PRINCIPLES

IN THIS CHAPTER, WE EXPLORE:

- **nutrients required by crops**
- **sources of nutrients**
- **nutrient and water cycles**
- **the fate of nutrients in farming systems**
- **pathogens and sources of nutrients**
- **the Nitrogen and Phosphorus Indexes, and**
- **using the systems approach.**

Many factors affect a crop's ability to obtain nutrients from the soil. To develop an effective nutrient management plan, you need to know what these factors are, how they interact, and how they influence your options.

MAJOR NUTRIENTS IN FARMING SYSTEMS

Most production systems in agriculture – both livestock and crop – depend on ample supplies of available nutrients. **Macronutrients (nitrogen, phosphorus** and **potassium)** plus **secondary nutrients (calcium, magnesium** and **sulphur)** are considered essential for plant and animal life. The primary biological function of each is described in the following chart.

In corn, a lack of phosphorus causes purpling of the leaves.

MACRO AND SECONDARY NUTRIENT FUNCTIONS

NUTRIENT	FUNCTION IN LIVESTOCK	FUNCTION IN PLANTS
NITROGEN (N)	• proteins for muscle, skin, internal organs • enzymes for metabolic processes	• proteins for tissue growth • enzymes for metabolic processes • photosynthesis and respiration
PHOSPHORUS (P)	• bone growth • energy transfer • milk, meat or egg production	• photosynthesis and respiration • energy transfer • cell division
POTASSIUM (K)	• muscular activity • blood pressure regulation • pH buffering	• plant structure • photosynthesis and respiration • water uptake by roots
CALCIUM (Ca)	• bone growth and repair • milk or egg production • reproductive functions	• cell wall strength • cell formation • enzyme activation
MAGNESIUM (Mg)	• enzymes • muscle relaxant	• photosynthesis • protein and enzyme activation
SULPHUR (S)	• component of several amino acids in proteins and enzymes	• component of several amino acids in proteins and enzymes

SOURCES OF NUTRIENTS

Most of the nutrients taken up by plants are supplied by the soil itself. However, the levels of some nutrients in soil are inadequate to support optimal growth.

Nutrient materials that can be added to the soil come in two major forms:

- ► **inorganic,** e.g., commercial fertilizers
- ► **organic,** e.g., a major portion of manures, crop residues, biosolids.

Organic sources include:

- ► manure from your own farm or others' farms
- ► nutrients from incorporated legumes
- ► residual nitrogen from previous manure and biosolid applications
- ► washwaters and manure treatment by-products
- ► biosolids, or other non-agricultural source materials.

As you develop a nutrient management plan, use the nutrients that are most readily available to your operation.

A good way to account for crop nutrients in your operation is to begin with the ones already on your farm, such as manure and plowdown crops.

Off-farm nutrient sources, such as commercial fertilizers and biosolids, should be used to make up for the required nutrients not supplied by on-farm manure.

Using specific amounts of commercial fertilizer provides a consistent, balanced and reliable nutrient source. Examples include starter fertilizers and/or commercial sidedress of N for corn.

COMMERCIAL FERTILIZERS

Commercial fertilizer materials are one of the major sources of nutrients for crops. There are pros and cons with their use.

COMMERCIAL FERTILIZERS

ADVANTAGES	DISADVANTAGES
• are in known and consistent concentrations and so allow for precise and timely applications • are readily available • can be blended to match crop requirements	• must be purchased off-farm • don't add organic matter to the soil • risk losing nitrogen portion outside of the growing season • carry a high energy cost associated with processing

How commercial fertilizers are produced

Nitrogen in the form of ammonia (NH_3) is manufactured by extracting the nitrogen gas from the atmosphere and hydrogen from natural gas. The initial product is **anhydrous ammonia** (82% N). All other commonly used nitrogen materials are then manufactured from ammonia. The forms most commonly used are urea (46%) and urea ammonium nitrate (28%) solution.

Common **phosphorus** fertilizer materials are made by treating rock phosphate (an unavailable form of phosphorus) with various acids in order to make the phosphates available for plant growth. Nitrogen can be added to the process to make nitrogen and phosphorus blends and to make phosphorus more available.

Potash fertilizer is made by crushing potassium chloride (muriate of potash) and washing the product to remove other salts.

Commercial fertilizers can be applied precisely – when crops need them.

Unlike organic sources of nutrients, commercial fertilizers can be blended to match crop requirements.

MANURE

Manure provides the same nutrients for crop production as commercial fertilizers. One of the main challenges with manure, however, is that we can't change the proportion of nutrients to meet crop needs. We must take the manure as it comes. Some forms of manure, such as solid poultry, are relatively concentrated compared to liquid veal manure, which is very dilute.

Some types of liquid manure are dilute. This makes them easy to handle with a wide variety of application equipment, but costly relative to the concentration of nutrients available.

MANURE	
ADVANTAGES	**DISADVANTAGES**
• contains many required nutrients • provides nutrients for several years after application • supplies organic matter to soils	• has variable nutrient content • cannot always meet crop needs • produces odour • can lead to water contamination if not properly managed • can be difficult to apply to growing crops

Unchecked runoff from improperly applied manure can contaminate surface water with nutrients, bacteria and organic debris.

Erosion control structures, such as Water and Sediment Control Basins (WASCoBs), will help reduce sediment load from cropland runoff.

Nitrogen in manure is present in both ammonium (inorganic) and organic forms. The proportion of each depends on the type of manure, and the amount and type of bedding material added.

The organic nitrogen in manure is eventually converted to ammonium through microbial action, and then further converted to **nitrate**. Ultimately, all of this N may be taken up by plants either as ammonium or as nitrate.

Phosphorus is present in organic and inorganic forms in the solid fraction of the manure. Repeated manure applications will increase P levels. At low soil-test levels, manure P is only 40% available as fertilizer phosphorus in the year of application. The remainder becomes available over time. At higher soil-test levels, the full amount of manure P is considered available as fertilizer P to plants. As P levels increase, so does the potential for surface water pollution, and high enough levels will be detrimental to plant health.

The nutrient content of manure is influenced by many factors:

- ▶ nutrition – in general, a better feed-conversion ratio leads to lower excretion of N and minerals in manure
- ▶ feed additives – feed additives that promote growth may also reduce excretion of N and P
- ▶ dilution – manure storage and volumes of water collected can influence the concentration of nutrients in manure
- ▶ bedding – amount and type of bedding (e.g., wood shavings) that resists breakdown is prone to tying up manure nutrients (e.g., N) making them temporarily unavailable to crops.

BIOSOLIDS OR NON-AGRICULTURAL SOURCE MATERIALS

Biosolids, which originate from sewage treatment, pulp and paper, and other sources, provide many of the same nutrients for crop production as manures or commercial mineral fertilizers.

