BEST MANAGEMENT PRACTICES

Managing Crop Nutrients

Canada

Ontario

OFA Ontario Federation of Agriculture

What is a Best Management Practice or "BMP"?

- a proven, practical and affordable approach to conserving soil, water and other natural resources in rural areas

Who decides what qualifies as a BMP?

- a team that represents many facets of agriculture and rural land ownership in Ontario, including farmers, researchers, natural resource managers, regulatory agency staff, extension staff and agribusiness professionals

What is the BMP Series?

- innovative, award-winning books presenting many options that can be tailored to meet your particular environmental concern and circumstances
- current BMP titles are:
  Buffer Strips
  Establishing Tree Cover
  Farm Forestry and Habitat Management
  Field Crop Production
  Fish and Wildlife Habitat Management
  Greenhouse Gas Reduction in Livestock Production Systems
  Horticultural Crops
  Integrated Pest Management
  Irrigation Management
  Livestock and Poultry Waste Management
  Managing Crop Nutrients
  Manure Management
  No-Till: Making It Work
  Nutrient Management
  Nutrient Management Planning
  Pesticide Storage, Handling and Application
  Soil Management
  Streamside Grazing
  Water Management
  Water Wells
  Woodlot Management

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- to purchase single or multiple copies and to order complete sets of BMP books, please contact: Ontario Federation of Agriculture, Attn: Manager, BMP, Ontario Agricentre, 100 Stone Rd. W., Suite 206, Guelph, Ontario N1G 5L3. Phone: 1-800-668-3276
- for an on-line order form, go to: http://www.omafra.gov.on.ca/english/products/best.html
- please note that prices vary per title and with quantity ordered

METRIC–IMPERIAL CONVERSION FACTORS

UNITS OF MEASURE

While Canada "went metric" over 30 years ago, many commonly used measurements such as land area are still expressed using imperial units. For your convenience, most of the measurements used in this manual are provided in both metric and imperial units. However, where common usage, common sense, space limitations or regulatory concerns dictate, one or the other may appear exclusively.

COMMON CONVERSIONS

1 gallon	=	4.546 litres	1 acre	=	0.405 hectare
1 gallon	=	1.201 US gallons	1 acre	=	43,560 feet^2
1 gallon	=	0.161 feet^3	1 lb/ac	=	1.12 kilogram/hectare
1 US gallon	=	3.785 litres	1 ton/ac	=	2.25 tonnes/hectare
1 US gallon	=	0.833 Imp gallon	1 gal/ac	=	11.2 litre/hectare
1 ton	=	0.907 tonne	1000 gal/ac	=	11200 litre/hectare
1 pound	=	0.454 kilogram	1000 gal/ac	=	11.2 metre^3/hectare
1 tonne	=	2205 pounds	1 metre	=	3.28 feet
1 foot^3	=	6.229 gallons	1 metre	=	39.4 inches

METRIC TO IMPERIAL (APPROXIMATE)

Litres per hectare x 0.09	=	gallons per acre
Litres per hectare x 0.36	=	quarts per acre
Litres per hectare x 0.71	=	pints per acre
Millilitres per hectare x 0.015	=	fluid ounces per acre
Grams per hectare x 0.015	=	ounces per acre
Kilograms per hectare x 0.89	=	pounds per acre
Tonnes per hectare x 0.45	=	tons per acre
Kilograms per 1000 L x 10	=	lbs per 1000 gallons

IMPERIAL TO METRIC (APPROXIMATE)

Gallons per acre x 11.23	=	litres per hectare (L/ha)
Quarts per acre x 2.8	=	litres per hectare (L/ha)
Pints per acre x 1.4	=	litres per hectare (L/ha)
Fluid ounces per acre x 70	=	millilitres per hectare (mL/ha)
Tons per acre x 2.24	=	tonnes per hectare (t/ha)
Pounds per acre x 1.12	=	kilograms per hectare (kg/ha)
Ounces per acre x 70	=	grams per hectare (g/ha)
Pounds per ton x .5	=	kilograms per tonne (kg/t)

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BLENDED LIQUID FERTILIZERS

ANALYSIS	WEIGHT US gal (lb)	WEIGHT Imp. gal (lb)	WEIGHT litre (lb)	WEIGHT litre (kg)	IMP. GAL/ TONNE	US GAL/ TONNE	LITRE/ TONNE
8–25–3	11.11	13.35	2.94	1.33	165.1	198.4	749.9
6–18–6	10.69	12.85	2.83	1.28	171.6	206.2	779.0
3–11–11	10.45	12.55	2.76	1.25	175.7	211.0	798.8
9–9–9	10.49	12.60	2.77	1.26	175.0	210.2	795.9
7–7–7	10.41	12.5	2.75	1.25	176.4	211.8	801.7
6–24–6	11.07	13.30	2.93	1.33	165.8	199.2	752.4
9–18–9	11.07	13.30	2.92	1.32	165.8	199.2	755
5–10–15	10.7	12.85	2.83	1.28	171.6	206.0	799
2–10–15	10.62	12.75	2.81	1.27	172.9	207.6	784.6
10–34–0	11.6	14.0	3.09	1.40	157.0	188.5	715.8

CONVERT TO METRIC

%	►	kg/1000 L	multiply by	10
%	►	kg/tonne	multiply by	10
mg/L	►	%	divide by	10,000

CONVERT TO IMPERIAL

%	►	lbs per 1000 gallons	multiply by	100
%	►	lbs per ton	multiply by	20
ppm	►	%	divide by	10,000

Note: 1 m^3 = 1000 L

INTRODUCTION

All of us need nutrients to live and thrive, and we rely on crops to provide much of our daily quota. Crop production repackages plant nutrients such as nitrogen, phosphorus and potassium into forms that we and other animals can use.

Crops need nutrients too. They grow properly only if they obtain nutrients in the correct amounts, at the appropriate times. Soils can supply many of the nutrients needed by crops, but often require additional nutrients from sources such as commercial fertilizers and manures.

Nutrients, whether in fertilizer or other materials, are both an essential input and a major cost for crop production. In Ontario, commercial fertilizer and lime applied to cropland cost farmers about $483-million annually. The manure from about 2.2-million cattle, 3.6-million hogs, and 47-million chickens and turkeys is also applied to cropland.

Livestock are an important part of the nutrient cycle in Ontario.

Cropland nutrients must be managed wisely to preserve the quality of our soil, air and water.

Many of Ontario's vital natural areas rely on private landowner stewardship, of which nutrient management is but one part.

A small number of farmers apply nutrients in excess of recommended rates. This is not a best management practice if it ignores costs, profits, and the environment. For example, applying more nitrogen than the crop can use will increase the risk of nitrate-nitrogen leaching from the soil, polluting precious groundwater resources. Runoff from snowmelt or heavy rains can carry nutrients such as phosphorus to streams, drains, and rivers. Eroding cropland can pollute surface waters, with sediment and nutrients attached to soil particles.

Nor is it wise to apply too few nutrients. Yield and profits will drop.

By adopting best management practices, you can do your part to reduce environmental risks without sacrificing productivity. This book will help you to understand the:

- importance of nutrients to your crops
- behaviour of nutrients in soil
- sources that add nutrients to soil
- factors that influence the supply of nutrients available to your crops
- effects of poor nutrient management.

This book also describes best management practices for:

- determining the amount of nutrients to apply
- applying nutrients for optimum efficiency.

Growing crops with insufficient nutrients will lower yield, quality, and returns.

Successful crop production depends on good nutrient management. Regular manure applications can help maintain nutrient and organic matter levels.

USING A SYSTEMS APPROACH TO MANAGE CROP NUTRIENTS

A **systems approach** to managing crop nutrients involves taking a step back and thinking about the big picture. How you manage nutrients will depend on many other components of your whole farm operation. Use a systems approach where:

- all components of the system, from barn to application to monitoring, are included in the nutrient management program
- all nutrients are inventoried – organic, inorganic, those that a crop needs, those already in a crop, and those already in the soil

- all nutrients (liquid and solid forms) are managed – according to land base, production goals, proximity to water resources, farmstead layout, equipment, and odour and safety concerns
- site conditions are assessed to determine limitations for facilities, suitable application rates, and proper separation distances from sensitive areas.

Here are some key considerations as you get started:

- baseline fertility levels with regular soil tests
  - knowing soil fertility levels and crop requirements is the best way to determine application rates
- special needs
  - some high-value crops have unique fertility requirements for quality, e.g., boron in rutabagas and potassium in tomatoes
- residual nutrients from previous crops
  - some legume crops can provide nitrogen (N) for crops in subsequent years, so you should account for and estimate the amount of N contributions from these crops
- organic sources
  - it may not be desirable to supply all of a crop's requirements from organic sources (manures, biosolids, legumes, etc.), as some nutrients may be oversupplied
- application timing
  - crops need to access nutrients at specific times for optimum quality and yields
- nutrient use efficiency
  - sustainable practices that waste less, meet crop needs and maintain soil fertility
- production versus profit
  - maximum yield will usually not be your most profitable yield
- other farm management considerations
  - nutrient management is part of a comprehensive crop production system that includes soil and water management, crop rotation, varietal selection, planting techniques, tillage system, and pest and weed management.

Making an inventory of crop nutrients is well worth the effort. Nutrient management affects crop:

- **growth**
- **maturity**
- **reproduction**
- **harvestability**
- **pest tolerance**
- **disease tolerance**
- **winter survival**
- **profitability**
- **standability**
- **quality**
- **yield.**

SAVING ON INPUTS

A deficiency of any given nutrient can limit crop growth and quality. Shown here are soybeans with a potassium deficiency.

A well-planned nutrient management system can save money in many ways. Putting one together will help you:

- save time and money by purchasing and applying only what's needed
- make better use of on-farm nutrient sources
- identify opportunities for using lower-cost alternative sources of nutrients, e.g., manure from a neighbouring farm, sewage biosolids and other non-agricultural source materials, or other forms of commercial fertilizers
- consider more efficient fertilizer application practices
- use rotations, cover crops, residue management, and sound soil management practices to conserve the nutrients in the soil.

Have you heard of Whole Farm Nutrient Accounting?

It seeks to account for all nutrients imported to and exported from a farm. The ultimate goal of the exercise is to have them balance each other.

Farm operations that import more nutrients than they export are at greater risk of nutrients accumulating excessively over the long run. At the other extreme, productivity will decline on operations where nutrients exported in crops or livestock are not replaced.

The greatest benefit of nutrient management planning will be realized by operations with the largest imbalance between nutrient imports and exports.

We'll be referring to other Best Management Practices books, especially *Soil Management*, *Manure Management*, *Water Management*, *Nutrient Management Planning*, *Field Crop Production*, and *Horticultural Crops*. We urge you to read these companion books: they'll help you situate your nutrient program within the big picture of resource management on your farm.

The need for quality as well as yield can increase the fertilizer requirements for some crops, like these whole-pack processing tomatoes, which need large amounts of potassium to ripen evenly.

NUTRIENTS AND THE ENVIRONMENT

Your efforts to manage nutrients should be all about efficiency: ensuring your crops' needs are being met in a timely manner for optimal growth and yields, and minimized input costs. Of course, efficiency is also important for environmental protection.

Agriculture is one of the sources of nitrogen and phosphorus pollution of water in rural areas. Crop nutrients leaving farmland can pollute water. Nitrate-nitrogen can leach into groundwater. Phosphates, bound to soil particles, can run off land to surface waters such as drainage ditches, streams, and rivers. Concentrations of these nutrients in water above tolerable limits can be harmful to humans, livestock, and wildlife.

This chapter sets out the environmental implications of unmanaged nutrients, to give you a general idea of why and where they are of societal concern. We hope this provides a helpful context for the next chapter, which takes a magnifying glass to the basics of nutrient chemistry.

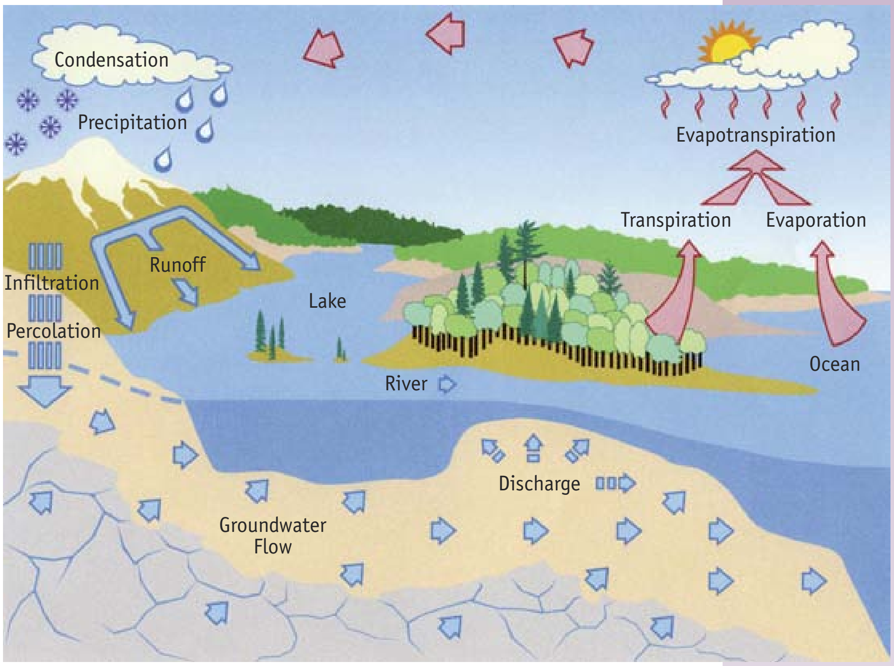
PHOSPHORUS (P) AND WATER QUALITY

In unpolluted fresh waters, aquatic plant growth, including algae, is limited by the low level of phosphorus. When phosphorus is added to water, more algae are able to grow.

In past decades, abundant algal growth has made the water in some lakes and rivers in Ontario unsuitable for drinking or swimming. It has also led to the death of fish and other aquatic animals from lack of oxygen in the water.

During the second half of the last century, phosphorus was a major pollutant in the Great Lakes–St. Lawrence River watershed. Phosphorus pollution came from many sources in urban areas, mainly effluent from sewage treatment plants, storm sewers, and industrial sources. Most of these were point sources (i.e., easy to locate).

Runoff to surface water or percolation into groundwater can carry nutrients if they are not carefully managed.



In rural areas, the sources of pollution have been effluent from sewage treatment plants in small towns, improper septic systems, storm sewers, manure runoff, cropland nutrient runoff, milking centre washwater, and eroded soil. Most of these are non-point sources (i.e., harder to pinpoint).

The risk of contaminating surface water rises when nutrients are managed inappropriately. Soil erosion and nutrient runoff can cause excess algal growth and a decrease in oxygen in surface waters, which degrade water quality for drinking, recreation, and fish habitat.

Due to efforts aimed at reducing phosphorus inputs to surface waters, it's no longer the threat to the Great Lakes that it was 20 years ago. Although portions of Lake Erie still have concentrations higher than desired, some locations are actually experiencing phosphorus concentrations that are lower than optimal for sustainable aquatic ecosystems. This is partly due to the removal of phosphorus from the aquatic system by zebra mussels.

Phosphorus loading to surface water is still an issue in small streams and tributaries, where excess algal growth can impact water quality habitat.

The invasion of exotic species like this zebra mussel has contributed to the reduction of nutrients in the waters of the Great Lakes.

Since 2000, areas in the Great Lakes have been identified as lacking in adequate nutrients such as phosphorus for healthy aquatic habitats.

Rural non-point sources of phosphorus contributed to excess algal and aquatic plant growth in parts of the Great Lakes.

Unchecked cropland runoff can lead to the pollution of surface waters.

Manure runoff can contaminate surface waters and drinking water supplies.

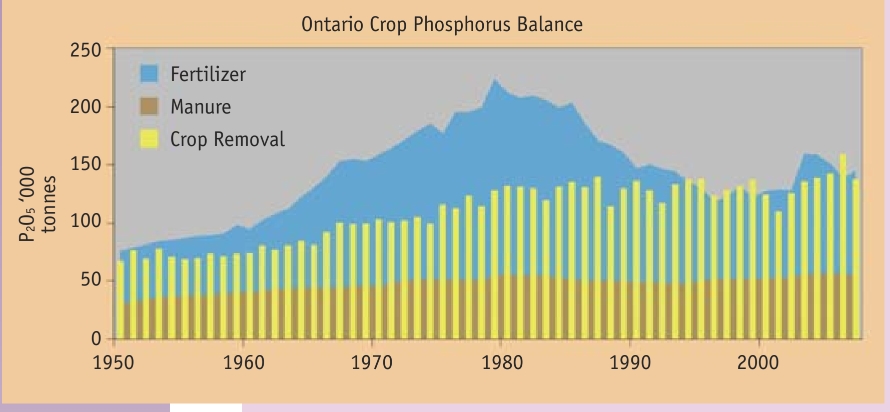
Elevated phosphorus concentration in rural area surface waters has three sources:

- **faulty septic systems near surface water**
- **farmsteads with improperly stored manure and washwaters**
- **eroding cropland with phosphorus attached to soil particles.**

Cropland soil conservation practices (e.g., reduced tillage) and erosion control structures (e.g., grassed waterways) will help to reduce erosion, runoff, and phosphorus loadings from cropland.

Manure storages can be designed to capture all contaminated liquids from livestock facilities and store them to prevent runoff.

Ontario Crop Phosphorus (P) Balance

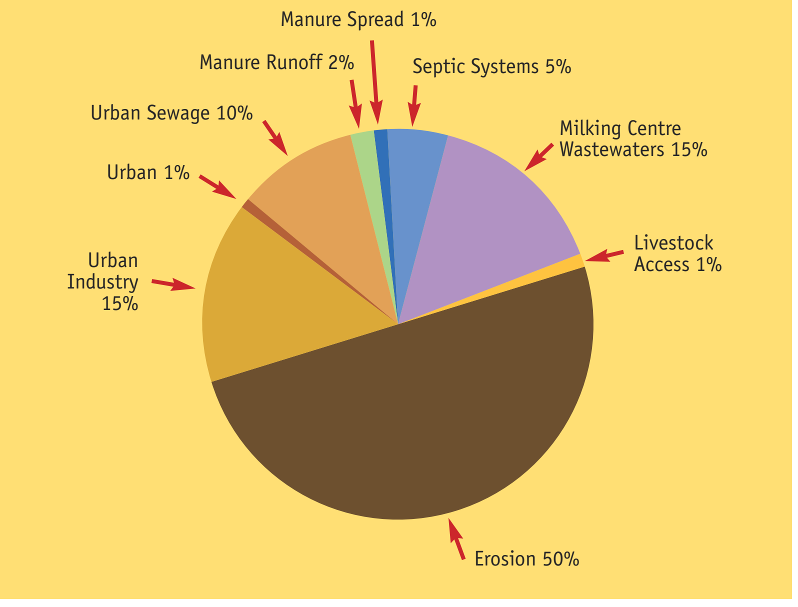


Use of nutrients in crop production has changed over time. These changes have had a profound effect on soil fertility, crop production, management practices and off-farm impacts. The accompanying graph illustrates an estimate of crop phosphorus removal as it relates to total crop inputs for the period 1950–2007. The inputs include commercial fertilizers and recoverable manures from cattle, swine and poultry.

Between 1950 and 1980, applications of P fertilizer increased more than three-fold. In most cases, P applications were increased to build up deficiencies in soil test levels. Some soils, however, were built up more than others. Crops like potatoes and tobacco tend to require high rates of P to boost soil test levels.

Since 1980, P fertilizer use has decreased to levels similar to the 1960s. Where soil P levels have been built up, lower rates of application suffice to provide optimum P nutrition for most crops. Moreover, improved soil and water conservation management has reduced P loss from Ontario cropland. Today, P additions and removals are much closer to balanced than a few decades ago.

Source: International Plant Nutrition Institute



Below are sources for phosphorus loadings to a typical Ontario watershed, from the greatest contributor to the least:

- **cropland runoff**
- **urban industry**
- **milking centre wastewaters**
- **urban sewage**
- **septic systems**
- **manure runoff**
- **applied manure**
- **livestock access.**

Source: Fanshawe Reservoir Clean Up Rural Beaches Study

NITROGEN (N) AND WATER QUALITY

Nitrogen exists in many forms in agricultural soils. Some forms, such as organic nitrogen and ammonium, are tied up in the soil and relatively unavailable to impact water quality. Nitrate (NO_3^-) and ammonia (NH_3) are the two forms considered to have an impact on water quality.

There are three main sources of nitrogen pollution in rural areas:

- septic systems
  - nitrate and ammonium from household and human wastes can contaminate groundwater and surface water
- livestock wastes
  - nitrate and ammonium-nitrogen from improperly handled, stored, or applied manure can run off to surface water or infiltrate soils and leach to groundwater resources
- cropland
  - nitrate and ammonium from commercial fertilizers and manures can run off to surface water through tile drains or leach into groundwater
  - nitrogen released from forage legume residues as they break down can leach into groundwater if fertilizer applications are not reduced to account for this.

The amount of nitrate that can leach into groundwater depends on the:

- amount of water draining through the soil
- amount of nitrate-nitrogen in the soil
- type of soil materials – permeable soils like sands or gravels are more prone to leaching.

Excess nitrate-nitrogen in the soil – from fertilizer, livestock manures, or legume plowdown crops – can make groundwater unsafe to drink.

Nitrogen in the ammonia form is very toxic to fish. Contamination of watercourses with materials containing large amounts of ammonia, such as liquid manure, can kill large numbers of fish.

Nitrate in groundwater is a concern because rural families depend on private wells for their water supply. Consuming water with high nitrate concentrations can cause illness, especially in infants, and reduce livestock performance. The maximum concentration of nitrate-nitrogen allowed under the Ontario Drinking Water Standard is 10 mg/L.

During 1991–1992, the Ontario Farm Groundwater Quality Survey tested 1,292 rural wells. Of these, 13.8% had nitrate-nitrogen concentrations greater than 10 mg/L. Shallow wells were more likely than drilled wells to have higher concentrations.

Young mammals are susceptible to health effects of high-nitrate drinking water.

When manure is applied after the growing season on fields with a high water table, or with bedrock close to the surface, nitrate may leach.

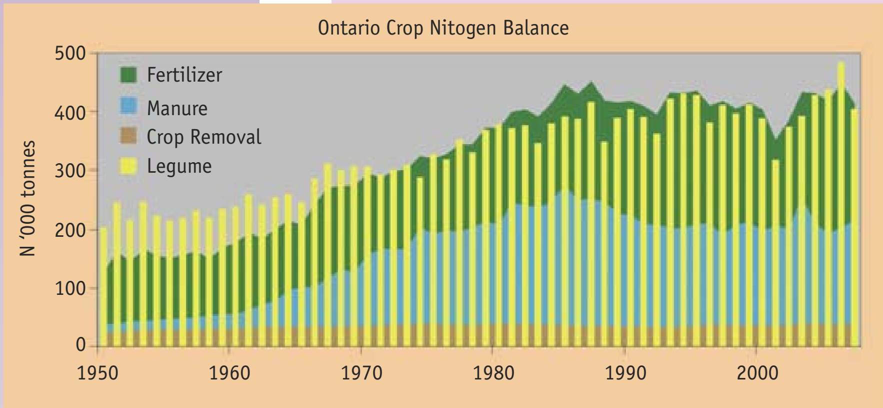
You run the risk of high levels of residual soil nitrogen if, during the growing season, more nitrogen is applied than removed.

Adopting BMPs for application timing and rates will reduce the risk of nitrate loss to shallow aquifers.

Cover crops can be sown following harvest of high N-use crops to "trap" nitrates for release during the next growing season.

Ontario Crop Nitrogen (N) Balance

Like phosphorus, the use of nitrogen in crop production has changed over time. The accompanying graph provides an estimate of Ontario crop nitrogen removal as it relates to total crop inputs for the period 1950–2007. The inputs include N-fixation by legumes, commercial fertilizers, and recoverable manures from cattle, swine and poultry.



Crop removal and legume N-fixation have both nearly doubled since the 1950s, due to improved land management, genetic improvement, and higher yields. Inputs of N from applied manure increased by about 40%.

The real story is with the use of commercial fertilizer N and the interaction with crop removal. Fertilizer N use increased 12-fold from the mid-1950s to its peak in the mid-1980s. Up to 1970, crop removal still exceeded N additions. From then to the early 1990s, the amount of N applied exceeded removal somewhat. But in the past 15 years, what's applied and what's removed is much closer to balancing. That's good news for agriculture and water quality.

