Forage

Nutrient Management Guide

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The production of high yielding, high quality forage requires a high level of management. Special attention must be paid to seedbed preparation; variety selection; grazing patterns; weed, disease, and insect pressures; harvest techniques; and marketing. Equally important, and the focus of this publication, is forage nutrition – more specifically grass, legume, and grass/legume mixtures.

Forage

Macronutrients	
Nitrogen	N
Phosphorus	P
Potassium	K
Sulfur	S
Magnesium	Mg
Calcium	Ca

Forage Nutrition

Forage is one of North America's most important crops. United States and Canadian figures suggest that much of this land is managed at a very low level, receiving little if any fertilizer.

Figure 1 illustrates the nutrient requirement of forage crops. It is of little surprise that several years of forage production can seriously deplete a soil's nutrient reserves. Nutrient removal is accelerated in hay production due to the removal of all above-ground plant material. This differs greatly from annual crops where straw and chaff residues are often returned to the soil. These crop materials build soil organic matter and add to the nutrient supply by recycling nutrients contained in the residue.

Nitrogen (N), phosphorus (P), potassium (K), and sulfur (S) are the nutrients most limiting to forage production.

Few soils can supply adequate nitrogen, phosphorus, or sulfur to meet a forage crop's full nutrient demand. Although potassium deficiencies are less common, they are often observed on poor quality land, on soils depleted by successive cropping with limited nutrient additions, and in high-yielding legume forages.

Micronutrients seldom limit forage yield; however, deficiencies are becoming more common as crop nutrient removal depletes the soil's nutrient reservoir. A response to micronutrient additions is evident under conditions of moderate to severe deficiency. Seed production responds more to micronutrient applications than dry matter yield. Perhaps the greatest benefits from micronutrient fertilization appear as improvements in feed quality and animal health.

Micronutrients	
Boron	B
Chloride	Cl
Copper	Cu
Iron	Fe
Manganese	Mn
Molybdenum	Mo
Zinc	Zn

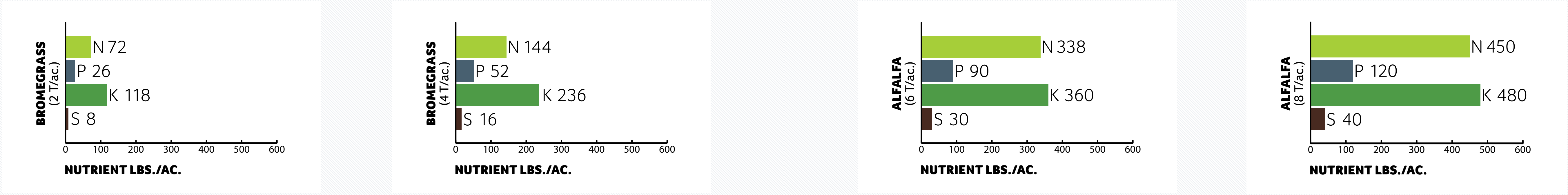
Role of Soil pH

Soil pH is the negative logarithm of the hydrogen ion activity of a soil (The Nature and Properties of Soil, Tenth Edition, Brady), or a numerical designation of acidity and alkalinity (Western Fertilizer Handbook, Ninth Edition). It is measured on a 0-14 scale, with values <7 being acidic, 7 neutral, and >7 alkaline.

There are a number of factors that can affect the pH of a soil, such as organic matter decomposition, parent material of the soil, precipitation, and fertilizer use. Generally speaking, soil pH values decrease in the U.S. as you move from the NW to the SE. For forage crops, target a pH in the range of 6.2 to 6.5 for grasses and 6.5 to 7.0 for legumes for optimal growth and development. Within this range, essential plant nutrients are most available to the plant.

If the pH is too high or too low, some elements may become toxic or unavailable to the plant, herbicide activity can be affected, and activity of nitrogen-fixing bacteria can be reduced. Apply lime to increase pH if needed or sulfur to lower pH, although the latter is rarely economical. It is always best to apply these materials well before planting to give adequate time for them to work. Another option in high pH conditions is to increase the rate of nutrients that are less available at high pH.

FIGURE 1. APPROXIMATE NUTRIENT UPTAKE (LBS./AC.) BY BROMEGRASS AND ALFALFA FORAGES



Source: International Plant Nutrition Institute

Nutrition Requirement

Nutrients are managed by using the concept of supply and demand. If a soil cannot supply sufficient nutrients to meet the crop's demand, fertilizer must be added to protect yield and crop quality. This may sound straightforward, but determining the soil's ability to supply nutrients and the crop's requirement for nutrients is not simple.

Soil Nutrient Supply

Deficiencies occur when nutrient supply is depleted below crop requirements. Although a soil may have supplied sufficient nutrients in the past, soil reserves can be depleted with time by crop removal. Demand may also increase beyond the soil's ability to supply nutrients when conditions for growth are better than usual, higher yield targets are set or crop varieties change. The size of the soil's nutrient reservoir and the crop's nutrient demand will determine when deficiencies appear.

Soil erosion contributes to the depletion of soil nutrient reserves through the removal of nutrient-rich soil and organic matter. While perennial forage crops typically provide excellent protection against erosion, thin stands resulting from disease, drought, stand aging, or insufficient nutrient supply can leave the soil vulnerable.

Soil nutrients must be present in a balance that satisfies plant requirements. Excess quantities or deficiencies of any one nutrient can lead to imbalances that limit yield and crop quality.

A soil test can provide an estimate of the soil's nutrient-supplying capacity. Although a soil test does not measure the amount of nutrients in the soil, it does provide an index of the soil's ability to supply nutrients. A soil test is likened to the oil dipstick in a car. It does not indicate how much is present, just that it is low or high.

The most accurate soil test recommendations are made when field variability is considered, and soil types are sampled and fertilized separately within a field. When only one sample is submitted to the lab, the resulting analysis represents the average nutrient content for all soil types of the field included in the sample. Fertilizer applications made based on this analysis provide surplus nutrients to some areas and insufficient nutrients in others.

Dividing a field into distinct soil types requires considerable knowledge of the field and its history. Each soil type may have a similar color, texture, cropping, and nutrient application history. Look for differences in slope, yield, crop growth, and the effects of soil erosion.

Be sure to sample to the appropriate depth for each nutrient. Handle the samples with care to prevent contamination and to obtain the best results.

Soil test results should not be used in isolation. Cropping history, scouting records, and field experience are valuable resources that must also be considered when formulating nutrient recommendations. In the hands of an agronomist and an experienced producer, this information provides a basis for confirming and fine-tuning soil test recommendations.

Deficiencies occur when nutrient supply is depleted below crop requirements.

Nutrient Demand

As yield potential increases, nutrient demand also increases to meet growth requirements. The amount of nutrients required to produce a target yield has been established for some soil and environmental conditions. However, this data may not exist for many forage crops, varieties, soil types, and climatic conditions. In these cases, estimates must be made to establish the crop's nutrient demand.

The first step in determining a crop's nutrient demand is projecting crop yields. Remember, crop production can be no greater than that allowed by the most limiting growth factor. In many cases, moisture will determine the upper limit; however, seed quality, variety, soil quality, nutrients, insects, weeds, diseases, and equipment will also affect yield.