Certificates of Approval are required by the Ministry of the Environment before non-agricultural source materials (NASMs) can be applied. Application must be done in accordance with provincial guidelines.

Biosolids provide many of the same nutrients as manure and commercial fertilizer.

PATHOGEN SURVIVAL

Manure contains bacteria, viruses and parasites. The variety and numbers of these micro-organisms make manure a beneficial soil amendment. However, some are referred to as pathogens because they can infect other livestock and humans.

A pathogen is any virus, bacterium, or protozoa capable of causing infection or disease in other 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 passed to humans.

Few pathogens survive for long when outside a livestock 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 – very high temperatures reached during composting
- freezing or freeze/thaw cycle – whereas moderate temperatures may extend the lifespan of pathogens
- low humidity, sunshine and dry field conditions
- manure decomposition – produces chemicals that kill some plant pathogens
- high and low pH – acidic soils and the use of liming materials will reduce pathogen survival
- absence of oxygen – liquid manure and the wettest part of stored solid manure are considered anaerobic environments (i.e., no oxygen).

Soil is good 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 following macropore flow or preferential flow to shallow aquifers or through tile drainage systems.

Pathogens can move to surface water via surface runoff or by livestock accessing streams and creeks. Livestock operations located upstream from municipal drinking water supplies or recreation areas should recognize the potential risks and develop their nutrient management plan accordingly. Pathogens are unlikely to directly contaminate groundwater.

Pathogenic bacteria found in livestock may infect humans if there's a direct pathway to drinking water supplies or recreational waters. In water wells, these bacteria can be controlled with chlorine or ultraviolet light filtration systems.

Manure treatment processes such as anaerobic digestion and composting can generate conditions required to reduce pathogens in manure.

LIVESTOCK NUTRITION AND NUTRIENT OUTPUT

Diet and feeding strategies are of critical importance to livestock and poultry health, performance and product quality. You can reduce feed wastage and improve performance by adhering to the general principles of animal nutrition, feed analysis and ration formulation.

Science-based nutritional strategies will improve the nutrient balances on livestock farms. These strategies are quite simple to implement and can have a significant impact on nutrient output and your operation's profitability. The most promising and practical of these strategies focus on two main principles: optimizing input and maximizing the efficiency of utilization.

Phytase can reduce excreted P from hogs by up to 50%.

Feeding more closely to the animals' requirements will reduce nutrients excreted for all livestock types. For **ruminants,** balancing P-containing mineral supplements will reduce P excretion. And by balancing ruminally degradable and undegradable protein sources, N excretion can be reduced. For **non-ruminants,** the biggest impacts will be realized by using phytase, reducing P-containing mineral supplements, or maximizing protein efficiency by balancing amino acids (potentially with synthetic amino acids). Using these strategies, N and P excretion can be reduced by up to 50% (see table).

Applying nutritional strategies to reduce excretion will increase the need for precise feed ingredient evaluation, feed formulation, manufacturing and delivery. Reducing water wastage from drinkers can also decrease manure volumes. Practices that improve performance and reduce feed wastage will help reduce nutrient levels in manure materials.

Nitrogen and phosphorus excreted in feces and urine are the main sources of water pollutants from livestock agriculture.

HOGS: POTENTIAL IMPACT OF NUTRITIONAL STRATEGIES ON EXCRETION OF NITROGEN AND PHOSPHORUS

STRATEGY USED	POTENTIAL REDUCTION IN NUTRIENT EXCRETION
Improve feed efficiency	3% for every 0.1 unit in improvement
Minimize feed wastage	1.5% for all nutrients for every 1% reduction
Match nutrient requirements	6–15% for N and P
Phase feeding	5–10% for N and P
Split-sex feeding	5–8% for N
Phytase	2–5% for N; 20-50% for P
Formulate on nutrient availability	10% for N and P
Amino acid balancing	9% for N for every 1% reduction in crude protein
Highly digestible feed ingredients	5% for N and P
Pelletize the ration	5% for N and P
700–1000 micron particle size	5% for N and P
Enzymes: cellulases, xylanases, etc.	5% for N and P for appropriate diet
Growth-promoting feed additives	5% for all nutrients
Low-phytase corn	25–50% for P

Note: The actual reduction in N and P will vary. The closer the feeding program is to recommendations, the lower the nutrient reduction in manure.

NUTRIENT AND WATER CYCLES

NUTRIENT CYCLE

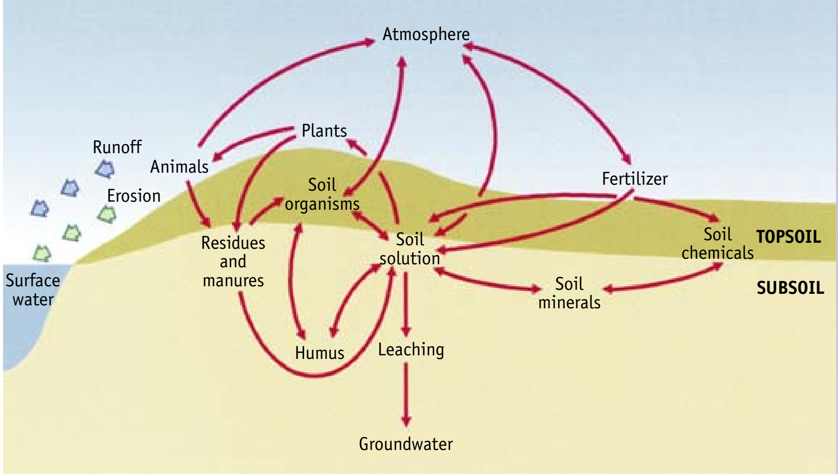
Nutrients are constantly cycling through the soil in different forms. As they do, nutrients are used by plants, lost from the soil, or converted to unavailable forms.

A basic understanding of the nutrient cycle and its interaction with the water cycle is the foundation of a sound nutrient management plan. It involves learning about 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 CYCLES



Nutrients exist in the soil in many forms. Chemical and biological processes change the chemical form of crop nutrients. Some nutrients move right through a cycle that consists of soil, crop, air, livestock and water components. Nutrient cycles consist of several components – soil, crops, livestock, manure, other nutrient materials, groundwater and surface water, and in the case of nitrogen and sulphur – the atmosphere.

