fertilizer blend

1. List materials on hand and grades.

Ingredient	Grade
urea	46-0-0
triple superphosphate	0-46-0
muriate of potash	0-0-60

2. Obtain nutrient requirement (kg/ha of N-P_2O_5-K_2O): **130-0-90**

3. Calculate ingredient required for each nutrient. Repeat for each nutrient:

Nutrient requirement ÷ proportion of nutrient = ingredient amount

130 ÷ 0.46 = 283

Nutrient requirement ÷ proportion of nutrient = ingredient amount

90 ÷ 0.60 = 150

4. Add weights of materials and calculate nutrients provided.

Material	Weight	N	P_2O_5	K_2O
Urea	283 kg	130	0	0
KCl	150 kg	0	0	90
Total	**433 kg**	**130**	**0**	**90**

The total weight of the blend at this point is the application rate. The units will be the same as the initial nutrient requirements.

5. Calculate the total amount of fertilizer required.

Application rate	x size of field	= total weight of fertilizer
433 kg/ha	x **20 ha**	= **8,660 kg**

6. Adjust material weights to give formula in kilograms per tonne.

Divide the weights of the individual materials by the total weight and multiply by 1,000.

Material	Weight	N	P_2O_5	K_2O
Urea	654 kg	301	0	0
KCl	346 kg	0	0	208
Total	**1,000 kg**	**301**	**0**	**208**
Grade (divide total NPK by 10)	—	30.1	0	20.8

Blank worksheets to copy and use are in Appendix A.

Worksheet B.
Example for NPK fertilizer blend

1. List materials on hand and grades.

Ingredient	**Grade**
Urea	46-0-0
Mono-ammonium phosphate (MAP)	11-52-0
Triple superphosphate	0-46-0
Muriate of potash (KCl)	0-0-60

2. Obtain nutrient requirement (or desired ratio or grade): **90-90-110 lb/acre**

3. Calculate ingredient (MAP) required for either N (for high P ratios) or P (for high N ratios).

nutrient requirement ÷ proportion of nutrient = amount of MAP (lb/acre)

90 ÷ 0.52 = 173

4. Calculate contribution of ingredient to other nutrient.

ingredient required x proportion of nutrient = contribution **173 x 0.11 = 19**

5. Deduct contribution from requirement to determine the residual nutrient requirement .

(**Note:** if contribution is greater than requirement, you calculated the wrong nutrient first. Return to step 3.)

Requirement – contribution = residual requirement **90 – 19 = 71**

6. Determine amount of ingredient to provide residual requirement (N source or P source).

residual requirement ÷ proportion of nutrient = ingredient amount

71 ÷ 0.46 = 154

7. Determine amount of muriate of potash to meet K requirement.

K nutrient requirement ÷ proportion of nutrient = ingredient amount

110 ÷ 0.60 = 183

8. Calculate any ingredients needed for any other micronutrients in the same way.

9. Add weights of materials and calculate nutrients provided.

Material	**Weight**	**N**	**P_2O_5**	**K_2O**
MAP	173	19	90	0
Urea	154	71	0	0
Potash	183	0	0	110
Total	**510**	**90**	**90**	**110**

The total weight of the blend at this point is the application rate. The units will be the same as the initial nutrient requirements.

10. Calculate the total amount of fertilizer required.

application rate	x size of field	= total weight of fertilizer
510 lb/acre	x **40 acres**	= **20,400 lb (9,251 kg)**

11. Adjust material weights to give formula in kilograms per tonne.

Divide the weights of the individual materials by the total weight (in the table from step 9) and multiply by 1,000.

Material	Weight (kg)	N	P_2O_5	K_2O
MAP	339	37	176	0
urea	302	139	0	0
potash	359	0	0	215
Total	**1,000**	**176**	**176**	**215**
Grade (divide total NPK by 10)	—	17.6	17.6	21.5

Now you can calculate the price of the fertilizer.