Source: International Plant Nutrition Institute

GREENHOUSE GAS EMISSIONS AND CROP NUTRIENTS

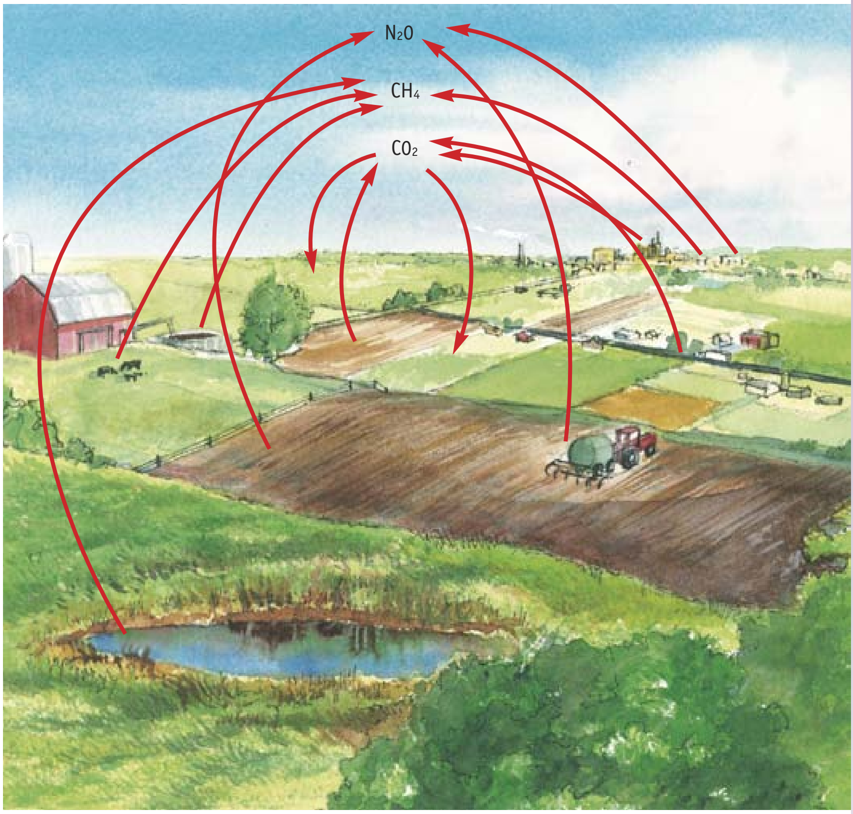
Climate change is linked to the emission of greenhouse gases such as carbon dioxide, methane and nitrous oxides. While some greenhouse gases are naturally occurring, increased levels of emissions are of mounting concern. Global temperatures have risen 0.74 °C over the past century, and this warming is thought to be related to elevated greenhouse gas levels.

The gases at issue are nitrous oxide, methane and carbon dioxide. The global warming potential of each compound, relative to carbon dioxide, follows this relationship:

carbon dioxide (CO_2) = 1
methane (CH_4) = 23
nitrous oxide (N_2O) = 296

In other words, nitrous oxide has 296 times more impact as a greenhouse gas than carbon dioxide.

In North America, agriculture is absorbing nearly as much carbon dioxide as it is emitting, and may even be a net sink for CO_2. Methane is emitted from the digestion of feed by ruminants, from manure storage, and from saturated soils, and accounts for about half the net emissions from agriculture. The other half of the net emissions is nitrous oxide. It is emitted sporadically, from soil and from manure storage.



Denitrification is the conversion of nitrate to nitrogen (N_2) gas. It's a naturally occurring process in saturated soils.

However, when conditions are wet or semi-saturated, the process is somewhat altered (less anaerobic) and nitrous oxide (N_2O) is formed. Nitrous oxide is the key greenhouse gas of concern from agriculture as its effect is 296 times more powerful than that of carbon dioxide.

NITROUS OXIDE FROM STORED MANURE

In Ontario, nitrous oxide (N_2O) appears to be the greenhouse gas component with the greatest opportunity for reductions.

The rate of N_2O production from manure depends on storage system, temperature and manure type. The highest rate of nitrous oxide from manure is emitted from a wet manure stack with a large proportion of bedding piled outdoors in warm weather.

The rate and extent of nitrous oxide emission from soil or stored manure depend on the concentration of oxygen in the soil or in stored manure, the amount of available N, and the amount of carbon.

Solid manures are mostly aerobic. However, anywhere in the pile where the manure materials are saturated, such as the bottom, nitrous oxide may be generated through partial denitrification.

NITROUS OXIDE FROM APPLIED MANURE AND FERTILIZER

When manure N is applied, it has two forms: organic N and inorganic N (NH_4^+).

The organic N fraction is mineralized to form ammonium (NH_4^+), which can be taken up by the plant, but most of it is converted to nitrate by nitrification. Nitrification of either manure or fertilizer ammonium can be one source of N_2O.

Nitrate N (NO_3^-) can be used by a crop or lost from the system by leaching, but some of it is vulnerable to denitrification to N_2O or N_2.

N_2O fluxes can occur anytime the soil has saturated zones. Much of the nitrous oxide from cropland and manure is emitted during thawing conditions of late winter and early spring.

ORGANIC CROP NUTRIENTS AND PATHOGENS

A **pathogen** is any virus, bacterium or protozoa capable of causing infection or disease in animals or humans. Pathogens range from parasites such as roundworms, to bacterium such as *Salmonella* and *E. coli*, to protozoa such as *Cryptosporidium parvum* and *Giardia*. Most livestock viruses are not easily passed to humans.

Manure and other untreated organic nutrients come from biological sources, and as such, contain bacteria, viruses and parasites. The variety and numbers of these micro-organisms contribute to the beneficial role of manure as a soil amendment. However, some are referred to as pathogens because they can infect livestock and humans.

Pathogen Sources

Pathogens in the environment can come from many sources, such as:

- improperly constructed septic systems
- runoff from manure storage or spreading
- grazing animals
- companion animals
- wildlife.

Programs to reduce pathogens in surface water must address all these sources, but cannot be expected to eliminate pathogens entirely. Treating surface water before drinking it is a necessity!

Grazing animals can be a source of pathogens.

PATHOGEN SURVIVAL

Few pathogens survive for long when outside a host. Most last only a few days. But some can last up to several months, depending on a number of environmental conditions. The following can limit pathogen survival:

- ► high temperatures, such as those reached during composting
- ► freezing or freeze/thaw cycle – whereas moderate temperatures can extend the lifespan of pathogens
- ► low humidity, sunshine and dry field conditions
- ► manure decomposition, which produces chemicals that kill some plant pathogens
- ► acidic soils – pathogens survive longer in neutral or alkaline soils
  - ▷ treating materials to raise the pH to high levels will also kill pathogens
- ► absence of oxygen – liquid manure and the wettest part of stored solid manure are considered anaerobic environments (i.e., no oxygen).

Improperly applied manure can be a source of pathogens.

Soil can be effective at trapping bacteria and other organisms, filtering out most protozoa and bacteria. Soils with high organic matter and clay content are more effective at filtering viruses. However, pathogens can bypass soil filters by preferential flow through large macropores (cracks and earthworm burrows) to shallow aquifers or through to tile drainage systems.

Pathogens can move to surface water via surface runoff, or by livestock or wildlife accessing streams and creeks. Groundwater is less likely to be contaminated than surface water. For more information on pathogens and pathogen survival, please see the BMP book, *Manure Management.*

Pathogenic bacteria from organic nutrient sources may infect humans if there's a direct pathway to drinking water supplies or recreational waters. In water wells that have been contaminated through poor construction or management, these bacteria can be controlled with chlorine or UV treatment.

ORGANIC CROP NUTRIENTS AND AIR QUALITY

Organic sources of nutrients can be a source of air pollution and odour. Bedding and dry manure can add dust and other particulate matter to the atmosphere.

PRIMARY MANURE GASES

COMPOUND	DESCRIPTION
CARBON DIOXIDE	• odourless • generated by microbial activity (anaerobic* and aerobic)
METHANE	• odourless • generated by anaerobic activity
AMMONIA	• sharp, pungent, irritating odour • generated by anaerobic and aerobic activity • water-soluble and less dense than air • readily disperses in open environment, resulting in it being more of an odour concern within barns than during land application
HYDROGEN SULPHIDE AND RELATED SULPHUR-CONTAINING COMPOUNDS	• hydrogen sulphide can build up to toxic levels, particularly in confined spaces, causing rapid death to humans or animals • hydrogen sulphide gas possesses a powerful "rotten egg" fragrance produced during anaerobic decomposition of manure • water-soluble and heavier than air • humans can readily detect very low concentrations of such compounds
VOLATILE ORGANIC ACIDS	• wide variety of types and characteristics • mostly produced under anaerobic conditions • important contributors to manure odour
PHENOLICS	• highly odorous compounds • found in raw manure and increase under anaerobic conditions

* "anaerobic" means oxygen-deficient

The amount and type of gases produced depend on the type of manure, and the way it is handled. Aerobic conditions will generate gases such as carbon dioxide and nitrous oxide. Anaerobic conditions (liquid manure, the centre of solid piles) can generate hydrogen sulphide, ammonia and methane.

Some gases are often trapped within the bulk of the manure until the storage is disturbed for spreading. This makes the smell much worse at spreading time.

Manure odour is strongest during application. For the most part, odour-causing gases are trapped in stored manure.

Researchers have identified over 160 gaseous compounds that originate from manure.

ENERGY USE

Much of the cost of supplying nutrients stems from the energy required to manufacture, refine, transport, or apply them. Efficient use of nutrients helps reduce both the cost of crop production and the consumption of non-renewable resources.

Ensuring you're applying nutrients only when you need them will help reduce costs and energy consumption.

UNDERSTANDING THE BASICS

Mineral fertilizers are a concentrated source of nitrogen, phosphorus and potassium. The amount of each is listed on the label.

As a grower, you want to choose the nutrient sources and application strategies that will meet the nutrient demands of your crops without wasting resources. Knowing what nutrients are needed by which crops, and understanding how those nutrients move through soil, water and the atmosphere, will help you get it right.

This chapter will help you learn more about:

- the nature of nutrients
- how crop nutrients move through nutrient cycles
- nutrients required by crops
- alkaline and acidic soils
- why crops may not be able to use all the nutrients you apply
- what happens to the fertilizer and other nutrients you apply
- how to diagnose deficiency symptoms.

WHAT ARE NUTRIENTS?

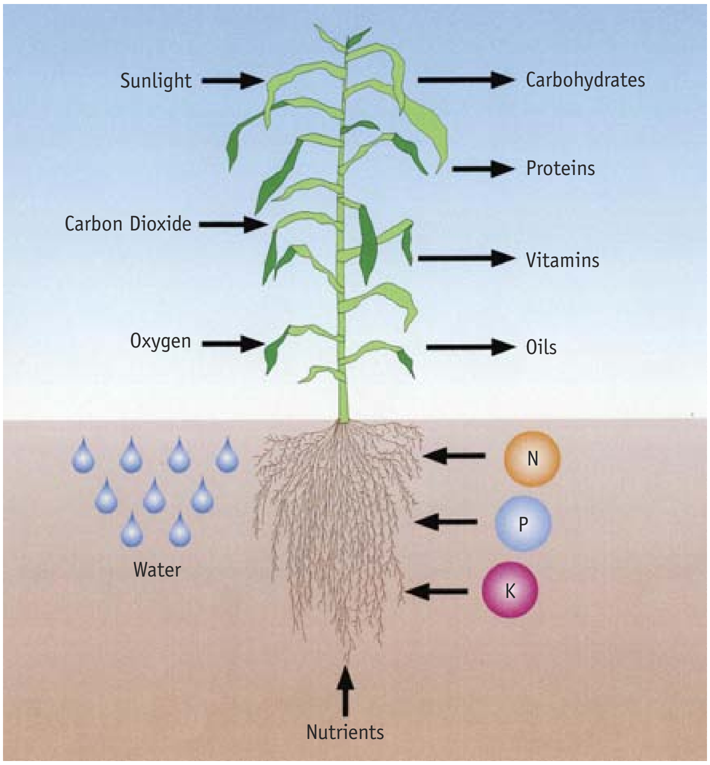
Plant nutrients are chemical elements, or simple compounds formed from them, needed by plants for proper growth and development. The most common elements in plants are carbon, hydrogen, and oxygen, which are obtained from air and water. All other nutrients are obtained from soil.

Six nutrients are required by crops in relatively large amounts. These are often referred to as **macronutrients**. The other nutrients are required in quite small amounts – often less than one kilogram per hectare per year. These are called **micronutrients**.

Mineral fertilizers are a concentrated source of nitrogen, phosphorus and potassium. The amount of each is listed on the label.

Nutrients exist in either **organic** or **inorganic** (mineral) form. Organic compounds are produced by living organisms and contain carbon. Inorganic compounds are derived from the breakdown of organic compounds or from chemical reactions. For example, protein is an organic form of nitrogen; ammonium and nitrate are inorganic or mineral forms.

Nutrients are naturally present in soil in inorganic forms, as the result of the weathering of soil minerals. Inorganic nutrients taken up by living organisms may be converted to organic forms that make up the tissue of plants, animals, and micro-organisms. Organic forms of nutrients in living organisms return to inorganic forms when these organisms die and decompose.



Green plants convert light, water air and plant nutrients into forms that people and animals can use. Without this process, the nutrients would be inaccessible.

ESSENTIAL NUTRIENTS FROM SOIL	
MACRONUTRIENT	**SYMBOL**
Calcium	Ca
Magnesium	Mg
Nitrogen	N
Phosphorus	P
Potassium	K
Sulphur	S
MICRONUTRIENT	**SYMBOL**
Boron	B
Chlorine	Cl
Copper	Cu
Iron	Fe
Manganese	Mn
Molybdenum	Mo
Nickel	Ni
Zinc	Zn

Nutrient and Soil Management: Plants Need Both!

Nutrients are essential for plant growth and reproduction, but they are only one of the essential inputs needed by crops.

Your soil's ability to support plants and to supply water, oxygen, and warmth to plants is also important. A lack of any one of these directly affects plant growth, and can impair your crop's ability to use nutrients present in the soil. Take another look at your present soil management program: if it considers only the amount of nutrients available to crops, it's probably unsatisfactory.

For available nutrients to be used efficiently, soil must have good structure, proper drainage, and good moisture-holding capacity. See Best Management Practices books, *Soil Management*, *Field Crop Production*, and *Horticultural Crops*, for more information.

Crops cannot obtain sufficient nutrients from soil that is in poor physical condition.

Crops also take up nutrients they don't need, but animals do, such as:

Cobalt	**Co**
Iodine	**I**
Chromium	**Cr**
Sodium	**Na**
Selenium	**Se**

THE NUTRIENT CYCLE

Soil organisms can temporarily tie up available nitrogen in the soil, leaving crops at a loss.

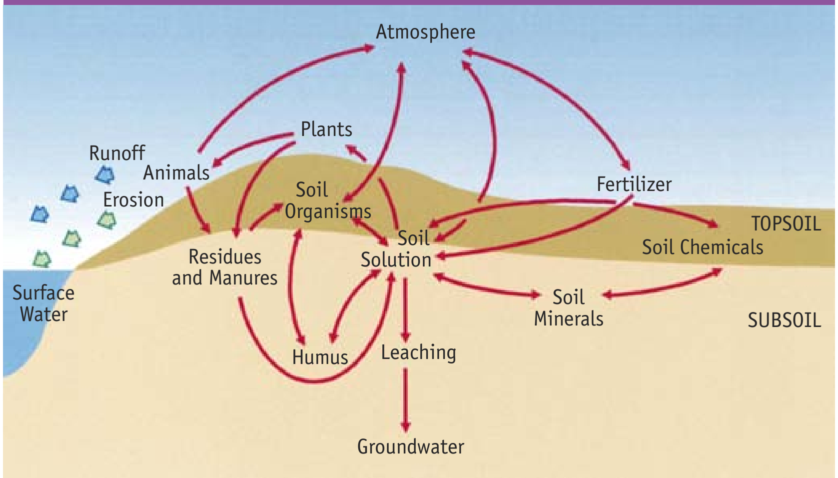
Nutrients are constantly cycling through different forms in the soil. As they react, nutrients are used by plants, lost from the soil, or converted to unavailable forms.

A basic understanding of the nutrient cycle is a cornerstone of a sound nutrient management program. It will involve learning the various forms in which nutrients exist, what influences the availability of specific nutrients, and how they're lost from the cycle.

Nutrients exist in soil in many forms, of which only a few are useful to plants. Regardless of whether you apply nutrients to soil in organic form (e.g., manures) or in inorganic form (e.g., commercial fertilizers), they must be in an inorganic form to be taken up by plants.

In soil that isn't frozen, chemical and biological activity is continually changing nutrients from one form to another, although a rough balance exists among them. Look at the nutrient cycle illustration for a general idea of the cycle through which nutrients flow.

NUTRIENT CYCLE



Bacteria in nodules on the roots of legume plants supply the plants with nitrogen.

SOIL COMPONENTS

Soil Solution

The mixture of soil moisture and the materials dissolved in it is called the **soil solution**. Only a small proportion of the total nutrients in soil are in solution. Most of the nutrients are either attached to soil particles or part of the organic matter.

The soil solution is the key component of the cycle for all nutrients, because they must be dissolved in water before they can be taken up by plants.

Soil Organic Matter and Organisms

Healthy soil is filled with many living organisms, ranging from bacteria to earthworms. These organisms are essential to the nutrient cycle because they break down organic matter, releasing its nutrient content. (See the Best Management Practices book, *Soil Management*, for much more information on this subject.)

At times, soil organisms can compete with plants for nutrients. Under some conditions, soil micro-organisms that break down residues low in nitrogen can temporarily consume much of the available nitrogen in soil, preventing its immediate use by plants. This nitrogen is, however, released again as the micro-organisms themselves die and decompose. The temporary tie-up of nitrogen can affect crop yields if it occurs at a time of high crop demand.

The bacteria associated with legume crops fix nitrogen from the air. The residues of alfalfa and clovers, in particular, can add large amounts of nitrogen to the soil. When such residues break down quickly, a large flush of nitrate-nitrogen can be released into the soil. If nitrate-nitrogen is not used by plants, much of it can be leached into groundwater.

CATION EXCHANGE

Fertile soils have the ability to provide nutrients when crops require them. In most cases, fertile soils have a relatively high clay plus organic matter content in the topsoil (e.g., clay loams). Clay and humus are able to hold more nutrients than other soil particles.

Because clay and humus particles are negatively charged, nutrients that are positively charged, called **cations**, are drawn to their surface. Nutrients held in this way resist leaching, but can be removed by plant roots.

They can also exchange places with other cations from the soil solution. This replacement of one cation by another is called **cation exchange**. The soil's ability to hold onto and exchange certain nutrients for plant growth is known as the **cation exchange capacity (CEC)**.

Exchangeable nutrients are readily available to plants and represent an important reserve, especially for calcium, potassium, and magnesium. A small amount of nitrogen in the ammonium form is also held by cation exchange.

Cation exchange capacity is the soil's ability to hold and exchange particular nutrients for plant growth.

Cations often "compete" for space on soil exchange surfaces.

WEATHERING, MINERALS AND CHEMICAL COMPOUNDS

The natural fertility of the soil on your farm was determined by two key factors:

- ► the type of rock from which the soil was derived
- ► the conditions under which the soil was formed.

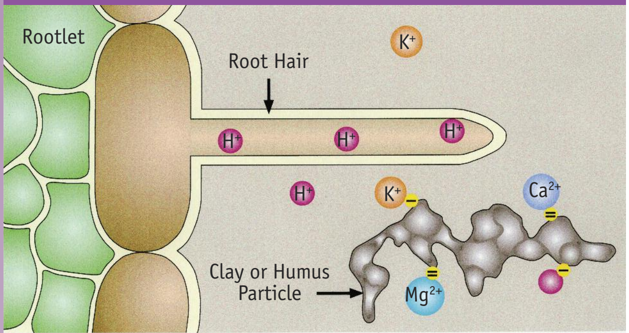
As a result, different soil types vary greatly in fertility and related properties.

Originally, most of the nutrients in soil (except nitrogen) were part of the chemical structure of rock. Over many thousands of years, various natural forces, together known as **weathering**, have broken down the rock and its minerals, releasing some of their nutrient content in forms that plants can use. Slowly, weathering continues to release small amounts of nutrients from these sources.

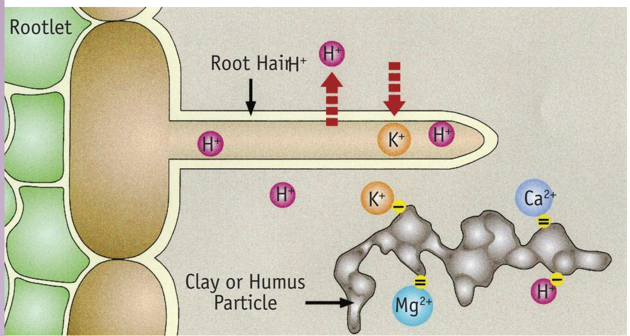
Many of the chemical reactions that occur in soils remove nutrients from soil solution. Some of these reactions produce compounds that are insoluble in water and thus unavailable to plants. Nutrients in these compounds remain unavailable until other reactions break the components down.

The pH of your soil influences which chemical reactions occur, and therefore which compounds are produced. The pH also affects the solubility of the compounds. Thus, the availability of most nutrients changes if the soil pH is changed.

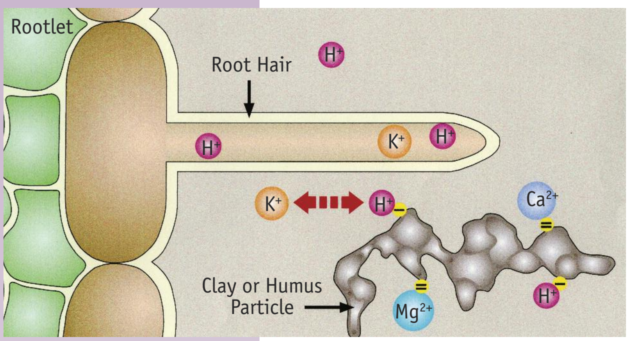
CATION EXCHANGE AND NUTRIENT UPTAKE



Nutrient cations are in the soil solution and attached to soil particles.



When a root absorbs a nutrient cation from the soil solution, it releases a hydrogen ion.

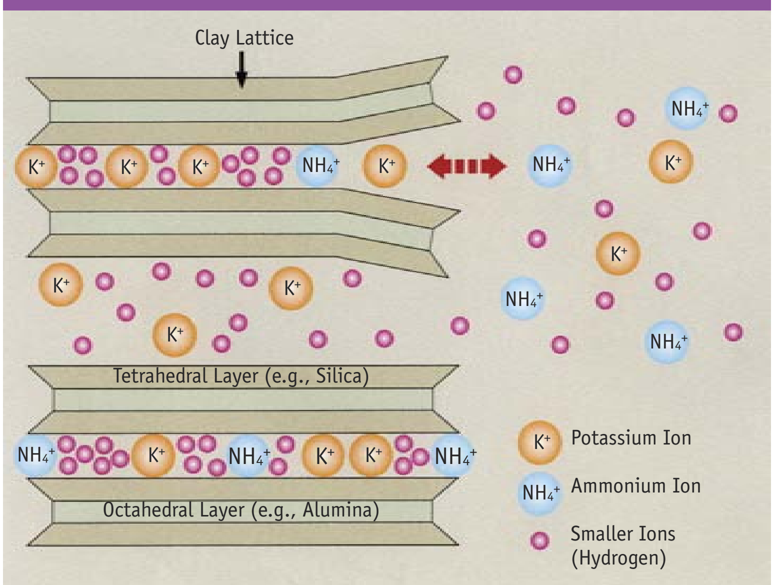


The hydrogen ion is then exchanged with the nutrient cation (K^+) from the soil particle.

H^+	**hydrogen ion**
K^+	**potassium ion**
Ca^{2+}	**calcium ion**
Mg^{2+}	**magnesium ion**
$^-/^=$	**negative charges on clay or humus particle**

Fixation of potassium or ammonium-nitrogen by clay particles can be a problem in regions with high clay contents, such as the Ottawa Valley.

FIXATION OF AMMONIUM AND POTASSIUM BY CLAY



THE ROLE OF SUBSOIL AND SOIL PARENT MATERIALS

Generally speaking, subsoil is much lower in fertility and contributes a much smaller proportion of the nutrients taken up by plants than does topsoil. Several factors contribute to this:

- most of the plant root system is in the topsoil
- nutrients have not been added to the subsoil
- the availability of many nutrients is reduced in alkaline parent materials as found in most of southern Ontario
- there is less organic matter in subsoil
- fewer nutrients have been released in subsoil because subsoil is less subject to weathering than topsoil.

Nevertheless, subsoils can be an important source of nutrients, especially during dry weather. When plants obtain most of their water from subsoil, they must also obtain nutrients there. Nutrients taken from the subsoil by deep-rooted plants are added to the topsoil when the residues from those plants decay.

Deep-rooted crops move some nutrients such as potassium to the topsoil.

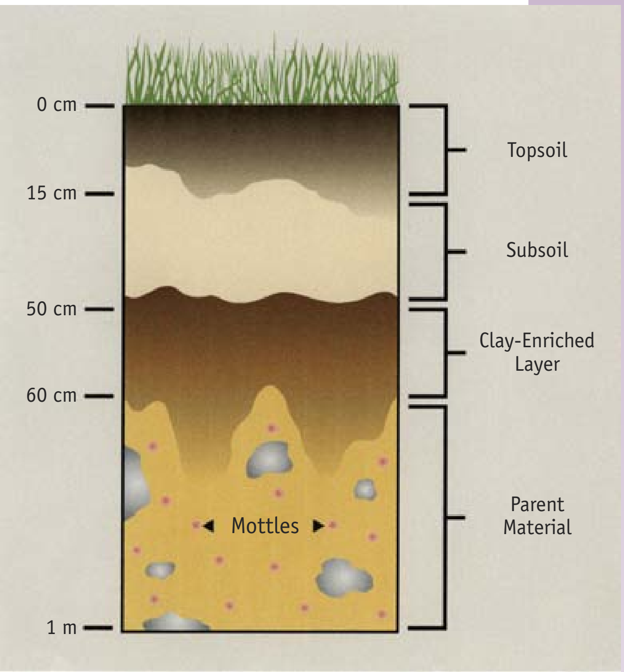
ADDITIONS TO SOIL

Residues, Manures, and Other Organic Materials

Many of the nutrients taken up by plants are returned to the soil in their residues. Livestock manures return most of the nutrients contained in feeds. These and other organic materials, like sewage or paper biosolids, composts and other organic wastes, are important reserves of nutrients.