Soil

- ▶ crop nutrients can be derived from weathering minerals in cropland soils
- ▶ nutrients can be added directly from the application of fertilizers, manure and other organic materials
- ▶ nutrients can be added indirectly to the soil from the breakdown of soil organic matter, soil animals, soil microbes, manure and crop residues
- ▶ soil microbes will break down soil organic matter, manure and crop residues for their own use or to transform to soluble forms – other microbes can transform some nutrients into gaseous forms that in turn escape into the atmosphere
- ▶ while in the soil solution, nutrients can be taken up by crops or microbes, exchanged with other nutrients from soil exchange sites, tied up by soil minerals (as unavailable forms) or leached to groundwater

Crops

- ▶ crops remove nutrients from soil solutions – when crop nutrients are harvested, they're lost from the system, fed to livestock or returned to soil as crop residues

Livestock

- ▶ livestock consume crops as feed or forages through grazing, use them for maintenance, production or reproduction, and return some portion of the nutrients directly or indirectly as manure additions

Manure and other nutrient materials

- ▶ when materials are incorporated:
  - ▷ organic portions are processed or tied up by soil microbes
  - ▷ inorganic portions go directly into the soil solution
- ▶ when materials are not incorporated:
  - ▷ certain nutrients may be directly lost to the atmosphere
  - ▷ others may be lost to surface runoff
  - ▷ remaining nutrients will go through the same process as incorporated nutrients

Water

- ▶ cropland runoff can remove nutrients from topsoil and deposit them downslope or into surface waters
- ▶ some nutrients in the soil solution are lost from the cropland system through leaching to tile drainage systems or to groundwater resources

Atmosphere

- ▶ atmospheric gases (e.g., nitrogen gas and methane) can be fixed by crops and soil microbes
- ▶ some nutrients in the soil solution can be transformed to atmospheric gases – some of which are harmful greenhouse gases (e.g., nitrous oxide, methane and carbon dioxide)

WATER CYCLE

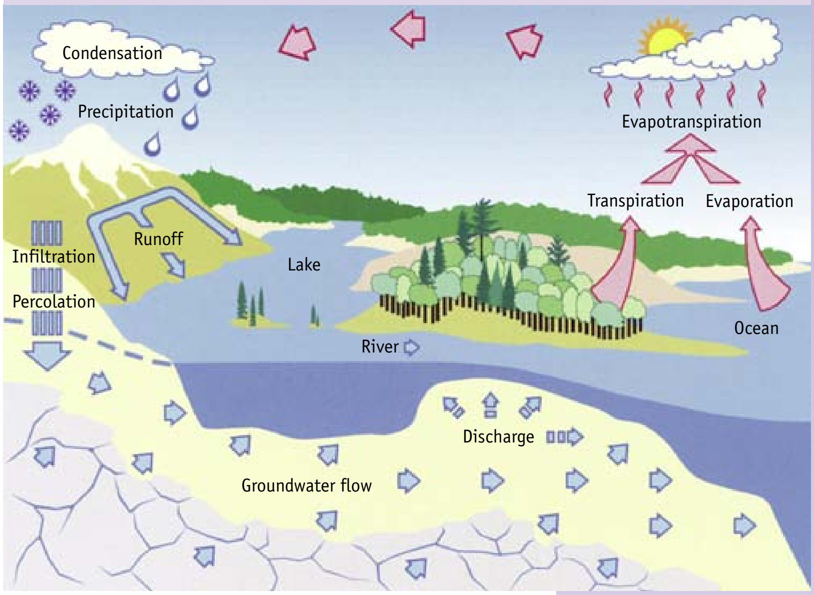
Water is in constant motion, continually recycling through the environment in a series of pathways called the **water cycle**.

Precipitation, mostly in the form of rain or snow, falls on land, buildings, and bodies of water. Precipitation can be temporarily stored in ponds, lakes and rivers, held by snow and vegetation, or stored as ice and snow.

Some of the water falling on land and buildings flows overland as runoff to bodies of surface water (e.g., lakes & rivers). Some of the water that's held by soil or vegetation will infiltrate through soil materials, to be stored as groundwater. Groundwater can then move to lakes, rivers, ponds, wetlands, wells, or to the soil surface. Groundwater flowing to the surface, or small surface water bodies, form part of a larger surface water system called a watershed.

At the soil surface, water can be evaporated directly to the atmosphere, or transpired (evapotranspiration) when plants release moisture during rapid growth.

THE WATER CYCLE



Water is in constant motion, continually recycling through the environment in a series of pathways called the water cycle.

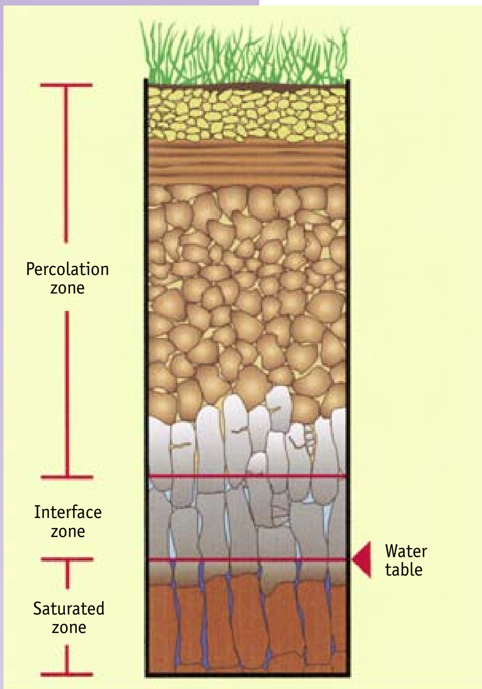
INTERACTIONS BETWEEN WATER AND NUTRIENT CYCLES

Pathways of water

In your fields, **precipitation** can:

- ▶ be stored on the surface as snow or ice
- ▶ evaporate at the soil surface
- ▶ infiltrate the soil
- ▶ be stored in the soil to be used by crops
- ▶ run off overland if precipitation exceeds the soil's infiltration capacity.

The proportion of water in any of these areas depends on soil characteristics (properties and quality), length and degree of slope, temperature and weather conditions, and the quality of cropland management.



Water moves – or percolates – through soil pores and cracks to a saturation zone known as the water table.

Nutrients and surface water

When water falls on a bare field in late spring, roughly two-thirds of it is evaporated back to the atmosphere, one-quarter runs off to ponds, watercourses, lakes and other depressional areas, and the remainder infiltrates the soil.

Continuous row-cropping, a decrease in forage-based cropping systems, and large equipment used in wet soil conditions can contribute to soil compaction, which reduces water's ability to percolate through soil. This can result in excess surface water in fields.

Excessive runoff is of particular concern, since it can take soil and the crop inputs in the soil (such as phosphates from applied commercial fertilizers or manure, and some pesticides) with it to pollute surface water. In addition to overland flow, excess surface water can lead to soil erosion. Erosion affects water quality because it can transfer high sediment loads to watercourses. That sediment will include topsoil, chemicals, nutrients (i.e., N and P) as well as microorganisms, including pathogens.

Nutrients and groundwater

Water enters soil through pores and cracks or holes and tunnels created by root channels, earthworms, insects and animals. Some of these pathways run continuously downward to the subsoil. These "macropores" can be direct channels for manure and nutrients applied at the surface to contaminate water. (tile and groundwater).