A blank chart for you to copy and use is in Appendix B.

Legalities

The Canadian Food Inspection Agency monitors and controls fertilizers and supplements sold in or imported into Canada. The purpose of the *Fertilizers Act* and Regulations is to ensure that fertilizer and supplement products are safe, efficacious and accurately represented in the marketplace.

Most fertilizer and supplement products are regulated; however, not all of these products require registration. Micronutrient products, fertilizer-pesticide products and supplements not found in Schedule II of the *Fertilizers Act* and Regulations (such as plant growth regulators, soil conditioners, wetting agents, microbial inoculants, etc.) require registration before they can be legally imported into and/or sold in Canada.

All products must be safe for plants, animals, humans and the environment. They must be effective, and they must be properly labelled. The minimum required information that must appear on a fertilizer or supplement product label is the name, grade (if any), brand (if any), name and address of the manufacturer or registrant, lot number (if any), registration number (where applicable), guaranteed analysis, directions for use (where applicable), product weight and appropriate cautionary statements. Some specialty fertilizer products and supplements will require additional information to appear on the label. In addition, the guarantees displayed on the product label must be met, as all products are subject to monitoring and inspection.

Many fertilizer manufacturers and blend producers are part of the Canadian Fertilizer Quality Assurance Program (CFQAP). Under this voluntary program, participants take their own samples and send them to accredited labs that submit the analyses to the Canadian Food Inspection Agency. The results are tabulated, and each manufacturer or blend plant that submits the minimum number of required samples is given a performance rating. The ratings are published annually in the Canadian Fertilizer Quality Assurance Report, which is distributed widely. A customer can ask for a supplier's CFQAP rating.

For more information, contact the Fertilizer Section, Canadian Food Inspection Agency, www.inspection.gc.ca.

All fertilizers must be properly labelled, whether they are registered or not. Information that appears on the label must include the name, grade, guaranteed minimum analysis, manufacturer, packager and product weight. Specific types of products need more information. The guarantees on a label must be met, and all products are subject to monitoring and inspection.

Fertilizer application

The aim of any fertilizer program is to get the nutrient into the crop plants where it will be used to improve yield and quality of the crop. Fertilizer that isn't placed where the roots can reach it when the crop needs it won't do the job.

Fertilizer placement is a compromise between applying the fertilizer in optimum concentrations precisely where and when the plant needs it and the practical considerations of the time and equipment available for applying the fertilizer. If you are considering a more costly fertilizer application system, there should be advantages in increased crop yield or reduced fertilizer cost that compensate.

The best placement for a particular nutrient (or combination) depends on how mobile the nutrient is in the soil, the concentration required by crop plants, how toxic the nutrient is at high concentrations, the soil texture and moisture status, and the crop being fertilized.

Crop safety

Plant tissue is sensitive to injury from high salt concentrations (osmotic pressure) or free ammonia, both of which can be produced by too much fertilizer in too small a volume of soil.

Plant symptoms

The symptoms of fertilizer burn are reduced root growth and blackened or discoloured areas on the roots, as if they were burned. Injury will be most severe with seedlings because young tissues are more sensitive, larger proportions of the plant tissue are affected by any injury, there is less reserve for re-growth following injury, and there is less opportunity for the plant to grow around the area of high concentration.

Concentration is key

The key factor in fertilizer injury is concentration rather than the total amount applied. Banded fertilizers are much more likely to cause injury than broadcast fertilizers.

If fertilizer is applied with a corn planter in a 2.5 cm band (1 in.) in rows 0.75 m (30 in.) apart, the concentration within the band is 30 times what it would have been if the fertilizer had been broadcast over the whole area. Also, the distribution along the row is not always even — as a result, fertilizer rates can be much higher at some points.

The concentration can be diluted as the fertilizer diffuses out of the band, but the amount of dilution depends on the texture and moisture content of the soil. Moist soils cause greater dilution. We commonly see fertilizer burn in dry springs and on coarse-textured, well-drained soils. Since coarse-textured soils with low organic matter also have less surface area to react with and adsorb fertilizer, the concentration in the soil solution will remain higher than in clay soils.