Nutrients in organic form are held in the soil and are gradually released in available forms as the organic matter decomposes. Some of the nutrients in organic materials are immediately available; more become available over time. Manure, for example, can continue to release nutrients for several years.

The availability of crop nutrients from organic sources is related to the ratio of carbon to nitrogen. The closer this ratio is to soil (12:1), the sooner and more likely organic forms of nitrogen will become available as crop nutrients following application.



Subsoils are less fertile than topsoil.

Organic matter that has rotted and become stable is known as **humus**. Humus forms an important part of a soil's ability to hold nutrients.

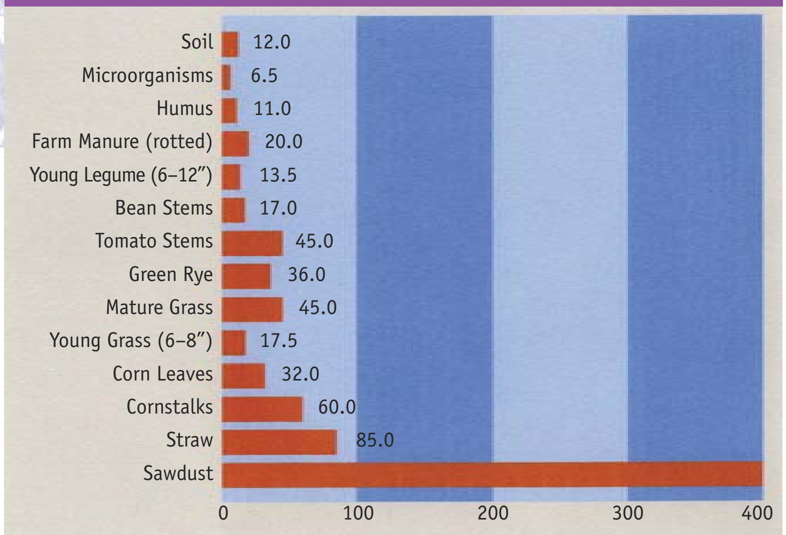
Soil Organic Matter: Finding the Right Balance

Soil organic matter plays crucial roles in maintaining soil structure and increasing the soil's capacity to hold onto water and nutrients. Building up organic matter levels will help you do both. However, the release of nitrogen and other nutrients that are sequestered in organic forms depends on the breakdown of organic matter.

The trick is finding the right balance between the stable organic compounds that stay in the soil for the long term, and the active fraction of organic matter involved in nutrient cycling.

Organic material with a chemical composition that's high in carbon relative to nitrogen content (i.e., a C:N ratio greater than 30:1) can tie up (immobilize) the available N in the soil, temporarily limiting its availability for crop growth. Over time, soil microbes use up the carbon and reduce the material's C:N ratio, eventually making its N available to crops.

CARBON-TO-NITROGEN RATIOS OF COMMON MATERIALS



Returning organic matter to the soil helps complete the nutrient cycle.

Fertilizers

Nutrients in most commercial fertilizers are in a soluble form. They enter the soil solution directly and become available to plants almost immediately. In the year of application, however, plants capture only a portion of the nutrients applied.

Because the addition of nutrients to the soil solution shifts the balance in the nutrient cycle, some nutrients are converted to less-available forms until the balance is re-established.

Of the nutrients applied in fertilizers, crops in the year of application typically take up:

- 50–70% of nitrogen
- 10–30% of phosphorus
- 20–60% of potassium.

Rain and snow add both nitrogen and sulphur compounds to the soil.

The proportion of nutrients taken up from organic materials in the year of application is even lower.

Some of the unused nutrients will become available in succeeding years and will be reflected in your soil test.

Regular application of phosphorus or potassium at rates above crop removal often causes the levels of these nutrients in the soil to increase. This eventually reduces the need for these nutrients to be applied.

Much of the nitrogen released during manure decomposition will be tied up and later released by soil microbes – and not always when the crop requires it. The challenge is to account for this effect when determining nutrient application rates.

Atmosphere

Dust, smoke particles, and other air pollutants fall with the rain and snow, adding trace amounts of most nutrients to the soil. Acid rain and snow also contain significant amounts of nitrogen and sulphur.

In southern Ontario, rainfall adds about 18 kilograms per hectare (16 lb/ac) of nitrogen to the soil, annually. The amount of sulphur received in precipitation each year ranges 8–13 kg/ha (7–12 lb/ac), with a similar amount received by dry deposition (dust and fine particles).

Waterlogged soils lead to the loss of nitrate as nitrogen gas to the atmosphere.

Atmospheric ammonia can be added to the soil after interacting with water vapour and acidic compounds to form ammonium. Ammonia and sulphuric acid can form fine particulate aerosols – better known as smog – in the atmosphere.

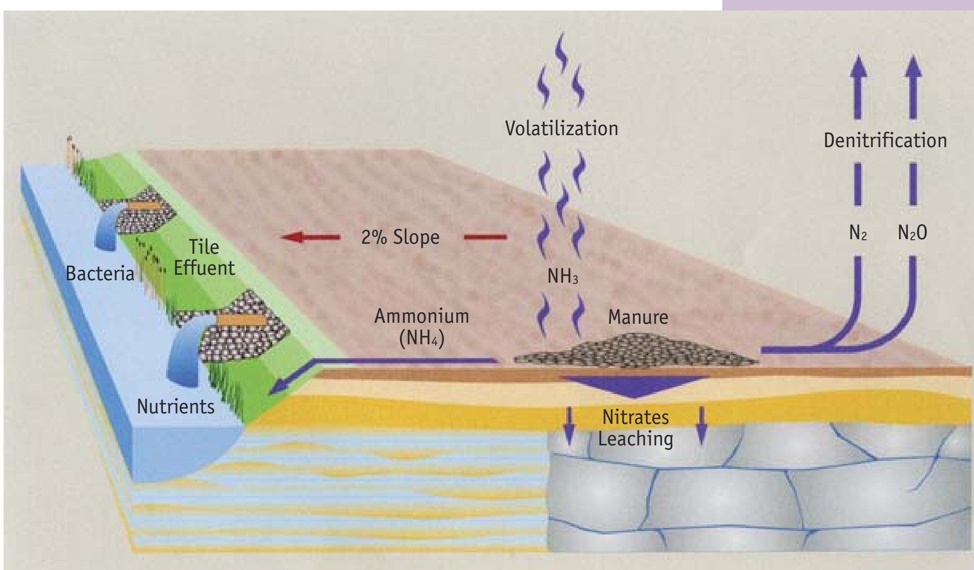
Losses from Soil

Nutrients in harvested crops are used by livestock and people. If their wastes are returned to cropland, the cycle is completed with relatively little loss – with the exception of nitrogen.

Proper nutrient management minimizes the losses of nutrients from organic sources to the air, surface water and groundwater.

Nutrients are lost from this cycle when they are released into the atmosphere, surface water, or groundwater.

Wind erosion is one way that nutrients become "lost" from the nutrient cycle.



SUMMARY OF NUTRIENT LOSSES FROM THE NUTRIENT CYCLE	
PROCESS	**DETAILS**
VOLATILIZATION	• defined as the loss of free ammonia (NH_3) to the atmosphere • manure-based ammonium (NH_4^+) will readily convert to ammonia • manure with higher levels of NH_4^+ will more readily produce NH_3 • rate of loss depends on temperature, humidity, wind speed, soil moisture, pH, vegetative cover, rainfall and infiltration – loss is greatest in warm, sunny, dry weather • loss increases with surface exposure – incorporation reduces loss
DENITRIFICATION	• in saturated soils, nitrates will be converted by microbes to nitrogen gas (N_2) • in semi-saturated soils and storages, nitrates will be converted by microbes to nitrous oxide (N_2O) • nitrogen (organic and ammonium) that converts to nitrate (nitrification) is also subject to denitrification
RUNOFF AND EROSION	• surface-applied manure is at risk of runoff • manure-based P and N nutrients will be transported with eroding materials and runoff • rates of runoff and erosion increase with slope, low infiltration rates, compacted or frozen soils, low vegetative or crop cover, intense rainfall or snowmelt
LEACHING	• involves the movement of soil solutions and their solutes out of the soil profile/rooting zone • for this to happen, there must be a high concentration of nitrates (and/or bacteria) in the rooting zone and a net movement of water through the soil profile • sandy and gravelly soils with high water tables are at greatest risk • prime sources of nitrate are: ○ improperly stored manure (e.g., uncovered solid or composted manure on bare soil) ○ nitrate fertilizers ○ mineralized legumes and applied manure
TILE EFFLUENT	• is the mass flow to tile of land-applied liquids through cracks and continuous macropores • nutrients (N, P and K) and pathogens can end up in surface waters • this is more of an issue with soils that have not been tilled prior to land application
IMMOBILIZATION	• nutrients are tied up by soil microbes in soil • soil microbial populations are large and diverse enough to remove available nitrogen from soil solutions before plants can use them • depends on the ratio of carbon to nitrogen (C:N) in crop residues or organic materials added to the soil ○ if high carbon/low nitrogen material such as straw or sawdust bedding is added to soil, the microbes will tie up available nitrogen ○ in time the microbes will run out of food, die, and release the nitrogen following mineralization
FIXATION	• phosphate is very reactive in soil: combines with calcium, magnesium, iron, manganese or aluminum, and becomes attached to the soil particles • a small amount remains in solution at any given time • much of the phosphate remains in a reserve form and is released into solution to replenish what's been removed by plants

NUTRIENTS IN SOILS AND PLANTS

In this section, you'll learn about the type, function, and deficiency symptoms of the macronutrients and micronutrients essential for crop growth.

This should help you diagnose and predict crop problems as they relate to nutrient deficiency.

THE MACRONUTRIENTS

Nitrogen (N)

Regardless of how nitrogen is applied to the soil, much of it will eventually be converted to the nitrate (NO_3^-) form. Plants take up most of their nitrogen as nitrate, in part because it's the most common inorganic form in soil.

Nitrate-nitrogen is very soluble in water and moves with soil moisture. This allows roots to obtain the nitrogen from almost any part of the soil from which they draw water. However, because of its solubility, nitrate-nitrogen also leaches very easily.

The level of nitrate-nitrogen in the soil can change quickly. In warm weather, large amounts can be released by the breakdown of organic matter. In wet weather, nitrate can be lost from well-drained soils through leaching. From saturated soils, it can also be lost due to conversion into nitrogen gas (N_2) by soil bacteria through denitrification.

In soil, the nitrogen in urea is converted to ammonium. However, in warm and moist conditions, much of the nitrogen from surface-applied urea can be converted to ammonia (gas) and lost to the atmosphere.

ELECTRICAL CHARGE

COMPOUND	SYMBOL	ELECTRICAL CHARGE
Nitrate	NO_3^-	Negative
Ammonium	NH_4^+	Positive
Ammonia (gas)	NH_3	Neutral

APPROXIMATE AMOUNT OF NUTRIENTS CONTAINED IN CROPS

CROP	YIELD PER ACRE	N lb/ac	P_2O_5 lb/ac	K_2O lb/ac	Ca lb/ac	Mg lb/ac	S lb/ac	Cu lb/ac	Mn lb/ac	Zn lb/ac
Alfalfa, hay	5 tons	364	65	300	135	25	25	0.07	0.55	0.53
Red clover, hay	2.5 tons	160	44	150	70	17	7	0.04	0.54	0.36
Timothy, hay	2.5 tons	90	30	90	20	6	5	0.03	0.31	0.20
Barley, grain	60 bu	60	24	18	1.5	3	4.5	0.04	0.04	0.09
Barley straw	1.5 tons	20	16	55	12	3	6	0.02	0.48	0.07
Corn, grain	150 bu	125	63	44	2	8	10	0.06	0.09	0.15
Corn, stover	4.5 tons	100	40	145	25	20	15	0.05	1.50	0.30
Oats, grain	80 bu	33	11	10	2	3	5	0.03	0.12	0.05
Oats, straw	2 tons	11	7	47	8	8	9	0.03	n.a.	0.30
Rye, grain	45 bu	29	12	9	3	4	10	0.03	0.33	0.04
Rye, straw	2 tons	12	5	32	10	3	4	0.01	0.18	0.09
Wheat, grain	80 bu	48	23	14	2	12	6	0.06	0.18	0.28
Wheat, straw	3 tons	30	5	51	12	6	10	0.02	0.32	0.10
Soybeans, grain	40 bu	78	17	28	7	7	4	0.04	0.05	0.04
Apples	500 bu	30	10	45	8	5	10	0.03	0.03	0.03
Beans, dry	30 bu	75	25	25	2	2	5	0.02	0.03	0.06
Cabbage	20 tons	80	37	130	20	8	44	0.04	0.10	0.08
Onions	7.5 tons	38	17	40	11	2	18	0.03	0.08	0.31
Peaches	600 bu	35	20	65	4	8	6	n.a.	n.a.	0.01
Potatoes	400 bu	80	30	150	3	6	6	0.04	0.09	0.05
Spinach	5 tons	36	15	30	12	5	4	0.02	0.10	0.10
Sweet potatoes	300 bu	45	8	75	4	9	6	0.03	0.06	0.03
Tomatoes	20 tons	80	28	160	7	11	14	0.07	0.13	0.16
Turnips	10 tons	45	23	90	12	6	n.a.	n.a.	n.a.	n.a.
Peanuts	1.25 tons	90	10	15	1	3	6	0.02	0.01	n.a.
Tobacco leaves	1 ton	56	6	120	75	18	14	0.03	0.55	0.07
Tobacco stalks	35	15	50							

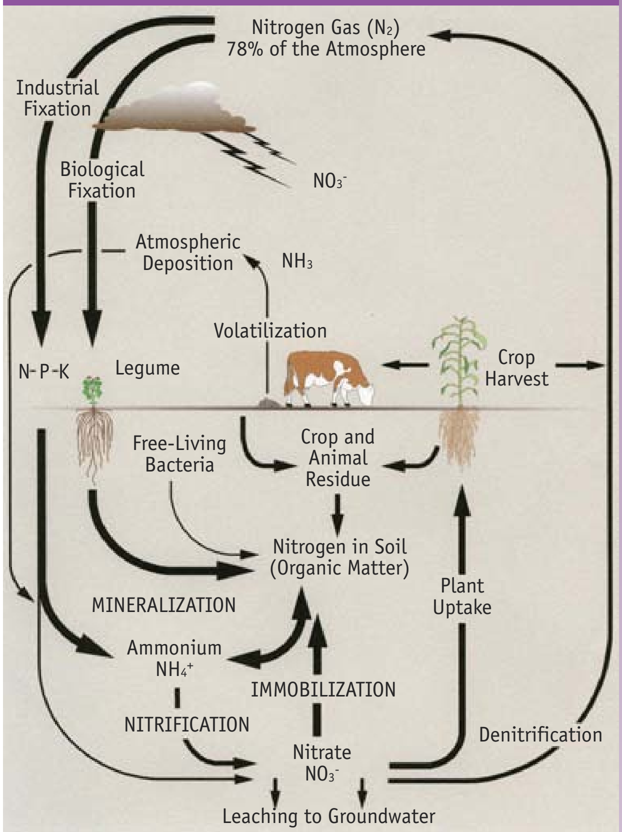
Phosphorus (P)

Phosphates are very reactive in soil, combining with calcium, magnesium, iron, or aluminum and attaching to the soil particles. Only a small amount remains in solution. Phosphates are removed from the solution quickly. But much of the phosphate remains in a reserve form and is released into solution to replenish what's been removed by plants.

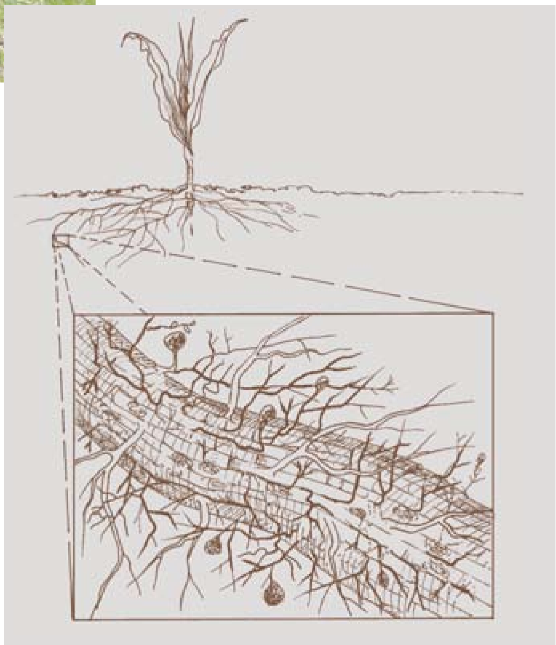
Phosphates move very little within the soil and are unlikely to leach. Phosphorus is lost from soil mainly through soil erosion. Since it doesn't move with soil moisture, it's absorbed only when roots grow to it.

Because low temperatures slow root growth and nutrient absorption, plants are often unable to obtain sufficient phosphorus during cold weather, especially when they are small.

THE NITROGEN CYCLE



In warm, moist conditions, up to half of the nitrogen content of urea left on the soil surface or on crop residues can be lost to the air as ammonia.



VAM, or vascular arbusclar mycorrhizzae, are symbiotic fungi that help crops with nutrient uptake, especially phosphorus.

The total phosphorus in the top 15 centimetres (6 in.) of soil is equivalent to 3000–5000 kilograms per hectare (2700–4500 lb/ac) of P_2O_5. However, less than 1% of the total P is available to crops.

Potassium (K)

Potassium moves in the soil more than phosphorus, but much less than nitrogen. The potassium ion is highly soluble in water and can leach in very sandy (or low CEC) soils.

The minerals that make up clay particles tend to be high in potassium. Many clay and clay loam soils contain an abundance of potassium. Sandy soils commonly are low in potassium.

Calcium and Magnesium (Ca and Mg)

Most of the soils in southern Ontario developed from parent materials that contain a lot of limestone that was ground up and deposited by glaciers during the last Ice Age. In areas west of the Niagara Escarpment and in parts of the Ottawa Valley, dolomitic limestone was predominant and the soils contain significant amounts of calcium and magnesium.

Soils in the clay belts of northern Ontario tend to contain abundant calcium and magnesium.

Soils formed from calcitic limestone tend to be low in magnesium.

Sulphur (S)

The chemistry and fate of sulphur is similar to nitrogen in soil. Sulphur is absorbed by plants as sulphate (SO_4^{2-}) and is prone to leaching. Originally, the soils in Ontario were low in sulphur and required fertilization with it. This is still the case in northwestern Ontario.

Northwestern Ontario aside, sufficient sulphur falls in acid rain and snow to eliminate any need of sulphur fertilization for most crops in the province.

These tomatoes show signs of blossom-end rot (BER). This occurs when there is not enough water in the soil for calcium to move to the developing fruit. This calcium deficiency symptom can be avoided with scheduled irrigations.

Levels of calcium and magnesium tend to be low in sandy soils and in acidic soils. See "Soil and Acidity and Liming" on page 35 for more information.

MACRONUTRIENTS IN SOIL AND PLANTS

NUTRIENT (FORM TAKEN UP BY PLANTS)	HELD IN SOIL BY...	DEFICIENCY SYMPTOMS	SOIL CONDITIONS MOST OFTEN DEFICIENT	EFFECTS OF EXCESS AMOUNT
NITROGEN • nitrate (NO_3^-) • ammonium (NH_4^+)	• organic matter • cation exchange sites (mineral and organic), held as ammonium	• reduced growth, yield, or quality • general yellowing of leaves • grass leaves yellow from tip to base, along midrib • seen in most non-legume crops	• underfertilized soils • waterlogged soils	• excessive vegetative growth • increased lodging • delayed maturity • increased risk of disease
PHOSPHORUS • phosphate ions ($H_2PO_4^-$) (HPO_4^{2-})	• organic matter • soil minerals	• reduced growth, yield, or quality • purple leaves in corn and cereals • seen in most crops	• underfertilized soils • marl soils • low pH soils	• reduced uptake of zinc
POTASSIUM • potassium ion (K^+)	• organic matter • cation exchange sites (mineral and organic)	• reduced growth, yield,or quality • yellow leaves, beginning at edges • increased risk of lodging • increased risk of some diseases • reduced winter-survival in forages • seen in alfalfa, tomatoes, rutabagas	• sands and loams	• reduced uptake of magnesium

MACRONUTRIENTS IN SOIL AND PLANTS (CONTINUED)

NUTRIENT (FORM TAKEN UP BY PLANTS)	HELD IN SOIL BY...	DEFICIENCY SYMPTOMS	SOIL CONDITIONS MOST OFTEN DEFICIENT	EFFECTS OF EXCESS AMOUNT
CALCIUM • calcium ion (Ca^{2+})	• organic matter • cation exchange sites (mineral and organic) • soil carbonates (lime)	• buds do not develop properly • young leaves twisted and yellow • blackhearts in celery • cavity spot in carrots • bitter pit in apples and pears • also seen in grapes, potatoes, tomatoes, cole crops, tobacco	• acidic sandy soils • unirrigated soils	• n.a.
MAGNESIUM • magnesium ion (Mg^{2+})	• organic matter • cation exchange sites (mineral and organic) • soil carbonates (lime)	• yellowing between veins of lower leaves seen in corn, tomatoes, apples, grapes, potatoes, carrots, celery, spinach	• acidic soils • sandy soils • following high rates of potash	• n.a.
SULPHUR • sulphate ion (SO_4^{2-})	• organic matter	• reduced growth, yield, or quality • general yellowing of leaves • seen in forages, cereals, canola	• northwestern Ontario	• n.a.

Secondary and Macronutrient Deficiency Symptoms

Most crops yellow and grow poorly if nitrogen is lacking.

Nitrogen deficiency in peaches.

In corn, a lack of phosphorus can cause purpling of the leaves.

Potassium deficiency on alfalfa leaves.

A lack of calcium can cause blossom-end rot in tomatoes and peppers.

A lack of potassium causes tomatoes to ripen unevenly.

Magnesium deficiency in celery causes yellowing of older leaves.

In corn, magnesium deficiency causes striping of the youngest leaves.

Magnesium deficiency in apples.

For more information about nutrient deficiency and toxicity, please see page 34.

Best indicators for micronutrient deficiencies are visual symptoms and tissue test results.

THE MICRONUTRIENTS

Plant micronutrients, their nutrient cycles, and their roles within plants have not been studied as much as macronutrients. In general, micronutrients are required for the proper functioning of various enzymes and other substances that regulate photosynthesis, respiration, plant growth, and reproduction.

MICRONUTRIENTS IN SOIL AND PLANTS

NUTRIENT	FERTILIZER SOURCES	DEFICIENCY SYMPTOM	SOIL CONDITIONS MOST OFTEN DEFICIENT	EFFECT OF EXCESS AMOUNT
ZINC	• zinc sulphate	• white stripes or patches near base of young leaves • seen in corn	• eroded, high pH soils, high in phosphorus	• excess may interfere with uptake of other micronutrients, causing deficiency
MANGANESE	• manganese sulphate, chelates	• yellowing between veins on young leaves • veins stay dark green • seen in soybean, cereals, beets, tomatoes, muck crops	• soils that were previously poorly drained: muck, marl, eroded, sandy, high pH soils	• on acid soils, excess manganese may reduce root growth • some apple varieties show “measles” on the bark
BORON	• borate	• new growth is stunted and discoloured • flower bulbs may abort • hollow stems cores • seen in alfalfa, cole crops, apples, celery, beets, spinach	• sandy soils • most soils (east of Niagara Escarpment) • dry soil conditions	• necrosis of leaf margins • new growth pale or whitish
COPPER	• copper sulphate	• limp or discoloured leaves • twisted leaf tips • thin pale scales on onions • poor colour in carrots • also seen in winter wheat	• muck soils • coarse sandy soils	• foliar sprays that are too concentrated will damage leaf tissue
MOLYBDENUM	• sodium molybdate	• leaves become yellow between veins • leaves twist and become whiplike • edges of leaves appear scorched • seen in cauliflower, broccoli, onions	• muck soils • acidic sandy soils	• excess molybdenum may cause symptoms that appear like iron deficiency
IRON	• Fe – chelated	• leaves become yellow between the veins • seen in blueberries	• rarely seen in Ontario	

*In addition to these nutrients that are essential for plants, animals require cobalt, sodium, iodine, and selenium.

Micronutrient Deficiency Symptoms

In alfalfa, boron deficiency causes reddening and stunting of new growth.

In corn, zinc deficiency causes striping of the youngest leaves.

Leaf tips of copper-deficient plants become twisted and die.

These soybeans are deficient in manganese.

Boron deficiency causes hollow stems in cole crops such as broccoli.

Boron deficiency in celery causes “cat scratches” on the stalks.

A deficiency of any given nutrient can limit crop growth and quality. These are soybeans with a potassium deficiency.