The factors that affect the crop's yield potential must be considered when establishing a yield goal.

The goal must reflect the yield potential of the variety, soil and climatic conditions, and management intensity. In order to increase yields, production barriers must be removed.

Liebig's Law of the Minimum

Nutrient management is one of the most important aspects to a successful crop. Understanding Liebig's Law of the Minimum can help you maximize the results of your fertilizer investment and achieve the highest possible yields. Make certain you know just how much yield – and economic return – you are leaving out in the field before making a decision for any crop.

Liebig's Law states that the yield achievable is dictated by the factor that is most limiting. Another way to visualize this concept is to illustrate it with a dam. The water being held back by the dam represents yield potential. Holes in the dam represent yield limiting factors that allow yield potential to be decreased as they leak. The goal is to identify which holes are leaking and plug them to maintain as much yield potential as possible.

For most non-legume crops, nitrogen is often considered the most important leak to plug, and that is generally accurate. Simply plugging the nitrogen leak, without considering other leaks in the dam, can lead to considerable yield loss, and inefficient nitrogen use. To get the most out of your fertilizer investment, it's important to ensure you are addressing as many leaks as possible.

Nutrient Uptake

Nutrient uptake is often restricted by the soil type, temperature, moisture, and nutrient balance in the soil. For example, phosphorus uptake is reduced by cool spring temperatures. Cool soil temperatures slow the movement of phosphorus to plant roots and slow root growth, creating a deficiency. This deficiency may occur even when soil phosphorus levels would be considered sufficient. For this reason, many producers apply a small amount of phosphorus with the seed at establishment.

Examples of other conditions that restrict nutrient uptake include soil hardpans, gravel lenses, salinity, acidity, and waterlogged soil. All of these conditions restrict nutrient uptake causing a deficiency to occur even when nutrient levels are sufficient in the soil. When developing a nutrient recommendation, it is important to identify the potential for restricted uptake and develop plans for managing the problem.

Salinity

Waterlogged soil

Nitrogen

Nitrogen rates
for grass may range from
40 to 200 pounds per acre.

Nitrogen Requirement

Grass

Most soils require the addition of nitrogen to obtain a profitable grass yield. The level of nitrogen required varies with the grass species, yield target, climate, soil, amount of residual nitrogen in the soil, and market conditions for the grass grown (Table I and Table II in appendix).

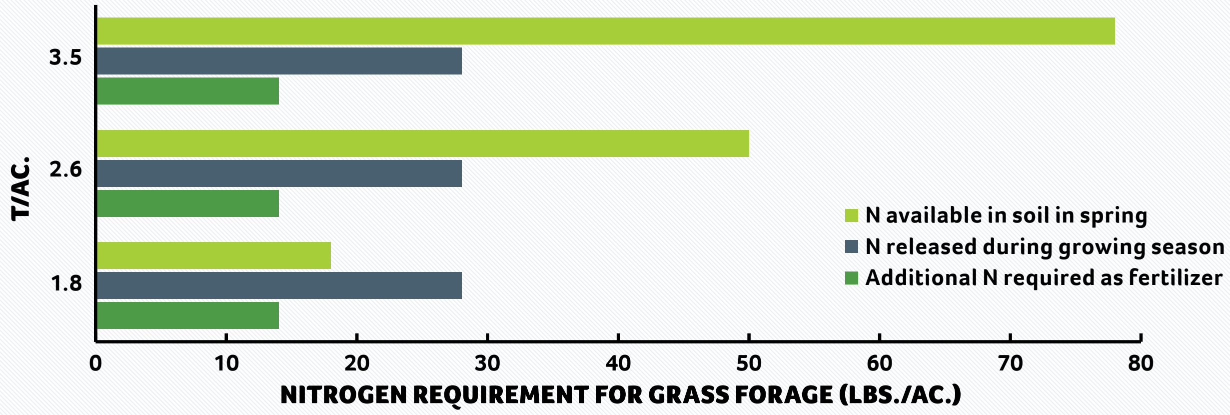
Nitrogen is involved in protein formation and is a major component of chlorophyll. Grass forage with inadequate nitrogen will show symptoms of reduced growth, greenish-yellow leaves (older leaves first, progressing to the entire plant), poor seed set, and lower yield. Poor nitrogen fertility will also result in low protein levels and reduced feed energy.

Available soil nitrogen, mineralized and applied, is the only nitrogen source available to an established grass stand. Soil nitrogen is slowly released during the crop year through the process of mineralization. This process provides only a fraction of the nitrogen most crops require. Forage grasses are aggressive nitrogen feeders, and additional nitrogen is usually required to reach a reasonable yield level. For example, Figure 2 shows the typical nitrogen requirement for a grass forage. From this data we can see that the amount of nitrogen mineralized through the growing season and the available stored soil nitrogen do not meet the crop's nitrogen needs.

Fertilizers supply the majority of the crop's nitrogen demand for maximum grass yield. Generally, there is little to no carry-over of nitrogen for the subsequent spring, since nitrogen requirements typically exceed nitrogen additions. This makes annual applications of nitrogen particularly important for grasses.

FIGURE 2. NITROGEN REQUIRED FOR VARIOUS YIELDS OF GRASS FORAGE

Source: Agriculture Canada, Lacombe, AB



Tables 1 and 2 provide a general indication of the type of yield response nitrogen fertilization can provide. These types of responses are common, given the fact that available nitrogen under hayland is generally low to negligible. This table also illustrates the effect nitrogen fertilization can have on protein levels. Note how the added nitrogen first satisfies the yield requirement and then the protein level. Protein levels are often higher when yields are limited by drought or crop stress.

Grasses require fairly large nitrogen application rates to maximize yields and protein levels. Recommended nitrogen rates for grass range from 40 to 200 pounds per acre depending on yield potential (Table I and Table II in appendix).

In the year of establishment, grass stands are typically fertilized at a lower level due to the stand's limited yield potential. Following establishment, annual applications of nitrogen will maximize the forage yield and maintain the productivity of the stand.

TABLE 1. DRY MATTER YIELD AND PROTEIN CONTENT OF BROMEGRASS HAY, FERTILIZED (34-0-0) ANNUALLY IN THE SPRING OF THE YEAR

Source: Agriculture Canada, Lacombe, AB

Locations in Alberta	Parameters	Level of Applied N (lbs./ac.)					
		0	45	90	135	180	270
North-Central 3 years @ 2 sites	Yield (T/ac.)	0.6	1.3	1.8	2.3	2.9	3.5
	Protein (%)	12.5	10.3	12.1	13.7	14.6	16.3
Central 4 years @ 4 sites	Yield (T/ac.)	1.7	2.6	3.3	3.7	3.8	3.8
	Protein (%)	11.2	11.6	13	14.4	15.2	15.8

Locations in Alberta	Parameters	Level of Applied N (lbs./ac.)						
		0	50	100	150	200	250	300
South-Central 19 years @ 1 site	Yield (T/ac.)	0.5	1.6	2.3	2.4	2.5	2.5	4.0
	Protein (%)	7.3	7.2	8.5	9.6	11	10.9	11.6

TABLE 2. BROMEGRASS YIELD AND PROTEIN WITH NITROGEN AND PHOSPHORUS FERTILIZATION, 31 SITE-YEAR AVERAGE, 1994-2001

Source: Kansas State University

Fertilizer Treatment | N-P_2O_5-K_2O	Forage Yield	Protein
0-0-0	1.3	7.2
40-0-0	2.4	7.9
80-0-0	2.7	8.9
120-0-0	3.1	10.0
40-30-0	2.7	7.6
80-30-0	3.2	8.5
120-30-0	3.5	9.7

Legume

Legume forage has a tremendous requirement for nitrogen (Figure 1, page 3), utilizing two to three times more nitrogen than grass crops. Fortunately, a legume can supply most of its nitrogen requirement by fixing atmospheric nitrogen.

