CHAPTER 4 ~ NUTRIENT MANAGEMENT AND PASTURE FERTILITY

INTRODUCTION

Soil fertility is an important factor in pasture production. It helps determine the yield and quality of the crop and has a direct effect on the species composition of the stand. In addition to water and sunlight, maintaining pasture fertility through the input of nutrients is key to support healthy plant growth.

Most nutrients are naturally supplied to the plant by the soil. However, some nutrients like nitrogen, phosphorous and potassium are often limiting if the soil is deficient. It may be necessary to add nutrients through an application of manure, chemical fertilizer, or by seeding legumes to fix nitrogen.

A healthy productive pasture cannot be maintained by nutrients alone. For pasture plants to capitalize on the nutrients from the soil, the plants must have a healthy root system. Overgrazed plants with small, weak root systems cannot take advantage of improvements to soil fertility (Leahy and Robinson 2000). Therefore, it is necessary to manage grazing as well as the nutrient status of the soil to maintain productive pastures. Refer to Chapter 2 for more information about grazing management or systems.

NUTRIENT CYCLING

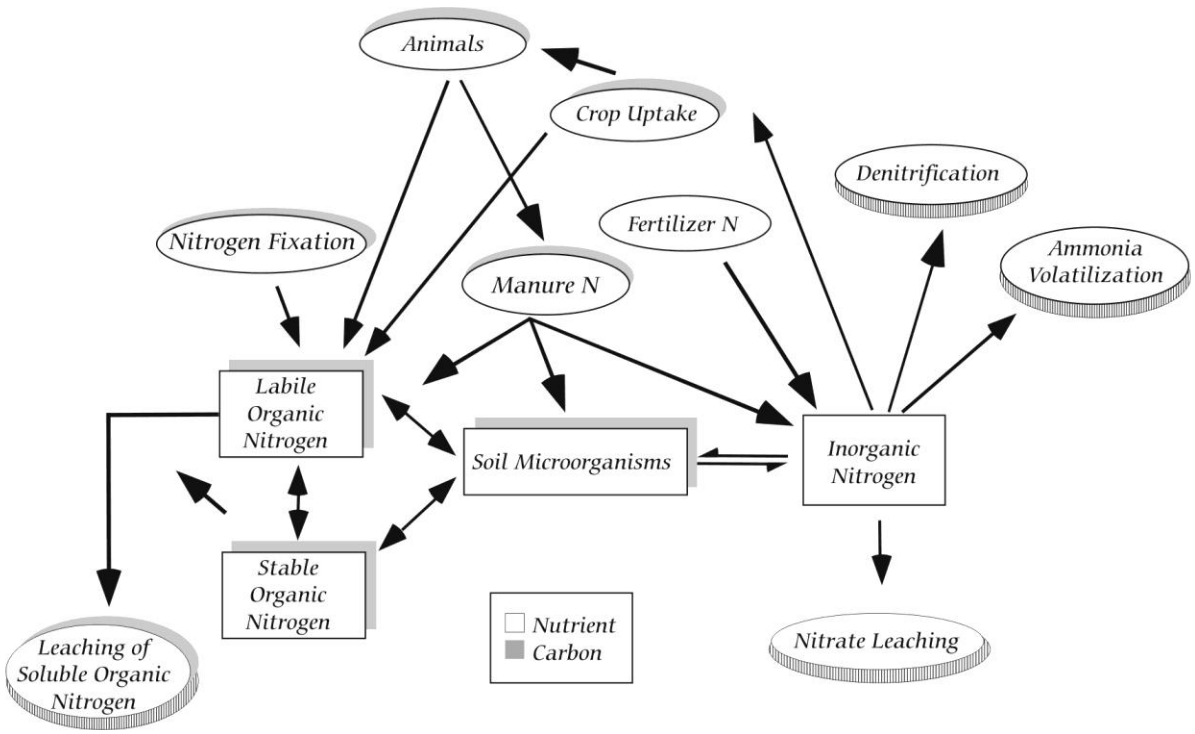
There are sixteen essential elements for plant growth. Of these, carbon (C), hydrogen (H), and oxygen (O) are supplied primarily by air and water. The remaining thirteen elements are mineral elements supplied by the soil. Of these, six are macronutrients and seven are micronutrients (Table 4.1). Both macro and micronutrients are essential, but macronutrients are required in higher amounts. Of the six macronutrients, nitrogen, phosphorous, and potassium are required in the highest amounts.

Table 4.1 Plant macronutrients and micronutrients

Macronutrients		**Micronutrients**		
Calcium (Ca)	Phosphorous (P)	Boron (B)	Iron (Fe)	Zinc (Zn)
Magnesium (Mg)	Potassium (K)	Copper (Cu)	Manganese (Mn)	
Nitrogen (N)	Sulphur (S)	Chlorine (Cl)	Molybdenum (Mo)	

NITROGEN

Figure 4.1 Nitrogen cycle



In the soil, nitrogen occurs primarily as organic nitrogen (found in soil organic matter, plant residues, and manure), with smaller amounts occurring as the plant available forms nitrate (NO_3^-) and ammonium (NH_4^+). Figure 4.1 and Table 4.2 describe the nitrogen cycle. In the soil, micro-organisms convert organic nitrogen to ammonium and nitrate through the processes of mineralization and nitrification. Symbiotic bacteria living in association with the roots of legumes convert atmospheric nitrogen to organic nitrogen through the process of nitrogen fixation. The nitrogen that is fixed is an important source, as it can supply both legumes and nearby non-leguminous plants.

Plants take up inorganic nitrogen, predominantly in the form of nitrate, but also in the form of ammonium. These plant available forms of nitrogen are supplied by soil organic matter, manure, additions of inorganic chemical fertilizer, or nitrogen fixation by legumes.

Nitrogen may be lost to the atmosphere through ammonia volatilization and denitrification, lost to the groundwater through nitrate leaching, or lost by surface runoff and erosion. Crop uptake and plant intake by animals as well as immobilization also remove nitrogen from the system.

Table 4.2 Nitrogen cycling

Nitrogen mineralization: soil micro-organisms convert organic nitrogen to inorganic nitrogen in the form of ammonium (NH_4^+). The majority of nitrogen is supplied to plants through mineralization.

Nitrification: soil micro-organisms convert ammonium (NH_4^+) to nitrite (NO_2^-) and finally to nitrate (NO_3^-). At pH levels below 5.5 and when O_2 is limiting (in wet or waterlogged soil), nitrification is inhibited. Nitrification is slow in cold soils. When nitrification is slowed or inhibited, ammonium (NH_4^+) accumulates and the supply of NO_3^- to plants is limited.

Nitrogen fixation: *rhizobia* bacteria at the roots of legumes convert atmospheric nitrogen to organic nitrogen.

Ammonia volatilization: The loss of gaseous nitrogen through the chemical conversion of ammonium (NH_4^+) to ammonia gas (NH_3). Ammonia volatilization is pH dependant, occurring under high pH conditions. Loss of nitrogen via ammonia volatilization is usually associated with manure application, as stored manure is reasonably alkaline (pH 8.5 to 9).

Denitrification: The loss of gaseous nitrogen as soil micro-organisms convert nitrate (NO_3^-) to nitrite (NO_2^-) and finally to gaseous nitrogen (N_2 or N_2O). Denitrification occurs in wet or flooded conditions where oxygen is limited (anaerobic conditions).