NUTRIENT DEFICIENCY AND TOXICITY

DEFICIENCY

Crops fulfill most of their nutrient requirements from soils. However, soils do not always supply the quantity or balance of nutrients when needed to meet production and quality goals. Nutrient deficiency in a crop is an indicator that the soil nutrient supply is inadequate for any number of reasons, such as:

- some soil types are prone to deficiencies of certain nutrients, because of the way in which the soils were formed
- some crops have a higher requirement for specific nutrients than other crops
- some soils may be depleted in nutrients due to previous cropping practices.

TOXICITY

If available at excessive levels, some nutrients are potentially toxic to plants. For example, the margin between boron deficiency and toxicity is quite narrow, and varies among crops. Cole crops and alfalfa have relatively high requirements for boron. In the year following application, however, boron applied for cole crops may cause damage to sensitive crops such as soybeans, field beans, and cereal grains. Nutrient toxicities may also occur due to pH changes in the soil, which make certain nutrients more available.

Chlorine

Chlorine is present in soil mainly in the form of the chloride ion (Cl-). Chloride is very soluble; much of the chloride in soil remains in the soil solution and is very prone to leaching. Although some compounds containing chlorine are toxic (e.g., chlorine gas and bleach), the chloride ion is not. Fertilizer materials containing chloride can be applied to the soil without damaging results.

However, the chloride ion does contribute to the "salt effect" of fertilizers, and chloride levels in the soil may affect the quality of some specialty crops such as tobacco.

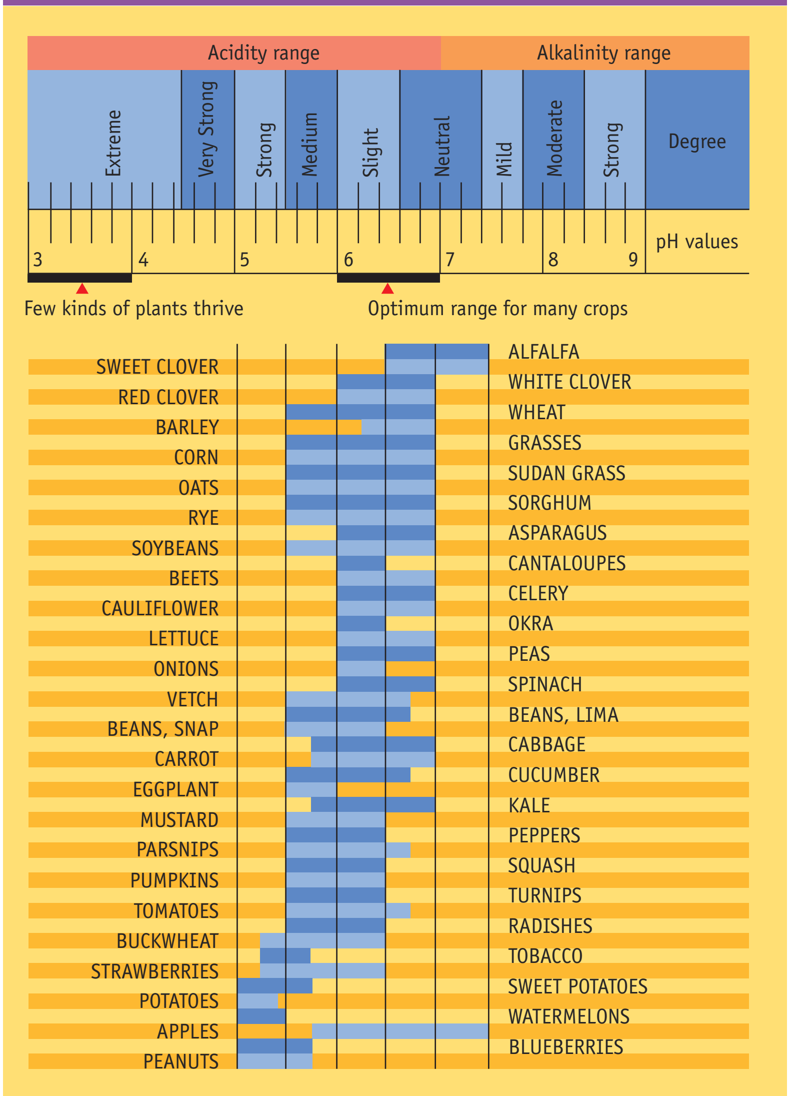
In acidic soils, some nutrients become toxic to some crops such as corn.

SOIL ACIDITY AND LIMING

Your soil's pH – whether it's acidic or alkaline – affects nutrient availability and crop performance.

Soils in Ontario range from slightly alkaline (pH between 7.1 and 8.0) to very acid (pH under 4.0), depending on the type of soil and the way it has been managed. Note: only 10% of the agricultural soils in Ontario have a pH of 6.0 or lower.

PREFERRED pH RANGES FOR CROPS



Why do soils become acidic?

- the acidity of soils increases as a result of uptake of nutrients by plants
- leaching removes nutrients, such as calcium and magnesium, that slow the rate at which soils become acidic
- acids are released when soil organic matter decomposes
- precipitation is normally acidic – in southern, eastern and central Ontario, the effect on soils is more pronounced due to the greater acidity of the rain and snow

Ammonium fertilizers will lower pH.

Many soils formed from limestone till contain lime and are naturally slightly alkaline. Because of the presence of lime in these soils, their pH changes very slowly. Soils formed from other types of rock contain little lime and their pH may change relatively quickly. This is especially true for sandy soils.

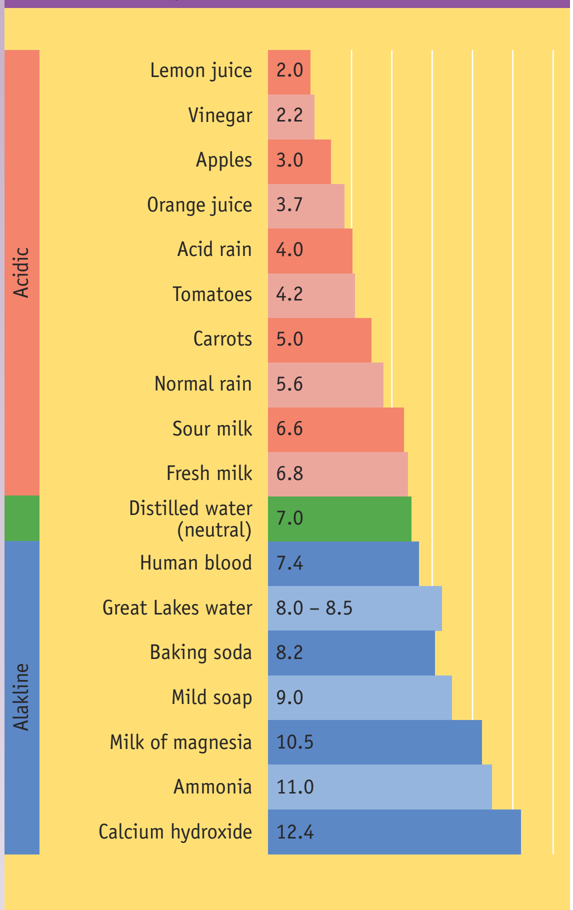
Soils naturally tend to become more acidic as a result of weathering and fertilizer inputs over time. The application of materials containing ammonium-nitrogen to soil can increase the rate at which susceptible soils become acidic.

✔ **Regularly soil-test fields to monitor changes in soil pH.** See page 56 for details.

The pH of soil does not normally increase. However, the pH of subsoil is often higher than that of topsoil. When topsoil is eroded away or if tillage is too deep, subsoil can be mixed with topsoil and the pH of the plow layer may increase.

When the pH decreases below 5 in mineral soils, growth decreases due to micronutrient toxicity, e.g., aluminum or manganese for apples.

THE pH OF COMMON LIQUIDS



Sandy soils tend to become acidic more quickly than do heavier soils.

EFFECTS OF SOIL pH

As soil is made **more alkaline** (higher pH), the availability of zinc, manganese, boron, copper, and iron is reduced.

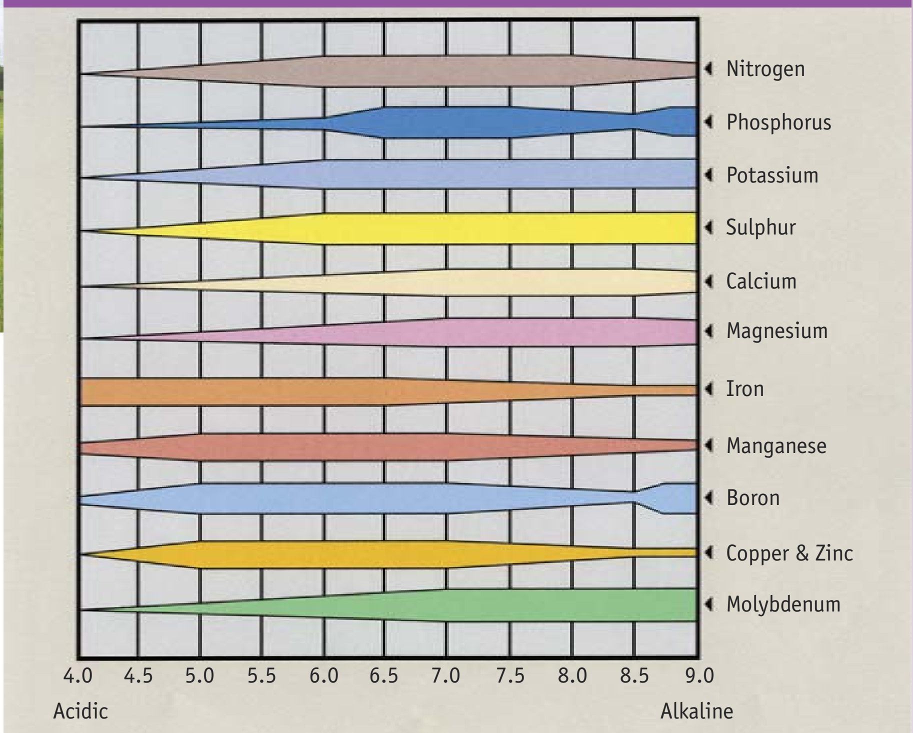
As soil becomes **more acidic** (lower pH):

- phosphorus, potassium, calcium, magnesium, and molybdenum are less available
- iron, aluminum, and manganese are more available, often to toxic levels
- cation exchange capacity of soil organic matter is reduced
- the activity of many soil micro-organisms, including those that fix nitrogen, is reduced.

Most crops do best when the soil pH is over 6.1. Blueberries and cranberries must be grown under more acidic conditions to prevent deficiencies of iron or manganese. Potatoes and tobacco are usually grown in slightly acid soils to reduce disease problems. Most other crops will grow well over a wide pH range, but none needs soil that is alkaline.

Acidic spots often occur unevenly in fields. Sample such areas separately.

EFFECTS OF SOIL pH ON AVAILABILITY OF PLANT NUTRIENTS



CORRECTING SOIL ACIDITY

Raising Soil pH

In Ontario, crushed limestone is the material used most commonly to raise soil pH.

Lime is being added to raise soil pH.

Limestone must be finely crushed to be effective. The rocks from which crushed limestone is made differ in their capacity to correct acidity. An index has been developed to combine the effects of these two factors.

Lime recommendations from the Ontario soil test are based on lime with an index of 75. For lime with a different index, rates need to be adjusted. (See Ontario Ministry of Agriculture, Food and Rural Affairs Publication 811, *Agronomy Guide*, for details.)

Agricultural limestone is usually a byproduct of aggregate extraction.

Recommendations for lime from the Ontario soil test consider the requirements of only the crop indicated on the soil test information sheet. However, you should consider the pH requirements of all crops included in the rotation. Acid soil may be required for certain high-value crops, such as potatoes. Otherwise, application rates for lime should be based on the crop with the higher requirement.

Dolomitic limestone from quarries on the Niagara Escarpment or in the Ottawa Valley contains both calcium and magnesium. Calcitic limestone (from most other quarries in the province) contains little magnesium.

Blueberries need more acidic conditions to prevent deficiencies in iron and manganese.

If your soils are low in magnesium, use dolomitic limestone to correct both the acidity and the low magnesium level. On soils with sufficient magnesium, use either calcitic or dolomitic limestone.

The effect of lime moves downward in the soil relatively slowly – about 2 centimetres (1 in.) per year. To correct acidity problems in the entire plow layer, lime must be mixed into the soil. Most uniform mixing will occur where the lime is spread and the field cultivated prior to plowing.

Lowering Soil pH

Elemental sulphur can be applied to lower the pH of some soils for crops that require acidic conditions. However, if the initial pH of the soil is over 7.0, it's almost impossible to lower the pH, due to the high lime content of the soil.

SOURCES OF NUTRIENTS

Most of the nutrients taken up by plants are supplied by the soil itself. Sometimes, the levels of particular nutrients in soil are too low to support adequate growth.

As discussed earlier, materials that can be added to the soil to supply nutrients are either inorganic (such as commercial fertilizers) or organic (crop residues, manures, and biosolids). There are many types of either kind, each with its own special properties, and pros and cons relating to cost, practicality, safety, and environmental protection.

The information in this chapter should help you develop a nutrient management program by:

- ▶ describing the sources of fertilizer materials and their fate in the soil
- ▶ assessing the materials you are using now, and materials you may consider using.

NUTRIENT TERMINOLOGY

Except for phosphorus and potassium, the nutrient content of most materials is expressed as the concentration by weight (percentage, parts per million, pounds per ton, kilograms per tonne, etc.) of nutrients in their elemental form – not in combination with other elements.

Phosphorus requirements and the phosphorus content of fertilizers are expressed as phosphorus in the pentoxide form, P_2O_5. Potassium is expressed as K_2O.

The available nutrient content of fertilizer is called its analysis or grade. It's shown as the percentage of nitrogen, P_2O_5 and K_2O, respectively. For example, 8-32-16 contains at least 8% (total) nitrogen, 32% (available) P_2O_5, and 16% (water-soluble) K_2O.

NUTRIENT CONTENTS OF COMMON FERTILIZER MATERIALS

MATERIAL	N (%)	P_2O_5 (%)	K_2O (%)	Ca (%)	Mg (%)	S (%)	Cl (%)
NITROGEN MATERIALS							
Ammonia, anhydrous	82	—	—	—	—	—	—
Ammonium nitrate	34	—	—	—	—	—	—
Ammonium sulphate	21	—	—	—	—	23.7	—
Calcium nitrate	15	—	—	19.4	1.5	—	—
Calcium ammonium nitrate	27	—	—	4	2	—	—
Sodium nitrate	16	—	—	—	—	—	—
Urea	46	—	—	—	—	—	—
UAN solutions	28–32	—	—	—	—	—	—
PHOSPHORUS MATERIALS							
Single superphosphate	—	20	—	20	—	12	—
Triple superphosphate	—	46	—	13.6	—	1.4	—
Bonemeal	2–4	*	—	20–25	—	—	—
Rock phosphate	—	*	—	33	—	—	—
POTASSIUM MATERIALS							
Potassium chloride (muriate)	—	—	60–62	—	—	—	47
Potassium-magnesium sulphate	—	—	22	—	11	22.7	1.5
Potassium sulphate	—	—	50	—	1.2	17.6	2.1
MULTIPLE NUTRIENT MATERIALS							
Diammonium phosphate (DAP)	18	46	—	—	—	—	—
Monoammonium phosphate (MAP)	10–13	48–52	—	—	—	—	—
Gypsum	—	—	—	22.5	—	16.8	—
Limestone, calcitic	—	—	—	25–40	0.5–3	—	—
Limestone, dolomitic	—	—	—	19–22	11–13	—	—
Magnesium sulphate	—	—	—	2.2	10.5	14	—
Potassium nitrate	12	—	44	—	—	—	1.1
Sulphur	—	—	—	—	—	30–99	—
Wood ashes	—	1.8	5.5	23.3	2.2	—	—

*these materials are highly variable in phosphorus availability

MINERAL FERTILIZERS

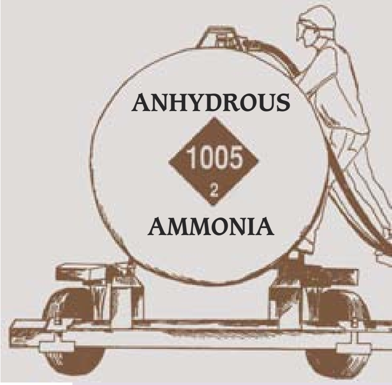
COMMON FERTILIZER MATERIALS

Commercial fertilizer materials are one of the major sources of nutrients for crops. Here are some of their advantages and disadvantages.

MINERAL FERTILIZERS	
BENEFITS	**SIGNIFICANCE**
• nutrients are concentrated in materials with consistent physical characteristics	• fertilizer materials are generally easy to transport, handle, and apply evenly and accurately
• nutrient content is known and consistent	• blends can apply nutrients to match crop needs based on soil tests, without the need to apply nutrients that are already present in adequate amounts
• nutrients are generally available quickly (or with predictable release for enhanced fertilizers)	• timing of application can be flexible, to match nutrient supply to crop uptake • overapplication of very soluble fertilizers can lead to crop injury
CHALLENGES	**SIGNIFICANCE**
• materials are made from non-renewable resources	• proper stewardship is necessary
• some materials, e.g., anhydrous ammonia, can cause injury	• these materials require special handling precautions to be applied safely

Anydrous ammonia is the first product generated during nitrogen fertilizer processing.

Handling nitrogen materials requires strict safety measures.



Nitrogen

Most of the materials used as nitrogen fertilizers are manufactured from the nitrogen gas in air and natural gas. Anhydrous ammonia (82% N) is the first product from this process. Most other commonly used nitrogen materials are then manufactured from ammonia.

Because ammonia requires the least amount of manufacturing, it costs less per unit of nitrogen than any other nitrogen fertilizer material. However, safety and handling costs are higher than for other materials. For a detailed comparison of nitrogen materials, refer to OMAFRA Publication 611, *Soil Fertility Handbook*.

The Steps in Manufacturing Nitrogen Fertilizers

natural gas	PLUS	nitrogen gas	=	anhydrous ammonia (82% N)
ammonia	PLUS	oxygen	=	nitric acid
ammonia	PLUS	carbon dioxide	=	urea (46% N)
ammonia	PLUS	nitric acid	=	ammonium nitrate (34% N)
ammonium nitrate	PLUS	urea		
	PLUS	water	=	UAN solution (28–32% N)

Most products designed to enhance the efficiency of N uptake delay the release of its soluble forms, ammonium and nitrate. The products fall into one or more of the following categories:

- **slow or controlled-release fertilizers** – 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 polymer (e.g., ESN®) or sulphur coatings, or incorporation into insoluble or organic compounds.
- **urease inhibitors** – a substance that inhibits the hydrolytic action on urea by the urease enzyme. An example is Agrotain®, which contains N-(n-butyl) thiophosphoric triamide (NBPT).
- **nitrification inhibitors** – a substance that inhibits the biological oxidation of ammonium to nitrate. Examples include N-Serve® (nitrapyrin) and DCD (dicyandiamide).
- **stabilized fertilizers** – fertilizers with substances added that extend the time the fertilizers remain in the urea or ammoniacal form. An example is SuperU®, a urea fertilizer containing both NBPT (a urease inhibitor) and DCD (a nitrification inhibitor).

Anhydrous ammonia is usually the least expensive fertilizer material per unit of nitrogen.

Phosphorus

Rock phosphate is insoluble in water and the phosphorus it contains becomes available to plants very slowly – taking 100 years or more. Common phosphorus fertilizer materials are made by treating rock phosphate with various acids.

Products designed to enhance efficiency of P uptake delay 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. One example is a grade of 11-52-0 monoammonium phosphate coated with maleic itaconic copolymer (AVAIL®) that is being marketed in North America.

Some deposits of phosphate rock are high in heavy metals like cadmium. The Fertilizer Act sets limits on the maximum concentration of heavy metals in fertilizers, such that applying the maximum recommended rate of any fertilizer for 45 years would not appreciably increase the concentration of that metal in the soil. The heavy metal concentration in the deposits of phosphate in Florida is very low.

Rock phosphate, which is mined mainly in the southern United States, northern Africa and Russia, is the source of almost all of the phosphorus in fertilizers.

Fertilizer Materials Made From Phosphate

Rock phosphate plus sulphuric acid produces:
- single superphosphate (0-20-0) or phosphoric acid.

Rock phosphate plus phosphoric acid produces:
- triple superphosphate (0-46-0).

Phosphoric acid plus ammonia produces:
- mono-ammonium phosphate (11-52-0) or diammonium phosphate (18-46-0).

Superphosphoric acid plus ammonia produces:
- ammonium polyphosphates, fluid (11-37-0).

The most common source of potassium is potassium chloride, also called muriate of potash (60% K_2O), and is mined in Saskatchewan, New Brunswick, and the United States.

Potassium

Muriate of potash requires little processing; the ore is simply crushed into granules of potassium chloride and sodium chloride, which are separated by flotation in brine.

Other sources of potassium include:

- ► potassium sulphate (50% K_2O)
- ► potassium nitrate (44% K_2O)
- ► sulphate of potash-magnesia (22% K_2O).

ORGANIC SOURCES

Many organic materials can be used to supply nutrients to cropland. These include crop residues and livestock manures and composts. Biosolids and other "non-agricultural source materials" (NASMs) approved by Ontario Ministry of the Environment can also be used.

ORGANIC NUTRIENT SOURCES

BENEFITS	SIGNIFICANCE
• contain many macronutrients and micronutrients	• a good single source of many nutrients for your soil
• supply organic matter to the soil	• soil structure improvement • increased nutrient- and water-holding capacity • improved drainage
• provide nutrients for crops over several years after application	• not all nutrients are immediately available – some of them are tied up in organic forms ○ over time, this material breaks down to available (inorganic and soluble) forms
• create an opportunity to close the loop in urban and rural nutrient cycling	• crop nutrients leave the farm in the form of fruits, vegetables, grains, and animal products for human consumption • organic nutrients in the form of sewage biosolids and other NASMs can be returned to the soil • the need to dispose of these wastes by landfilling or burning is reduced • organic nutrient sources are treated as resources – not wastes to be disposed of • for minimal costs, other than time and energy, most of these nutrients can be applied with readily accessible equipment

Every effort should be made to apply manure evenly. For more info on BMPs for application, please see the BMP book *Manure Management*.

Adding organic material to soil can bring many benefits. However, it's really important to test organic materials so you know exactly what nutrients they contain. See pg. 73 for more information.

Manure and biosolid application systems often have high axle loads, risking soil compaction.

LIVESTOCK MANURES

Although storage, handling, and spreading of manure can pose several problems on livestock farms, manure is a valuable resource. Nutrients retained on your farm reduce both the risk of damage to the environment and the cost of what might otherwise have to be spent on commercial fertilizers.

The nutrients in manure as they pertain to crop removal are significant. See the chart on pg. 26.

Variable Nutrient Content

Manure consists of undigested feed, plus bedding, wasted feed, and/or water. Depending on the type of livestock and the ration being fed, fresh manure can contain:

- up to 80% of the nitrogen originally present in feed
- up to 75% of the phosphorus originally present in feed
- 80 to 95% of the potassium originally present in feed.

The average nutrient contents of several types of manure are shown in the next table. Contents of individual samples, however, may range from one-tenth of the average to double the average! Be aware of the wide range in the nutrient contents of manure – use of average values often results in applications of nutrients that don't match crop requirements.

Nutrient contents of organic materials are usually reported as percentage by weight of the elemental form (e.g., %N, %P, %K).

Phosphorus and potassium must be converted to P_2O_5 and K_2O respectively. Ammonium-nitrogen and micronutrient contents are usually reported in milligrams per kilogram (mg/kg) or milligrams per litre (mg/l).

To convert:

- mg/kg to pounds/ton, divide mg/kg by 500
- mg/l to pounds/1000 imperial gallons – divide mg/l by 100.

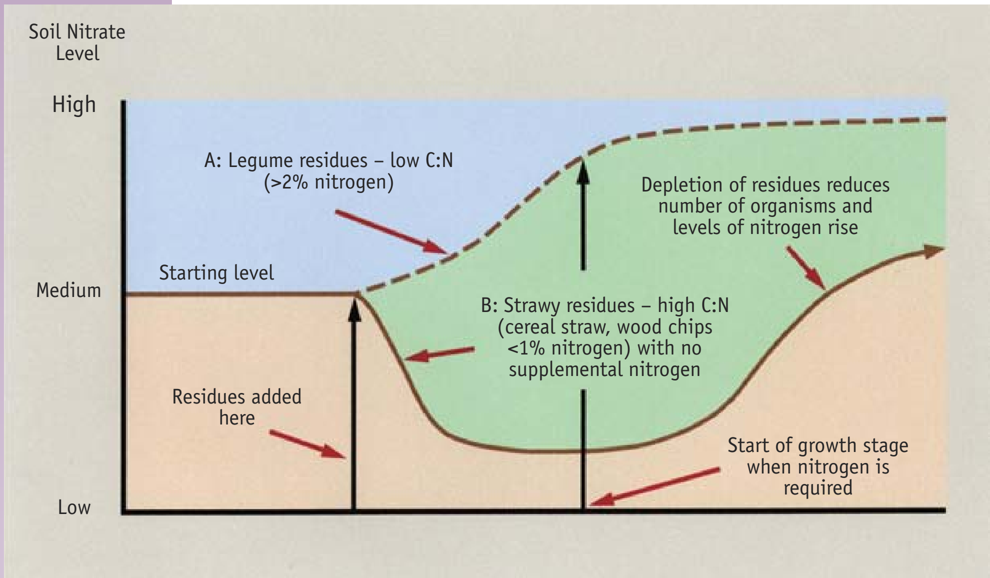
Test your manure regularly for nutrient content. It's the only way to obtain an accurate estimate.