How much water enters will depend on your field's natural characteristics and your management choices.

Several natural characteristics affect the amount of water in soils, namely: soil type and structure, slope, depth to water table, depth to bedrock, precipitation, season and weather.

Management practices also affect soil moisture content. Soils with high amounts of crop residue will allow more infiltration and higher soil moisture. The same is true for soils with high organic matter content.

Soil type

The type of soil (e.g., sandy loam or clay) determines how much water is held in your soil, and how much is available for use by crops.

Your soil's water-holding capacity will also depend on the amount of organic matter and the number of soil layers. Soils with layers of various-textured soils (known as "stratified") will slow the speed with which water moves downward through soil profiles.

In uniform soils, the water table will move up and down with the seasons. If a layer of soil occurring naturally or caused by cultivation restricts water movement, a perched water table may be present.

Knowing your soil types is the first step to maintaining and improving them, and managing water effectively.

NUTRIENT LEACHING

Nutrients in solution will move with soil water. Leaching occurs when these nutrients, nitrates for example, move through soil pores and large cracks below the root zone. The amount of leaching is related to:

- **the concentration of nutrients in the soil solution**
- **the overall supply of available nutrients in the soil**
- **soil texture – water moves quickly through sandy soils, and cracked clay soils**
- **soil layering or stratification, which will slow the movement of water though the soil profile**
- **coarse fragments – soils with large volumes of stones and gravels are more prone to leaching**
- **soil depth to bedrock or water table – less soil depth means quicker travel time.**

The site features most connected to groundwater contamination are:

- soil texture
- depth to bedrock
- depth to groundwater.

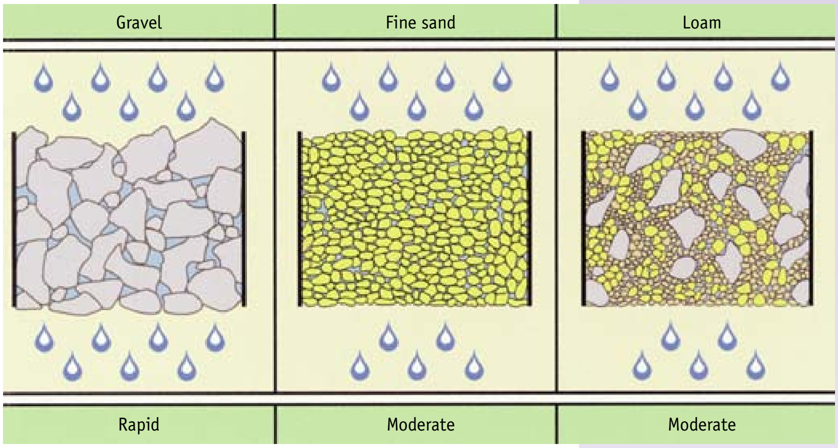
Soil texture

Soil texture, which is the relative coarseness or fineness of the soil particles, is the most important determining factor in measuring the ease and speed with which water and contaminants can move through the soil to groundwater.

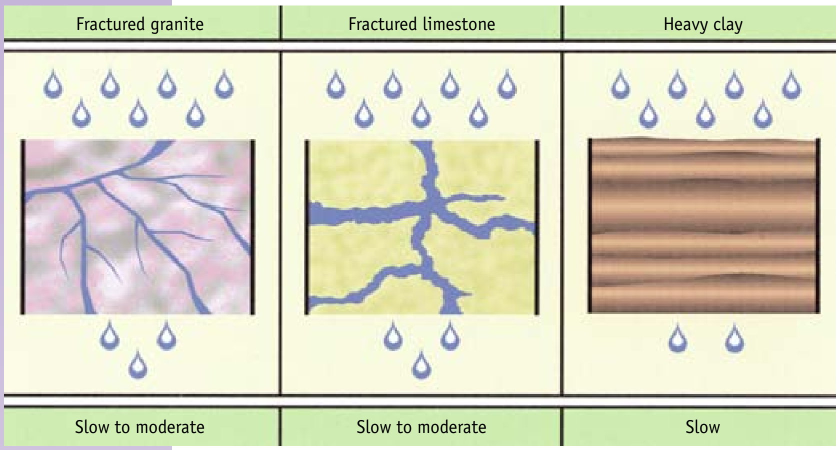
Coarse-textured soils such as gravels and sands have large pore spaces between the soil particles. This allows water to quickly percolate downward to the groundwater.

In fine-textured soils such as clays and clay loams, water and contaminants move through soil very slowly. They act as a natural filter and allow for biological and chemical breakdown of contaminants before they reach groundwater. Fine-textured soils provide better natural protection for groundwater.

Soil texture can be assessed using hand-texturing methods or with laboratory particle-size analyses. Soil maps can also help you identify soil texture at a particular site.



Water percolates quickly through sands and gravels and very slowly through clays.



Most bedrock types are not impenetrable. Water moves through cracks and fissures to shallow water tables.

Depth to bedrock

Shallow aquifers are often present in regions where bedrock is close to the surface. This is particularly true with fractured bedrock types such as limestone, dolomite, sandstone and weathered shales.

Open fractures in the bedrock allow rapid movement of water and contaminants to groundwater. If the depth of soil over the bedrock is shallow (less than 90 cm or 3 ft), there is little opportunity for filtration or restricting the flow of contaminants to the bedrock layer.

Depth to bedrock can be determined using hand or mechanical excavation equipment.

Soil maps and surface geology maps can give a general indication of bedrock depth. One simple visual clue of shallow bedrock depth is bedrock exposure at the soil surface. Also, if you've had experience with excavations or digging post-holes in the area, you'll have some indication if depth to bedrock is an issue.

Depth to groundwater or water table

Filtering and treatment of contaminated water by natural processes primarily takes place in soil above the water table in the unsaturated zone of soil. In a naturally occurring, high water table, water and contaminants have little time to move through unsaturated soil before reaching shallow aquifers.

Water table depths can fluctuate significantly, depending on the season. In Ontario, the water table is usually highest in the spring or fall.

Depth to water table can be assessed by:

- digging a hole in June or September and observing the depth to free water in the hole
- using soil colour features (rust spots and blue-grey colours in soil layers) and the soil drainage method by referring to a local soil map to assess drainage class (e.g., imperfect or poor drainage).

REDUCING THE RISK OF GROUNDWATER CONTAMINATION FROM MANURE APPLICATION ON SHALLOW SOILS

HYDROLOGIC SOIL GROUPS (HSGs):

Soils are classified into five Hydrologic Soil Groups based on the soil's runoff potential. These soil groups consider the water movement through the soils within a 90 cm (3 ft) soil profile rather than just the surface texture to a 20 cm (8 in.) depth. The HSGs are AA, A, B, C and D. AAs generally have the smallest runoff potential and Ds the greatest.