Nitrate leaching: nitrate (NO_3^-) is very water-soluble and may be lost as water moves through the soil profile to the groundwater. Nitrate leaching becomes prevalent when rainfall levels are high. Nitrate leaching is exacerbated when there is an excess of nitrate in the soil.

Nitrogen immobilization: soil micro-organisms convert ammonium (NH_4^+) back to organic nitrogen.

The nitrogen cycle in the soil is dynamic and is influenced by several factors. Mineralization, nitrification, nitrogen fixation, denitrification, and immobilization are biological processes; therefore they are influenced by such factors as soil pH, temperature, oxygen, and moisture.

Why is Nitrogen Important?

- It is an essential component of protein, which is necessary for healthy plant growth
- It is an important component of chlorophyll, which is essential to photosynthesis
- It is a component of nucleic acids, which contain the genetic information of the plant
- It aids in the uptake of other nutrients
- It is involved in root growth and development

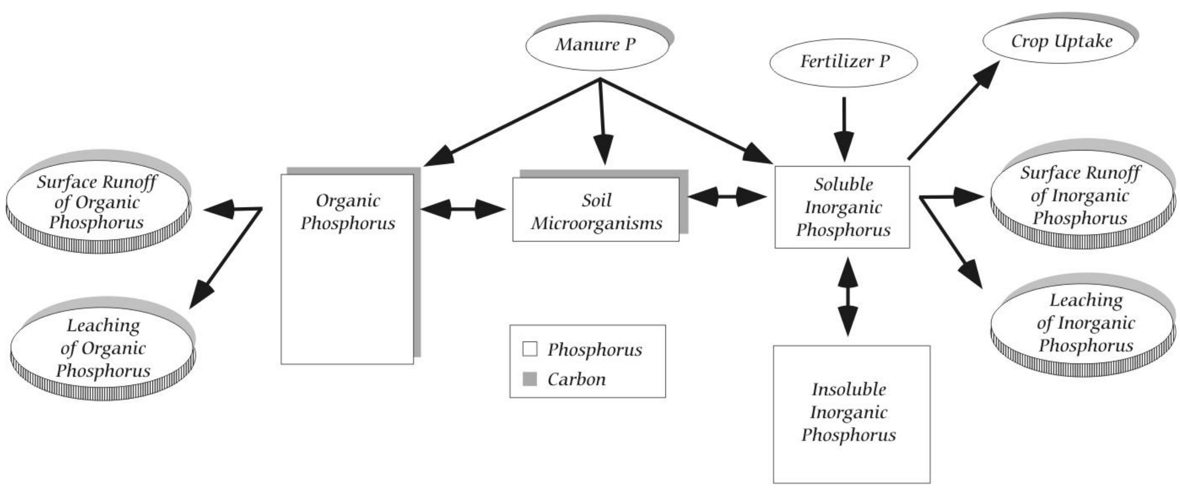
- It is involved in the use of carbohydrates by the plant
- It contributes to healthy vegetative growth and photosynthetic activity

With so many pathways for loss, managing nitrogen to reduce loss is important. Nitrogen loss can lead to nitrate contamination of groundwater, which has associated human health effects. Along with phosphorous loading, nitrogen loading of surface water can contribute to eutrophication. To reduce nitrogen losses to the environment:

- Apply recommended rates of nitrogen. It is also helpful to calibrate fertilizer and manure spreading equipment so that applications are more accurate and nitrogen is not over applied. When nitrogen is over applied, it may be lost to the environment via nitrate leaching or denitrification.
- The timing of nitrogen application should match the time of maximum plant demand. This way the nitrogen will be taken up by the plant and not lost to the environment.
- A split application of nitrogen will reduce the occurrence of excess nitrogen in the soil not taken up by plants.
- Best management practices for manure application should be employed to reduce nitrogen loss to the environment.
- Proper rotational grazing will help to more evenly distribute nutrients across the pasture which will reduce the occurrence of high concentrations of nitrogen that could potentially be lost to the environment.

PHOSPHOROUS

Figure 4.2 Phosphorous Cycle



Phosphorous occurs in the soil as organic phosphorous, soluble inorganic phosphorous in solution, and insoluble inorganic phosphorous. Plants take up soluble phosphorous in the forms of $H_2PO_4^-$ and HPO_4^{2-}. The amount of soluble phosphorous that is available for plant uptake is small compared to the other forms that occur.

Figure 4.2 and Table 4.3 describe the phosphorous cycle. Phosphorous is added to the soluble pool through mineralization of organic phosphorous and the dissolution of phosphorous from the surfaces of clays and minerals. Phosphorous becomes available to plants through these processes as well as from additions of manure or chemical fertilizer (soluble inorganic phosphorous fertilizer). Phosphorous may be removed by fixation, immobilization, surface runoff and erosion. Plant uptake and animal intake of plants also removes phosphorous from the soil.

Plant availability of phosphorous is pH dependant due to phosphorous fixation. At pH levels below 6.0, iron (Fe^{2+}) and aluminium (Al^{3+}) ions can form compounds with soluble inorganic phosphorous. At pH levels above 7.0, compounds with calcium ions (Ca^{2+}) may be formed. These compounds make soluble inorganic phosphorous unavailable for plant uptake. Between pH 6.0 and 7.0, soil phosphorous is most available for plant uptake because reactions with iron, aluminum, or calcium are least likely to occur within this range.

Table 4.3 Phosphorous cycling

Phosphorous mineralization: Similarly to nitrogen mineralization, soil micro-organisms convert organic phosphorous to inorganic phosphorous ($H_2PO_4^-$ and HPO_4^{2-})

Phosphorous dissolution: Phosphorous that is held in the insoluble inorganic pool (on the surfaces of clays or minerals) is slowly dissolved into the soil solution where it becomes available for plant uptake.

Phosphorous fixation: The chemical reaction between soluble inorganic phosphorous and calcium (Ca^{2+}), iron (Fe^{2+}) or aluminium (Al^{3+}). Phosphorous becomes unavailable for plant uptake due to the compounds that are formed in the reaction.

Phosphorous immobilization: soil micro-organisms convert inorganic phosphorous ($H_2PO_4^-$ and HPO_4^{2-}) back to organic phosphorous making it unavailable for the plant.

Why is Phosphorous Important?

- It is an essential component of the compounds that store energy in plant cells and is critical for plant processes such as photosynthesis
- It is important for enhancing root growth and development
- It plays an important role in flowering, fruiting, seed formation, and crop maturation
- It is a structural part of all cell membranes and many other cellular components