Water

Large volumes of water are often added to manure, intentionally or otherwise, through cleaning of livestock equipment, leaks during livestock watering, groundwater entry, rainfall, or runoff. This dilutes its nutrient content and adds to the amount of material to be handled and to the cost of storage, hauling, and spreading.

Bedding

Bedding is another factor. Bedding increases the organic matter content of manure, but reduces the concentration of most nutrients, especially nitrogen. Cereal straw usually contains less than 1% nitrogen; wood shavings contain less than 0.2% nitrogen. In breaking down these materials, micro-organisms in the manure and soil tie up available nitrogen.



Shown here is the effect on available nitrate-nitrogen for crops when two kinds of residues are worked into the soil. When straw residues are added (B), the soil organisms multiply rapidly and use up most of the mineral nitrogen in the soil. After a few weeks, nitrate begins to appear and reaches a new high level. Legume residues (A, upper line) cause an increase in nitrate-nitrogen levels soon after they are added.

Where soil nitrogen levels are low, use of large quantities of bedding, especially shavings, can reduce the amount of nitrogen immediately available to the crop.

AVERAGE NUTRIENT ANALYSES OF LIVESTOCK MANURES												
MANURE TYPE		DRY MATTER	TOTAL N[1]	NH_4-N	P_2O_5[2]	K	Ca	Mg	S	Zn	Cu	Mn
		Fresh Weight Basis										
		%	%	%	%	%	%	%	%	ppm	ppm	ppm
SWINE	liquid	3.8	0.40	0.265	0.13	0.17	0.12	0.06	0.06	85	30	22
	solid	29.8	0.90	0.258	0.47	0.56	n.a.	n.a.	0.14	172	103	n.a.
POULTRY	liquid	10.6	0.83	0.558	0.3	0.3	1.6	0.08	0.08	70	11	64
	solid	52.6	2.37	0.550	1.11	1.17	4.6	0.28	0.16	238	33	204
DAIRY	liquid	8.5	0.36	0.153	0.09	0.24	0.49	0.14	0.04	48	17	40
	solid	24.2	0.61	0.128	0.17	0.50	1.54	0.36	0.08	95	29	107
BEEF	liquid	7.95	0.52	0.179	0.13	0.43	0.7	0.3	0.04	57	14	61
	solid	28.6	0.73	0.101	0.23	0.57	1.5	0.41	0.09	129	36	112
SHEEP	solid	31.3	0.76	0.186	0.27	0.70	1.5	0.38	n.a.	170	20	140
HORSE	solid	33.41	0.42	0.068	0.13	0.36	1.7	0.56	n.a.	73	23	113

Data from manure analysis provided from Ontario laboratories collected between 1992 and 2004; micronutrient data were obtained from a smaller subset of data.

[1] Total N = Ammonium-N + Organic N

[2] %P = total phosphorus

Year of Application – Nitrogen

Crops are able to obtain only a portion of the nutrients applied in manure in the year of application.

ESTIMATED NITROGEN AVAILABLE FROM MANURE	
CROP YEAR	NITROGEN AVAILABLE*
Application year**	40–60%
1st year after application	1–4%
2nd year	0.5–2%
3rd year	0.2–1%

* expressed as percentage of the total initially applied

** 80% for liquid poultry manure

Because a higher proportion of the nitrogen in poultry manures is present as ammonium-nitrogen, 75–85% of the nitrogen in poultry manures can become available in the first year.

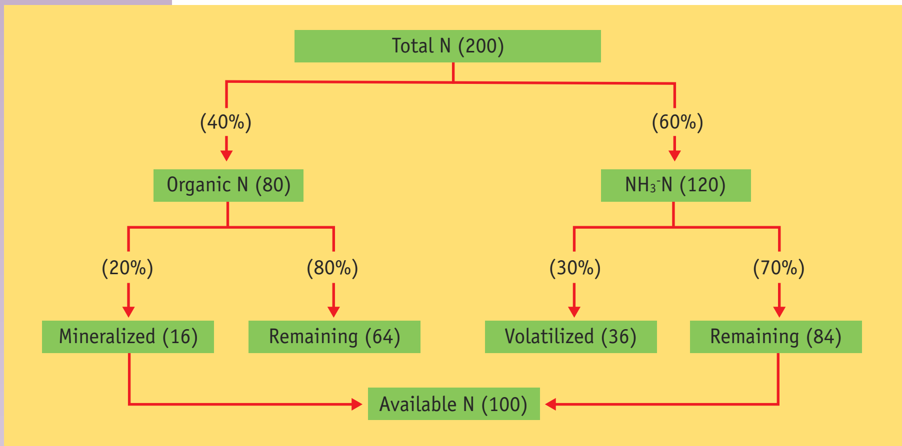
Nitrogen, in the ammonium form, is immediately available to crops, but typically at least 30% of it is lost. Up to 30% of the organic nitrogen becomes available in the first cropping year, depending on the type of manure and the amount of bedding used.

At best, 50–60% of the total amount of nitrogen from manure is available in the first crop-year after application.

Year of Application – Phosphorus and Potassium

Only 40% of the phosphorus in manure can be expected to become available as fertilizer phosphorus in the year of application. The balance of the phosphorus is absorbed by the soil, and will be reflected in the soil test value. Check your manure analysis report to verify the form of P being reported – available or total. It will have a profound impact on your calculations for nutrient balance.

Potassium is present in a soluble form and 90% of the total potassium in manure is available as fertilizer potassium in the year of application.



As the organic matter from manure breaks down in the years following application, it continues to supply nitrogen to the soil.

CROP RESIDUES

By returning crop residues to soil, you are:

► ensuring that part of the nutrients taken up by your crop is recycled
► helping maintain the organic matter content of your soil.

Residues left on or near the soil surface also help to reduce soil erosion.

PREVIOUS CROP	NITROGEN (LB/ ACRE)
Established forage – under 1/3 legumes	0
Established forage – 1/3–1/2 legumes	49
Established forage – over 1/2 legumes	100
Perennial legumes plowed in seeding year	40
Corn following red clover plowdown	73
Corn following red clover (no-tillage)	60
Corn following soybeans or edible beans	27
Corn following silage corn	12
Corn following cereals (straw removed)	11
Other crops	0

The Best Management Practices series has an entire book devoted to no-till practices.

Residues from cereals and grasses tend to be low in nitrogen. Because soil micro-organisms require nitrogen to break down such materials, the supply of nitrogen available to crops can be temporarily reduced when large quantities are returned to the soil.

The nitrogen fixed from air by some legume crops, especially the forage species, can add significantly to the supply of this nutrient in soil.

OTHER AGRICULTURAL MATERIALS

Nutrients are also found in other agricultural wastes such as washwaters, runoff from livestock yards and feed storages, and leachate from greenhouses and nurseries. The nutrient content of the material will depend on the conditions surrounding use and storage of the water.

These agricultural materials should be considered a nutrient resource and managed to maximize the benefit of their use.

Nutrients from washwaters need to be managed.

In Ontario, the application of sewage biosolids requires prior approval by the Ministry of the Environment.

Information regarding the use of sewage biosolids can be found in the publication, ***Guidelines for the Utilization of Biosolids and Other Wastes on Agricultural Lands*.**

NON-AGRICULTURAL SOURCE MATERIALS (NASMs)

SEWAGE BIOSOLIDS

Sewage biosolids from municipal sewage treatment plants can be a valuable addition to cropland.

To reduce the risk of biosolid runoff and to maximize nutrient utilization, restrictions are in place on the timing and location of the spreading of sewage biosolids and other NASMs. Sites to which biosolids are to be applied must be approved by the Ontario Ministry of the Environment.

To reduce the risk of contamination, a waiting period before harvesting of forages and fruit crops must be observed following biosolid application.

Unprocessed wastes from septic tanks, cesspools, and holding tanks cannot be used on cropland without approval from the Ontario Ministry of Environment.

Some factors considered in site approval for application of NASMs are:

- soil test for P
- soil pH
- slope of the field
- soil organic matter content
- natural soil drainage
- soil depth to bedrock
- snow cover and frost
- distance to wells, water table, watercourses, bedrock or homes.

Sewage biosolids are a good source of many nutrients, except potassium. Because the levels of phosphorus and zinc in sewage biosolids are often high, these materials can be an excellent means of correcting deficiencies of these nutrients in soil.

However, the high phosphorus content also means that levels of phosphorus in soils receiving sewage biosolids can be raised to undesirable levels.

In Ontario, most biosolids are produced by anaerobic digestion. These contain 3–9% nitrogen on a dry weight basis (dwb), of which 30–40% is in the ammonium form. De-watered biosolids contain less nitrogen (~ 4% of dry weight), because much of the soluble nitrogen is removed with the water.

SAMPLE ANALYSIS OF ANAEROBIC SEWAGE SLUDGE*

Total solids	3%
pH	7.1

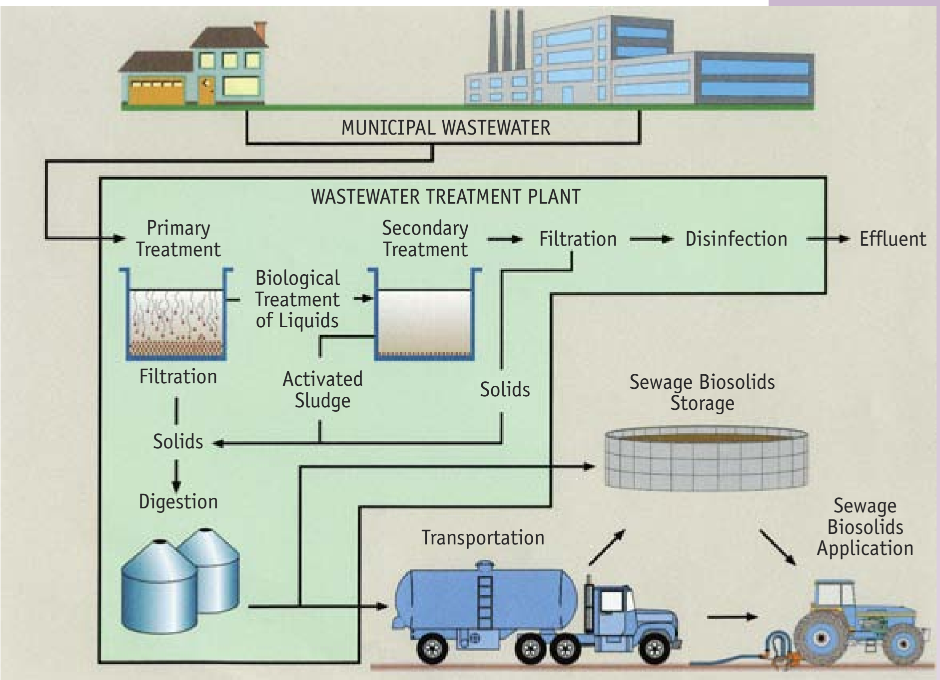
Nutrient content

Total phosphorus	3.67% (dwb)
Total nitrogen	6.5% (dwb)
Ammonium-nitrogen	2.3% (dwb)
Zinc	500 mg/kg
Potassium	trace

*sewage biosolids are also tested for arsenic, cadmium, cobalt, chromium, copper, mercury, molybdenum, nickel, lead, and selenium.

The nitrogen content of aerobic sewage biosolids is also lower than that of anaerobic sewage biosolids. Much of the nitrogen in aerobic biosolids is present in the organic form.

Guidelines for application rates of biosolids have been established to minimize the risk of contaminating soil with metals. Sewage biosolids are regularly analyzed for their content of the 11 regulated metals (see next page). Those that exceed the guideline for any one of these metals may not be applied to cropland.



Recycling processed sewage biosolids from municipal sewage treatment plants can provide cropland with valuable nutrients.

Heavy Metals

This term is used loosely to refer to a group of elements – mostly metals, with high atomic weight – that are of concern in the environment. These elements, if present at sufficient concentrations, can affect human or animal health, or they may reduce the growth of plants. Note that some of these elements are essential nutrients at lower concentrations. The harmful effect of these elements may be a direct toxicity, or may be due to competing with another essential element, creating a deficiency of that element.

The 11 regulated metals in Ontario are:

- Arsenic As
- Cadmium Cd
- Cobalt Co
- Chromium Cr
- Copper Cu
- Mercury Hg
- Molybdenum Mo
- Nickel Ni
- Lead Pb
- Selenium Se
- Zinc Zn

Heavy metals are often naturally occurring in soil, but may be at higher levels because of past additions of biosolids, industrial wastes, or pest control products. Of the 11 regulated metals, four are essential for both plants and animals, and three more are essential for animals. Further, these elements may provide growth-promoting benefits beyond the amount that is considered essential. Elevated metal concentrations in manure can occur if feeds have been supplemented with these elements. Elevated metals in sewage biosolids have traditionally been linked to industrial wastes, but strict sewer by-laws have almost eliminated this source in most municipalities. Biosolids that exceed limits for the regulated metals cannot be land-applied.

To view current compliance information regarding sewage biosolids (non-agricultural source materials (NASMs)) for the Nutrient Management Act, look up:
http://www.omafra.gov.on.ca/OMAFRA/index.html/nutrientmanagement

Sewage biosolids can add organic matter and nutrients to the soil. Follow the guidelines for proper handling and application procedures.

OTHER OFF-FARM SOURCES OF NUTRIENTS

Our society produces a wide variety of other waste materials. These include leaves, residential garbage, wood chips, paper, pulp, and food processing wastes. Many of these materials could be beneficial to soil as a source of organic matter and nutrients. Some wastes – cement kiln dust, for example – can also be used to correct soil pH problems, where appropriate.

The nutrient content of wastes depends on the materials from which they were made. Those derived from leaves, paper, or wood usually are low in nitrogen and may require supplementation to avoid inducing nitrogen deficiency in crops.

Because of the potential for contamination of the soil and environment, only waste materials approved by the Ontario Ministry of the Environment may be applied to approved sites.

Before a material will be approved, it must be demonstrated that:

- the nutrients or organic matter it contains will benefit the crop or soil
- it will not pose a risk to crops, soils, people, animals, or the environment.

Other guidelines relating to the use of NASMs on farmland are similar to those for sewage biosolids. (See *Guidelines for the Utilization of Biosolids and Other Wastes on Agricultural Lands*.)

Other sources such as paper waste biosolids can provide organic matter and nutrients to soil.

NUTRIENT MANAGEMENT PLANNING IN 10 STEPS

The flow chart gives you a bird's-eye view, so you'll know what to expect. In subsequent chapters, we'll explain how to develop each step, and then put the entire plan into action.

We've covered a lot of ground in terms of general nutrient know-how. It's time to put that knowledge to work for you on your operation.

Nutrient management planning has become associated with manure, but the same principles apply no matter what source of nutrients you're using: manure, NASM, compost or commercial fertilizer.

Step 1:
Set goals for nutrient management planning

- establish why you're doing the plan
- seek advice
- create a vision for what the plan will accomplish

Step 2:
Take inventory of what's available within the operation

- identify resources on the farm
- describe site characteristics, e.g., soil test
- detail current management practices

Step 3:
Analyze data to apply what you have against what you need to do

- enter data into NMAN or other program
- determine land base requirements
- assess risks of off-site movement

Step 4:
Develop options to manage risk, decrease input costs, and handle all nutrients generated

- list possible management practices
- remember the systems approach

Step 5:
Make decisions, selecting options to meet your goals

- remember economics and common sense
- honour personal and business goals
- use available resources
- set proper application rates and separation distances

Step 6:
Put your decisions into action

- make an operational plan
- complete day-to-day activities
- account for the impact of outside forces, e.g., weather, markets

Step 7:
Keep records to document what actually takes place

- Maintain:
  - application records
  - livestock records
  - cropping records

Step 8:
Monitor the impact of your actions on production and off-site impact

- Monitor:
  - nutrient levels
  - water quality in wells and tiles
  - crop and livestock performance
  - nuisance impacts

Step 9:
Adjust your plan and upgrade technology where appropriate

- use information from record-keeping and monitoring
- modify plan by repeating Steps 3–6

Step 10:
Plan for the unexpected with a contingency plan

- identify resources
- communicate with others
- document actions

In the nutrient management planning process:

- ▶ all nutrients are inventoried – including nutrients found in the soil and in a growing or harvested crop, and those considered to be deficient
- ▶ all nutrients are managed – according to land base, production goals, proximity to water resources, farmstead layout, equipment, and safety concerns.

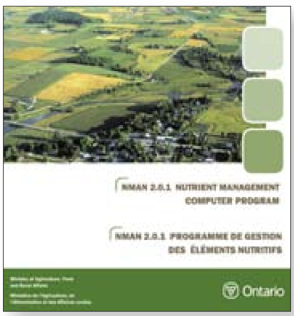
The process integrates the calculation of:

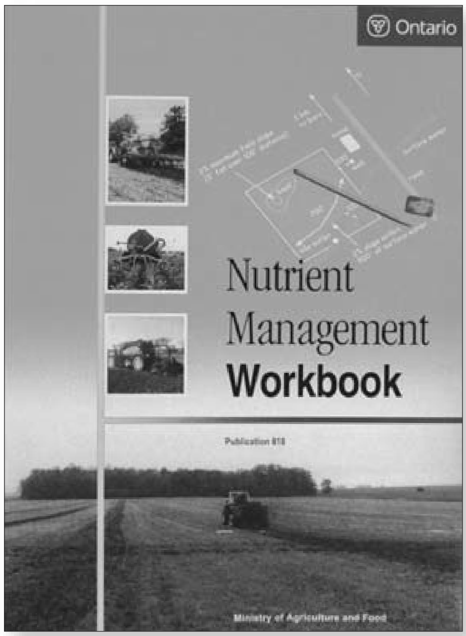
- ▶ application rates
- ▶ separation distances, and
- ▶ acreage needs

with

- ▶ farmstead planning
- ▶ odour issues and neighbourly relations
- ▶ application technology
- ▶ soil and water conservation practices, and
- ▶ contingency plans.

Understanding the principles of crop nutrient management will help you through the steps of developing and operating your nutrient management plan. The next chapter addresses aspects of Step 2 – assessing what nutrients you already have on-farm and in the field.





Nutrient management planning is an in-depth process. But it doesn't have to be overwhelming – especially when you take it step-by-step.

BMPs FOR DETERMINING WHAT NUTRIENTS YOU NEED

Poor sampling methods may make test results unreliable. This chapter will show you how to do it right, and how to interpret results.

TESTING FOR NUTRIENTS AND INTERPRETING TEST RESULTS

✔ **Test for nutrient levels and use this information to set fertilizer and manure rates.**

This chapter will explain why this is so important, as well as:

- how to take and handle samples for nutrients
- more about the different tests
- the advantages and disadvantages of several procedures for interpreting the test results.

Basing your applications on a soil test will:

"Applying fertilizer every year without taking a soil test is like adding a litre of oil to the crankcase before you start the tractor each time. At best, you'll waste some dollars...at worst, you'll damage the engine (your soil), or spill the excess somewhere we don't want it."

– Keith Reid, OMAFRA Soil Fertility Specialist

- improve crop growth and standability
- show how nutrient levels change with time
- improve crop tolerance of insects and diseases
- improve crop maturity and quality
- assure optimum yields
- improve profitability
- protect the environment.

Whether it's soil fertility, pH, nitrate levels, plant tissue, manure, or other organic materials, test first. If you add too little, your yields and returns suffer. If you add too much, you've wasted energy, time, and money – and you risk polluting the environment.

Sampling takes time and costs money, but the tests are relatively inexpensive. For example, if a 20-acre field was sampled once every three years at a cost of $15/analysis, the cost per acre per year would be $0.25.

SOIL TESTING

The best way to estimate the fertility of the soil is through the use of an OMAFRA-accredited soil test. You can't make good decisions for nutrient use without knowing the supply of available nutrients in soil. Soil testing is also the only reliable way to determine soil pH.

✔ **Test every field at least once every three years.** Sandy soils may need to be sampled more frequently, as their nutrient levels and pH change more rapidly.

(The soil test for nitrate-nitrogen is an exception: see page 62).

Soil testing is not an exact measure of soil fertility, but it is the best estimate. In soil testing, chemicals that remove nutrients from the soil sample are used to estimate the nutrients that plants will be able to take up. The procedures used for the basic OMAFRA-accredited soil test (phosphorus, potassium, magnesium, and pH) are well-defined and provide consistent results. OMAFRA-accredited tests for zinc, manganese, and nitrate-nitrogen are also available.

Soil testing should be the first step in making a nutrient management plan.

For most other nutrients, soil testing procedures that provide a reliable basis for making fertilizer recommendations for Ontario soils have not been developed.

When fields are soil-tested regularly, changes in nutrient levels over time can be monitored and recorded. If the results of a soil test for a field differ greatly from the trend of previous results, contact the laboratory as soon as the results are received so that your sample can be retested.

Soil testing is a three-stage process.

1. Sample the soil.
2. Get it analyzed.
3. Interpret the results.

SOIL SAMPLING

Inaccurate soil test results usually occur because samples were taken or prepared improperly. Here's how to do it right.

Planning the Sampling

✔ **Prepare a map showing all the areas to be sampled** and assign each a permanent number to use each time the field is sampled.

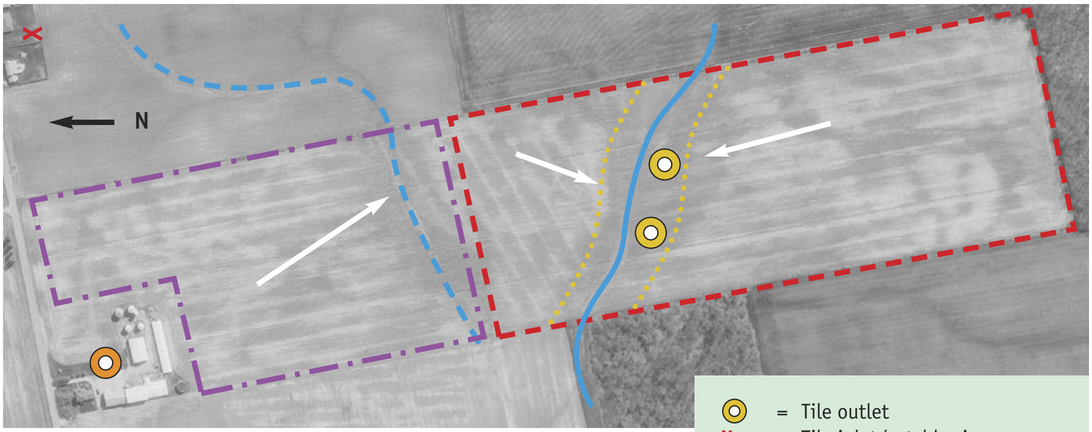
✔ **Where non-agricultural source materials (NASMs) are to be applied, soil sampling locations must be geo-referenced** – you must provide at least the GPS co-ordinates of one corner of the field, and the distance and direction of the area sampled.

✔ **Delineate areas that should be sampled separately.**

✔ **Prepare maps showing all relevant features to be sampled**, e.g., slopes, watercourses, previous field boundaries.

✔ **For each field, maintain a record** of the crops grown each year and the results of previous soil tests.

Maintaining good records of what was grown, where and when, and previous soil test results is well worth the effort in nutrient management.



Good maps aid in record-keeping and in directing custom applications.

Here's how to collect soil samples.

Step 1

Take only 6-inch soil cores. A consistent depth is important.

Step 2

Collect a minimum of one core per acre from random points over the field area. The recommended maximum sampling area is 25 acres (10 ha) to account for variation in soil fertility within and between fields.

Step 3

Use a clean plastic pail.

Step 4

Break up lumps of soil.

Step 5

Place thoroughly mixed samples directly into a clean sample bag in the field.

Step 6

Label samples according to field name.

Taking samples when the soil is dry enough to mix evenly will give more consistent results.

Timing the Sampling

✔ **Take soil samples when soil is dry enough to crumble easily and mix well**

- ► only a few grams of soil are used in the laboratory, so thorough mixing is critical.

✔ **Air-dry any samples that are too wet to be mixed easily, then mix them**

- ► never heat a soil sample to dry it, because this can affect the availability of several nutrients.

✔ **If possible, sample at the same time of the year and at the same stage of the rotation,** where appropriate

- ► on many farms, sampling after wheat harvest in a corn/soy/wheat rotation is easy to do, easy to remember, and gets the results back in lots of time to plan a fertilizer program.

See the soil nitrate section for specific requirements for soil nitrate testing.

Equipment

✔ **Use a sampling tube**

- ► a tube makes it relatively easy to obtain a core of soil, and consistently sample to the proper depth – usually 15 centimetres (6 in.).

Soil sampling tubes are available from many farm supply outlets and some local Soil and Crop Improvement Associations.

✔ **Collect the cores in a clean, stainless-steel or plastic pail**

- ► don't use a galvanized metal pail because the coating wil contaminate the sample with micronutrients
- ► don't use pails that contained chemicals (e.g., cleansers), as phosphates from detergent residue can also contaminate the sample.