Nitrogen deficient legumes are typically stunted, pale green in color, and low yielding. Leaflets may be club shaped and leaf margins can take on a rounded, chlorotic appearance.

Nitrogen Fixation

When legumes are properly inoculated with Rhizobia bacteria, 50 to 100 percent of their nitrogen requirements can be supplied by the nitrogen fixation process. Legume roots are able to form an association with nitrogen-fixing bacteria in the soil. These bacteria are capable of capturing atmospheric nitrogen, changing it into a form the plant can use, and supplying it to the legume plant.

The root nodule is the site of the fixation activity. It is formed by the infection of the legume root hair by the Rhizobium species of bacteria. Within the nodule, bacteria first converts nitrogen into the ammonia form. It is then converted into amino acids and the amino acids are transferred to the plant. In this manner the plant obtains the nitrogen necessary for growth and development.

Active nitrogen fixation requires a healthy legume plant and an active root nodule. Both the bacteria and the legume are essential for the process to occur and both benefit from the relationship.

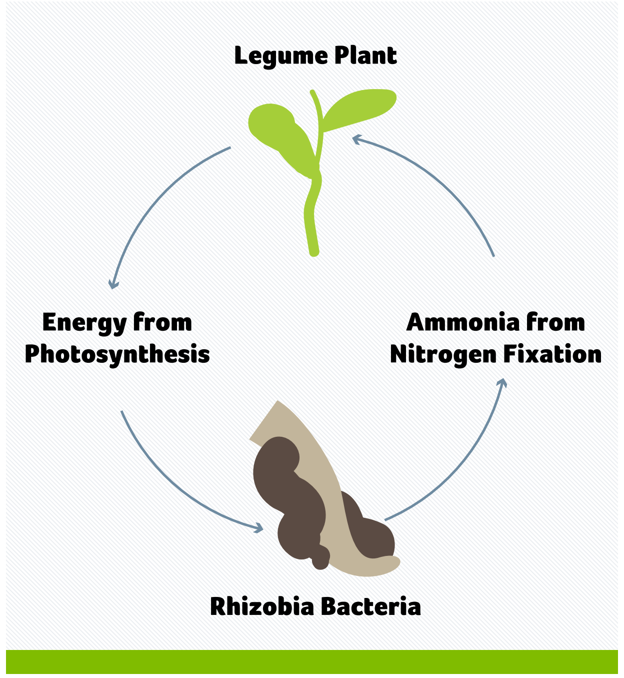
To determine if nitrogen is actually being fixed, carefully dig up the legume roots and gently shake or wash away the soil to expose the nodules. Slice open a nodule and note the inner color; a deep red or pink nodule indicates that its contents are fixing nitrogen.

For an annual legume, this test can be performed about three to four weeks after emergence. For perennial and biennial legumes, the nodules can be checked about six to eight weeks after emergence.

An established stand should have active nodules by late spring or early summer, depending upon the growing conditions for crop development.

The amount of nitrogen fixed varies with the legume species, variety, environment, and fertility management of the crop. The healthier the plant, the greater the potential for nitrogen fixation.

If the crop's nutrient requirements are not satisfied, the process of nodulation and nitrogen fixation will be reduced or absent. Generally, any factors that limit plant growth also directly or indirectly limit the fixation process. Other conditions that specifically inhibit nitrogen fixation include drought, soil acidity, water-logged soils, and high soil nitrate levels.



Selection and Care of Rhizobium Inoculant

There are many different types of Rhizobium inoculants available. It is important to use the proper inoculant for the forage legume grown, since different legumes require different Rhizobium species.

Inoculants are sold and applied to the seed in many different forms. The key to successful inoculation is careful handling of the inoculant.

1. The inoculant must remain moist and should be stored away from direct sunlight and heat. Rhizobia are living organisms which will quickly die in adverse conditions. Check the expiration date on the container to ensure a good quality inoculant.
2. The inoculant must be properly attached to the seed at the correct rate. Some inoculants are sold with a sticker to help the inoculant adhere to the seed. If a sticker is not included with the inoculant, powdered milk, honey, or syrup can be used. It is important that neither this sticker, nor any other product applied to the seed, is toxic to the bacteria.
3. Do not store the inoculated seed too long after application. Keep it covered in a cool location and plant it soon after inoculation. Rhizobia bacteria survive very well once it is established in the soil, but it does not survive long when it is exposed on the seed.

Adding Nitrogen

Legume crops do not generally require added fertilizer nitrogen; however, there are situations where nitrogen appears to produce a response. This likely occurs when the nitrogen fixation process is not functioning properly, and the plant cannot obtain the nitrogen it requires for healthy growth and development.

At establishment there is generally a lag period of three to five weeks from the time of inoculation and seeding to the time of nitrogen fixation. During this early stage, the legume is establishing a leaf area capable of capturing the sun's energy, and a root system capable of exploring and obtaining nutrients from the soil. At this time the relationship between plant and Rhizobia is parasitic. The nodules draw nutrients from the plant but do not return nitrogen to the plant. Only after this stage does the plant begin to gain the benefits from the nitrogen-fixing bacteria. As a result, legumes use soil nitrogen during establishment when the fixation process is not capable of supplying its nitrogen requirement. At this stage, nitrogen fertilizer may be beneficial for crop establishment if the soil nitrogen level is below 20 to 25 pounds of nitrate nitrogen per acre (6-inch depth). When soil nitrogen levels are above 25 pounds, there should be sufficient nitrogen for the legume to establish and be nourished until the fixation process begins to supply nitrogen. This may explain why there are occasional claims of a response to nitrogen fertilizer.

Nitrogen applied in excess of these levels can reduce the amount of nitrogen supplied by fixation. The level of reduction is related to the amount of fertilizer nitrogen added in excess of the legume's early requirement. This occurs because soil mineral nitrogen, especially nitrate-nitrogen, inhibits Rhizobia, and the legume will preferentially use soil nitrogen rather than fix its own nitrogen.

Nitrogen fertilizer may have a place in increasing the dry matter yield of aging or unproductive stands. Stands in their last year(s) of production that are no longer fixing their own nitrogen in sufficient amounts benefit from nitrogen additions. In this case, the additional nitrogen allows for one more year of reasonable growth before plow-down. The decision to apply nitrogen should be based on a cost-to-benefit analysis. There is seldom an agronomic or economic benefit of adding nitrogen to healthy legume forage stands.

The key to successful inoculation is careful handling of the inoculant.