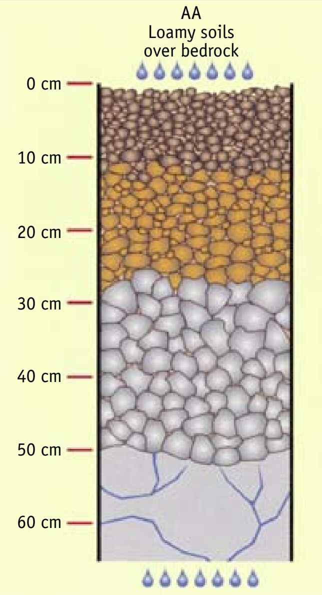
Soils that are shallow to bedrock would move up one category in HSG. For example, a clay loam soil that is shallow to bedrock on a HSG D would move up to HSG C.

All soils in Ontario have been rated into HSGs. These ratings help to determine N Index risk assessments and loading limitations for proposed nutrient application rates.

SHALLOW TO BEDROCK SOILS:

There are some locations where risk of contamination is so high that manure should never be applied. In other situations, risk may still be high, but management around manure type, application timing and incorporation may reduce those risks to acceptable levels.

- no manure should ever by applied on or within 3 metres (10 ft) of exposed bedrock
- where manure is applied without pre or post tillage, there should be no rain in the weather forecast
- where liquid manure is injected, the application band should disturb 50% of the surface area to reduce risk of a concentrated band moving downward



Group AA are all soils that are shallow to bedrock <60 cm (2 ft) and all group A soils that have a depth of less than 0.9 m (3 ft) to bedrock.

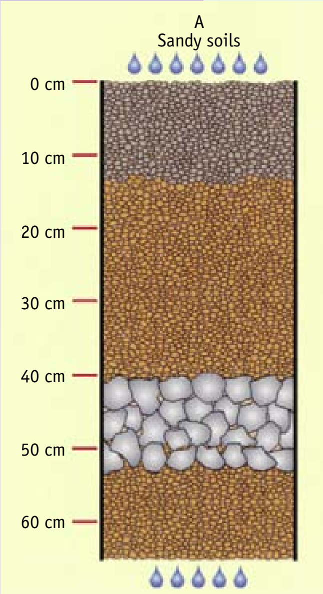
DEPTH TO BEDROCK	LIQUID MANURE	SOLID MANURE
0–15 cm (6 in)	no application	no application Oct–May; < 22 t/ha June–Sept (<10 ton/acre)
15–30 cm (6–12 in)	no application Oct.–May; pre-till, or <40 m^3/ha (<3600 gallons/acre)	pre-till, or <45 t/ha (<20 ton/acre)
30–90 cm (1–3 ft)	pre-till, or <40 m^3/ha (<3600 gallons/acre)	no restriction

SOILS WITH SHALLOW GROUNDWATER:

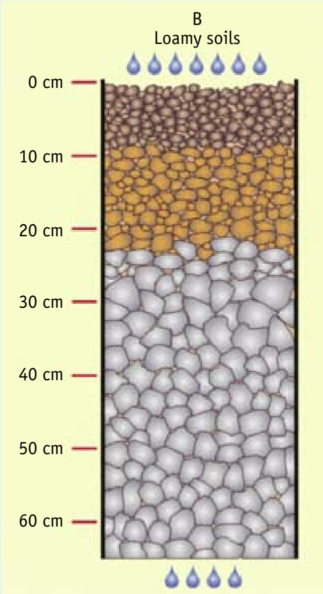
▶ when the water table is near the surface, saturated soils, wheel tracking and risk of getting stuck will discourage application – assess risk according to conditions at application time

POTENTIAL FOR GROUNDWATER CONTAMINATION

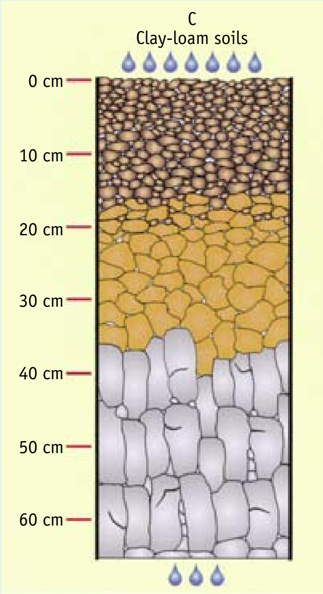
HYDROLOGIC SOIL GROUP	DEPTH OF UNSATURATED SOIL AT THE TIME OF APPLICATION		
	<30 cm (1 ft)	30–60 cm* (1–2 ft)	>60–90 cm* (>2–3 ft)
CATEGORY A: RAPID (SAND)	no application	high	moderate
CATEGORY B: MODERATE (LOAM)	no application	moderate	low
CATEGORY C: SLOW (CLAY/LOAM)	no application	low	very low
CATEGORY D: VERY SLOW (CLAY)	no application	low	very low



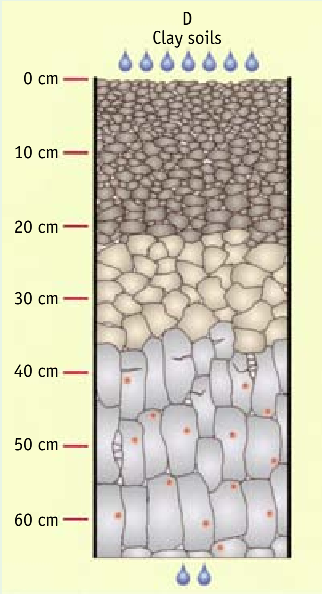
Group A is sand, loamy sand or sandy loam types of soils. They have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels and have a high rate of water infiltration.



Group B is silt loam or loam. It has a moderate infiltration rate when thoroughly wetted and consists chiefly of moderately deep to deep, moderately well to well-drained soils.



Group C soils are sandy clay loam. They have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine structure.



Group D soils are clay loam, silty clay loam, sandy clay, silty clay or clay. This HSG has the highest runoff potential. They have very low infiltration rates when thoroughly wetted and consist of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface and shallow soils over nearly impervious material.

Application guidelines are determined from the following table for the risk category identified:

GROUNDWATER CONTAMINATION POTENTIAL	LIQUID MANURE	SOLID MANURE
HIGH	No application	Pre-till, and <45 t/ha (<20 tons/acre)
MODERATE	Pre-till, and <40 m^3/ha (<3600 gallons/acre)	Pre-till
LOW	Pre-till or <40 m^3/ha (<3600 gallons/acre)	No restriction
VERY LOW	No restriction	No restriction

NITROGEN: ENVIRONMENTAL RISKS AND THE N INDEX

Some of the very same macronutrients that are essential for sustaining animal, crop and soil life are, in excessive quantities, harmful to water and air quality.

Regardless of how nitrogen is applied to the soil, much of it will eventually be converted to the nitrate 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.