Proximity to plant

The risk of injury also increases with the proximity of the seed or transplant to the fertilizer band. With the fertilizer too close, there is little opportunity for dilution by the soil water. There is also little or no chance for the roots to grow beyond the zone of concentration. Nitrogen and potassium in particular can be harmful to seedlings and to seed germination. Cold soils, which slow root growth, can magnify these effects.

When a fertilizer is banded with the seed, the safe rate of nutrients is much less than that of fertilizer banded 5 cm to the side and 5 cm below the seed. Even at recommended rates, seed-applied fertilizer will slow germination and emergence slightly, as the salt effect slows the absorption of water. Applying fertilizer with seed is not appropriate for all crops.

Types of injury

Salt injury occurs when the concentration of ions in the soil solution is greater than the concentration within the plant. When this happens, water is pulled across the cell membranes and out of the root. The root tissues are injured by desiccation, as if they had been singed by heated air.

Any soluble compound in a high enough concentration will cause salt injury. The greater the solubility of a fertilizer, the greater the potential to cause salt injury. The acids and hydroxides are somewhat less likely to cause injury, but these ingredients as used in fertilizer manufacture are combined into other soluble compounds before application.

Ammonia injury occurs when there is free ammonia in the soil solution. Normally, this compound would be dissolved as the ammonium ion, but with high concentrations and particularly with alkaline conditions, some of the ammonium will be released as ammonia. This could occur with applications of anhydrous ammonia or high rates of liquid manure, or if urea or di-ammonium phosphate (DAP, 18-46-0) is banded near the row. The symptoms of ammonia injury are similar to salt injury, and they often happen together.

Crop susceptibility

Not every crop is equally sensitive to fertilizer injury. In general, grasses (monocots) are much less susceptible than broadleaf crops (dicots). Within the grasses, cereals are more tolerant of high banded fertilizer rates than corn.

Among the broadleaf crops, soybeans and edible beans are more susceptible than forage legumes or canola, but they are all much more sensitive than corn.

In general, seeded vegetables are quite sensitive to fertilizer injury.

Application methods

Broadcast

Broadcast fertilizer application is by far the fastest and least expensive method. The fertilizer is spread evenly over the soil surface and then incorporated into the soil for most field crops. This gives the greatest possible dilution, which minimizes the risk of fertilizer burn. Broadcast application also maximizes the contact between the fertilizer and the soil, which results in faster immobilization reactions than with banding.

Fertilizer burn can still occur on very sandy soils with low organic matter. High rates of urea and potash spread on these soils can cause seedling injury under dry conditions, especially if combined with banded or seed-applied fertilizer.

Whether a granular fertilizer is spread by a pull-type or self-propelled spreader, there are two types of delivery systems: spinners and pneumatic (airstream). Either will do a good job if properly operated and maintained.

Spinner spreaders

Spinner spreaders use one or two rapidly spinning disks with paddles to throw the fertilizer granules out from the spreader. A consistent granule size is important because smaller particles do not travel as far and they spread out in an uneven pattern. Windy conditions can also distort the spread pattern, as does a buildup of fertilizer on the distributor or the paddles. Frequent cleaning is necessary, but the areas needing cleaning are easily accessible.

Spinner-type spreaders are relatively simple mechanically and relatively inexpensive. The power requirements are modest, so that any tractor capable of pulling the spreader has lots of power for the spinners. These are the most popular types of spreaders for rental units because of their low cost, generally trouble-free operation and ease of repair in the field.

Pneumatic spreaders

Pneumatic spreaders use a high-velocity airstream to carry the granules through a boom to distributors spaced about 1.7 m (5 ft) apart. These spreaders have a higher power requirement because the fan that creates the airstream runs at high speeds. These spreaders are also more complicated because of the moving parts in the fan and the metering system that distributes the fertilizer evenly to each of the boom sections.