Because soil fertility levels can vary a lot within short distances, the larger the area represented by a sample, the less reliable the results.

Samples can be taken with a shovel or trowel, but a tube is much more convenient.

Eroded areas should be sampled separately.

Sampling Pattern

The sample must truly represent the area being sampled.

✔ **Collect at least 20 cores,** even in small fields.

✔ **Take at least 2 cores per hectare** (or 1 per acre), randomly covering the entire area.

✔ **Limit the area per sample to no more than 10 hectares** (25 acres).

Subdivide larger fields into appropriately sized blocks that can be treated separately if required.

✔ **Avoid taking cores from:**

- ► fertilizer bands from the previous year and clumps of manure or crop residues
- ► areas where manure, fertilizer or lime were stockpiled
- ► old fencerows or barnyards
- ► dead furrows or highly eroded areas
- ► areas close to roads.

Divide large fields into smaller areas for soil sampling.

Sampling in Variable Fields

Fields with large variations in fertility pose a problem for both sampling and fertilization. Samples that represent the average of the whole field could result in over-fertilization of some areas and under-fertilization of others.

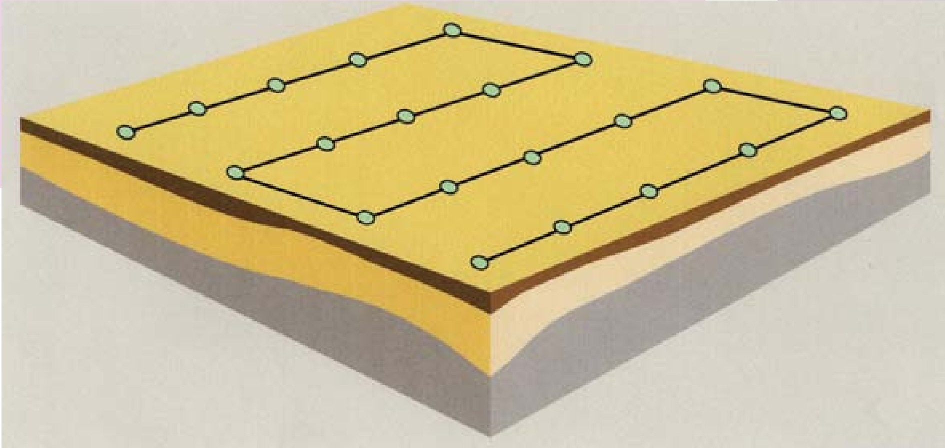
Past fertilizer or manure applications will have the biggest impact on current soil tests, and this usually followed field boundaries.

✔ **In areas that were once several fields, take a separate sample from the area representing each "old" field and submit each separately.**

In variable fields, sample different soil types separately, if possible.

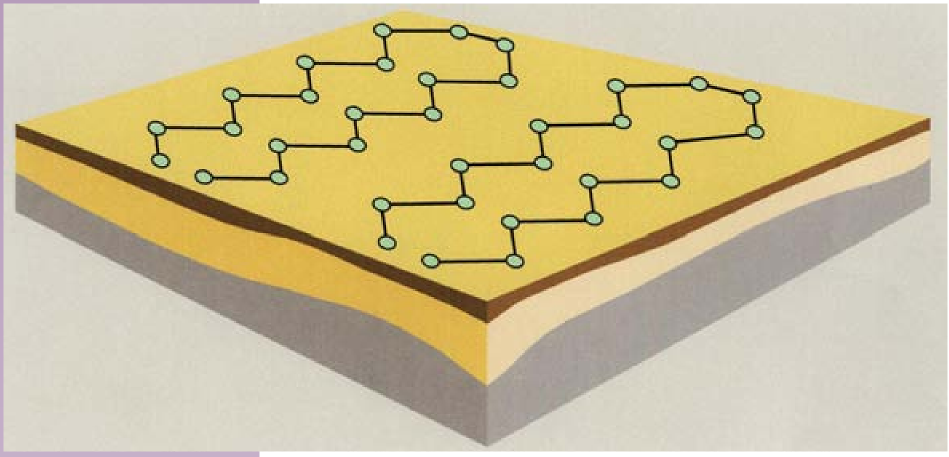
Grid Sampling

In some areas of Ontario, fields are sampled on a grid pattern. Samples are taken at regular intervals and the soil test results are loaded into a computer to generate maps showing fertility ranges across a field. These maps can be used by operators of variable-rate spreaders to apply different rates of fertilizer.



This is what grid sampling looks like in a field.

Natural variability is more difficult to deal with because it's irregular and often unpredictable. Soil pH and soil nitrate-N, in particular, can vary with soil texture and topography. If different zones in a field can be readily identified and fertilized separately, then it's best to take a separate sample from each zone.



Otherwise:

- sample the whole area randomly
- take separate samples from spots where the crop is doing poorly and submit them separately.

Use a zig-zag pattern to cover evenly the area being sampled.

Submitting Your Samples

Once enough cores have been collected, complete the next steps.

1. Mix the sample thoroughly.
2. Fill the soil sample box with this mixture.
3. Submit the sample to the laboratory of your choice
   - information regarding soil testing laboratories can be obtained from your local OMAFRA office or from the OMAFRA website (see back cover)
   - for results that are linked to Ontario research and the Ontario fertilizer recommendations, ask for an accredited test from an accredited laboratory.

Testing corn fields for nitrate-nitrogen can help reduce the risk of elevated nitrate levels in groundwater.

ONTARIO SOIL NITRATE-NITROGEN TEST

Soils can vary greatly in their ability to supply nitrogen. The amount of nitrate-nitrogen present in the soil at planting or side-dress time can indicate a soil's capacity to supply nitrogen.

In general, the higher the concentration of nitrate-nitrogen in the soil, the lower the amount of nitrogen required for optimum yields. Soil nitrate levels can be changing rapidly during the pre-side-dress sampling time, so interpretation of sample results should take into account the weather conditions at the time of sampling.

A soil nitrate-nitrogen test is beneficial for:

► crops that require relatively large amounts of nitrogen

► crops prone to lodging because of high nitrogen levels

► fields that have regularly received manure or other materials high in nitrogen

► fields where nitrogen may be lost through leaching (sands, gravel soils) or through denitrification (imperfect or poorly drained soils).

At time of printing, OMAFRA recommendations based on the nitrate-nitrogen soil test are available only for corn and spring barley.

Sampling Procedures for Nitrate-Nitrogen Soil Tests

Detailed recommendations for taking, handling, and submitting soil samples for nitrate-nitrogen analysis are found in OMAFRA Publication 811, *Agronomy Guide for Field Crops*.

The depth of your sample is important. Nitrate-nitrogen is more mobile in the soil than either phosphorus or potassium. Soil samples taken to a depth of only 15 centimetres (6 in.) are not reliable for nitrate-nitrogen.

✔ **Take a separate, deeper soil sample (30 cm or 1 ft) for the soil nitrate-nitrogen test.**

Caution: microbial action in the sample could change its nitrate content if it is not handled properly.

✔ **Chill or freeze samples** as soon as possible.

✔ **Pack the samples in insulating material when shipping them to the lab**
  ► samples may be air-dried by spreading thinly on a plastic sheet and leaving for 1–2 days.

In some situations, nitrogen recommendations based on the soil nitrate-nitrogen test should be modified. The nitrogen in manure, legumes, and other organic matter applied or plowed down in late fall or early spring may not have converted into nitrate and may not be detected by the soil N test. Information will be provided with the test results on how to make appropriate adjustments.

The recommendations based on the soil nitrate-nitrogen test have not yet been adequately evaluated where:

► legumes or manure were plowed down in the late summer, fall or early spring
► the crop is to be planted no-till following a perennial legume.

Sampling for nitrate-nitrogen must be deeper than for other soil tests.

In the early spring, soil nitrate-nitrogen tests may not show nitrates from organic materials applied in the fall.

Ontario Accredited Soil Test Laboratories Ltd.

FARM SOIL REPORT

Report 62269 for G Smith
Received 10/09/08
Printed 15/09/08

Soil pH tells you whether you will need lime or not.

Nitrate N is only analyzed on separate, deeper samples.

	Analytical Values					mg/kg	milligrams per	
#	Field I.D.	Lab #	pH	BpH	O.M. %	NO_3-N	Phosphorus NaHCO$_3$	Bray P
1	field 1 North half	998701	7.1		3.5		28 H	
2	field 1 South half	998702	7.2		3.2		33 VH	
3	field 2 North half	998703	6.9		4.0		35 VH	
4	field 2 South half	998704	5.7	6.8	2.8		25 H	
5	field 3 North half	998705	7.0		3.8		14 M	
6	field 3 South half	998706	7.1		3.3		26 H	
7	field 1 eroded knoll	998707	7.6		1.8		50 VH	

Field ID is critical to match soil test results to the correct fields.

Lime is recommended where the soil pH value indicates it is needed for the crop to be grown. The rate is based on the buffer pH.

Crop to be Grown:	Field I.D.	Recommended Application (kg/ha) N	P_2O_5	K_2O	Mn	Zn	Lime Recommendations (t/ha)
Corn*							
1	field 1 North half	100*	20	0			0
2	field 1 South half	100*	0	0			0
7	field 1 eroded knoll	100*	0	0	0	4	0
Alfalfa (Established)							
3	field 2 North half	0	0	0			0
4	field 2 South half	0	20	0			2
Soybeans							
5	field 3 North half	0	20	30			0
6	field 3 South half	0	0	0			0

**Refer to the Corn N Calculator for specific N recommendations for your soil, yield and previous crop conditions*

Fertilizer recommendations will provide economically optimum results when used with average or above-average management.

litre of soil (ppm)

K	Mg	Ca	Texture	Mn		Zn		% Base Saturation		
				ppm	Index	ppm	Index	K	Ca	Mg
187 VH	112	2049	M					4.1	8.0	87.9
220 VH	167	2236	M					4.3	10.6	85.1
210 VH	127	1242	M					6.0	11.8	68.9
175 VH	158	897	C					5.2	15.2	51.8
108 VH	118	2710	F					1.9	6.6	91.5
160 VH	120	2814	F					2.7	6.5	90.9
235 VH	150	3257	M	2.5	14	1	14	3.3	6.9	89.8

Most soil tests for micronutrients are unreliable. For manganese and zinc, the soil test is combined with soil pH to index availability.

Base saturation is estimated from the measured cations. It DOES NOT change fertilizer recommendations.

APPROACHES TO MAKING FERTILIZER RECOMMENDATIONS

Growers sometimes receive very different fertilizer recommendations for identical samples sent to different laboratories. Some variation in recommendations can be explained by the use of different testing procedures. Much of it, however, is due to the way in which test results are interpreted. The approach chosen should be appropriate to the yield potential of the crop in question, to the soil, and your farm management.

In this section we'll look at the principles underlying some of the approaches commonly used in Ontario and the strengths and weaknesses of each approach.

There are two major approaches to managing soil-test nutrient levels in fields: **sufficiency** and **build-up and maintenance**.

SUFFICIENCY

The objective of the sufficiency approach is to maximize net returns to fertilizer investments in the year of application. For fertilizer to show a profit, adding it must produce a yield response great enough to more than offset the costs involved in applying it. In other words, the fertilizer must produce additional yield above that possible without an application.

This means that soil tests are generally kept in lower ranges where crop response is expected.

The sufficiency approach carries no long-term financial commitment. The objective is to turn a profit to fertilization in one crop season. It therefore carries a higher risk of losses from under-fertilization.

For this reason, it's a good approach on land that is leased for short terms or when cash flow is limited and no capital exists for longer-term financial investments.

BUILD-UP AND MAINTENANCE

The build-up and maintenance approach seeks to build soil tests to levels where nutrients do not usually limit yields. This is accomplished by adding more nutrients than crops remove. The extra nutrients increase soil test levels. Enough extra is added every year to build soils to desired levels within the desired time frame – typically four years.

This approach accepts reduced or negative net returns to fertilizer additions in the build years in hopes of capturing greater positive net returns in future years, arising from higher, more consistent yields.

Fertilizer is viewed as a long-term investment that carries smaller risk that soil fertility will limit productivity. This approach assumes that as soil fertility levels increase, the probability of crop response to fertilizer declines.

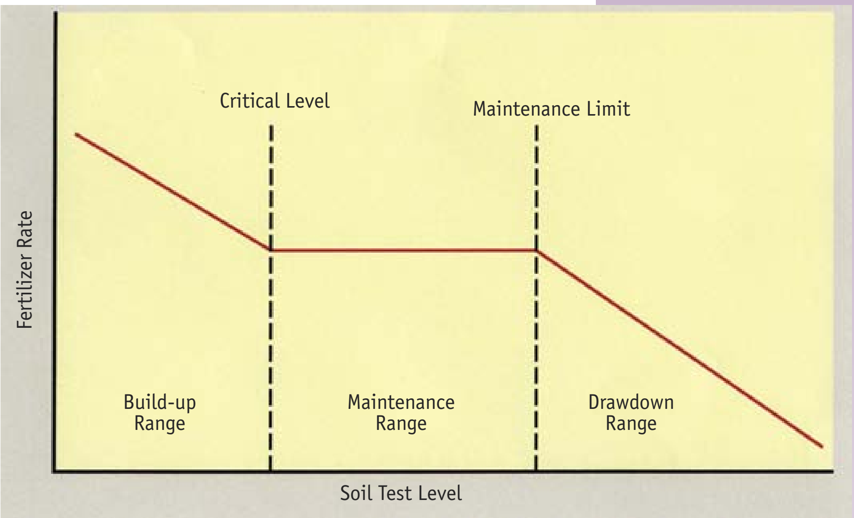
This long-term view is best on land that is owned or under a long-term lease and where cash flow is sufficient to sustain the initial capital investments.

strengths

- ► maintains soil tests for immobile nutrients at high levels
- ► ensures the nutrient does not limit crop yields

weaknesses

- ► rates recommended using this approach during the build-up phase are often higher than the yield increases can pay for in the short term
- ► not suitable for mobile nutrients (like nitrogen) where the nutrient not utilized in the year of application is subject to loss



In the build-up and maintenance approach, nutrients are applied to meet the crop's annual needs and to raise the soil test into the High rating range. For soils testing in the High range or above, fertilizer is recommended at the rate of crop removal so that soil test levels should not decline.

BASE SATURATION RATIOS

This approach is used mainly for potash recommendations, and occasionally for calcium or magnesium. Nutrients are applied in an attempt to balance potassium, calcium, and magnesium present in the soil within specified proportions.

strength

- ▶ recognizes antagonisms that may occur between calcium, magnesium and potassium

weaknesses

- ▶ may recommend unrealistically high rates of potassium because many Ontario soils are naturally high in calcium and magnesium
- ▶ there is little to no publicly available data to support a specific ratio or saturation percentage to recommend for economic profitability

In well-managed soils, the ratio of potassium:calcium:magnesium can be within a wide range, provided all are adequate, with little or no effect on crop performance.

INTERPRETING THE BASIC ONTARIO SOIL TEST

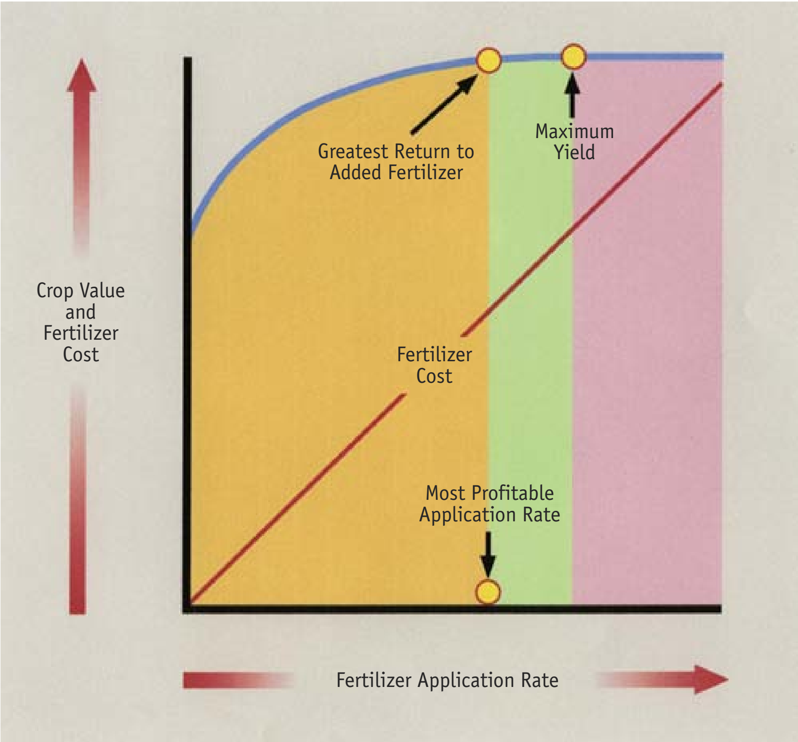
Reports from different soil testing laboratories may vary in format, but most contain the following information:

- ▶ **the recommended amount of each nutrient to apply**
  - ▷ the suggested rates are expressed in actual nutrients and must be translated into a recommendation for the amount and type of fertilizer material or manure to apply
  - ▷ recommendations for lime are usually shown in tonnes per hectare of lime with an index of 75

Results may be presented in many ways. The following units are approximately equal:

- **parts per million (ppm)**
- **milligrams per kilogram (mg/kg)**
- **milligrams per litre (mg/L).**

As the soil test value for a nutrient increases, the application of that nutrient produces less increase in yield, and the most profitable application rate decreases.



The response of crops to added nutrients decreases as the level of fertility is increased.

- ► **the numerical value of the soil analysis for each nutrient tested**
  - ▷ nutrient recommendations are based on this soil test value, using the results from field trials
  - ▷ although the soil test value is usually expressed in parts per million (ppm), it is best used as an indicator of the probability of crop response
  - ▷ crop nutrient requirements can be determined from tables in OMAFRA crop production recommendations publications, which are listed on page 71
  - ▷ by recording soil test values over several years, you can chart changes in soil fertility, as another indicator of the suitability of the rates being applied
- ► **the soil test rating for a nutrient, as an indicator of how abundant or deficient that nutrient is for the intended crop, and how likely a crop is to respond to adding that nutrient**
  - ▷ ratings may change if the crop is changed
  - ▷ ratings are also helpful in adjusting fertilizer recommendations, as indicators of whether to increase or decrease application rates from those suggested on the report.

The following chart shows what the ratings indicate for an intended crop.

PROBABILITY OF RESPONSE TO ADDED NUTRIENTS AT DIFFERENT SOIL TEST LEVELS

SOIL TEST VALUE	RESPONSE RATING	PROBABILITY OF RESPONSE	OPTIMUM FERTILIZER RATES ON RESPONSIVE SITES
LOW	High response (HR)	Profitable response in most cases	High
MEDIUM	Medium response (MR)	Profitable response in about half the cases	Medium
HIGH	Low response (LR)	Profitable response rare	Low – starter only may be sufficient
VERY HIGH	Rare response (RR)	Profitable response very rare	Very low – often starter only
VERY HIGH	No or Negative Response (NR)*	Generally not profitable to apply fertilizer*	Nil

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

If you're required to complete a Nutrient Management Plan (NMP), you must base your maximum allowable application rate for manure and other organic materials on results from an OMAFRA-accredited soil test. Send your samples to an accredited lab, ask for the accredited tests, and specify the OMAFRA fertilizer recommendations for the report.

Very few fields have uniform nutrient levels. Even with adequate soil test levels, there may be pockets within the field that will respond to added nutrients.

ONTARIO APPROACH

Phosphorus and potassium rates recommended by OMAFRA were developed using a sufficiency-level approach. Research and on-farm experience continue to demonstrate that these rates are sufficient for most situations, even when yield levels are well above average.

The recommendations are based on the results of field trials conducted for each crop to determine the optimum rate for each level of soil fertility. Only the amount that should maximize return to added fertilizer in the current cropping year is recommended.

When nutrients are applied as recommended, this approach will gradually increase soil fertility where recommendations meet or exceed the amount removed by the crop.

Crop yields show a pattern of diminishing returns to increasing rates of applied fertilizer – the amount of extra increase in yield decreases with each extra unit of fertilizer applied, and eventually will not cover the extra cost. The most profitable rate of nutrient application will produce a yield slightly lower than the maximum yield.

On soils with response ratings that are Low Response (LR) or greater, often it does not pay to apply that nutrient. But some growers may consider applying rates up to crop removal, to maintain the High soil test and to cover the possibility that the crop may respond to the nutrient. With a LR rating, you would expect a yield increase less than half the time.

General Recommendations

General recommendations for nutrient requirements for various crops can be found:

- ▶ in the appropriate OMAFRA crop recommendation publication (see below)
- ▶ through the nutrient management software or workbook (entitled "NMAN") available through OMAFRA, and
- ▶ on the OMAFRA website.

These recommendations have been set so that following them will provide the maximum economic return to fertilizer most often.

For greater detail and more crop-specific information, please see these OMAFRA publications:

Publication 611, *Soil Fertility Handbook*
Publication 811, *Agronomy Guide for Field Crops*
Publication 360, *Fruit Production Recommendations*
Publication 363, *Vegetable Production Recommendations*
Publication 370, *Production Recommendations for Greenhouse Floriculture*
Publication 371, *Growing Greenhouse Vegetables*
Publication 384, *Turfgrass Management Recommendations*
Publication 298, *Flue-Cured Tobacco Production Recommendations*
Publication 383, *Nursery and Landscape Plant Production and IPM*
Publication 610, *Production Recommendations for Ginseng.*

For accurate results, it's essential to follow recommended sampling techniques.

TISSUE TESTING

Chemical analysis of plant tissue can be used for diagnosing problems in the field, or for making fertilizer recommendations. While the analytical procedures for each will be the same, the sample collection and the interpretation of the results can be quite different.

Tissue testing can help diagnose and verify site-specific crop performance.

Tissue nutrient levels are affected by:

- **excessive levels of other nutrients**
- **low temperatures**
- **damage from soluble salts**
- **soil acidity**
- **root rot or other diseases**
- **insect damage**
- **compacted soil**
- **drought**
- **flooding.**

TISSUE TESTING FOR RECOMMENDATIONS

Tissue analysis is the most reliable way to estimate the nutrient status of tree fruits or grapes, since these perennial crops have root systems that extend far below the normal depth of soil sampling. A soil sample should be collected at the same time, to relate the nutrient status of the tree to soil conditions like pH.

Tissue analysis is also the most reliable way to identify deficiencies of most micronutrients in crops. It's seldom worthwhile to collect random tissue samples from crops with no noticeable problems, since the micronutrient supply in most of our soils is adequate. Regular tissue testing can be a benefit, however, in areas with a history of deficiencies of a particular micronutrient, or for high-value crops.

This type of test is normally collected at a particular point in the growth of the crop, and the results are compared to tables of "critical" values. Fertilizer is applied if the nutrient concentrations are below the critical value.

Collecting Tissue Samples for Routine Tests

Routine tissue tests are appropriate for many tree fruit crops, where the root system extends far below the top six inches of soil.

Collect samples from across the entire block, segregating different varieties or areas with particular production problems.

Samples must be collected at specific times during the crop's growth to provide meaningful information to guide fertilizer applications.

In some high-value annual crops, regular tissue testing can track nutrient accumulation and identify developing deficiencies so they can be corrected before yield is affected.

Deficiency symptoms often remain on old leaves after the crop has recovered.

To guide nitrogen applications, systems are being developed to use leaf colour or sap nitrate content as indicators of nitrogen status of plants.

TISSUE TESTING TO DIAGNOSE PROBLEMS

Tissue testing is most likely to be helpful where crops are growing poorly, and visual symptoms and the results of soil testing are inconclusive.

Tissue testing only shows the nutrient status of the crop on the day that the sample was taken. It does not indicate whether enough nutrients will be available to maintain the crop through the growing season or if the crop has recovered from an earlier deficiency.

Collect samples from the edge of the affected area. Plants that are slightly affected are often more reliable indicators than are those that are severely stunted or dead.

Interpret the results of tissue tests with caution and only after thoroughly investigating the condition of the crop and soil. Having a nutrient below the Critical level doesn't necessarily mean there will be any benefit to applying a fertilizer containing that nutrient.

Less information is available to help you interpret the results of plant analysis than for soil testing. Sufficient data have been collected for some crops to establish Normal and Critical ranges.

Please note that these guidelines are useful only if the samples have been taken at the same stage of growth and from the same part of the plant as the research samples. Therefore it's essential that the recommended procedures for collecting tissue samples be followed closely.

If a problem appears much before the recommended sampling stage, its cause might be identified by taking separate samples from the problem area and comparing the results with those from a healthy spot some distance away.

Additional information on tissue testing and the interpretation of the results can be found in the OMAFRA publications listed on page 71.

MANURE TESTING

SAMPLING

As with soil testing, proper sampling is the most important aspect of manure testing. The composition of manure can vary significantly from one area or depth of storage to another. Thus, it's essential that the sample represent the entire volume of manure, not just the surface. Be sure to collect sub-samples from several different areas of the storage or load and at varying depths.

Liquid Manure

Step 1

Agitate manure completely before taking samples.

Step 2

Collect a minimum of five grab samples from different parts of the storage. Grab samples can be collected either directly from the storage, or as the storage is being emptied.

Step 3

For large storages, collect at least one additional sub-sample per 200 m^3 of material.