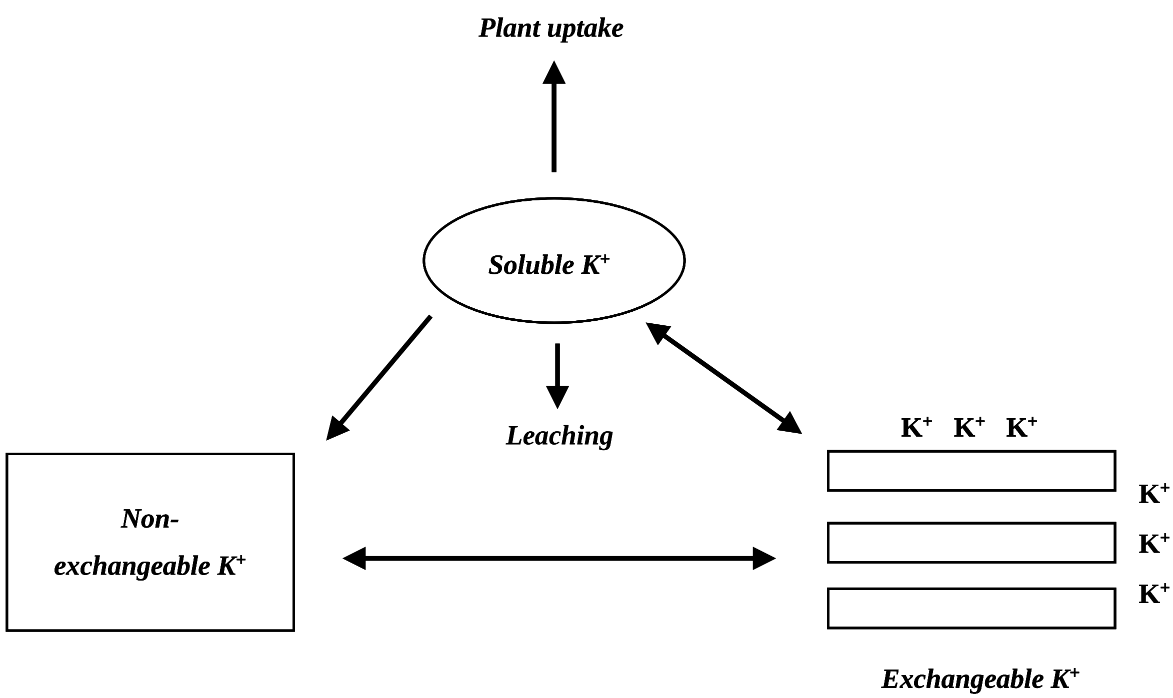
Soluble inorganic phosphorous is taken up by plants by diffusion from the soil solution to the plant roots. However, the diffusion of phosphorous to the root can be slow. Mycorrhizae are plant root fungi that can translocate phosphorous to the plant root. In this way, the root fungi essentially increase the length and surface area of the plant root and thus increase plant available phosphorous.

Phosphorous is an important nutrient for legumes. Legumes require higher amounts of soil phosphorous than grasses; therefore, to maintain a healthy stand of legumes in the pasture, phosphorous levels must be maintained. Maintaining legume content in the pasture has several benefits, namely the nitrogen supplying capacity resulting from nitrogen fixation.

Phosphorous is lost to the environment primarily through surface runoff and erosion. Excessive losses of phosphorous to the environment are of concern due to the potential for the eutrophication of surface water. It is important to always base phosphorous applications on a soil test to reduce the occurrence of over applications of the nutrient. Management practices such as the establishment of riparian buffers can help control surface runoff and erosion and reduce phosphorous loading of surface water.

POTASSIUM

Figure 4.3 Potassium cycle



The forms of potassium in the soil as well as the cycling of this nutrient differ quite substantially from that of nitrogen or phosphorous (Figure 4.3). In the soil, potassium occurs as soluble K^+, exchangeable K^+ held on the surfaces of clays and minerals, and non-exchangeable K^+ tied up in mineral complexes. Plants take up soluble K^+ from the soil solution in large quantities. As K^+ is taken up by the plant, exchangeable K^+ is released to supply more soluble K^+. Non-exchangeable K^+ is not readily plant available. The weathering of clay minerals makes this non-exchangeable form available to plants over a period of years. Conversely, by the process of fixation, soluble and/or exchangeable K^+ may become unavailable and held as non-exchangeable K^+.

Potassium can be lost from the soil by crop uptake and leaching, but leaching losses are generally small. Legumes require more potassium than grasses; therefore, adequate potassium is important for maintaining legume content in pastures.

Why is Potassium Important?

- It is involved in the activation of enzymes that are responsible for many physiological plant processes
- It plays a role in nutrient and sugar transport within the plant
- It is essential to water regulation within the plant
- It is essential for increased winter hardiness of legumes

CALCIUM

Legumes including clover, alfalfa, and birdsfoot trefoil are heavy calcium consumers. On average, the upper limit of calcium required for grasses is the lower limit of what is required by legumes. Calcium is essential for root nodulation and nitrogen fixation, and the appropriate level of available soil calcium increases the germination rate of clover seeds. Also, soil calcium levels increase molybdenum availability within the soil, which is another essential nutrient for nitrogen fixation by legumes.

Not only is calcium essential to plants, animals require large amounts of calcium as part of a healthy diet. Calcium is essential for animal health particularly in the formation of bones and teeth. It is also needed in large amounts by growing, pregnant and lactating animals (see hypocalcemia in the animal health section of this manual). Calcium is also essential to soil organisms, and it stimulates bacterial growth which has “trickle-up” effects to the rest of the pasture ecosystem.

As calcium is immobile within the plant, it is important for there to be an adequate supply in the soil so that newly forming leaves will not be limited. Dolomitic and calcitic limestone will provide adequate amounts of calcium, and will increase the soil pH. An increase in soil pH (5.9-6.5) increases the plant availability of nutrients in the soil. Gypsum (17% sulphur, 22% calcium) and wood ash also contain significant amounts of calcium. Gypsum is an excellent amendment that adds calcium as well as sulphur without changing the pH. Wood ash is a by-product of power cogeneration from large pulp and paper mills. Wood ash adds calcium, sulphur, and appreciable amounts of other nutrients including phosphorus and potassium. Before wood ash is to be applied as a pH conditioning amendment, soil tests may be necessary to determine if potassium and phosphorus levels are sufficient to prevent nutrient loading in pasture soils. Application rates and the suitability for wood ash application to pastures have yet to be determined in Nova Scotia.

Why is calcium important?

- Essential for root nodulation and nitrogen fixation
- Aids in the germination of clover seeds
- Makes other important nutrients plant available
- All plants require calcium for the regulation of cellular functions, leaf development, and protein synthesis
- It helps with water regulation within the plant cell elongation and cell division
- Cell elongation and cell division

SULPHUR

Sulphur (S) is a macronutrient that plays an essential role in plant metabolic functioning, and is often overlooked. It can be considered the fourth most important nutrient behind nitrogen, phosphorus, and potassium. The sulphur cycle is very similar to the nitrogen cycle, and in areas with high annual precipitation and sandy soils, sulphur is readily leached from the soil. Until recently, most of the sulphur required by plants was either fixed/deposited from the atmosphere, or derived from organic matter. When soils are waterlogged, bacterial mineralization of sulphur from organic matter will lead to a reduction of the sulphate form of sulphur and result in the formation of hydrogen sulphide (a gas that leaves the soil). The various versions of the Clean Air Act in the United States and Canada, have led to a decrease in the amount of sulphur available to plants from atmospheric deposition. This reduction in atmospheric sulphur is a reason for producers to monitor soil sulphur levels, and consider adding sulphur as part of a nutrient management plan.

Recent reports have shown that sulphur in pasture soils is directly linked with nitrogen use efficiency, especially in sandy soils (Brown et al. 2000). Therefore, if nitrogen is increased in the soil and sulphur is not, plant sulphur deficiencies will occur. A greenhouse study examining the effects of sulphur and nitrogen use in mixtures of perennial ryegrass and white clover was conducted to see how the plants responded to different fertilizers with regular cutting (Tallec et al. 2008). The authors showed that the ratio of nitrogen to sulphur (N:S) was important for plant development, especially legumes. Grasses responded more to nitrogen than sulphur, and clover responded more to sulphur than nitrogen. The authors suggested that sulphur may be the key to balancing the ratio of legumes to grasses in pastures. A balanced soil contains a nitrogen to sulphur ratio (N:S) of 8:1 .