However, the metering can be more precise than with the spinner-type spreaders, and the mixing action of the airstream allows the addition of small quantities of granular herbicides or micronutrients in the field.

Because the distributors are relatively close together, these spreaders are not affected by wind as much as the spinner type. The self-propelled units often have a wider spread pattern than spinner spreaders, allowing greater throughput from the same power unit. Plugging is not a frequent problem because of the high velocity of the airstream, but the spreader does need to be monitored in humid conditions or when using damp materials.

The pneumatic spreader is relatively expensive and complicated and thus not generally suitable for an individual; it has, however, taken over the largest part of the market for custom application.

Tru-Spread system

The Tru-Spread system uses a screw conveyor to deliver granular fertilizer across the width of a boom and drop it through openings on 17.5 cm (7 in.) spacing. These machines are also quite accurate and unaffected by wind.

Spraying equipment

Most broadcast fertilizer is in granular form, but a sizeable quantity of liquid N solution is soil-applied on winter wheat. Small quantities are applied by broadcast as a herbicide carrier for corn.

The spread with this equipment is usually even, although there is the chance of drift in windy conditions. Some field sprayers do not perform well with liquid fertilizers because they are not designed to handle large volumes or are not protected against corrosive fertilizer materials.

Variable-rate fertilizer

The simplest variable-rate applicators are conventional spreaders of any type fitted with a global positioning system (GPS) receiver and a link to the controller. This allows the unit to variably apply one material or blend. This system may require multiple passes over the field to meet the fertilizer requirements. However, the equipment is less expensive than the multi-bin variable-rate unit. Having to do a number of passes slows application and may lead to increased soil compaction.

Multi-material variable-rate applicator units have multiple bins, and the discharge from each can be controlled individually. This allows the application rate of multiple materials to be varied in a single pass over the field.

Variable-rate application of lime can be done using a lime applicator equipped with a GPS receiver and a variable rate controller. Or, application zones within the field can be mapped and flagged and specific rates applied to each with a conventional lime spreader by dead reckoning.

Banding

Banding is applying fertilizer in a band beside and below the seed in the case of row crops or with the seed of cereals. A common practice on corn is to apply a starter band of dry fertilizer 5 cm (2 in.) beside and 5 cm (2 in.) below seeding depth. A common error is the placement of fertilizer at a 5 cm (2 in.) depth from the surface of the soil. The correct positioning is 5 cm (2 in.) below seed depth. If the seed is planted 5 cm (2 in.) deep, the starter band should be set for a 10 cm (4 in.) depth.

Banding requires fertilizer boxes and metering systems on the planter or drill and an extra opener on planters to place the fertilizer into the soil. This can require extra power to pull the planter, and the time to fill the fertilizer boxes slows the planting. The advantage is that the fertilizer is located at a high concentration where the roots of the seedlings will intercept it. This is particularly important for P, which is required early in the growth of many crops.

It is important to take care with banded fertilizer, since the high concentration also increases the risk of fertilizer burn. The rates of N and K must be limited, particularly where urea or di-ammonium phosphate is the N source. Band pH may also influence availability of other nutrients in the soil — see sidebar entitled "Soil pH in Starter Fertilizer Bands" in Chapter 3.

Planting equipment must also be set properly to place the fertilizer the right distance from the seed. If the fertilizer openers shift too close to the seed row, the risk of burn increases. If the openers shift away from the row, the seedlings may not be able to intercept the fertilizer early enough.

Metering equipment for banded fertilizer is fairly simple, with a delivery auger in the bottom of the fertilizer boxes dropping the fertilizer through an adjustable gate. The rate can be varied with the speed of the auger, the size of the gate opening or the pitch of the auger flighting. The alignment of the delivery auger must be checked carefully. If the auger is shifted to one side, it can deliver 50% more fertilizer to one side of the box than to the other.