Step 4

Use a clean, non-metallic container (e.g., a 20-litre plastic pail) to collect the samples.

Step 5

Place the grab samples in a larger non-metallic container with a lid (e.g., a plastic garbage can). Keep the container covered except when adding samples.

Step 6

Mix the resulting composite sample thoroughly.

Step 7

Collect the sample to be submitted to the lab from this mixture.

Step 8

Fill sample bottles to no more than one-half to two-thirds capacity, so that there is enough headspace in the bottle to allow for the build-up of pressure and prevent bursting. Normally, one 500 mL sample bottle is sufficient.

Solid Manure

Step 1

Obtain samples from different depths. This is most easily accomplished when the storage is being emptied. If a pile must be sampled at other times, then equipment to take cores from the entire depth of the pile will be necessary.

Step 2

Collect at least 10 grab samples, for piles of 100 m^3 or less. For larger piles, take proportionately more.

Step 3

Place these grab samples in a larger non-metallic container with a lid (e.g., a plastic garbage can), and keep the container covered except when adding samples.

Step 4

Once all the grab samples have been collected, empty them onto a large, clean surface for mixing. Chop and mix the material with a clean shovel, then divide the pile into quarters.

Step 5

Discard two opposite quarters and combine the remaining two. Repeat the process until a composite sample of approximately 1 kg remains.

Sample bottles are available from the laboratories providing manure analysis or from some OMAFRA offices.

SHIPPING

When the sub-samples have been mixed together thoroughly, follow the next five steps.

1. Half-fill a clean, plastic sample bottle and close the lid tightly.
2. Place the bottle in a strong plastic bag and tie bag securely.
3. Pack the bag, bottle, and completed information sheet into a box with sufficient packing to protect them from damage.
4. Keep the sample cool until it can be taken to the lab or shipped by courier
   - ► gases produced in samples kept at warm temperatures can cause the bottle to burst.
5. Samples must arrive at the laboratory within two days of shipping
   - ► time courier shipments so that there's no risk of the sample being held by the courier over a weekend.

BMPs FOR APPLYING NUTRIENTS

Put the right rate of each nutrient at the right time in the right place. In a nutshell, this is your BMP for applying nutrients.

The challenge, of course, is in reaching this goal for a wide range of crops, soils and weather conditions, and using a range of materials. The BMPs suggested here build on the basics, and try to account for the various conflicting forces to optimize profitability, practicality and environmental stewardship.

This chapter will guide you through:

- getting the right rate
  - accounting for nutrients from all sources
  - BMPs for application of liquid manure and biosolids
  - balancing nutrient input with removal in the long term
  - calibrating spreaders and planting equipment with fertilizer attachments
- at the right time
  - matching plant uptake
  - avoiding soil compaction
  - suiting the crop rotation
- in the right place
  - placing for maximum availability to crop
  - exercising extra care in areas at high risk of contaminating surface water or groundwater.

We'll begin with a brief outline of Nutrient Use Efficiency, since it is at the heart of improving profits and reducing environmental impacts from nutrient use.

"Nutrient use efficiency has many definitions. Several of them focus on a crop's ability to recover an applied nutrient. Short-term increases in such efficiencies are easily attained by reducing rates. But rates lower than optimum can reduce the long-term efficiency of cropping systems.

Sustainable efficiency focuses on:

- **ensuring all nutrients are used, not wasted**
- **meeting crop needs**
- **maintaining soil fertility."**

– Dr. Tom Bruulsema, International Plant Nutrition Institute

NUTRIENT USE EFFICIENCY

Nutrient Use Efficiency (NUE) refers to how well a crop uses available soil nutrients. As more nutrients are taken up and used by the crop, fewer nutrients remain in the soil to be lost (i.e., leached, volatilized) or immobilized.

Nutrient management systems that strive to improve NUE incorporate practices will:

- provide the required amount of available forms of nutrients when the crop needs them
- place nutrients where the crop roots can access them
- reduce the amount of nutrients (e.g., nitrate) in the soil when the crop can't use it
- account for and manage all sources of plant-available nutrients
- follow good cultural, soil and water management practices to encourage vigorous crop growth.

BMPs FOR IMPROVING NUE

AREA	BMP
CROP ROTATIONS	✔ rotate crops because crop growth is improved by following a crop with any crop but itself in a rotation, therefore increasing nutrient uptake ✔ grow a legume or forage before a crop with high N requirements ○ legumes and forages fix N from the atmosphere, which can be used by subsequent crops
VARIETAL SELECTION	✔ consider choosing cultivars that produce the highest yield with the same inputs as they will have the highest nutrient and water use efficiency
TILLAGE	In reduced tillage systems: ✔ band in the root zone as it's more beneficial (compared to surface broadcast)
NUTRIENT SOURCE	✔ don't necessarily try to supply all of a crop's needs with manure-based N ✔ apply manure to meet part of the N requirements of the crop, and then add nitrogen fertilizer for the balance to prevent over-application of phosphorus, and compensate for uneven manure application
TIMING	✔ use split application for grains and oilseeds, so most of the N is applied just before maximum crop uptake
TRAP CROPS	✔ use trap crops in the off-season to recycle plant-available N

Legume cover crops provide nitrogen to the subsequent crop.

Trap crops such as oilseed radish are cover crops grown in the off-season that trap and release applied nutrients for next year's crop.

Cover crops help prevent soil erosion and build soil organic matter, retaining more nutrients in the field.

Improve NUE and you will:

- **increase yields and improve product quality**
- **lower fertilizer input and application costs**
- **reduce the risk of runoff and groundwater contamination.**

Achieving this goal is hampered by variability in crop requirements, and imprecision in determining needs and application rates.

RIGHT RATE

RIGHT RATE – SUMMARY OF BMPs

BMP	DETAILS
✔ Soil test (see pp. 56–61)	• test regularly, same point in rotation, same place in field
✔ Tissue test (see pp. 71–72)	• for perennial and high-value crops, verify nutrient content and adjust application program • for all crops, diagnose nutrient deficiencies
✔ Interpret fertility test results (see pp. 68–71)	• use only the information from the test that is relevant to your situation • look for trends in soil fertility levels over time • determine whether sufficiency or build-up and maintenance is appropriate for your situation • use OMAFRA recommendations as a starting point
✔ Account for nutrients from all sources	• account for the available nutrients from manure or previous crop • meet the N needs of the crop with a combination of manure and fertilizer
✔ Adjust for environmental limitations	• account for liquid loading and runoff risks as defined by depth to bedrock, depth to water table, slope and soil texture
✔ Balance nutrient input with removal in the long-term	• meet crop needs for N • build up soil test P and K to desired levels and maintain them by balancing nutrient input with removal in the long-term
✔ Calibrate application equipment	• use BMPs to calibrate solid manure spreaders • use BMPs to calibrate fertilizer attachments for planting equipment • use BMPs to calibrate liquid manure application equipment

Taking care to maximize nutrient availability from these sources, and accounting for these nutrients in your fertilizer program will turn "waste" into "resource."

ACCOUNT FOR NUTRIENTS FROM ALL SOURCES

Since the manure and legumes are already on the farm, it makes sense to use these nutrients before spending money on fertilizers.

Where manure is applied to meet all the nitrogen needs of a crop, the amount of P applied exceeds the amount removed by the crop. If this is continued for a number of years, the phosphorus soil test will build up to the point where there is no benefit to the crop from additional P, and the risk of contaminating adjacent surface water increases.

With annual manure applications, this P buildup can be avoided. Limit the manure application to provide no more than two-thirds to three-quarters of the N requirement of the crop. The remainder of the N requirement can be provided by mineral fertilizer. Where manure is applied only once every two or more years, it may be appropriate to use a higher rate of manure N, but be sure the manure rates do not exceed the requirements of the crop.

Including some nitrogen from mineral fertilizers is a good idea. Nitrogen release from organic materials is dependent on the weather, and in cool, damp seasons, the crop may not receive enough nitrogen from organic sources for optimum growth and yield. Also, manure application is often uneven, so parts of the field receive insufficient manure to meet crop requirements. A blanket application of mineral N fertilizer helps to increase overall yields by ensuring all parts of the field have received some N.

Reducing the N application rate from manure also reduces the amount of P being applied. In situations where soil test P isn't excessive, use manure P to furnish all P requirements – provided N requirements are not exceeded. Be sure to account for N from previous manure applications.

Only 40% of the manure P is considered to be available to crops in the year of application, but this is primarily because of uneven application or placement where crop roots cannot easily reach the P in the manure. At least 80% of the total applied P will eventually contribute to an increase in soil test P.

"I use the NMAN program as a tool to balance nutrient inputs from manure and commercial sources. Balancing the nutrient inputs has saved us significantly in fertilizer costs, is better for the environment, and allows us to achieve what we feel is an economic yield."

– Dave Biesenthal, Walkerton

Manure application is often uneven, so some parts of the field will fall short of crop requirements from manure. Reduce the manure application rate, and supply the balance with a uniform application of mineral N fertilizer to ensure all parts of the field have received some N.

ADJUST FOR ENVIRONMENTAL LIMITATIONS

Some sites are inherently more vulnerable to losses (particularly nitrate leaching) than others, and application rates should be adjusted to reflect this. Risk factors include soils with high runoff potential, shallow soils over bedrock, and soils with groundwater close to the surface.

Two factors contribute to the risk of nutrients moving away from where they are applied:

- the total amount of nutrient applied, and
- the volume of material used to carry those nutrients.

Where manure is applied only once every two or more years, it may be appropriate to use a higher rate of manure N. However, be sure the manure rates do not exceed the requirements of the crop.

Nutrients that are not utilized by the crop and not held tightly by the soil can be carried to surface water or groundwater. This type of loss will occur equally with nutrients from commercial fertilizer and organic sources, so the key management factor is to **keep application rates balanced with crop requirements.**

More dilute materials, such as manure or biosolids, may be applied at high volumes to meet crop requirements for nutrients. There is a risk that these materials, particularly the liquid materials, might move from where they are applied either at the time of application or during a subsequent rainfall or snowmelt.

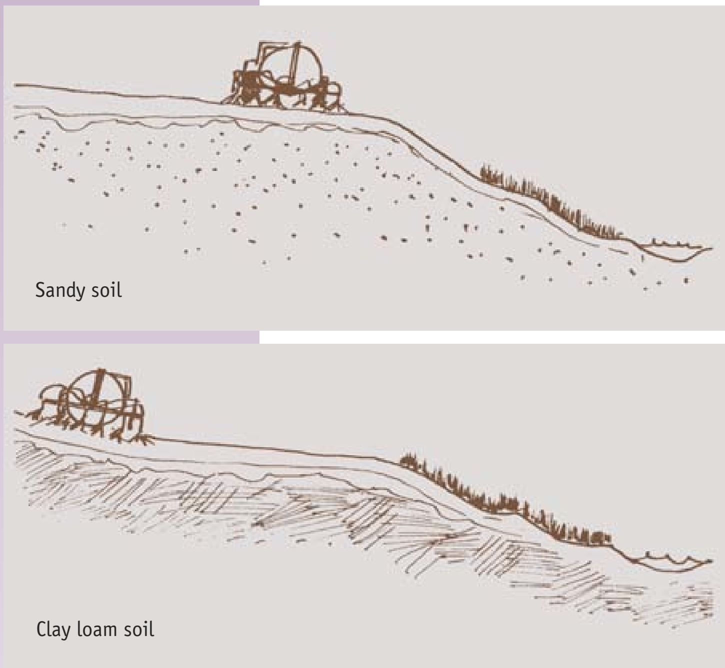
Ensure Proper Closure of Trenches from Fertilizer Openers

Where manure or fertilizer has been applied in bands running up and down slope, the slots left by the opener can be a starting point for rill erosion during rainfall events.

Even worse than the soil movement in this circumstance is the movement of concentrated nutrients that could be carried directly into surface water.

Ensure that equipment is properly set to prevent this from happening, or invest in a different toolbar configuration for effective closure of the slot.

APPLYING LIQUID MANURE AND BIOSOLIDS



The risk of surface runoff is less on sandy soil than on clay soil, but the risk resulting from excessive infiltration is higher.

Surface Runoff

The risk of runoff increases with soils of low permeability, and with increasing slope. The risk of runoff is much greater from a sloping field than from a level one, and from a clay soil than from a gravelly soil.

✔ **Don't apply liquid materials at rates where the material would run off the application site.**

Infiltration

Liquids applied at high volumes can move down through cracks, earthworm burrows and other large holes in the soil. This may increase the risk of contamination of groundwater, or of surface water if there is preferential flow to field tile. The risk of groundwater contamination is increased if there is fractured bedrock close to the soil surface, or if there is shallow groundwater.

Avoid preferential flow through large cracks or holes.

✔ **Keep application rates low enough that there is no ponding** on the surface.

✔ **Pre-till the soil** to break up any large cracks or earthworm burrows.

✔ **Avoid application when soils are wet.**

For more details on specific limits to manure application, refer to the *Manure Management* BMP book, or to the NMAN software and workbook.

Application of nutrients on exposed bedrock increases the risk of groundwater contamination, and will not provide any crop yield increase. Keep manure applications back at least 3 metres (10 ft).

Potential for Surface Water Contamination from Manure Runoff

Manure contains both nutrients and pathogens, which should stay out of water. Determining how far to keep manure applications from watercourses depends on many factors, including:

- soil moisture absorption capacity at the time of application
- slope near the watercourse
- soil texture, and
- manure type, application method and volume.

Where manure is incorporated a few days before planting, the separation distance may not need to be as wide as surface-applied manure (same slope and texture) in early spring. Where surface water enters a watercourse as a stream of concentrated flow, a separation distance that includes the path of flow would be more logical than a constant width along a watercourse.

BALANCING NUTRIENT INPUT WITH REMOVAL IN THE LONG TERM

Over the long term, the application of nutrients (particularly phosphorus) should balance fairly closely the removal of those nutrients by the harvested portion of crops. In low-testing soils, nutrient applications above crop removal are appropriate to produce profitable crops, and to build up the fertility of the soil.

For example, in a corn–soybean–wheat rotation, crop removal over the three years of the rotation would be about 400 lb/ac of N (190 from legume fixation), 145 of P_2O_5 and 140 of K_2O. Applying 7000 gallons/acre of liquid swine-finishing manure, split between the corn and the wheat, would supply 266 lb/ac of available N, 147 of P_2O_5 and 175 of K_2O. This balances the P removal very closely, and only slightly over-supplies N and K over the rotation.

If the manure were only applied to meet the N requirement of the corn, at about 4,000 gallons per acre, the phosphate and potash would be applied at less than crop removal, and the balance would have to come from either soil reserves or commercial fertilizer.

With commercial fertilizer application, sometimes the long-term view is appropriate. It's not uncommon, for example, to apply extra fertilizer to a corn crop, so there is more residual fertility in the soil to support the soybean crop to follow.

CALIBRATING FERTILIZER ATTACHMENTS ON SPREADERS AND PLANTING EQUIPMENT

Calibrate by following these steps.

1. **Assess the uniformity of spread pattern:**
   - ▶ drills/planters – rate delivered should be uniform across equipment width
   - ▶ broadcast equipment – typically, relative delivery rates should be higher immediately behind spreader, and drop steadily as the distance from point of spreading increases
   - ▶ where delivery rates are inconsistent, consult operator's manual for adjustment.
2. **Determine effective spreading width:**
   - ▶ drills/planters – the effective spreading width is the width of the equipment
   - ▶ equipment with spread patterns – where delivery rates drop off as the distance from the point of spreading increases
   - ▶ the spreading width is determined by the distance between the point on the right and left side of the swath, where the application rate is one-half the rate through the centre section of the swath.
3. **Calibrate:**
   - ▶ method #1
     - ▷ fill the equipment to a given level
     - ▷ travel a distance until area covered is equal to one acre
     - ▷ determine amount required to refill to the given level
   - ▶ method #2
     - ▷ weigh the equipment
     - ▷ spread several acres
     - ▷ reweigh the equipment
     - ▷ divide weight difference by number of acres covered.

Note: area covered is determined by multiplying the effective spreading width by the distance traveled.

For more detailed information on calibrating a liquid manure spreader, see the appropriate OMAFRA factsheet. It shows equations to calculate travel speed based on application rate required, width of application, and time it takes to empty a load.

For BMPs to calibrate solid manure spreaders or liquid manure application equipment, see the BMP book, *Manure Management*.

Once the effective spreading width is determined, the overlap of the one-half rate swaths will result in a uniform application rate over the field.

RIGHT TIME

RIGHT TIME – SUMMARY OF BMPs	
BMP	**DETAILS**
✔ Plan point in crop rotation	• plan your crop rotation and nutrient applications to maximize nutrient use
✔ Schedule to avoid compaction	• watch for soil moisture conditions and weather patterns – plan accordingly
✔ Schedule to match operational concerns	• consider availability of equipment and labour • consider windows of opportunity (e.g, spring planting)
✔ Choose best time in growing season to match crop needs	• pre-plant, with planting, side-dress, split application, fertigation
✔ Consider season of application	• fall vs. late summer • late fall vs. winter • spring vs. fall
✔ Use cover crops	• manage residual N
✔ For manure – choose the right time to minimize losses and nuisance	• avoid rainfall events and hot, humid days • consider neighbours' needs and concerns

PLANNED POINT IN CROP ROTATION

Commercial fertilizer is generally applied immediately prior to the time a particular crop needs the nutrient, and the economics of fertilizer application are applied only to that crop. There are times, however, when a longer view is appropriate.

The timing of manure application is more complex, since considerations such as the need to empty out storage, or concerns about soil compaction, come into play. You need to balance maximized nutrient use from manure with the availability of suitable land to receive manure through the year.

Including a diverse mix of crops in the rotation allows for improved nutrient utilization and increased opportunities for nutrient application.

If your fields are wet, reschedule field operations.

SCHEDULE TO AVOID COMPACTION

✔ **When the field is wet, stay off** with all equipment.

✔ **Ensure soil is at proper moisture conditions at tillage depth** before applying nutrient materials.

✔ **Prevent compaction** with:
- good drainage – tile drainage should be installed in fields with variable drainage
- longer crop rotations that include forages/cereals for improved soil quality
- forage crops – leave in for longer than one year.

✔ **Limit the amount of traffic** across a field.

✔ **Restrict the area that will be compacted** – create a long, narrow "footprint" with tire arrangement, e.g., radials, large tires, tracks.

✔ **Reduce pressure on the soil by keeping tire pressures low** to increase the size of the footprint (radial tires only).

✔ **Keep axle loads as low as possible**, ideally less than 5 tonnes/axle.

SCHEDULE TO MATCH FIELD OPERATIONS

✔ **Plan and schedule all field operations** – especially for narrow windows of opportunity such as spring planting season.

✔ **Consider contingencies for nutrient application** when the situation (e.g., weather, available equipment and labour) prevents scheduled application operations (i.e., early surface broadcast of P+K or lime materials).

CHOOSE OPTIMAL TIME IN GROWING SEASON TO MATCH CROP NEEDS

To ensure full-season crops like corn get sufficient nitrogen when they need it, consider side-dressing nitrogen just prior to the time of maximum crop uptake.

In general, fertilizer should be applied as close to when the crop needs it as possible, particularly for nutrients that can move easily in the soil (e.g., nitrogen) or nutrients that are subject to tie-up in unavailable forms. This has to be balanced with the availability of time and equipment to apply the fertilizer at the optimum time.

With manure and biosolids, there are additional challenges from the nutrients in organic form, which need to break down before they are available to crops.

The nutrients showing the greatest response to time of application are nitrogen and phosphorus. Nitrogen that is not taken up by crops can be lost through leaching or denitrification, so should not be applied much before planting. With full-season crops like corn, there is significant opportunity for loss between planting and crop uptake. It's therefore advantageous to side-dress nitrogen just before the time of maximum crop uptake. Fertigation provides the opportunity to fine-tune nutrient applications even more, providing multiple doses of small amounts of nutrients to meet the demands of the crop.

Some crops have a high demand for phosphorus as seedlings, so these crops benefit from starter applications of P. Transplanted crops, like tomatoes, often respond to phosphorus in the transplant water to encourage rapid establishment of the transplant. Other crops, like soybeans, do not have a high demand until the crop's root system is well-established, and these are able to utilize residual fertility in the soil almost as efficiently as banded fertilizer.

Fertigation is a means of applying fertilizer materials in solution to micro-irrigation systems. It provides an opportunity for growers to add both nutrients and moisture to high-value crops in measured amounts where and when the crops require them.

Nutrient concentration can be changed to meet the changing nutrient and moisture requirements of growing crops. For more information, please see the BMP book, *Irrigation Management*.

Definitions of Fertilizer-Timing BMPs

Preplant	–	fertilizer applied prior to seeding
Side-dress	–	fertilizer applied in row adjacent to crop row
Split application	–	fertilizer applied at least twice per season
Starter	–	fertilizer applied at time of seeding, generally with/near the seed

CHOOSE THE BEST SEASON FOR APPLICATION

For Fertilizers

The best season to apply depends on seasonal climate patterns, local weather and field conditions, crop grown, and fertilizer material.

On horticultural crops, late-season application of N-fertilizers on sandy soils can increase the risk of N leaching, especially if the field is over-irrigated.

For Manure

The goal of application is to get the manure to the desired crop when it needs it, in the right amount and with the least environmental impact. Notifying your neighbours of your intent to apply will ease concerns. The following chart summarizes application BMPs for each season.

For cool-season forages and cereals, spring is the time that growth and nutrient demand are greatest for nitrogen. P+K can be applied at any time – usually when they can be combined with another nutrient application.

For most field crops, the best season to apply most fertilizers is at planting time for early season growth and, if necessary, in late spring for the remainder of the requirement.

Forages can utilize nutrients from manure at times when other fields are unavailable for application.

SEASONAL BMPs FOR MANURE APPLICATION

SEASON	BMP	WATCH FOR:
SPRING	✔ apply to crops with the highest nitrogen requirement – high-yielding crops will use the N more efficiently ✔ pretill strips prior to injection to reduce tile effluent ✔ incorporate solid-spread, liquid-broadcast or irrigated liquid manure within 24 hours ✔ adopt good neighbour practices ✔ side-dress in row crops, e.g., dribbling	• soil compaction from tanker loads and traffic • runoff from excessive rates or poor soil conservation practices • denitrification – loss of N-gases to atmosphere on wet soils • tile effluent – when tiles are running, monitor and cease application if effluent is observed • rill erosion along strips and runoff • spills in irrigated or tractor-mounted systems • excessive odours and drift • ammonia loss – incorporate within 24 hours
SUMMER	✔ apply liquid manure to grassy pastures and hayfields – land is dry and less prone to compaction ✔ apply liquid manure to forage and pastures to be reseeded/rotated ✔ side-dress liquid manure on row crops ✔ apply liquid manure on cereal stubble ✔ apply liquid manure after forage crop cuts before regrowth has started	• ammonia loss from surface-applied manure if not washed in by rain • N loss from denitrification • potential for nitrate leaching if N not utilized • rill erosion and runoff along injection strips • "smothering" of forages – low rates and even application will prevent this
FALL	✔ apply solid or liquid manure prior to establishing winter cereals or cover crops ✔ apply and incorporate manure following corn or soybean harvest – as late in the fall as possible so soil temperatures have cooled	• risk of ammonia loss from surface applications onto warm (>10 °C) soils • risk of leaching if not absorbed by actively growing cover crop – avoid application on sandy soils • risk of denitrification in early fall • runoff and water quality risks • soil compaction from tanker loads and traffic
WINTER	✔ don't spread manure on frozen or snow-covered ground – store it	• runoff and risks to water quality

Winter Application

Winter application is not a best management practice. There is no crop to absorb the nutrients, and too great a risk of runoff to surface water.

There may be times, however, when winter application is necessary, and justified. If, for example, the storage has filled prematurely, it will be better to spread some manure in winter rather than face a spill when the storage overflows.

For more information about the limits on winter application, see the OMAFRA factsheet on applying manure and other agricultural source materials in winter.

USE COVER CROPS

Plant cover crops to reduce nutrient losses.

Some cover crops fix nitrogen, but all require nitrogen to grow. Grass cover crops (such as rye) and brassicas (such as oilseed radish) are excellent scavengers of nitrogen left behind by the main crop or from manure and fertilizer applications.

Cover crops can help to reduce nitrogen losses due to leaching. This reduces the potential for movement of nitrates to shallow aquifers. When the cover crop is killed, nutrients held in the plant tissues are returned to the soil and can be used by the following crops:

- **non-legume green manures** can serve as "catch crops" planted after harvest to absorb leftover inorganic nitrogen, thus minimizing losses
- **winter rye** grows anytime the temperature is above freezing, absorbing up to 60-lbs. soluble nitrogen during late fall and early spring
- **annual ryegrass**, while not as hardy as rye, is an excellent nitrogen scavenger if planted by September 15
- **spring cereals** planted in August will "catch" nitrogen in the fall, then winterkill, leaving an easy-to-till residue for early spring planting
- **overseeding a catch crop into vegetables** prior to harvest keeps the soil continuously covered by live plants, thus further conserving nitrogen
  - land that comes out of production during summer can be planted to a warm-season crop like **sudangrass or buckwheat** – since buckwheat is a light feeder, sudangrass may be the crop of choice for a really rich soil.

Oats planted in late summer will catch nitrogen released from applied manure.