High nitrogen and phosphorus levels in water allow excessive growth of aquatic plants.

Nitrogen, when in nitrate (NO_3^-) form, moves easily with soil water. As a result, it can travel through and below the root zone, and potentially enter groundwater.

The level of nitrate-nitrogen in 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, or from saturated soils, by conversion into nitrogen gas by soil bacteria through a process called denitrification.

In soil, the nitrogen in urea is converted to ammonium. However, under certain circumstances, the ammonium can be converted to ammonia gas. A significant portion of the nitrogen content of urea can be lost when urea is left on the soil surface or on crop residues under warm, humid conditions with high soil-moisture content.

The fate of manure nitrogen

In manure, nitrogen has two forms: inorganic and organic. The main form of nitrogen will vary, depending on the type of manure (liquid vs. solid).

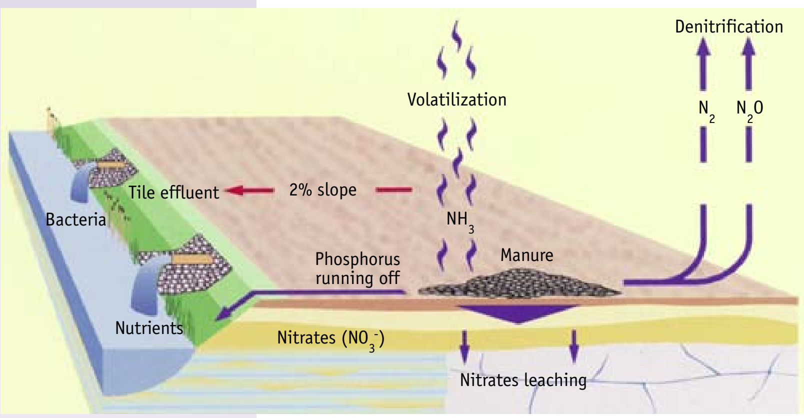
Manure runoff can harm aquatic habitat. Ammonia gas from manure runoff may cause fish kills.

A key inorganic form is **ammonium (NH_4^+)**. NH_4^+ is available for plant growth but highly volatile as it can convert to ammonia gas (NH_3). NH_4^+ can be a problem if raw manure runs off into surface water because the toxicity of the ammonia results in fish kills.

The organic nitrogen component in manure is quite stable and will eventually become converted to ammonium through a process known as mineralization. In soil, ammonium will be held to soil surfaces (clay and organic matter). It is available to plants and is subject to a process called nitrification – whereby soil microbes change ammonium to nitrite and nitrate (NO_3^-).

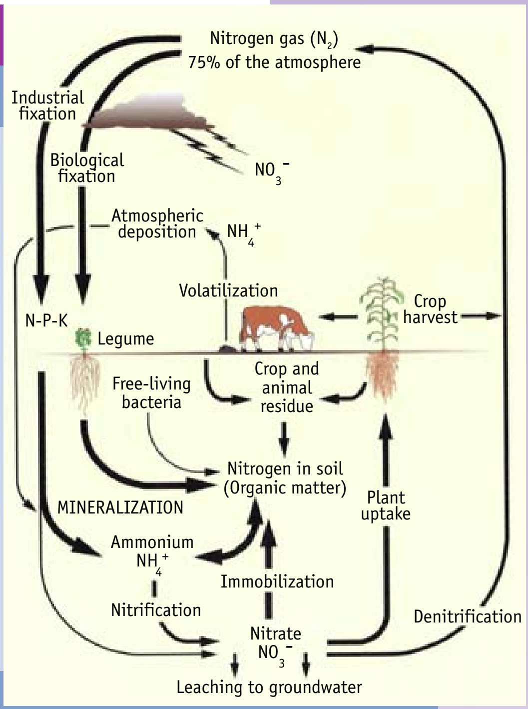
Nitrate in the soil is subject to several fates:

- taken up by plants
- absorbed by soil microbes (immobilized)
- leached through the soil beyond the root zone
- found in cropland runoff
- transformed, in wet soils, by soil microbes through denitrification to N gases such as nitrogen gas (N_2) and nitrous oxide(N_2O). Nitrogen gas makes up 78% of the atmosphere while nitrous oxide is a greenhouse gas that has about 300 times the warming capacity of carbon dioxide.



Applied manure nitrogen adds ammonium and nitrate to the soil N reserve. Some of this N is lost as ammonia (NH_3). Much of this ammonium and nitrate may be taken up by plants. Nitrate not taken up by plants can be leached or converted to nitrogen gas.

NITROGEN CYCLE – Here's what happens to the "key players" in the nitrogen cycle.



N-INPUT	PROCESS / FATE
COMMERCIAL FERTILIZERS	Nitrogen gas (N_2) is fixed to manufactured fertilizers with urea, ammonium and nitrate components
MANURES	Solid and liquid manure, wastewaters and biosolids add organic and inorganic nitrogen forms to the soil
LEGUMES	Nitrogen gas (N_2) is fixed by microbes in soil and legume plants and provides an organic N-form to the soil
CROP RESIDUES	Organic N is added from crop root systems and residues (including cover crops)
ATMOSPHERIC INPUTS	Some NO_3^- is added to soil by heat and lightning
N RESERVES IN THE SOIL	**PROCESS / FATE**
SOIL ORGANIC MATTER	Organic N is part of soil organic matter (humus)
AMMONIUM (NH_4^+)	NH_4^+ can be held on soil and humus particles on exchange sites
NITRATE (NO_3^-)	NO_3^- in soil solution and in moisture is held by soil particles
N CHANGES IN SOIL (by soil microbes)	**PROCESS / FATE**
MINERALIZATION	Organic N breaks down into ammonium
NITRIFICATION	Ammonium is converted to nitrate
IMMOBILIZATION	Ammonium and nitrate are tied up by soil organisms
VOLATILIZATION	Conversion of ammonium-N to ammonia gas
DENITRIFICATION	Conversion of nitrate to nitrogen gases, N_2 and N_2O
LEACHING	NO_3^- in soil solution moves downward out of root zone potentially into groundwater

As we saw earlier in this chapter, there are many factors that influence just how easy it is for nitrogen and phosphorus to follow pathways to surface water and groundwater. Soil type and slope, proximity of ground or surface water, the weather and the season, your management practices and the fertility levels will all affect risk.

To assess risk, those factors that influence nutrient movement off the field need to be looked at on a site-by-site basis. Factors are then weighed together to arrive at a risk "Index", better known as the Nitrogen or Phosophorus Index. The following section explains how these work.

The Nitrogen (N) Index

The Nitrogen Index is a tool for reducing the risk of nitrate contamination of groundwater. It evaluates the vulnerability of nutrient management practices with respect to the movement of nitrates. The N Index combines source and transport factors to assess the risk of nitrate movement to groundwater on a field-by-field basis.