Non-atmospheric sources of sulphur may include fertilizers such as ammonium sulphate (24% sulphur, 21% nitrogen) and Sul-po-mag (11% magnesium, 22% potassium, 23% sulphur). Gypsum and wood ash (see above) also contain significant amounts of sulphur. Gypsum is an excellent amendment that adds calcium as well as sulphur without changing the pH. Wood ash adds calcium, sulphur, and several other nutrients.

Why is sulphur important?

- It is important for the formation of roots, amino acids, proteins,
- Essential part of plant structural components
- Pivotal part of nitrogen fixation, and the activation of vitamins and enzymes within the plant

MAGNESIUM

Although magnesium is not often considered to be that important, it is required by plants in roughly the same proportions as phosphorus and sulphur. When magnesium is limited in the plant (particularly if the ratio of potassium to magnesium is high) animal health may be affected (see “hypomagnesaemia” in the animal health section of this manual). Magnesium is somewhat more forgiving than calcium, as it is mobile and can be translocated within the plant.

Sources of magnesium include dolomitic limestone (10% magnesium, 22% calcium), Sul-po-mag

(11% magnesium, 22% potassium, 23% sulphur), magnesium sulphate (Epsom salts) (10% magnesium, 10% sulphur). Application of magnesium to pastures should be done based on soil tests, as excessive levels in the soil limit calcium availability. The calcium to magnesium ratio (Ca:Mg) in a balanced soil should range between 5:1 and 7:1.

Why is magnesium important?

- Is important for animal health
- It is an important component of chlorophyll and is essential for photosynthesis
- Essential component in enzyme functions and controls respiration at the cellular level
- Involved in the translocation of starch and the formation of proteins and lipids

Effect of Grazing Animals on Nutrient Cycling

Nutrient cycling in a pasture differs from that which occurs in non-grazed cropland due to the influence of the grazing animals. In addition to regular nutrient transformations and cycling, nutrients are taken up by the grazing animal in the herbage it consumes and returned in the form of urine and dung. Grazing animals will recycle about 75-85% of the nutrients they consume (Bellows 2001). Returned nutrients are partitioned differently between urine and dung. Potassium is primarily excreted in the urine, and phosphorous, calcium, magnesium, copper, zinc, iron, and manganese are primarily excreted in the dung. Nitrogen, sodium, chlorine, and sulphur are excreted in both urine and dung (Haynes and Williams 1993).

Table 4.4 provides some estimates of daily nutrient returns from a lactating dairy cow, a beef feeder, and a mature sheep.

Table 4.4 Daily nutrient returns per animal

	Animals per 454 kg animal unit (AU)	Total N (kg/day per AU)	Total P_20_5 (kg/day per AU)	Total K_2O (kg/day per AU)
Lactating dairy cow (625 kg)	0.7	0.28	0.07	0.14
Beef feeder (350-500 kg)	1.1	0.14	0.11	0.13
Mature sheep (60 kg)	7.5	0.20	0.07	0.18

(US Department of Agriculture Natural Resources Conservation Centre 1992)

At the quantities returned, manure is a valuable source of nutrients for the pasture. For example, Thomas (2001) has calculated that in 24 hours on pasture, 100 grazing cows can deposit dung and urine equivalent to 20 kg N/ha, 4.5 kg P_2O_5/ha, and 16 kg K_2O/ha.

Although a significant source of nutrients, the manure deposited by grazing animals is not distributed evenly throughout the pasture. Grazing animals tend to congregate in particular areas, around water sources, supplemental feed troughs, or in shaded areas. For example, manure deposited from cattle grazing on a 0.44 ha pasture at a stocking density of 5 steers/ha resulted in a zone of nutrient enhancement near the water source and extending 10-20 m into the pasture; the water source was located in one corner of the pasture (West et al. 1989). In another example, Franzluebbers et al. (2000) found nutrient concentrations for a 0.7-0.8 ha pasture to be the greatest within a 30 m radius around the water and shade sources. When nutrients from the grazing areas are transported to the congregation areas, the distribution of fertility across the pasture becomes uneven.

The following management strategies will help ensure more uniform distribution of nutrients across the pasture:

- Management intensive grazing, clipping and harrowing, and measures to prevent grazing animals from camping in particular locations, will improve the distribution of nutrients within the pasture (Thomas 2001).
- Locating water, shade, or supplemental feed sources in different areas of the pasture will reduce the animal congregation that might occur if are all located in the same area (Bellows 2001).
- Using a portable water source that can be periodically relocated in a pasture may help to more evenly distribute nutrients from dung and urine (Bellows 2001).
- Locating a water source in an area known to be low in nutrients may help to offset the deficiency (Bellows 2001).
- Subdividing larger pastures may help to better distribute nutrients as congregation areas will be distributed among several pastures (Bellows 2001).
- Leaving longer grass behind when grazing animals are rotated out of the pasture will enable excess nutrients that may be in an area of congregation to be taken up by the vegetation still present (Thomas 2001).

Recognizing that nutrients are not evenly distributed by grazing animals will enable management decisions to make the best use of nutrients returned by the grazing animal.

Effect of Urine and Dung Deposits

Dung and urine patches result in increased grass growth in the surrounding area. The high concentration of nitrogen in urine favours grass growth, as do the nutrient concentrations of dung. The effect of urine may last several months, while the effect of dung many be as long as two years (Haynes and Williams 1993). Dung patches generally kill underlying vegetation, resulting in bare soil areas that can allow weeds to creep in (Haynes and Williams 1993). Urine patches may scorch or burn the vegetation (Leahy and Robinson 2000).

The breakdown of dung is by both physical (rainfall and animal treading) and biological processes; therefore, both the climate and stocking rate will affect the rate of breakdown (Haynes and Williams 1993). Intensive rotational grazing will speed up the physical breakdown of dung by trampling. Harrowing will also enhance the physical breakdown and spread the dung to more evenly distribute nutrients (Leahy and Robinson 2000).

Rejection of herbage around dung patches can be a problem as the vegetation near the patches is wasted and the vegetation between patches may be overgrazed. Rejection is less of a problem for sheep than cattle as sheep dung is deposited as pellets instead of as one large patty (Haynes and Williams 1993). The period of rejection depends on the time for the dung to breakdown (Leahy and Robinson 2000).

Intensive rotational grazing can minimize rejection. In addition to speeding up the breakdown of dung, intensive grazing forces cattle to graze closer to dung patches because of the higher grazing pressure. Grazing animals do not usually reject the herbage near urine patches; in fact sheep prefer to graze in these areas (Leahy and Robinson 2000).

Nutrient Management Planning

Nutrient management planning evolved from intensive livestock and crop production areas where leaching of nitrogen into groundwater systems and surface movement of phosphorous and pathogens into watercourses were having major environmental impacts. Nutrient management planning involves matching nutrient requirements to realistic crop production yield targets and understanding the nutrients available from fertilizer, manure, and the soil. Effective nutrient management planning optimizes nutrient use for optimal crop production while minimizing the potential for environmental impact (Burton and Fairchild 2003).