Grass and Legume

The nitrogen requirement of a mixed forage stand is determined by its composition. The legume component has a high nitrogen demand and an ability to meet its needs through nitrogen fixation, while the grass component has a high nitrogen demand but is dependent on soil nitrogen, nitrogen transferred from the legume, and fertilizer nitrogen. Most studies indicate that nitrogen transferred from the legume is typically insufficient to maximize grass production and quality. As a result, fertilizing a mixed stand will often increase yield by stimulating the grass component.

Applying nitrogen fertilizer can stimulate grass growth to the point that it out-competes the legume, shifting the stand composition in favor of the grass. Although it may result in increased production, it often reduces overall forage quality by reducing the high protein and high-quality legume component of the stand.

In an attempt to maximize production and maintain the legume component of the stand, most recommendations suggest varying the nitrogen application rate based on stand composition. The higher the legume component, the lower the nitrogen recommendation (Table I in appendix).

Nitrogen Transfer

Grasses growing in close proximity to legumes often appear to be greener and healthier than grasses further removed. The grass appears to benefit from fixed nitrogen by way of decomposing nodules, root exudates, old roots, and leaves, both from the current and previous year's growth.

It is difficult to quantify the actual amount of nitrogen that may be transferred under each individual situation. Research work undertaken by Agriculture Canada (Swift Current) from 1980 to 1984 suggested that crops such as creeping red fescue and bromegrass obtained about 60 percent of their nitrogen requirements from a legume such as alfalfa or birdsfoot trefoil. This study also suggested that the benefit is greatest where the two species are in close proximity, and that Russian wildrye, crested wheatgrass, and Altai wildrye obtain benefits similar to creeping red fescue. Depending on the time of the growing season and the growth habit of the two crops, the grass and legume can actually compete for soil or fertilizer nitrogen. For example, a grass species that starts spring growth two to three weeks before a legume does not have to compete for nitrogen, but a grass species that resumes growth when alfalfa does may have to. The legume may go through a period in early spring where it depends on soil nitrogen because the fixation process is not yet functioning in providing nitrogen to the legume.

Application Methods and Timing

Application Methods and Timing

The efficiency of nitrogen fertilizer is affected by the method of placement and application timing. The best application for a forage will depend upon the soil type, climate, forage variety, growth stage, and management practices.

Seed Placement

Only a small amount of nitrogen can be safely seed placed with forages. Application rates should not exceed 10 pounds of nitrogen per acre when using a double disc press drill or equipment with similar spread patterns. Floater or spreader type systems can be used to apply fertilizer and seed at the same time. In this case, the spreading action of the equipment effectively separates the seed and fertilizer, reducing contact. This separation reduces the potential for seed or seedling injury.

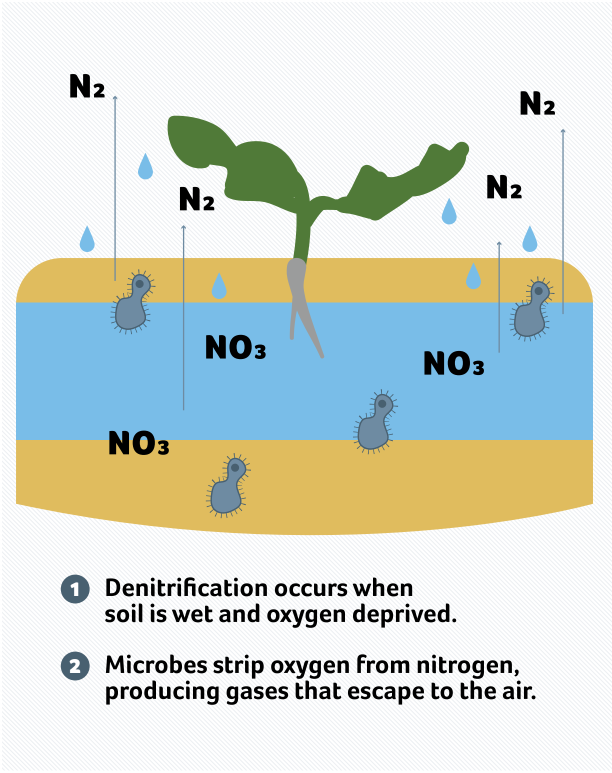
Broadcasting

Full broadcast and incorporated nitrogen is a common practice; however, it is not recommended in moist or wet areas due to the high potential for denitrification losses. The greatest loss occurs when nitrates accumulate in the fall and the soil becomes waterlogged in the spring. Under these conditions nitrate (NO_3) is converted to nitrogen gas (N_2), nitrous oxide (N_2O), and other gases by soil microbes and lost to the atmosphere (Figure 3). Losses are typically low in semiarid regions due to lower moisture levels.

The efficiency of spring broadcast and incorporated nitrogen is greatest where there is sufficient and timely rainfall to move the nitrogen into the rooting zone. In these areas, broadcast and incorporated nitrogen produces yields similar to banding. Broadcast and incorporated nitrogen can be immobilized when large amounts of crop residue are added or present in the soil. A portion of the immobilized nitrogen will be released over time as soil microbes die and decompose. Immobilization can be managed by reducing residue and fertilizer contact through banding or by increasing application rates to offset delayed nitrogen availability.

Under dry conditions, broadcast nitrogen is susceptible to surface stranding. This nitrogen is positionally unavailable as roots do not function well in dry soils.

FIGURE 3. SOIL MICROBES CONVERT NITRATE (NO_3) TO NITROGEN GAS (N_2) WHEN THE SOIL BECOMES WATERLOGGED. THIS PROCESS IS CALLED DENITRIFICATION.



Topdressing

Topdressing is the most common method of applying nitrogen to established grass stands due to its lower cost and ease of application. The effectiveness of the application can be reduced when moisture is insufficient to move the nitrogen into the rooting zone.

It is important to note that broadcast nitrogen is susceptible to volatile loss of ammonia (gassing off). The extent of these losses depends on climate, soil type and condition, and type of fertilizer applied (Table 3).

When loss potential is low, most commonly applied granular nitrogen fertilizers produce satisfactory results. When loss potential is high, select a fertilizer product that has a low susceptibility to volatilization or use a urease inhibitor, if applying urea, or controlled-release fertilizer.

Volatilization losses from urea are generally small during the initial period after application and take time to accumulate. Under a high volatilization potential, losses from some surface applied products typically range between 10 and 15 percent over one to seven days, but may be greater if rainfall does not move the nitrogen into the soil.

Fall applications of urea can be made when the volatilization potential is reduced by cool soil temperatures. Fall applications of nitrate forms are not recommended in wet areas due to the potential of denitrification and leaching losses. Spring applications should be made prior to the resumption of grass growth. The best timing will depend on the environmental conditions and the growth habit of the grass. Some grasses resume growth quite early in the spring and a fall application may be necessary. While in other areas, fall loss potential is high and spring application is the better choice.

For spring surface applications where volatilization potential exists, urease inhibitors can be added to urea to reduce potential losses. Polymer-coated fertilizers also have potential to reduce losses when volatilizing conditions occur because only a small amount of the soluble fertilizer is exposed to the environment. These practices should be evaluated on the basis of net return and potential benefits.