The nitrogen cycle is complex, and factors contributing to both nitrate source and transport often interact. When manure nitrogen converts to the nitrate form, it will move through the soil with water rather than bind to soil particles.

Source risk factor

The net amount of nitrate in the soil following harvest may have come from:

- nitrogen applied for growing the current year's crop
- nutrients applied after crop harvest
- residual nitrogen in crop residues, especially legumes
- mineralized N and nitrified materials from soil organic matter.

In the case of nitrogen applied for this year's crop, it is the amount of N applied in excess of crop requirements that is of most concern.

For nutrients applied after harvest – as with fall application of manure – there is an increased risk of nitrate movement to groundwater. The timing and method of application and the type of manure will influence risk.

The risk of N movement is greatest on shallow soils.

Transport risk factor

The transport factor evaluates the opportunity for nitrate to move down, with water, through the soil to groundwater.

In Ontario, crops are normally removing more water from the soil during the growing season than is being added as precipitation, so there's no leaching during the growing season except under abnormally wet conditions.

The fall, winter and early spring usually brings more precipitation than evaporation, so water can move down through the soil profile. This is the reason we are concerned with the amount of nitrate in the soil after the growing season, when there is no crop to absorb the nitrate and the risk of loss is high. Cover crops grown after crop harvest help reduce this risk of loss by taking up nutrients and holding them in an organic form until spring.

PHOSPHORUS: ENVIRONMENTAL RISK AND THE P INDEX

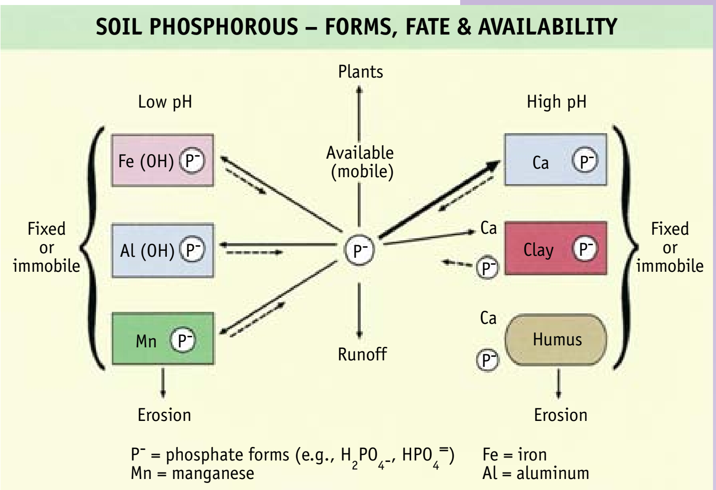
In manure, phosphorus (P) is associated with the solid fractions; therefore a higher portion is present in solid manures.

Inorganic P in solution is referred to as phosphates (PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^{-}$). Phosphates are very reactive in soil and combine with calcium, magnesium, iron, manganese, or aluminum, and become attached to the soil particles.

In soils with low pH, phosphorus is immobilized to form iron, manganese and aluminium compounds. In soils with a high pH, phosphorus can be found attached to clay and humus particles or tied up with calcium and magnesium compounds. Only a small amount (5%) is available to plants at any given time.

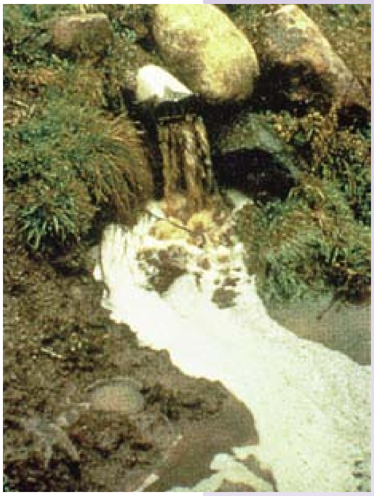
Phosphates in solution are very reactive. They can quickly be immobilized or taken up by plants. However, much of the phosphate remains in a reserve form and is released into solution to replenish what plants have removed. Since it doesn't move with soil moisture, phosphorus is unlikely to leach.

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



Phosphates are very reactive in soils. In acidic soils, it can be tied up by iron, aluminum and manganese compounds. In high pH soils, it can be tied up by calcium and magnesium compounds, as well as clay particles and soil organic matter.

Soil P is often attached to soil particles and will reach surface waters with cropland runoff.



Washwater containing phosphate-based detergents from some dairy farms reaches surface waters through direct hookups to tile lines.

In Ontario, phosphorus is the limiting factor for algal growth. If you reduce phosphorus in surface water, you'll have fewer algal blooms.

The fate of phosphorus

In the year of application, manure P is only 40% as available as fertilizer P. Therefore, 100 lbs of P_2O_5 from manure is equivalent to 40 lbs of P_2O_5 from fertilizer. When it comes to the long-term change in soil-available P (soil test P), manure P does not differ as much from fertilizer P. Over time, 80% of the P in manure is available for crop uptake.

In solution, phosphates can be taken up by plants, lost in soil runoff, or a very small amount may move through the root zone through soil cracks. Any phosphorus that ends up in surface water can promote algal blooms. As these aquatic plants die and decompose, oxygen levels in the water drop to levels that can kill fish and other aquatic life.

The Phosphorus (P) Index

The purpose of the Phosphorus Index (P Index) is to assign a value to the risk of surface water contamination through nutrient application to cropland. So, for example, on fields where soil phosphorus levels, as determined from soil tests, are very high and erosion potential is high, the risk of phosphorus contamination of surface water from manure application is also high. There may be a need to restrict P application, or to reduce erosion. The following chart lists the field and management practices that are considered when arriving at a P Index.

FACTORS CONSIDERED IN THE P INDEX TO ESTABLISH MINIMUM DISTANCE SEPARATIONS FOR MANURE APPLICATION ADJACENT TO WATERCOURSES

INFLUENCING FACTOR	FIELD MEASUREMENT OR INPUT NEEDED DETERMINING THE P INDEX
NATURAL FIELD CHARACTERISTICS account for a field's soil erosion potential and water runoff potential	• soil texture/erodibility • slope length • slope gradient (adjacent to watercourse) • rainfall energy • distance to the watercourse
FIELD MANAGEMENT PRACTICES adjust the field's soil erosion potential	• tillage system (e.g., no-till) • cross-slope/contour farming • crop rotation, forages, cover crops
NUTRIENT MANAGEMENT PRACTICES account for factors such as the current P levels in soil as well as how and how much P is being applied to a field	• soil fertility levels • manure and fertilizer application rates • method of manure and fertilizer application (e.g., incorporated vs. surface-applied)

Note: the P Index-based separation distances for P application do not need to be considered if the soil sample P test result is below 30 ppm.