Pop-up

Pop-up is the term for fertilizer applied with the seed of row crops, even though it actually delays germination slightly. This method has the advantage of producing relatively large yield responses in corn (up to 0.5 t/ha (8 bu/acre) in one study) with low rates of fertilizer, even at higher soil test levels where response from banded or broadcast fertilizer would not be expected. This method also gives a consistent increase in seedling vigour.

Because of the close proximity of the fertilizer to the seed, this method has a higher risk of injury than any other. You must adhere to the maximum safe rates (see Table 8-6), and the equipment must be calibrated to apply the fertilizer evenly. Pulses in fertilizer application can easily result in wavy crop growth as some areas receive higher-than-required concentrations of fertilizer while others don't get enough.

Liquid fertilizers are most commonly used for seed application because they can be metered precisely and handled easily. To avoid pulses, the fertilizer should be delivered to the seed openers under pressure and metered through an orifice. Care must be taken that the fertilizer delivery tube is centred in the seed opener. Liquid fertilizer dribbling onto the opener disks will result in mud buildup and plugging.

Side-dressing

Side-dressing is the application of fertilizer, primarily N, between the rows of growing crops. This applies the N closer to the time when the crop needs it, which can increase the efficiency of N use. It also minimizes the risk of nitrate leaching on sandy soils or of denitrification on poorly drained soils.

In corn, the most common forms of side-dressed fertilizer are anhydrous ammonia and UAN solution.

Anhydrous ammonia is attractive because of its low cost per unit of N, and on the clay soils of southwestern Ontario it has also provided a yield advantage over other forms of N. It must be injected deep enough into the soil so that the injection slot seals over, otherwise the losses to the atmosphere will be too high. The power requirements and application costs are higher for anhydrous, and it must be handled carefully to be safe.

UAN solutions do not need to be injected deep into the soil, making the power requirements for application modest. In high-residue situations, the solution must be placed below the surface residue layer to prevent volatilization losses of ammonia. The cost for UAN solution is relatively high, but safety and ease of handling have made it a popular choice.

In high-residue situations, injector knives can catch on and drag residue. To prevent this, no-till applicators are equipped with coulters to cut the residue and improve penetration into firm ground. Another approach is the spoke-wheel injector, which pokes the N solution into the soil with minimal disturbance of the residue. These work quite well, but the initial cost is higher than for other side-dress equipment.

Granular fertilizers are used for side-dressing vegetable crops and tobacco but are not as common in corn.

Deep banding

Some farmers have experimented with banding P and K fertilizers 15–20 cm (6–8 in.) below the row, especially in no-till and strip-till situations where the soil is firm. This may increase the availability of fertilizers under dry conditions and protect them from immobilization reactions. Limited Ontario trials, however, have not shown a yield response to deep banding. It may be useful in some situations.

Foliar

Foliar fertilizer can be an excellent supplement to soil-applied nutrients. It can correct deficiencies quickly and is not susceptible to tie-up in the soil. There is a chance the nutrient will be washed off or the carrier will dry up before the nutrient is absorbed. The use of a spreader-sticker may increase absorption of the fertilizer through the cuticle.

Limited quantities can be applied to the leaf before the tissue is damaged. Therefore, deficiencies of micronutrients, where plants only require a few grams per hectare, are corrected more easily than those of macronutrients. Foliar application of manganese, for example, is the most effective way to correct manganese deficiencies.

Be sure to check pesticide labels before mixing foliar nutrients with any pesticide spray. In particular, manganese and glyphosate are known to antagonize each other's effectiveness.

Foliar application of urea has been successful in many crops. Urea-N can be applied to leaves at much higher concentrations than P or K. The grade chosen should be for feed or foliar uses, since it is lower in biuret, a by-product that can harm plant tissue. There is little research that supports maximum safe rates, but results from some experiments suggest that a single foliar urea application should not exceed 22 kg/ha (20 lb/acre) of N, and the concentration in the spray should be less than 2%.