The development of a nutrient management plan requires knowledge of the nutrient status of the soil, the crop to be grown, and the source of the nutrients supplied (e.g. manure or chemical fertilizer). With this information, decisions can be made about which fields would benefit from additional nutrients, the amount of additional nutrients required, and the type of nutrients to supply.

Nutrient Losses

Often the only nutrients that a pasture receives come directly from the grazing animal; however, as with other crop systems, the rate and timing of nutrient additions will influence nutrient losses. Ensuring proper timing, application rate, spreader calibration, and application technique will help reduce nutrient loss.

Permanent sod pastures reduce nutrient loss. With a permanent sod cover there is more opportunity for nutrient uptake by plants and less potential for loss by erosion.

Nutrient losses generally occur from urine and dung patches, where nutrient levels in the soil tend to be the highest. When these levels exceed plant demand, nutrient loss becomes a risk. The likelihood of loss is even greater in animal congregating areas, as soil nutrient levels can become even more elevated.

Nitrogen is the most likely nutrient to be lost from urine and dung patches. Nitrate (NO_3^-) levels beneath dung patches can become elevated and potentially lost to the groundwater (leaching) or the atmosphere (denitrification). Ammonium (NH_4^+) levels can also build up beneath urine patches and become a source of gaseous losses by ammonia volatilization. Or, if the ammonium is converted to nitrate it may also be lost to the groundwater or the atmosphere.

Phosphorous is less mobile and not as likely as nitrogen to be lost from dung and urine patches. However, if phosphorous levels in the soil become quite high, there is the potential for loss by leaching and erosion. Soil phosphorous may build up if manure is regularly applied to the same fields year after year. Soil testing and the use of manure on fields known to have low soil phosphorous levels will help reduce phosphorous loss.

Potassium is taken up by the plant and is stored within the plant in a stable form more than any other nutrients. It is returned to the soil through urine.

Maintaining a balance between nutrient inputs (manure, fertilizer, supplemental feed) and removals (harvested hay, consumed feed, animals removed) will help maintain adequate fertility for productive pasture growth and reduce nutrient loss resulting from excessive nutrient input. Taking measures to reduce animal congregation behaviour and thus areas of concentrated nutrients may reduce the potential for nutrient loss. Maintaining an actively growing sod will encourage nutrient uptake and reduce erosion.

SOIL TESTING

Soil testing is critical to managing soil fertility. It is also important in assessing soil health and determining the crop production potential for a field. Soil testing provides information on soil nutrient levels as well as other soil characteristics such as soil organic matter, pH, cation exchange capacity (CEC; the ability of the soil to hold positively charged ions such as Ca^{2+}, Mg^{2+}, H^+, K^+, and Na^+), and base saturation (the percent CEC occupied by basic cations Ca^{2+}, Mg^{2+}, K^+, and Na^+). It should be noted that soil tests in Nova Scotia do not provide information about soil nitrogen levels. Soil tests in Nova Scotia report soil nutrient levels in kg/ha. Historically, phosphorous has been reported as P_2O_5 and potassium has been reported as K_2O; therefore, nutrient recommendations are also reported as P_2O_5 and K_2O.

A soil test also provides recommendations for nutrient and lime applications. Nutrient and lime applications should always be made based on a soil test. Although soil testing in Nova Scotia does not currently measure soil nitrogen, a soil test report provides nitrogen application recommendations based on the general nitrogen requirements for pastures. Using the information from the soil test and the legume content of the pasture, nutrient management decisions can be made.

Soil testing should be done every three years to monitor the fertility of the soil. Most of the nutrient cycling in a pasture happens in the top 10 cm of the soil. Therefore, soil samples for pastures should be taken to a depth of 10 cm. to collect a representative sample. A composite sample made up of several individual samples taken from the field is the best way to provide a representative soil sample for soil testing. Table 4.5 summarizes information from Singh (2002) and AgraPoint about soil sampling. More information about how to take a field soil sample can be obtained from AgraPoint's extension website: http://www.extensioncentral.com

Table 4.5 Soil sampling method for pastures

Soil sampling for pastures
Necessary Equipment
• Soil probe or shovel • Bucket (plastic or non-galvanized metal) • Boxes from the soil test lab (or Ziploc bags) • Waterproof marker for labelling box or bag
Number of Samples
• Take one composite sample per pasture • Take about 20 individual cores for each composite sample, no matter how small the sampling area is • Mix the soil from individual cores thoroughly to make a composite sample to be sent to the lab for analysis • The composite sample sent to the lab should be about 2 cups of soil
Sampling Location
• Samples should NOT be taken near roads, fence rows, or highly eroded areas • Soil from high yielding and low yielding areas should not be combined in the composite sample • Areas of non-uniform slope, color, texture, drainage, and cropping practice should be sampled separately
Sampling Depth
• 10 cm for pastures
Sampling Time
• Ideally after harvest, but samples may be obtained at any time of the year • Fall sampling will allow results to be returned in time to plan for the upcoming season • Early fall sampling will allow results to be returned in time for fall lime application • Results from spring sampling may not be returned in time to make decisions regarding fertilizer and/or lime application for that year • It is best to try to always sample at the same time of year
Sampling Frequency
• Every 3 years for a general indication of fertility • Sample more frequently to monitor soil improvement, especially if trying to produce high quality herbage

Soil tests may be obtained through Laboratory Services of the Nova Scotia Department of Agriculture:

Nova Scotia Department of Agriculture
Quality Evaluation Division, Laboratory Services
176 College Road (Harlow Institute)
Truro, Nova Scotia B2N 5E3
http://www.gov.ns.ca/agri/qe/labserv/index.shtml#analytical

Supplying Nutrients to the Pasture

Effective fertility management for a pasture should always begin with a soil test. Once nutrient requirements are known, nutrients may be added through applications of manure, chemical fertilizer, or seeding a legume to supply nitrogen. Lime is a soil amendment that should be considered if soils are acidic, as pastures are less productive under acidic conditions.

Nutrient Recommendations

Macronutrient Recommendations

Pastures in Nova Scotia are predominantly grass pastures, whether seeded or native grasses. While these pastures may still have legume content, they are often at least 70% grass. Generally the legume content of a pasture determines the nutrient levels required, due to the nitrogen supplying capacity of legumes and the differing soil phosphorous and potassium requirements of legumes and grasses. It is important to try and estimate the legume content of a pasture. This can be difficult, and experience suggests that most individuals overestimate the legume content, especially when it comes to white clover content.

If a pasture has not been soil tested, the recommendations in Table 3.6 may be used to determine approximate nutrient requirements. The table outlines nutrient recommendations for pastures that are more than 85% grass, 70 to 85% grass, and pastures that are more than 30% legumes. Establishing 30% legume content is an ideal target, however it is often difficult to maintain even 20% legume content.

The general nutrient recommendations for a grass pasture (>85% grass) in Nova Scotia are 100-150 kg N/ha, 30 kg P_2O_5/ha, and 90 kg K_2O/ha (Table 3.6). Note that the nitrogen is split over three applications with 50 kg N/ha applied in the early spring to stimulate growth, 50 kg N/ha in mid-June, and 30 kg N/ha in early September. The early September application of nitrogen is recommended when moisture is not limiting to promote growth through the fall. The phosphorous and potassium requirements are split over two applications in mid-June and early September.

Although the information in Table 4.6 provides guidelines for nutrient requirements, nutrient applications should always be based on a soil test.