Undersown catch crops efficiently reduced nitrogen losses when mineral fertilizer or manure was applied at normal rates (90–110 kg N/ha). Undersown catch crops can reduce nitrogen leaching by up to 60%, when compared with soil that was conventionally tilled in August–September.

Nitrogen use by the succeeding crop has been inconsistent from non-legume cover crops, but some estimates have suggested that 20–30% of catch crop nitrogen is available to the following crop under ideal management.

Don't let cover crops like rye get over-mature in the spring: otherwise, available soil N will actually be immobilized as the rye straw decomposes.

OFF-SITE IMPACTS

Avoid denitrification. Don't add manure to soils that are already high in mineral nitrogen.

Producers applying manure face the challenge of balancing the goals of nutrient efficiency with other agronomic, environmental and social objectives. Manure management practices designed to provide the maximum amount of nutrients, along with balanced manure nutrient application at or near the time of optimum crop uptake can, in certain circumstances, conflict with BMPs aimed at preventing soil compaction, field work timeliness, reducing greenhouse gas emissions, lowering survival rates of manure pathogens, and reducing odours.

As a manure manager, you must take conflicting goals into consideration, and select the best approach based on the unique conditions specific to your farm at the time of application.

Applying manure when it will maximize the availability of nutrients will generally also avoid off-site impacts to water or air quality. So it's a win–win: doing the right thing will also improve the state of your wallet. There are, however, some other considerations in manure application to ensure your neighbours are not adversely affected.

Weather

Weather conditions at, or shortly after, manure application will determine the impact you have on your neighbours or on the environment. A rain shower can help to incorporate manure into the soil, stopping odour and nitrogen loss, but a heavy rain will carry raw manure off the fields and into surface water. Warm, humid conditions will increase the volatile losses of both ammonia and odorous compounds from manure, and can create very intense odours. Windy conditions will dilute the smell, but will also carry it for long distances.

Applying manure to meet all your crop's nitrogen needs may also mean that levels of phosphorus and potassium will rise. If this is repeated over several years, high soil-test levels can build up and increase the risk of environmental harm. This buildup occurs faster if the nutrient value of manure is ignored, and fertilizer is applied as well.

Low-trajectory manure irrigation technology is designed to reduce odours and drift during application.

Plant field windbreaks to reduce odours during application.

Injecting liquid manure below the surface almost eliminates odours.

Neighbours

Like it or not, we live within a community and that means having neighbours. Whenever possible, try to avoid manure application when your neighbours are likely to be outside and the breeze is carrying odour toward their houses.

Many nuisance complaints due to odour occur just after manure has been applied to cropland. Fortunately, there are a number of management practices that will reduce odour intensity and duration if conducted timely and properly.

RIGHT PLACE

RIGHT PLACE – SUMMARY OF BMPs

BMP	DETAILS
✔ Put nutrients in the right place	• place nutrients where crops can access them • band fertilizers with row crops • inject liquid manure or incorporate immediately • avoid salt injury • avoid ammonia toxicity • consider foliar where suitable, e.g., Mn on soybeans
✔ Keep nutrients away from surface waters and wells	• establish buffer strips • follow BMPs for separation distances from surface waters, wells, and other sensitive areas • close the slot properly when subsurface-applying manure or fertilizer • reduce erosion and runoff through contour cropping, no-till, and reduced tillage systems
✔ Reduce groundwater contamination	• know where your environmentally sensitive cropland areas are • follow BMPs for application in areas shallow to bedrock and with shallow aquifers

PROPER PLACEMENT – METHODS

The effective placement of fertilizers can maximize both yield and nutrient use efficiency, thereby increasing net profit for the producer and reducing environmental impact.

Granular fertilizer can be broadcast (surface-applied), broadcast-incorporated ("plowdown"), surface-banded, or deep-banded.

Liquid fertilizer can be broadcast, banded with either a shank or dribble applicator, or applied to the growing plants (foliar application or fertigation).

Banding can be performed prior to seeding, with/near the seed ("starter" or "pop-up"), or after planting.

Fertilizer Placement Definitions

Band – any method where fertilizer is applied in concentrated strips, usually below the soil surface
Broadcast – uniform application across soil surface
Deep band – subsurface application, usually more than 10 cm (4 in.) below surface
Dribble – surface bands of fertilizer
Dual – simultaneous application of N and P
Fertigation – fertilizer applied with irrigation water
Foliar – liquid application to the leaf surface
Knife – band application below the surface
Plowdown – deep incorporation of broadcast fertilizer
Point injection – liquid fertilizer applied at single points
Pop-up – slang term for seed-placed fertilizer
Seed-placed fertilizer – fertilizer placed with seed; some portion may be in direct seed contact
Side-dress – subsurface application of fertilizer between the rows
Surface band – concentrated band of fertilizer placed on the surface of the soil rather than below
Top-dress – fertilizer broadcast on top of plants

Broadcasting is the most efficient way to apply large amounts of fertilizer quickly.

Broadcast

Broadcast fertilizer can be incorporated, which increases root contact and plant growth, especially for the more immobile nutrients such as P and K. Precision agricultural equipment can help the applicator avoid fertilizer distribution problems.

Banding

Fertilizer can be banded on the soil surface, or below the surface (subsurface banding).

Granular fertilizer can be subsurface-banded with either gravity-feed openers or air drills.

Fertilizer and seed can be applied simultaneously via air drills, which distribute the seed and fertilizer in a band up to 10 centimetres (4 in.) wide. Other designs use one line for seed, and one line for fertilizer, often 5 cm (2 in.) below and 5 cm to the side of the seed.

Liquid fertilizer, such as anhydrous ammonia and UAN, can be band-applied through knives mounted on shanks. It can also be surface-banded or “dribbled” over the row either beside or following a packer wheel.

Broadcast Versus Banding

It's hard to beat broadcast fertilizer for speed, convenience, crop safety and low cost of application. If there were no advantages to band placement of fertilizer, we could expect that all fertilizer would be broadcast. These advantages do exist, but we need to understand what advantages are provided for different nutrients, and manage accordingly.

Weed densities can be lower with banded nutrient applications compared to broadcast applications, because fewer nutrients are available to the weeds and more are available to the crop.

WHEN TO BAND

REASON FOR BANDING	WHERE IT FITS
REDUCING LOSSES TO THE ATMOSPHERE	• Nitrogen as anhydrous ammonia must be banded below the surface to avoid losses. • Urea or UAN solution is subject to volatilization if it's left on the surface, so subsurface banding prevents this loss without requiring tillage for incorporation. (Surface banding will have the same effect, but to a lesser extent.)
REDUCING LOSSES TO SURFACE WATER	• Concentration of both N and P in runoff water is reduced when these nutrients are placed below the surface rather than broadcast.
REDUCING IMMOBILIZATION IN THE SOIL	• Phosphate combines with many soil minerals to form insoluble compounds. Banding phosphate fertilizers, particularly in low-testing soils, reduces the contact between the soil and fertilizer, delaying the immobilization of the phosphate. • Some micronutrients are also subject to immobilization, so banding allows a longer time period before they are unavailable to crops.
INCREASING AVAILABILITY TO CROPS (STARTER OR SIDE-DRESS APPLICATIONS)	• Cereals and corn require high concentrations of phosphate at a seedling stage, when the root system is small. Placing a concentrated band of phosphorus fertilizer near the seed increases the availability to the plant when it needs it the most. • Some micronutrients (particularly zinc) are also required in highest concentrations by the seedling stage of the crop. • Availability of nitrogen and potassium can be reduced during dry weather. Banding places these nutrients into soil that is more likely to remain moist, enhancing availability to the crop. Care is needed that the bands of these nutrients are not too close to the roots. • Small amounts can be applied uniformly across the field.

Foliar Application

Due to the potential for leaf burn and the inability to supply sufficiently large amounts of required nutrients, macronutrients are generally not foliar-applied.

Conversely, micronutrients are sometimes foliar-applied because most are quite immobile in the soil, required in small amounts by crops, and produce positive growth responses.

Foliar application involves spraying liquid fertilizer directly on leaf surfaces.

Fertigation

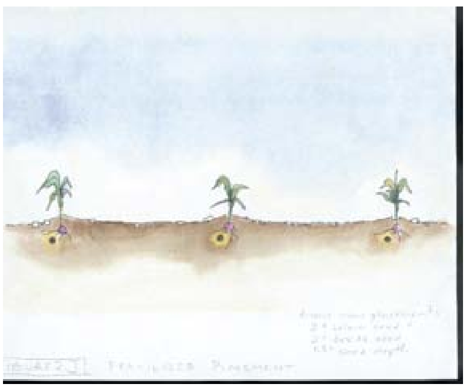
Fertigation is the application of fertilizer through an irrigation system. It can be an attractive alternative to traditional fertilization methods for some nutrients on particular crops (e.g., N) because fertilizer can be applied throughout the growing season.

PROPER PLACEMENT – FINE-TUNING

Roots and Placement

A goal of fertilizer placement is to maximize root–nutrient contact, without causing emergence or establishment problems from excess salt. This is especially important at the early stages of crop/root development.

Placing fertilizer in the region that will have the highest density of fine roots, or in a location that the fertilizer will move to this region, is needed to optimize yield. The impact of this placement will be greatest with nutrients that the crop requires in high concentrations during early growth (e.g., P and Zn on corn).



Proper fertilizer placement will avoid seedling damage.

This seedling has suffered salt burn.

Salt Effect

Placing fertilizer with the seed raises the possibility of poor germination and delayed emergence due to high salts.

The effect is highly dependent on the specific fertilizer's salt index. For example, KCl (0-0-60) and urea (46-0-0) have the two highest salt indices, and therefore have a high potential to negatively impact seed germination if placed with the seed.

Conversely, MAP (11-52-0) has a low salt index and causes only minimal germination problems.

Urea (46-0-0) and DAP (18-46-0) can both release free ammonia in the soil when banded, which can cause emergence problems.

These reductions depend on the concentration of fertilizer in the band, and its proximity to the row. Wide rows, narrow fertilizer bands, and placement with the seed all reduce the safe rates of fertilizer that can be banded.

Ammonia Toxicity

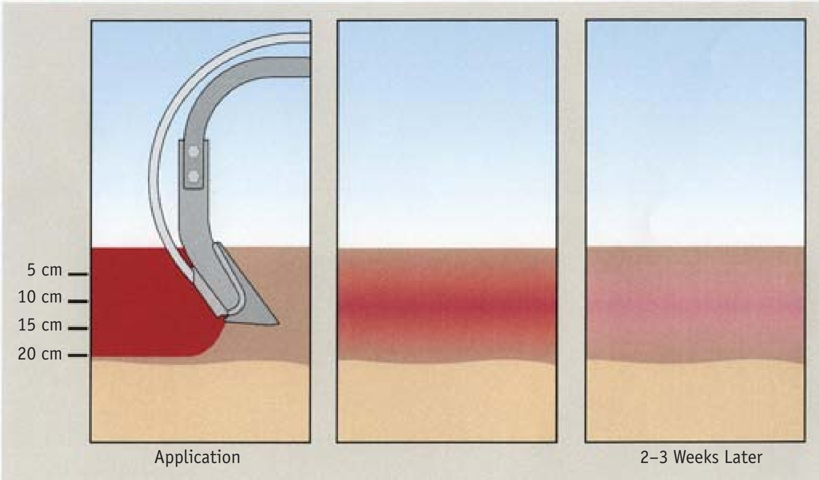
Roots are very sensitive to damage from ammonia. Side-dressed anhydrous ammonia must be placed well away from the row. Preplant ammonia must be applied in such a way that seedlings are not exposed to it.

The risk of injury from pre-plant anhydrous ammonia can be reduced by:

- ► applying several days before planting
- ► applying at least 15 centimetres (6 in.) deep
- ► using a narrow spacing between the outlets (to reduce the concentration in each band).

Ammonia can be released from urea or DAP (18-46-0). Use of either of these materials in starter fertilizer can greatly reduce the amount that can be applied safely.

Reduce volatilization losses by incorporating soon after application.



Ammonia concentration in the soil is reduced over time as the ammonia is converted to nitrate.

More complete guidelines for maximum safe application rates can be found in the OMAFRA production recommendations. See the back cover for more information.

✔ **Incorporate manure**.

The ammonium portion of manure can volatilize rapidly, particularly when the manure is applied in warm, breezy conditions. The rate of ammonia loss will be highest immediately after manure application, and decline as the ammonium in the manure is depleted. Injection, or incorporation as soon after application as possible, will stop ammonia volatilization and improve the availability of nitrogen from manure.

Where manure is incorporated, available nitrogen for the following spring's crop is predicted to be near 50% of the total nitrogen content of the sample.

Ammonia released by fertilizers can be toxic to plants.

KEEPING NUTRIENTS AWAY FROM SURFACE WATER AND WELLS

Crop nutrients are best kept close to crop roots. Use soil and water conservation BMPs and keep separation distances to help soil and applied nutrients remain in place.

✔ **Establish buffer strips.**

✔ **Keep soil and nutrients in place** with soil conservation BMPs and structures.

✔ **Keep your distance** – follow BMPs for separation distances from surface waters, wells and other sensitive areas.

Buffer Strips

Buffers are designed to keep crop operations away from surface waters and to reduce the likelihood that cropland soil and nutrients leave the field. They also help manage many other environmental concerns, such as soil erosion, flooding, and fish and wildlife habitat.

Buffer strips are strips of land that have permanent vegetation located next to bodies of water (streams, rivers, etc.). These small strips of land can have a big impact in protecting surface water.

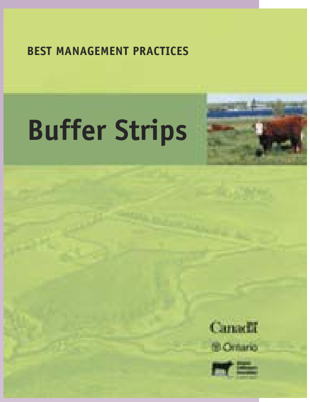
Buffers can reduce pollutants from reaching the water source through:

- ► sediment filtration
- ► infiltration
- ► plant uptake.

Sediment is trapped by dense vegetation in the buffer, keeping it out of the stream. This is particularly important for filtering out phosphorus that's often trapped on soil particles. The vegetation in the buffer area improves soil structure, and creates plant-root channels in the soil that improve soil infiltration. Infiltration slows down surface runoff and incorporates water-containing nutrients into the soil, where they can be used by plants growing in the buffer area.

Buffers also provide a physical separation of field activities from surface water, reducing the likelihood of spills or improper application having a direct impact on the stream or pond.

For a great deal more information about buffer strips, see the BMP book devoted to them.



REDUCING CROPLAND EROSION AND RUNOFF WITH EROSION CONTROL STRUCTURES AND SOIL CONSERVATION BMPS

As valuable as they are, even well-managed buffer strips cannot control erosion and runoff from cropland by themselves. Much of the risk of surface runoff and concentrated flow from cropland can and should be managed in the field by soil and water conservation structures and practices. Buffer strips are one part of this soil and water conservation system – in other words, they are the last line of defence.

Erosion control structures are in-field, constructed features designed to reduce soil loss and safely convey surface water to a properly protected outlet.

Soil conservation options range from reduced tillage practices (e.g., no-till, residue management) to slope management (e.g., strip cropping), to soil management practices that improve soil quality and reduce runoff.

Good artificial drainage may be the key to successful implementation of other BMPs. It can reduce surface runoff during some seasons by allowing more water to soak into the soil.

Erosion Control Structures – Water and Sediment Control Basins (WaSCoBs) for Concentrated Flow

In any given field, the rate of soil loss and runoff will be even greater if the runoff can collect in draws or convergent pathways, concentrating the flow as it runs downhill. Unchecked, these draws can lead to rills and gullies. To prevent or reduce the risk of gully erosion, you must:

- provide some form of cover to protect the floor of the draw
- reduce the steepness of the slope
- reduce the length of run, or
- divert the flow below the surface.

In fact, most erosion control structures are designed to attain one or more of these goals. For example, water and sediment control basins reduce the slope length and divert the flow below the surface.

You should seek technical advice for design and construction. Common examples include grassed waterways, drop pipe structures, terraces, and water and sediment control basins.

This is a well-constructed WaSCoB with established forage cover.

WaSCoBs are earthen embankments across draws, with retention basins and drop pipe structures to convey water to an adequate tile outlet. The duration of temporary ponding is carefully engineered to reduce the risk of damaging the crop.

Erosion control structures are designed to control erosion and safely convey surface water to an adequate outlet. You should always seek technical advice for design.

Soil Conservation Practices

Don't underestimate the value of healthy soils near riparian areas. Soil management BMPs improve soil quality and build resistance to erosive forces by adding organic matter, improving soil structure and increasing infiltration rates.

Soil management BMPs include cover crops, crop rotation and reduced tillage systems.

Grassed waterways are dish-shaped, graded and grassed channels placed in draws with subsurface drainage tile, intended to divert and transfer runoff to a properly protected outlet.

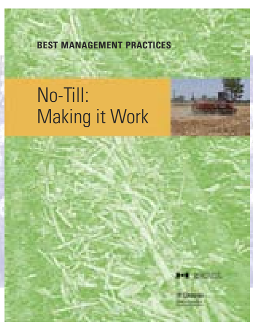
Cover crops such as fall-planted rye, oats and barley will tie up nutrients and protect the soil between crops.

Reduced tillage systems, including no-till, help maintain soil quality and will reduce erosion and runoff rates.

Crop rotations that include annual and perennial crops will add organic matter, help maintain soil quality, and keep soils covered longer.

Where conventional tillage is used, it will take many years of using a good crop rotation to build up organic matter. In conservation cropping systems, organic matter levels may increase more quickly.

For more details, see the Best Management Practices books, *Soil Management* and *No-Till: Making it Work*.



Cropland Conservation Practices

Conservation practices are non-tillage practices intended to control erosion by reducing the effect of slope and increasing soil cover. Two examples are shown below.

Contour strip cropping – alternate strips of row crops, cereals and forages on the contour level to slow surface flow and increases infiltration rates.

Field strip cropping – strips of row crops, cereals and forages at uniform widths across the main, simple slope. On complex slopes, this makes it easier to manage than contour strip cropping.

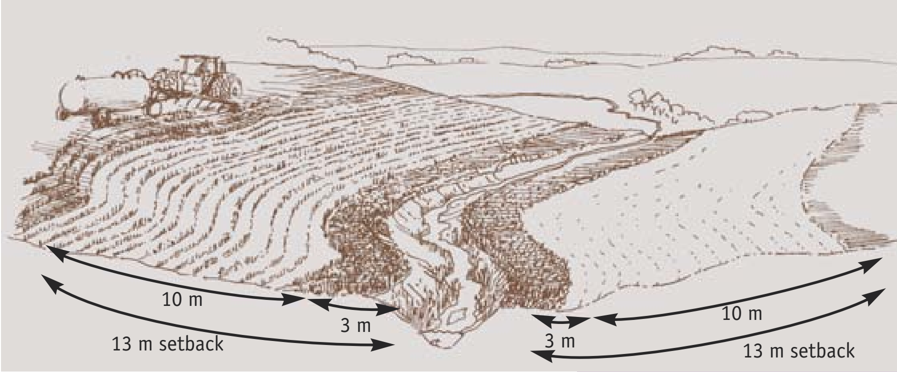
Separation Distances

Application of nutrients should be kept far enough away from surface water and groundwater to prevent contamination by runoff.

Separation distances are measured horizontally across the field to surface water and wells, and vertically to underground water features. The minimum distance required between water resources and nutrients vary with the risk associated of the material being applied.

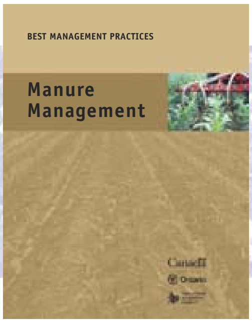
Separation Distance to Surface Water

In most cases, protecting surface water means a zone immediately adjacent to the surface water where nothing is applied, and a wider zone outside of this where extra care should be taken to keep nutrients from moving, by reduced rates, immediate incorporation, improved erosion control, or a combination.



For commercial fertilizers, a minimum separation distance of 3 metres (10 ft) should be established between the area of application and any watercourse.

For organic materials, the setback distances should be increased as the runoff potential from the field increases. On permeable soils in good condition, there may not be a large risk of runoff at the time of application, but movement during a subsequent rainfall can carry nutrients and other contaminants into surface water.



More information regarding setbacks from surface water can be found in the *Manure Management BMP*.

Separation Distances to Wells

Since any well is a potential conduit from the surface to groundwater, one of the most effective ways to protect water resources is to keep nutrients at a safe distance. This has led to the development of minimum separation distances to wells and groundwater when applying nutrients. The next chart outlines the setback distances required from wells.

SETBACK DISTANCES FROM WELLS FOR LAND APPLICATION OF NUTRIENTS*

SETBACK FROM...	FERTILIZER	MANURE	BIOSOLIDS	OTHER NUTRIENTS GENERATED BY FARMS (e.g., washwaters, silage leachate)
PRIVATE WELLS (Drilled)	3 m (10 ft)	15 m (49 ft)	15 m (49 ft)	15 m (49 ft)
PRIVATE WELLS (Other type)	3 m (10 ft)	30 m (98 ft)	90 m (295 ft)	30 m (98 ft)
MUNICIPAL WELLS	100 m (328 ft)	100 m (328 ft)	100 m (328 ft)	100 m (328 ft)

*All of the distances listed are measured horizontally across the surface of the ground.

Nutrient Leaching

Nutrients in solution will move with soil water. Leaching occurs when these nutrients (e.g., nitrates [NO_3^-]) move through soil pores below the root zone. The amount of leaching is related to:

- the concentration of nutrients in the soil solution
- the permeability of the soil, influenced by the texture (sandy or gravelly soils are more permeable than clays) and structure (presence of large cracks and pores) of the soil
- the amount of excess water available to carry nutrients down through the profile (greatest from late fall through spring)
- soil depth to bedrock or water table – less soil depth means quicker travel time.

Groundwater Protection

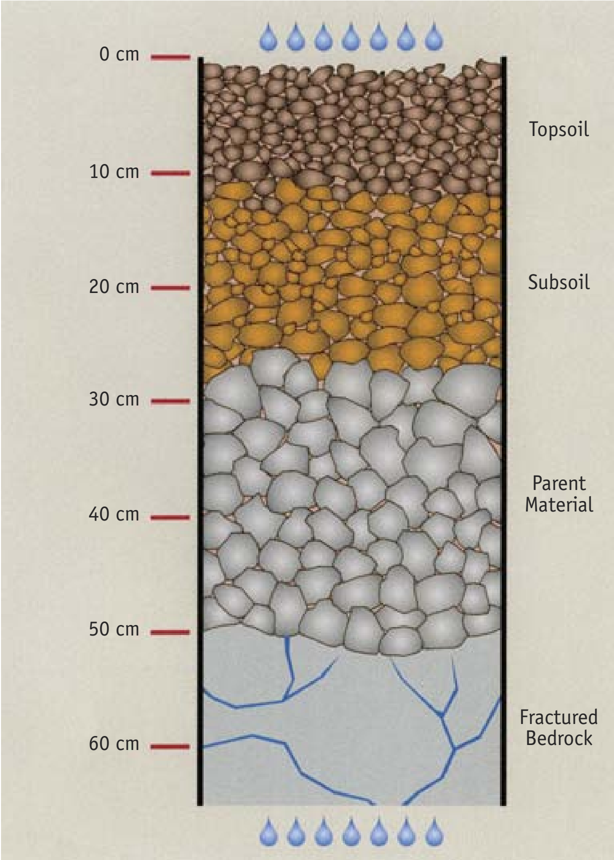
Most of the bedrock underlying Ontario's agricultural areas is extensively fractured. This is an advantage when it comes to providing water-bearing strata for wells to tap into, but it is a concern where the bedrock is close to the surface. Contaminants that enter this fractured bedrock can travel directly into an aquifer with little or no filtering,

Extra care needs to be taken with nutrient applications on areas with shallow bedrock. These areas are generally lower-yielding than deep soils, so the nutrient removal by crops will be less, and the ability of the soil to hang onto nutrients will be reduced.

✔ **Do not apply manure on or within 3 metres (10 ft) of exposed bedrock.**

For more details about limits to manure application on shallow soils, see the aforementioned BMP *Manure Management*.

Know where your environmentally sensitive cropland areas lie. Follow BMPs for application for areas shallow to bedrock and with shallow aquifers.



Shallow soils over bedrock provide less protection for groundwater because there's less opportunity for filtering or breakdown of contaminants prior to reaching fractured bedrock.

AND NOW IT'S UP TO YOU

It's time to put the theory and advice into practice. Both science and on-farm experience attest to the many good reasons for developing a nutrient management plan for your operation, not to mention the due diligence you demonstrate to your community.

Underlying any well-conceived plan is an understanding of the basics:

- knowing what nutrients do for crops and how they behave in soil will help you better predict crop needs
- understanding the cycles of these nutrients helps prevent losses to the system
- knowing the pros and cons of inorganic and organic nutrient sources helps you choose the right combination for your operation.

Use this book as a constant companion before you plan, as you plan, and as you adjust your plan in the coming years.

Agencies and Offices

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For More Information

A number of books in the Best Management Practices series pertain to facets of crop nutrients. They include:

Buffer Strips
Field Crop Production
Manure Management
Nutrient Management Planning
No-Till: Making It Work
Soil Management

For information on how to get copies, please see page i.

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