TABLE 3. CONDITIONS AFFECTING THE POTENTIAL FOR NITROGEN LOSS THROUGH VOLATILIZATION

Source: Nutrien

High Volatilization Potential	Low Volatilization Potential
Climate	
Less than one-half inch of rainfall	Greater than one-half inch of rainfall
High soil temperature	Low soil temperature
Moist soil surface	Dry soil surface
High wind speed	Low wind speed
Soil	
Coarse soil texture	Fine soil texture
Low organic matter content	High organic matter content
High lime content	Low lime content

Recent research suggests that nitrogen fertilizer should not be applied to snow covered fields when the underlying soil is frozen. However, applying nitrogen in late fall or early winter on thawed fields when there is minimal snow cover (1 to 2 inches) may be acceptable when spring application is not an option, and fertilizer must be applied. In this case the snow cover must be thin enough to allow the fertilizer granule to reach the ground and dissolve into the unfrozen soil.

Soil microbes consuming crop residue utilize soil and fertilizer nitrogen. This nitrogen is temporarily tied up in the microbes. This process is called immobilization.

Split Application

Nitrogen can be applied in a single annual application or in a split-rate fashion. There are advantages and disadvantages to both methods. Split-rate applications show little value in dry areas that produce only one harvest but can be beneficial in moist areas where multiple cuts are obtained. A split application rate usually favors equalized production and uniformity of protein over the growing season. Split applications have merit in two or three cut systems and where application rates exceed 60 pounds of nitrogen per acre.

Table 4 compares large single applications and split applications on bromegrass. On average, split applications allowed for greater production uniformity and an opportunity for the producer to vary the fertility program based on prevailing fertilizer and crop prices, and environmental conditions.

The performance of split applications may depend on the production environment as illustrated in Table 5 on the next page. In this Utah study, applying nitrogen in multiple applications during the season was superior to a single application in a high yield environment with adequate moisture throughout the growing season. When moisture is sufficient for sustained regrowth, nitrogen applied later in the season produces significant additional forage. In a low yield environment with limited moisture and regrowth, split nitrogen applications did not produce as much forage as a single application of the same total rate. In the low yield environment, most of the forage is harvested from the first cutting, and nitrogen applied for the first harvest should not be reduced.

Splitting the total amount of nitrogen into multiple applications reduces first-cutting production. Nitrogen applied later produces little if any extra forage.

TABLE 4. YIELD OF SMOOTH BROMEGRASS WITH NITROGEN FERTILIZER (46-0-0) AS SINGLE INITIAL OR ANNUAL APPLICATION

Source: Agriculture Canada, Lacombe, AB

Location in Alberta Volatilization Potential	Level of Applied Nitrogen Fertilizer (lbs./ac.)				
	0	Single 135	Annual 3 x 45	Single 267	Annual 3 x 89
North-Central (T/ac.) Total – 6 station years	1.8	3.6	4	4.6	5.4
	0	Single 267	Annual 4 x 45	Single 356	Annual 4 x 89
Central (T/ac.) Total – 16 station years	8.1	10.7	11.9	12.6	14.1

TABLE 5. FORAGE GRASS YIELDS WITH SPLIT APPLICATIONS OF NITROGEN

Source: Utah State University

Low yield environment		High yield environment	
Limited moisture, 2 cuttings		Adequate moisture, 5 cuttings	
Nitrogen rate (lbs./ac.) and timing	Yield (T/ac.)	Nitrogen rate (lbs./ac.) and timing	Yield (T/ac.)
0 (control)	0.62	0 (control)	1.1
50 April	0.91	50 April	3.2
100 April	2.03	100 April	5.9
50 April + 50 June	1.26	150 April	6.5
150 April	2.28	100 April + 0 June + 50 August	6.6
75 April + 75 June	1.83	100 April + 50 June + 50 August	7.8
50 April + 50 June + 50 August	1.41	120 April + 80 June + 0 August	7.6

Banding

Banding into established stands has advantages and disadvantages. On the positive side, nitrogen is placed in the crop's rooting zone where it is protected from volatilization losses and can be easily reached by crop roots. On the negative side, banding damages the rooting system, requires more time, and is harder on equipment. The best results appear when applications are made in moist soil and with equipment which minimizes root damage. On older stands, root damage may be less of a concern as these stands can be root bound and may benefit from the banding operation. Granular, liquid, or anhydrous ammonia nitrogen sources can be banded (Table 6).

Liquid nitrogen sources may be applied in a surface strip or dribble band. This application method results in a concentrated nitrogen band, with little crop injury since the band is surface applied. Strip banding liquid greatly reduces potential volatile losses that can occur with broadcast application of liquid nitrogen fertilizers.

Nitrogen can be applied in concentrated pockets or "nests" using a spoke wheel injector. This system places the fertilizer in the rooting zone with minimal crop damage. Although this method of application is effective, equipment availability is limited.

Some forage producers use a single large application of nitrogen at the time of establishment to sustain the stand for several years. This allows the producer to reduce labor requirements and maximize fertilizer pricing advantages. Research studies show yield increases in the first year, moderate increases in year two, and that the benefits of the large application do not often persist into the third year. By comparison, yearly nitrogen applications usually result in greater productivity during the life of the stand and allow for equalized production. Large applications in excess of the crop's immediate requirement can also present an environmental concern in high rainfall areas.

TABLE 6. BANDING NITROGEN INCREASES BROMEGRASS YIELDS AND PROTEIN

Source: Kansas State University

Application method	Crude protein (%)	4-year average yield (T/ac.)
Control (no nitrogen)	7.0	1.3
Broadcast*	8.4	2.6
Dribble band*	9.2	3.0

**Averages of 60 and 120 pounds of nitrogen per acre*

The best application for a forage will depend upon the soil type, climate, forage variety, growth stage, and management practices.

Phosphorus

Phosphorus is a major component in a fertility program for both grass and legume forage.

Phosphorus Requirement

All Forages

Phosphorus plays a vital role in energy transfer, photosynthesis, nutrient transport, plant genetics, and as a structural component of the plant. When phosphorus supply does not meet crop requirements, growth, yield, and quality are reduced.

Most soils cannot supply sufficient phosphorus to meet the requirements of a high-yielding forage crop. Typical phosphorus responses include increased yield, improved crop quality, reduced disease, and extended stand life. Often there is no visible difference between phosphorus-sufficient and phosphorus-deficient plants. Unless there is a severe deficiency, variations in plant height or size may be the only noticeable symptoms. Yield monitoring and feed, plant, or soil analysis may be the only ways to positively identify the deficiency. The best source of information usually comes from crop inspections, yield monitoring, and soil testing.