Even though urea is the nutrient most rapidly absorbed by leaves, it often takes many applications to get enough N into the plant to make a difference. For this reason, foliar application of macronutrients tends to be economical more often in high-value horticultural crops than in common field crops.

Transplant starters

Starter solutions are water-soluble or liquid fertilizers that provide a source of fertilizer surrounding the root ball. These solutions always include P, which is important for root development, and may also include N and K.

Transplanted stock will benefit from readily available nutrients to encourage new root growth and overcome transplanting shock. Transplants receive starter fertilizer via the transplant water or are fed a starter before going to the field.

In using starter fertilizer at transplanting, the objective is to gain the benefits of early growth but avoid plant injury. Fortunately, the primary nutrient of interest in a starter — phosphorus — is fairly safe. Nitrogen and potassium salts can pose more of a risk. Including micronutrients in a starter solution increases the potential toxicity to the transplants. Different brands or batches of starter with the same fertilizer analysis can vary in salt levels, depending on the ingredients used to formulate them.

Be aware that the salt level of the transplant solution can vary through the day, as the tanks are refilled. Fertilizer concentration can also pulse up and down when using a metering system.

Salt levels (electrical conductivity or EC) are often expressed based on a certain fertilizer concentration, such as 1.5 L in 100 L of water. Table 8–4, below, shows a comparison of several starter fertilizers that were tested by former OMAFRA Vegetable Specialist, Janice LeBoeuf.

Table 8–4. Comparison of the electrical conductivity (EC) of 1.5% and 2.5% starter solutions and nutrient content of the fertilizer concentrate

Fertilizer[1]	EC (mS/cm) 1.5%	EC (mS/cm) 2.5%	g/L or g/kg of fertilizer concentrate			
			N	P_2O_5	K_2O	N + K_2O
3-18-18	7.31	12.01	41	244	244	285
9-18-9	7.42	11.86	117	234	117	234
6-24-6	7.84	13.32	82	328	82	164
6-24-6	8.34	13.12	82	328	82	164
10-31-4 IBA & PHCA	10.12	16.16	131	407	52	184
10-34-0	10.22	15.16	131	446	0	131
10-50-10 (dry soluble)	10.80	16.81	100	500	100	200
Water	0.00	0.00	0	0	0	0

[1] EC for a sample of a particular batch of each formulation. Fertilizer products of the same analysis can vary greatly in salt levels. Always test your own solution with an EC meter.

Look for a starter that will give you an adequate rate of phosphorus at a low EC and an acceptable price (notice how you need twice as much of low-analysis products to deliver phosphorus levels equivalent to a 1.5% solution of 10-34-0). Remember, the presence of some ammonium nitrogen provides a benefit, but potassium and micronutrients are not particularly beneficial in a starter and can increase the risk of damage.

Fertigation

Fertigation is a method of applying water and nutrients through a drip irrigation system. It can be used to increase the yield and quality of many vegetable crops.

A stock solution of soluble (greenhouse grade) fertilizer is dissolved in a tank and introduced through a valve into the irrigation system either by suction or pressure. The fertilizer solution should be fed through the system slowly. After the fertilizer has passed through the system, continue to irrigate to flush the system.

DO NOT mix fertilizers containing calcium, phosphates or sulphates as these can precipitate out and plug emitters.

Broadcast all of the phosphate requirement and approximately 30%–50% of the nitrogen and potash requirement prior to planting. The remainder should be injected through the drip irrigation system. Use soil tests to determine phosphate and potash requirements. Table 8–5 outlines recommended application rates for tomatoes, peppers and vine crops.