Table 4.6 Nutrient recommendations for pastures

Timing	Nutrient Requirements (kg/ha)			Example analysis	Application rate (kg/ha)
	N	P_2O_5	K_2O		
> 85% Grass					
• Early spring	50	0	0	34-0-0	150
• Mid-June	50	15	45	21-6-18	250
• Early September	32	9	21	21-6-18	150
70-85% Grass					
• Early spring	35	35	35	19-19-19	200
• Mid-June	32	9	27	21-6-18	150
> 30% Legumes					
• Early spring	20	20	60	10-10-30 + 0.2 Boron	200

Revised from the Forage and Corn Variety Evaluation Task Group. Atlantic Forage Guide. Atlantic Canada

Micronutrient Recommendations

Micronutrient requirements for pastures should also be considered. Boron (B) is an essential plant nutrient, but is only required in small amounts. Legumes have a much higher requirement for B than grasses. In general, Thomas (2001) indicates pastures with a high legume content (>30%) require B at a rate of 1 kg B/ha every two years. Over-fertilizing B is problematic because excessive levels of B can be toxic.

Levels of chlorine, iron, manganese, molybdenum, and zinc are usually adequate, but copper may sometimes be deficient. As with B, over-fertilizing with Cu can be toxic to livestock. Regular soil testing to monitor micronutrient levels is recommended as there may be a benefit to micronutrient applications if deficiencies exist.

MANURE

Manure is a source of nutrients for pastures. It provides a supply of nitrogen, phosphorous, potassium, several micronutrients and organic matter. The nutrient content of manure is both organic and inorganic and can be highly variable depending on the source and type. If manure is to be used as a nutrient source, care must be taken to ensure excessive nutrients are not applied to the soil. Excessive phosphorous loading in the soil may be a problem if manure is continually applied to the same field year after year.

Manure nitrogen occurs as ammonium (NH_4^+), a readily available form and organic nitrogen, which slowly becomes available through mineralization. The ammonium nitrogen may be lost to the atmosphere from storage, through handling practices, or at the time of spreading. The amount of manure nitrogen available to the growing crop is the amount of NH_4^+ that is not lost to the atmosphere and the organic nitrogen that is mineralized. The phosphorous in manure is considered to be 40% available in the year of application. The potassium content of manure is readily available, with 90% available in the year of application (Burton and Fairchild 2003).

Manure testing provides information about the nutrient content of manure. This information helps determine where and at what rate manure should be applied. In combination with soil testing, manure testing will help make effective use of nutrients available in manure. Like soil testing, manure should be tested approximately every three years or when a major change is made to the feed ration.

When collecting a manure sample, follow the Manure Application Guidelines from the Nova Scotia Department of Agriculture (2006):

- A manure sample should be a composite sample made up of several individual samples.
- Agitate liquid manure in storage before collecting a sample.
- Do not collect samples from the surface of a solid manure pile as the sample will not be representative of the rest of the manure.

If the manure has not been tested, nutrient approximations may be made based on the information given in Table 4.7.

Table 4.7 Nutrient content of stored manures

Animal	Manure Type	Dry Matter (%)	Total N (kg/tonne)	Ammonium-N (kg/tonne)	P_2O_5 (kg/tonne)	K_2O (kg/tonne)
Beef	Semi-solid	13	2.7	0.8	2.3	5.3
	Solid	21	4.3	1.0	1.6	4.6
	Average	17	3.5	0.9	1.6	3.4
Dairy	Liquid	9	3.1	1.5	3.0	5.8
	Semi-solid	16	4.4	1.9	2.3	4.7
	Solid	22	5.0	1.5	5.5	3.1
	Average	15	4	1.6	--	--
Sheep	Solid	50	7	2.9	4.6	12
Poultry	Semi-solid	17	7.7	4.2	19.2	11.5
	Solid	32	15.2	6.6	31.1	8.4
	Litter pack	71	33.9	8.4	57.5	19.2
	Average	51	25	6.4	43.5	14.4
Swine	Liquid	5	2.5	1.7	1.8	1.1
	Semi-solid	15	5.3	2.4	5.0	2.2
	Solid	24	7.6	3.0	4.8	5.4
	Average	15	5.1	2.4	3.9	2.9

Burton, D and Fairchild, G. 2003. Atlantic Canada Nutrient Management Planning. Province of Nova Scotia

The effectiveness of manure as a nutrient supply for pastures depends on when it is applied, the rate of application, and the uniformity of the application (Leahy and Robinson 2000). Manure application in early spring is optimal because of the plant demand for nutrients at this time. However, this is often not practical as grazing animals tend to reject herbage where manure has been spread during the grazing season. Therefore, it is often more advantageous to spread manure in the fall. Table 4.8 lists the general guidelines for manure application in Nova Scotia.

Table 4.8 Guidelines for applying manure in Nova Scotia

Manure Application Guidelines

- Avoid applying manure between October 1st and April 1st due to the high potential for nutrient loss through surface runoff and erosion.
- Avoid spreading manure on frozen or snow covered ground as nutrient losses can easily result through surface runoff.
- Avoid spreading manure on very wet soils.
- Avoid spreading manure on areas of exposed bedrock.
- Only apply manure on land with less than a 10 % slope. There is a high chance of nutrient loss through surface runoff when manure is spread on steep slopes.
- Ideally manure is incorporated after application; however, this is not possible when applied to unbroken pasture sod. For liquid manure, injection or the use of toolbars on the back of spreaders can reduce losses.
- Calibrate manure spreaders to improve the accuracy of nutrient application.
- Spread manure as evenly as possible.
- Manure should not be spread within 30 m of a drilled or dug well on a clay loam soil or within 60 m on a sand or gravely soil.
- Manure should not be spread within 3 m of a ditch.
- Manure should not be spread within 5 m of brooks, rivers, or lakes.

Nova Scotia Department of Agriculture 2006

LEGUMES

Legumes are valuable species in a pasture because of their symbiotic relationship with *Rhziobia* bacteria. *Rhziobia* bacteria form nodules at the roots of leguminous plants to fix atmospheric nitrogen. The nitrogen that is fixed is available to the host legume, as well as nearby non-leguminous plants. Legumes supply the nearby non-leguminous plants with nitrogen primarily as the nodules and legume residues decompose (Havlin et al. 1999).

White clover has considerable nitrogen fixing potential but it is prone to winter injury (Thomas 2001). Legumes such as red or white clover can typically fix about 100 kg N/ha per year (Havlin et al. 1999). In a pasture with a healthy population of legumes, the nitrogen that is fixed is a valuable supply of nitrogen, reducing the need for additions of nitrogen fertilizer.

The nutrient requirements of legumes differ from those of grasses. In a pasture with 30% legume content or more, additional nitrogen fertilizer is not needed, and in fact will suppress nitrogen fixation by the legumes. In Atlantic Canada, it is recommended to maintain 30% white clover content in the pasture, although this can be difficult. Despite legume content, a fertilizer application of 20 kg N/ha in the spring might be beneficial to the grass content of the pasture (Thomas 2001).

Using less fertilizer nitrogen will promote legume content in a pasture. Less nitrogen reduces the competitive nature of grasses. Dry matter yield will be reduced because of suppressed grass growth; however, in addition to savings in fertilizer, forage quality and animal performance will be improved. In a study comparing a pure orchardgrass pasture fertilized with nitrogen and an orchardgrass and white clover mixed pasture where no nitrogen was applied, Papadopoulos et al. (2001) reported higher weight gains for lambs raised on the mixed pasture. Dry matter yield and stocking density for the mixed pasture were lower, but the higher quality forage resulted in overall higher animal weight gains.