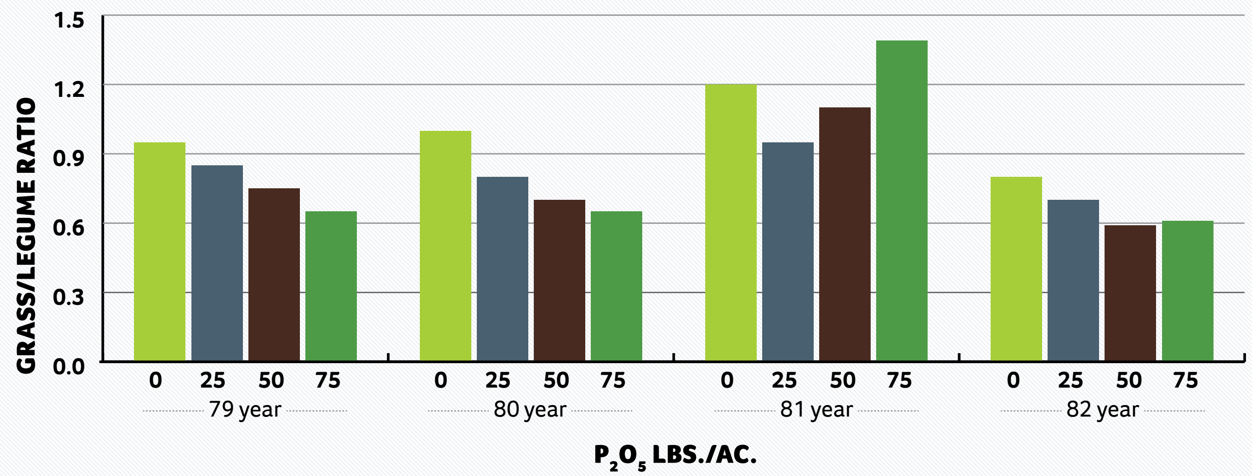
Phosphorus is a major component in a fertility program for both grass and legume forage. Of the two crops, legumes have a greater phosphorus requirement (Figure 1, page 3).

As a result, fertilizer recommendations for phosphorus on forage legumes are often 1.5 to 2 times that of forage grasses, ranging from 10 to 50 pounds P_2O_5 per acre for grasses, and 20 to 100 pounds P_2O_5 per acre for legumes (Table I in appendix). Phosphorus deficient legumes will struggle to generate the sugars needed to "pay" nitrogen fuxing bacteria for their work. This may induce a yield drag due to low nitrogen supply.

Phosphorus applications can cause a shift in the composition of mixed stands in favor of the legume (Figure 4). The phosphorus appears to provide the legume with a greater benefit, allowing it to gain a competitive advantage over the grass forage.

FIGURE 4. GRASS TO LEGUME RATIO OF MIXED FORAGE AS INFLUENCED BY PHOSPHATE FERTILIZATION OVER A FOUR-YEAR PERIOD

Source: Proceedings of the 22nd Alberta Soil Science Workshop, 1986



Application Methods and Timing

When phosphorus fertilizer is applied to moist soil, water immediately moves to the fertilizer granule. The movement of phosphorus fertilizer is generally 0.5 to 2 inches from the application site, depending upon the soil type and its reactivity.

The granule begins to dissolve, forming a concentrated fertilizer solution around it. The solution moves slowly through the soil, dissolving compounds and releasing ions such as calcium, magnesium, aluminum, and iron. These ions react with some of the phosphorus fertilizer to form precipitates that are less soluble than the original fertilizer. The phosphorus precipitates are not available to plants but may become available and utilized by subsequent crops.

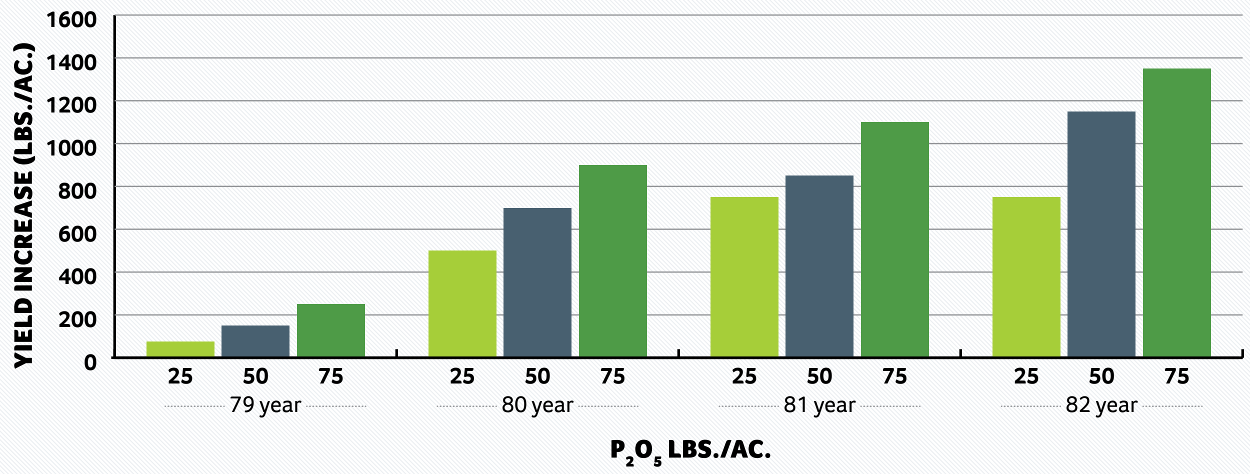
Phosphorus fertilizer can also be absorbed by soil microorganisms and immobilized in their bodies. This phosphorus enters the organic pool of phosphorus and is slowly released when the organism dies and decomposes.

The method of placement and timing have a major effect on the availability of fertilizer phosphorus and its accessibility to plant roots. Due to the low mobility of phosphorus in soils, and the high phosphorus requirement of forage crops, agronomists may recommend building soil phosphorus levels prior to establishment. This practice provides an adequate supply of phosphorus that is immediately accessible to the forage.

Applications of phosphorus to established stands are typically surface broadcast. Due to the low mobility of phosphorus in soil, this fertilizer phosphorus can be stranded at the soil surface and may not produce the maximum response in the year of application. With time and repeated applications, phosphorus levels will build, and the response will improve (Figure 5).

FIGURE 5. YIELD INCREASE (LBS./AC.) OF MIXED FORAGE AS INFLUENCED BY PHOSPHORUS FERTILIZATION OVER A FOUR-YEAR PERIOD IN THE FOOTHILLS OF SOUTH CENTRAL ALBERTA

Source: Proceedings of the 22nd Alberta Soil Science Workshop, 1986



Seed Placement

When phosphorus levels are low and spring conditions are cool and moist, seed placement is generally the most effective method of application. Cool, moist soils slow the movement of phosphorus to the roots, resulting in a deficiency. This can occur even when soil phosphorus levels are considered to be adequate. For this reason, small amounts of seed placed phosphorus are recommended.

Unfortunately, most forages are sensitive to seed placed fertilizer. Fertilizer phosphorus can be applied with the seed to a maximum of 15 pounds P_2O_5 per acre when using a double disc drill and a 6-inch row spacing. Higher rates may be applied when using equipment that scatters the seed and fertilizer over a larger area.

Banding

Banding is an effective method of phosphorus placement because it reduces fertilizer contact with the soil. This decreases the conversion of highly available phosphorus fertilizer to less available forms. Due to the high phosphorus-fixing capacity of many soils, it is generally preferable to increase the availability of phosphorus in soils by banding, rather than by increasing root contact through broadcasting. As a result, banding fertilizer phosphorus is often recommended over broadcast applications for establishment. Differences in banding and broadcast application efficiencies disappear as soil test phosphorus levels increase.