Table 8–5. Nitrogen and potash injection schedules

Growth stage	Rate of N and K_2O to inject per week (kg/ha)		
	vine crops[1]	peppers	tomatoes
transplanting to fruit set	5	3–5	2.5
fruit sizing to harvest	10	7–10	5
harvest	5	3–5	2.5

[1] Cucumbers, melons, summer squash

Combining methods

The choice of starter fertilizer will depend on the crop to be grown, the mineral fertilizer requirements and the equipment available. It is often as 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 advantages to splitting the fertilizer application are savings in time and labour and less risk of fertilizer injury to the seedling. The recent interest in strip tillage provides another alternative to fertilizer placement and timing.

Deduct applications of starter fertilizer and side-dressed fertilizer from the total mineral requirement. Any balance remaining should be broadcast. If only tiny numbers remain, you may want to 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 (for P and K only).

Fertilizer worksheet

Once you have established the crop requirements, you need to determine how the required nutrients are to be supplied. Economics and environmental concerns dictate that we make the best possible use of all sources of nutrients. This includes organic forms of nutrients, either already on the farm or imported, as well as mineral fertilizers.

Maximum safe rates of nutrients

Maximum safe rates of any nutrient source should be observed to avoid injury to the crop. The rates listed in Table 8–6 may cause symptoms of injury or retardation of growth in up to 10% of all cases. Use lower rates where possible. Since fertilizer injury can occur when the concentration of fertilizer is too high, uneven application can cause intermittent problems even though the average rate is low enough to be safe.

Dilution has a large influence on what rates are safe. Injury is most common when the weather is dry and in coarse-textured soils with low organic matter.

Narrower rows will increase the safe rate per hectare, because the same amount of fertilizer is spread over a greater length of row.

Proper equipment maintenance is important to prevent fertilizer injury. If the fertilizer opener moves closer to the seed, fertilizer burn will occur at rates that would have been safe otherwise.

Fertilizer source and placement

Use on-farm nutrient sources first as they will be applied to farm fields anyway, and base application rates on meeting crop N or P requirements.

Many farmers find it beneficial to split nutrient requirements between organic and mineral sources, providing some insurance against variability in manure applications. Off-farm organic nutrient sources such as sewage biosolids and municipal compost can also be considered.

Commercial fertilizers are used to supply the crop requirements not available from other nutrient sources. Apply commercial fertilizers as close as possible to when the crop requires the nutrients and as close as possible to the plant.

Table 8–6. Maximum safe rates of nutrients in fertilizer

LEGEND: NR = not recommended – = no data

		N kg/ha			$N + K_2O + S$ kg/ha		
		Row space:			Row space:		
		75 cm 30 in.	38 cm 15 in.	18 cm 7 in.	75 cm 30 in.	38 cm 15 in.	18 cm 7 in.
Banded 5 cm to the side x 5 cm (2 in. x 2 in.) below seed							
corn[1]	urea	40	–	–	79	–	–
	other fertilizers	52	–	–	117	–	–
soybean[2], pea, dry beans	ammonium sulphate	30	60	–	NR	NR	–
	other fertilizers	NR	NR	–	90	180	–
with the seed[3]							
corn	other fertilizers	NR	NR	–	10	20	–
winter wheat, triticale, barley	other fertilizers	–	–	15	–	–	40
spring oat, barley, wheat	urea	–	NR	10	–	–	30
	other fertilizer — sand	–	NR	35	–	–	55
	other fertilizer — clay	–	–	45	–	–	70
canola	ammonium sulphate — sand	–	–	22	–	–	11
	ammonium sulphate — clay	–	–	22	–	–	33
broadcast, strip till							
corn	urea	200	–	–	250	–	–

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.

Fertilizer recommendations and application rate calculation

Worksheet C is an example of a worksheet used to calculate the rate of fertilizer application. (See Appendix C for a blank version to copy.)

Enter the N, P_2O_5 and K_2O requirements on the top line. Deduct the available nutrients from legumes, manure or other organic sources to determine the amount of mineral fertilizer needed to meet the total requirements.

Either metric or imperial units can be used in this worksheet.