Even if the P Index calculated for a particular field is high, it's often not necessary to restrict phosphorus application to the entire field, because only a portion of the field directly connected to the watercourse is likely to be "delivering" the phosphorus. As a result, only those areas adjacent to a watercourse or that have the highest risk of sediment delivery potential need to be avoided.

The P Index is higher on steeply sloping fields.

POTASSIUM

In manure, potassium (K) has two forms: inorganic and organic. Approximately 75% is in the liquid fraction and is readily available to plants. The remaining 25% can be found in the organic portion of manure solids.

In soil, K has three forms:

- unavailable K – as much as 90–98% is held by minerals
- slowly available K – up to 10% held by clay minerals
- available K – 1–2% in solution or held by minerals. K ions will leach in sandy soils.

Despite the relative low availability in soil, K maintains a dynamic equilibrium. Potassium ions that are taken up by plants are rapidly replaced by exchangeable potassium from reserves in the soil.

Potassium from farm sources does not lead to water quality issues in Ontario because the available potassium is in equilibrium with unavailable forms of potassium in the soil. Extremely little K leaches or is found in cropland runoff. Potassium is not a limiting factor for aquatic plant growth.

***Caution:* High soil-test levels of potash and high potash levels in manure can lead to high potassium (K) levels in forages, resulting in milk fever problems in dairy cows. Alternatives to high K forages include off-farm sources of low K hay and/or dilution with low K forages such as corn silage, or anion/cation balancing.**

SUMMARY OF MANURE NUTRIENT LOSSES AND INTERACTIONS WITH THE WATER 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	• manure-based nitrogen (ammonium) converts to nitrate and nitrite (nitrification) • 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 N_2O
RUNOFF AND EROSION	• surface-applied manure is at risk of runoff • manure-based P + 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	• defined as 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 nitrate (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, and ○ mineralized applied manure and legumes
TILE EFFLUENT	• defined as the mass flow of applied liquids to tile outlets • all manure-based nutrients (N,P and K) and bacteria can end up in surface waters, as effluent seeps through cracks and continuous macropores (without pre-cultivation) • this is more often an issue with no-till soils and soils prone to cracking
IMMOBILIZATION	• nutrients are tied up by microbes in soil • soil microbial populations are large and diverse enough to remove available nitrate and phosphate from soil solutions before plants can use them • rate of immobilization depends on the ratio of carbon:nitrogen (C:N) of crop residues or manure 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 any available nitrates ○ in time the microbes will run out of food (carbon) and release the nitrogen following mineralization
FIXATION	• phosphates are very reactive in soil and combine with calcium, magnesium, iron, manganese or aluminum, and become attached to the soil particles • a small amount remains in solution at any given time – they are removed from the solution quickly • much of the phosphate remains in a reserve form and is released into solution to replenish what's been removed by plants

MICRONUTRIENTS AND TRACE ELEMENTS

Manures are rich in crop-required micronutrients such as boron, chlorine, iron molybdenum and zinc. They are also a source of micronutrients required for animal health, including zinc, copper, selenium, chromium, iodine and cobalt.

Manure type and management directly affect plant and animal micronutrient levels. For example, zinc and copper levels from swine and poultry manure are most often higher than from other manure types. For soil fertility, this means that annual manure applications aimed at meeting P and N needs may result in higher-than-expected soil levels of certain micronutrients.

Sheep have a low tolerance for copper in their diet – test your manure for micronutrients before applying to sheep pastures.

Some research studies have shown a buildup of elements such as copper and/or zinc in fields with a history of heavy manure application. However, recent studies of manure nutrient contents have not shown this to be a problem in Ontario when compared to biosolids standards. The take-home message is to be aware that feeding micronutrients over nutritional requirements in livestock feeds and medicines could have a negative impact on long-term soil quality.

To control soil levels of micronutrients:

- manage sources of micronutrients in livestock feeds and treatments
- test manure and soil for micronutrient levels (to provide a baseline)
- adjust your nutrient management plan and application operations if necessary.

SYSTEMS APPROACH TO NUTRIENT MANAGEMENT PLANNING

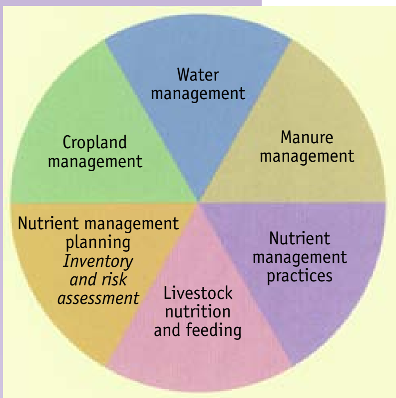
A general understanding of nutrient sources, changes and losses is the foundation of an effective **nutrient management plan.** The next step focuses on operation: accounting for the nutrients and assessing risks of losing them.

Before you get started, remember the big picture. Think of what you're assessing and planning for as a management system. A management system consists of a set of distinct yet interactive management practices (e.g., nutrient application) or groupings of practices (e.g., livestock nutrition and feeding) that affect management outcomes.

A comprehensive management system includes all key components that affect desired outcome. In a comprehensive management system, **a planned change will impact other components of the system as well as the system itself.**

When you use a management system to predict and assess the impact of a specific practice on management components, you're using the **systems approach.**

COMPONENTS



A systems approach to nutrient management planning includes the following components.

1. Water management

- ► proximity to surface waters, depth to water tables and aquifers, as well as drainage, irrigation and surface water management practices

2. Nutrient management – inventory and risk assessment

- ► accounting for all nutrient sources and levels in farm operation plus assessment of environmental risks and limitations for nutrient management

3. Nutrient management practices

- ► testing for nutrient levels, selecting nutrient sources, scheduling applications, calibrating application and assessing impact

4. Livestock nutrition and feeding

- ► focus on reducing, modifying, supplementing and targeting diets and feeding practices to improve use efficiency and reduce inputs

5. Manure management

- ► manure and other waste collection, transfer, storage and handling systems

6. Cropland management

- ► best management practices that protect soil and water plus reduce nutrient loss (includes cropping and tillage practices)

Using the systems approach is the most effective way to develop your nutrient management plan. A good example of this is the Environmental Farm Plan process.

A SYSTEMS APPROACH AT WORK IN A LIVESTOCK OPERATION

While developing an NMP (i.e., *Component 2: nutrient management – inventory and risk assessment*), a livestock producer learns that he has excessive P levels in most of his fields. To address this, the producer:

- ► **lowers manure P levels by reducing P supplements to his animals *(Component 4: livestock nutrition and feeding)***
- ► **changes his manure application practices by incorporating surface-applied manure *(Component 3: nutrient management practices)*; and**
- ► **complies with specified separation distances for application *(Component 1: water management)*.**

By using the systems approach, this livestock producer has saved money on production inputs and reduced impacts on surface water quality.