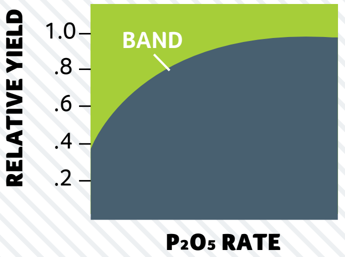
Phosphorus can be banded in late fall or spring with similar results. Bands should be placed 2 to 3 inches below the soil surface into moisture. Depths greater than 3 inches are generally not economically beneficial and increase equipment stress.

In-crop banding can be used to supply phosphorus to forage crops. Research results are variable, but studies have shown positive results with subsurface banding in established forages. New stands appear to suffer some damage and yield loss from disc-and-knife-type openers, while older stands may benefit at times. This is likely a result of root damage in new stands and a reduction in sod-bound conditions that restrict air and water movement in old stands. Increased disease levels due to root damage is a concern in new and old stands. Implements that minimize root damage should be used for in-crop banding. Yield loss due to stand damage appears to be greatest under dry conditions and in coarse textured soils.

Broadcasting

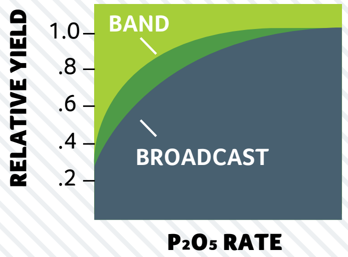
Broadcast and incorporated phosphate applications increase root and soil contact with the fertilizer material, but the benefits of increased root contact are often negated by decreased phosphorus availability. To obtain performance similar to banding and seed placement, application rates must increase when phosphorus levels in the soil are low. Typical relationships between broadcast and band applications are described in Figure 6.

RELATIONSHIPS BETWEEN BROADCAST AND BANDED PHOSPHORUS



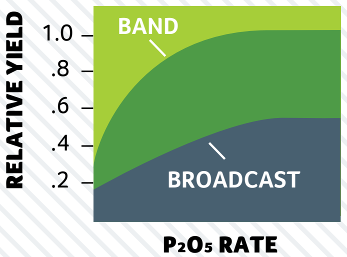
Typical Conditions

- High soil test level
- Warm, moist soil
- Thorough incorporation



Typical Conditions

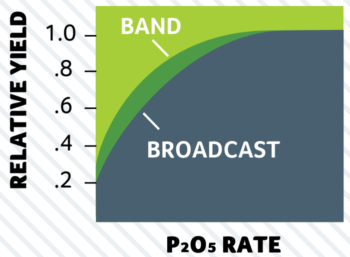
- Low soil test level
- Cold, wet soil
- High phosphorus fixing soils



Typical Conditions

A. • Cold, wet soil
 • Early growth critical

B. • Low soil test level
 • Minimal incorporation
 • Dry soil surface



Typical Conditions

- Low phosphorus fixing soil
- Heavy residue cover
- Warm, moist soil surface
- No tillage or cultivation

In established stands, broadcast phosphorus cannot be incorporated. Phosphorus availability is dependent on soil moisture to dissolve the fertilizer granule and moving into the crop's rooting zone. During the year of application fertilizer phosphorus only moves 0.5 to 2 inches into the soil. Under dry conditions, this phosphorus can be stranded at the soil surface. This may still be adequate to sustain plant growth if the stand provides enough ground cover to prevent evaporative moisture loss and allow root growth near the soil surface.

Large broadcast applications at establishment can be incorporated into the root zone where the phosphorus will be more available than if left on the surface. The effectiveness of this application depends on soil type, climatic conditions, and fertilizer rate. In many cases, large broadcast applications are agronomically equal to smaller applications top-dressed annually.

Some soils have a large capacity to fix or "tie-up" fertilizer phosphorus. In these soils, phosphorus fixation usually increases with the time fertilizer has to react with the soil, and a single large application may be less effective.

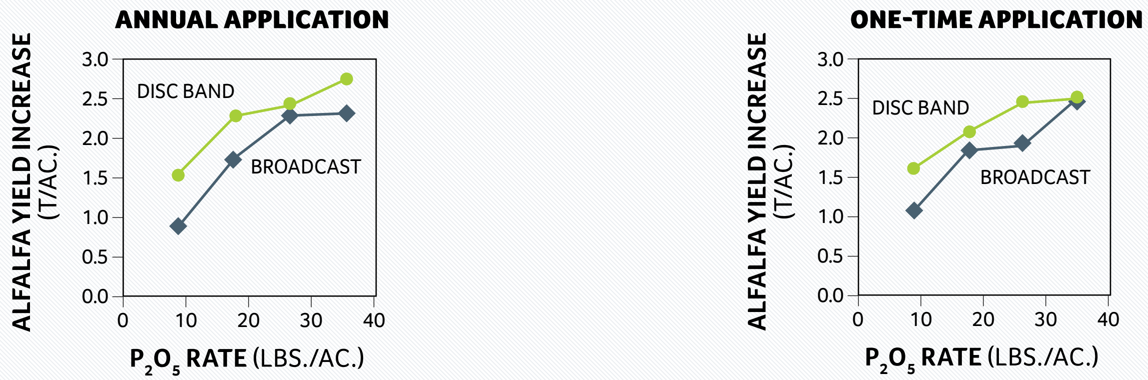
In soils of high phosphorus-fixing capacity, such as high-lime soils, annual applications in the spring close to the time of plant uptake may be more effective. The decision to apply a large broadcast treatment or apply a smaller amount annually may also be determined by cash flow and land tenure. Land ownership or long-term tenure may favor a large buildup application. Cash flow deficiency or short-term land tenure may favor annual application according to soil test.

Typically, fall applied phosphate fertilizer is recommended for established stands, as this provides time for the granules to dissolve and move into the soil. A comparison of broadcast and band applications is shown in Figure 7.

In this study (Figure 7), yield increased with increased phosphate application rates, and disc type banding generally improved yields over broadcast applications. Very high phosphate rates, either band applied or broadcast as a one-time application, effectively increased yield.

FIGURE 7. COMPARISON OF BROADCAST AND BANDED PHOSPHORUS ON ESTABLISHED ALFALFA.
Yield increase is the increase over the unfertilized check and is the total of five years of production. Annual application rate was applied every year for five years. One-time application rate was applied in the first year of the five-year study.

Source: Agriculture and Agri-Food Canada, Saskatchewan



Potassium

Potassium is contained within the stems and leaves.

Potassium Requirement

Potassium is required in large quantities for healthy crop growth and development. Due to the high demand, many forage crops can benefit from applications of potassium.

Potassium deficiencies are most common on well-drained, coarse-textured soils; however, deficiencies are becoming more widespread as soil nutrient levels are depleted by crop removal. This is especially apparent on hayland because of the high potassium removal with each harvest.

Potassium regulates water balance, enzyme activity, starch synthesis, nitrogen uptake, and protein production in the plant. The majority of the plant potassium is contained within the stems and leaves.

Grass

Potassium-deficient grasses may exhibit signs of pale green to yellow color on leaf tips and margins. The discoloration may progress over the entire leaf, and often the incidence of disease increases. Disease may become so severe that a correct diagnosis is difficult.