Worksheet C.
Fertilizer application calculations

Crop to be grown:	corn
Previous crop:	barley with red clover
Manure applied (type, amount):	solid dairy manure (10 tons/acre), spring incorporated
Other organic nutrient sources:	none
Starter fertilizer (rate, analysis):	(140 lb/acre) 8-32-16
Supplemental N (rate, analysis):	none

Requirements	**N**	**P_2O_5**	**K_2O**
Requirements — kg/ha (lb/acre)[1]	157 (140)	50 (45)	81 (72)
less legumes	45 (40)	0	0
less manure	34 (30)	34 (30)	157 (140)
less other organic amendment	0	0	0
Total mineral fertilizer requirements	78 (70)	17 (15)	0
less starter fertilizer	12 (11)	49 (44)	25 (22)
less side-dressed fertilizer	0	0	0
Total broadcast fertilizer requirements	66 (59)	0	0

[1] Requirements as total crop need. Check whether recommendations are already adjusted for legumes and manure credits.

In this example, the total broadcast fertilizer required is 59 lb N/acre, or 128 lb/acre of urea. The starter fertilizer application could also have been reduced.

If a more complex blend is required, it could be calculated using the Fertilizer Blend Worksheet, p. 200.

References

Drury, C.F., X. Yang, W.D. Reynolds, W. Calder, T.O. Oloya, and A.L. Woodley. 2017. "Combining urease and nitrification inhibitors with incorporation reduces ammonia and nitrous oxide emissions and increases corn yields." *Journal of Environmental Quality*. 46:939-949.

Garcia, M.C., J.A. Diez, A. Vallejo, L. Garcia and M.C. Cartagena. 1997. "Effect of applying soluble and coated phosphate fertilizers on phosphate availability in calcareous soils and on P absorption by a rye-grass crop." *J. Agric. Food Chem* 45(5) 1931–1936.

Other resources

California Plant Health Association. 2002. *Western Fertilizer Handbook*, 9th ed. Upper Saddle River, N.J.: Prentice Hall.

California Fertilizer Association. 1998. *Western Fertilizer Handbook*, 2nd Horticulture Edition. Upper Saddle River, N.J.: Prentice Hall.

Canadian General Standards Board. Hull, Canada K1A 1G6. www.tpsgc-pwgsc.gc.ca/ongc-cgsb/index-eng.html

Follet, R.H., L.S. Murphy and R.L. Donohue. 1981. *Fertilizers and Soil Amendments*. Englewood Cliffs, N. J.: Prentice-Hall.

Follet, R.H. et al. *Farm Chemicals Handbook*. Willoughby, Ohio: Meister Publishing Company.

Frye, W. 2005. "Nitrification Inhibition for Nitrogen Efficiency and Environment Protection." *IFA International Workshop on Enhanced-Efficiency Fertilizers*, Frankfurt, Germany, 28–30 June 2005.

Hall, William. 2005. "Benefits of enhanced-efficiency fertilizers for the environment." *IFA International Workshop on Enhanced-Efficiency Fertilizers*, Frankfurt, Germany, 28–30 June 2005.

Havlin, J.L, J.D. Beaton, S.L. Tisdale and W.L. Nelson. 2005. *Soil Fertility and Fertilizers: An Introduction to Nutrient Management*. 7th ed. Upper Saddle River, New Jersey 07458: Pearson Education Inc.

Hoeft, Robert G., Emerson D. Nafziger, Richard R. Johnson and Samuel R. Aldrich. 2000. *Modern Corn and Soybean Production*, First Edition. Savoy, IL 61874-0248: MCSP Publications. mcsp-pubs.com

Stratus Ag Research. 2016. *Fertilizer Use Survey: 2016 Crop Year.* http://fieldprint.ca/fertilizer-use-survey/.

UNIDO and IFDC. 1998. *Fertilizer Manual* (3rd edition). 615 pages. ISBN 0-7923-5032-4. Kluwer Academic Publishers. www.unido.org/resources/publications/publications-type/co-published.