To establish and maintain legume content in a pasture, legumes also require higher amounts of phosphorous, potassium, calcium, sulphur, boron, and molybdenum than grasses. The root systems of legumes are such that they are less efficient at extracting soil nutrients than grasses, and therefore are more prone to nutrient deficiencies. When these nutrients are deficient, nitrogen fixation will be limited.

Phosphorous is often the nutrient limiting the growth of legumes. To encourage the growth of legumes, adequate levels of phosphorous must be maintained, which may require applications of manure or fertilizer. In Atlantic Canada, boron may be deficient. To promote legume content this deficiency should be addressed. In general, boron may be required at a rate of 1 kg B/ha every two years. Sulphur and molybdenum are generally sufficient. Soil testing to monitor these nutrient levels is recommended.

Soil pH will also affect the nitrogen fixing activity of legumes. Many legume species and *Rhizobia* bacteria are sensitive to acidic conditions. To maintain a productive stand of legumes in the pasture, soil pH should be monitored and maintained at a level between 6.0 and 6.5.

Legumes require specific species and strains of *Rhizobia* bacteria for nitrogen fixation. Using the proper inoculate for the legume at the time of seeding will promote nitrogen fixation by helping make sure the proper *Rhizobia* bacteria for the legume is present in the soil. In many cases legume seed is pre-inoculated with the appropriate bacteria.

LIME

Soil pH is a measure of the acidity or alkalinity of the soil. Soil acidity is caused by the presence of hydrogen (H^+) ions in the soil. As the presence of H^+ ions increases, the soil becomes more acidic.

The soil surface has a negative charge. With this charge, positively charged ions (cations) can be held by the soil surface. Both basic and acidic cations are held by the soil. The basic cations, Ca^{2+}, Mg^{2+}, Na^+, and K^+, neutralize acidity. The acidic cations, H^+ and Al^{3+}, contribute to acidity (H^+ contributes directly to acidity and Al^{3+}releases H^+ when it combines with water). Due to their properties, H^+ and Al^{3+} ions are held more strongly by the soil than the basic cations. With rainfall, the Ca^{2+}, Mg^{2+}, Na^+, and K^+ can be leached from the soil, leaving behind the acidic cations. The loss of the basic cations increases the acidity of the soil (Advisory Committee on Soil Fertility).

The acidity of the soil may also be increased by:

- acids that are produced as organic matter in the soil decomposes
- acids that are deposited by acid rain in the region
- acids that are produced by ammonium based nitrogen fertilizers

Soil acidity can have a considerable influence on the productivity of pastures. For the following reasons, the control of soil acidity should be incorporated into pasture management:

- **Phosphorous fixation.** At pH levels below 6.0, aluminium (Al) and iron (Fe) can react with soil phosphorous to form phosphorous compounds. At pH levels above 7.0, compounds with calcium ions (Ca^{2+}) may be formed. This is called phosphorous fixation and reduces the availability of phosphorous to plants and limits normal plant growth. Phosphorous is most available between a pH of 6.0 and 7.0.

- **Al and Mn toxicity.** Below pH 6.0, aluminium (Al) and manganese (Mn) become more plant available and can increase to toxic concentrations and adversely affect normal plant growth (Advisory Committee on Soil Fertility).

- **Fertilizer use efficiency.** Fertilizer use is less efficient in acid soils. At pH 6.0, the fertilizer use efficiency is 80%, but at pH 5.0, it is less than 50%. This is particularly significant for phosphorous fertilizer due to phosphorous fixation (Table 4.9).

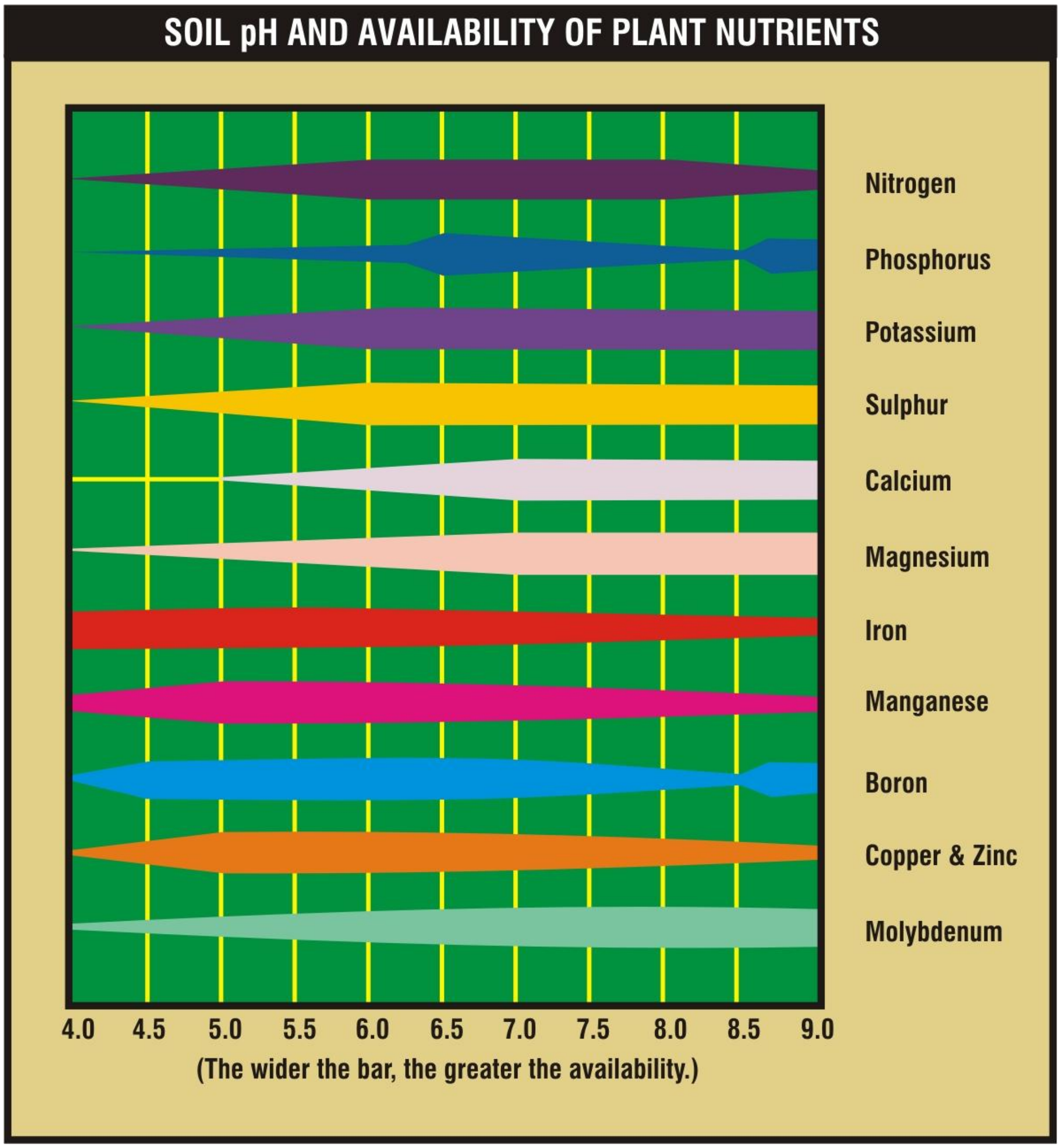
Table 4.9 Fertilizer efficiency at various soil pH levels

	pH = 6.0	pH = 5.5	pH = 5.0	pH = 4.5
Nitrogen efficiency	89%	77%	53%	30%
Phosphorous efficiency	52%	48%	34%	23%
Potash efficiency	100%	77%	52%	33%
Overall efficiency	80%	67%	46%	29%

Advisory Committee on Soil Fertility. Atlantic soils need lime. Publication No. 534-84, Agdex No. 534. Atlantic Provinces Agricultural Services Co-ordinating Committee

- **Nutrient availability.** At pH levels below 5.5 the macronutrients nitrogen, phosphorous, potassium, sulphur, calcium, and magnesium become less available, potentially limiting normal plant growth. At a pH of 5.5 or lower, nutrients are approximately 1/3 available. At a pH between 5.6 and 5.9, nutrients are about 2/3 available. Nutrients are most available at a pH of 6.0 or higher. In contrast, at lower pH levels some micronutrients, iron, manganese, copper, and zinc become more available, and can potentially increase to toxic concentrations (Table 4.10).

Table 4.10 Nutrient availability and pH



Best Management Practices. Nutrient Management. 1994. Ontario Ministry of Agriculture, Food and Rural Affairs

- **Plant sensitivity.** Many pasture species are sensitive to acidic soil conditions and are most productive at a pH between 6.0 and 7.0 (Advisory Committee on Soil Fertility) (Table 4.11).

Table 4.11 Forage species sensitivity to soil pH

Sensitive to acidity (prefers soil pH ≥ 6.5)	Low tolerance to acidity (prefers soil pH ≥ 6.0)	Moderate tolerance to acidity (prefers soil pH ≥ 5.5)
Alfalfa	Kentucky bluegrass	Alsike clover
Smooth bromegrass	White clover	Birdsfoot trefoil
Sweet clover	Orchardgrass	Meadow fescue
	Red clover	Redtop
	Ryegrass	Reed canarygrass
	Timothy	Tall fescue

Forage and Corn Variety Evaluation Task Group. Atlantic Forage Guide. Atlantic Canada

- **Weed tolerance.** Several weeds are able to tolerate low pHs. Acidic soil conditions may result in an increased presence of weeds in the pasture (Table 4.12)

Table 4.12 Weeds that tolerate low pH levels and may indicate acidic soil conditions

Indicator weeds			
Coltsfoot	Eastern bracken	Knapweed	Plantain
Common mullein	Field horsetail	Moss	Prostrate knotweed
Curled dock	Garden sorrel	Nettle	Sheep sorrel
Dandelion	Hawkweed	Ox-eye daisy	Silvery cinquefoil

Singh 2006

- **Response to nitrogen.** Plant response to nitrogen depends on adequate supplies of potassium and phosphorous. Both phosphorous and potassium enable a plant to utilize nitrogen and produce higher yields and more true protein. The reduced availability of phosphorous and potassium at low pH levels means the plant will be less able to respond to nitrogen (Thomas 2001).

- **Activity of micro-organisms.** Many of the micro-organisms that are responsible for nutrient transformations in the soil are not well suited to acidic environments. The natural supply of nutrients may therefore be inhibited at acidic pHs.

About Lime

There are two forms of soil acidity: active and reserve acidity. Active acidity is the measure of H^+ ions in the soil solution. Reserve acidity is the measure of H^+ ions bound by clay surfaces and/or soil organic matter. Both active and reserve acidity factor into how much lime may be needed to neutralize the soil (Advisory Committee on Soil Fertility).

When the pH of the soil is too low, it can be raised with the addition of lime. The amount of lime required will depend on the active and reserve acidity of the soil. To increase the soil pH, both the active and reserve acidity must be neutralized. A soil with high clay and/or organic matter will require more lime than a sandy soil because of the higher reserve acidity of the soil (Advisory Committee on Soil Fertility).

Liming materials vary in their ability to neutralize acidity, depending on the chemical composition, neutralizing value, and fineness of grind. Pure calcium carbonate has a neutralizing value of 100; agricultural limestone will have a lower neutralizing value due to impurities. The fineness of grind determines how fast the lime will act in the soil. Limestone with a finer grind has more surface area in contact with the soil and will be faster acting (Advisory Committee on Soil Fertility).

Agricultural limestone is typically calcitic (calcium carbonate) or dolomitic (calcium magnesium carbonate) limestone. Calcitic lime adds calcium and increases pH; dolomitic lime adds calcium and magnesium while increasing soil pH. When the magnesium content of the soil is low relative to the calcium content, dolomitic limestone should be used (Advisory Committee on Soil Fertility).

Applying Lime

Always apply lime based on a soil test. In Nova Scotia, provincial soil tests indicate the amount of lime recommended to raise the soil pH to 6.0 or 6.5, depending on the crop to be grown. Lime is slow acting; therefore, the timing of the application is important. Ideally, lime should be applied in the fall prior to the growing season. Lime applied in the spring will still have some benefit. In pasture production, lime will most likely be surface applied to an unbroken sod. In this case, more frequent light applications of lime are better than one heavy application. Higher amounts of lime may be incorporated at the time of ploughing and re-seeding.

When applying lime, follow these guidelines from the Advisory Committee on Soil Fertility:

1. Always apply lime based on a soil test
2. Do not apply more than 4 tonnes/ha (1.5 tonnes/acre) of lime a year to unbroken sod
3. Lime applications equivalent to 0.5 tonnes/ha per year will be required to maintain a desired pH
4. Use dolomitic limestone if the magnesium content of the soil is low relative to the calcium content
5. Applications should be spread over several years if there is a high lime requirement
6. If ploughing a field where the lime requirement is more than 6 tonnes/ha, plough down half and incorporate the rest into the surface soil

SUMMARY POINTS

- Soil test every three years to monitor the fertility of the soil
- Base all nutrient applications (fertilizer, manure, lime) on soil test information
- To reduce potential nutrient loss, apply recommended rates of nutrients
- Employ best management practices for manure application to reduce nitrogen losses to the environment
- Calibrate fertilizer and manure spreading equipment to make applications more accurate
- Time nutrient applications with plant demand to encourage plant uptake rather than loss to the environment
- Maintaining an actively growing pasture sod will help reduce nutrient losses to the environment
- Although manure is a valuable nutrient source for pastures, grazing animals do not evenly deposit nutrients across a pasture; recognizing this enables management decisions to make the best use of nutrients returned by the grazing animal
- Nitrogen is often the most limiting nutrient in pastures
- Split applications of nitrogen will reduce the occurrence of excess nitrogen in the soil which may be lost to the environment and will improve nitrogen use efficiency
- Grasses require more nitrogen than legumes. As the legume content of a pasture increases, the need for applied nitrogen decreases
- If the legume content of the pasture is 30% or more, it is not necessary to apply additional nitrogen. In fact, applied nitrogen will suppress nitrogen fixation by the legumes
- Legumes require more soil phosphorous, calcium and potassium than grasses; therefore, adequate potassium and phosphorous is important for maintaining legume content
- Manage the pH of the soil to promote phosphorous availability; phosphorous is most available to plants between pH 6.0 and 7.0
- Fertilizer use efficiency is pH dependent. At pH 6.0, fertilizer use efficiency is 80%, but at pH 5.0, it is less than 50%