Forage grasses are less responsive to potassium than legumes. A strong response by grasses is usually limited to soils that test relatively low in exchangeable potassium. Since greater demand is placed on the soil as yield and plant size increase, high nitrogen use on forage grass may lead to a potassium deficiency.

Potassium application on forage grass does not always relate to a yield increase; often the response is measured as an improvement in crop quality, winter survival, and disease resistance.

Potassium recommendations for establishing a grass stand range from 45 to 90 pounds of K_2O per acre and 30 to 60 pounds of K_2O per acre for established stands (Table I and II in appendix). This recommendation assumes that the application will be broadcast and incorporated or banded.

Legume

Potassium-deficient legumes often exhibit pale gray or whitish spots on leaf tips and margins. These spots may grow together to form a whitish band around the leaf margin.

Forage legumes such as alfalfa show a strong response to potassium fertilization. Unlike grasses, legumes have been shown to respond to potassium even when soil test potassium levels are in the medium to high range. Potassium also has a dramatic effect on yield (Table 7), stand longevity, and winter survival (Table 9). In many cases, response to potassium increases with stand age.

A general potassium recommendation for a forage legume may range from 60 to 150 pounds of K_2O per acre for establishment, and 100 to 200 pounds of K_2O per acre for established stands (Table I and III in appendix).

The Wisconsin study (Table 8) shows the response of alfalfa to applied potassium at various soil-test levels. Where response to potassium was observed in this study, about 210 pounds applied potassium was sufficient to produce maximum response except in very deficient soils. This rate of potassium was also sufficient to maintain soil-test levels at the yields produced. Alfalfa grown on soils testing greater than 150 ppm potassium did not respond to additional applied potassium.

Grass & Legume

Legumes in a mixed stand generally show a much greater response to potassium than grasses; however, it appears that potassium does not influence stand composition to a significant degree. The health of the plant may be the issue when comparing grass and legume forage response to potassium. The legume depends upon nitrogen fixation for its nitrogen, and any nutrient deficiency in the legume may be reflected in reduced fixation. A healthy plant is better able to support the nodules and bacteria. As a result, a shortage of potassium can become critical, as it affects the plant's overall growth and ability to fix nitrogen. Additionally, if the legume is unable to maintain normal growth and development due to the lack of potassium, the grass crop may also suffer due to a lack of nitrogen transfer.

TABLE 7. ALFALFA YIELD RESPONSE TO POTASSIUM INCREASES WITH STAND AGE

Source: International Plant Nutrition Institute

Age of stand (yrs.)	Yield increase with added potassium (K) (T/ac.)			
	Québec	New York	Manitoba	Missouri
1	0.1	0.6	0.2	0
2	0.2	0.7	0.3	0.9
3	0.4	1.1	0.9	1.1
4	0.7	1.8	1.2	1.5
5	–	–	1.7	1.4

Potassium application is measured as an improvement in crop quality, winter survival, and disease resistance.

TABLE 8. ALFALFA RESPONDS TO POTASSIUM AT MEDIUM TO HIGH SOIL-TEST POTASSIUM. YIELDS ARE AVERAGE OF 1994-1997.

Source: University of Wisconsin

Applied K_2O	Soil-test potassium (K) level (ppm)				
	<70	70-90	90-120	120-150	>150
lbs./ac./yr.	T/ac. (dry weight)				
0	3.0	3.1	3.3	3.2	3.6
70	3.3	3.4	3.3	3.5	3.5
140	3.3	3.3	3.4	3.5	3.5
210	3.4	3.6	3.6	3.5	3.6
280	3.7	3.6	3.6	3.5	3.5
350	2.9	3.6	3.6	3.7	3.6

TABLE 9. THE EFFECT OF POTASSIUM FERTILIZER IN PROTECTING ALFALFA FROM WINTERKILL ON A SANDY LOAM SOIL

Source: Agriculture Canada, Brandon, MB

Year	With potassium*		Without potassium*	
	Stand Density**	Yield (T/ac.)***	Stand Density**	Yield (T/ac.)***
1970 (seeded)	–	–	–	–
1971	98	1.1	102	1
1972	102	1.4	90	1.1
1973	97	2	82	1.1
1974	98	1.9	51	0.6
1975	102	2	35	0.4
1976	100	1.9	15	0.2
1977	95	1.8	15	0.2

* *Received an annual application of 100 pounds of K_2O per acre.*
** *Number of plants in three 1-meter row lengths taken in May and expressed as a percentage of the same count taken in the previous September.*
*** *First cut only.*
Initial soil test: *231 pounds of exchangeable potassium per acre (0-6 inches).*

Application Methods and Timing

The method used to apply potassium is important because of the reactive nature of this nutrient. When potassium contacts certain clay minerals, it can become fixed in the clay and unavailable for plant uptake. Application methods such as banding, which reduce fixation and increase root contact, are preferred.

Seed Placement

Seed placement of potassium will minimize the soil contact and optimize root contact; however, this method of application can cause seedling damage from elevated salt levels created by the potassium fertilizer. Since potassium is not often recommended for grasses, seed placement restrictions are typically not an issue.

Potassium recommendations for legumes are usually great enough that seed placement of the recommended rate is not a viable option. Special circumstances do exist when a floater or spreader system is used to apply fertilizer and seed. The spreading action of the equipment separates the seed and fertilizer. This separation reduces the potential for seed or seedling injury caused by seed-placed potassium.

Banding

Banding is typically more efficient than broadcasting when potassium rates are low. The differences in efficiency between band and broadcast applications begin to disappear as rates of application and soil test levels for exchangeable potassium increase.

Band applications are normally made prior to establishment but can also be made in-crop. In-crop application of potassium can be an effective method of providing the forage crop with an available source of potassium; however, the issue of root and stand damage is a concern.

Broadcasting

When broadcasting potassium, application rates are often increased to provide benefits similar to those obtained by banding. Small rates of potassium are commonly doubled.

Potassium sufficient for the life of the stand may be applied at the time of establishment or an annual application program can be developed.

Sulfur

Sulfur is the building block of proteins, enzymes, and vitamins.

Sulfur Requirement

The importance of sulfur in a forage fertility program cannot be overemphasized. Due to the high sulfur demand of most forages, many soils are incapable of supplying sufficient sulfur to produce a high yielding crop. Soils with low organic matter or a coarse texture typically have a low sulfur-supplying capacity and require sulfur fertilization.

Sulfur deficiencies can appear on any soil that is continuously cropped or subject to leaching. Continual removal of the above ground plant material quickly depletes soil nutrient reserves. Sulfur is the building block of proteins, enzymes, and vitamins and is a key ingredient to the formation of chlorophyll. Inadequate sulfur will restrict the yield potential and effective use of other nutrients.

Sulfur also plays a key role in legume nutrition and therefore, nodule health and function. Sulfur-deficient grasses and legumes are generally shorter in stature and exhibit pale green to yellow colored leaves. This discoloration is localized on the newer, upper growth of the plant.

Grass

Responses to sulfur in grasses are becoming more common as soil sulfur levels are depleted by continuous cropping practices and leaching. Decreased sulfur from atmospheric deposition is also increasing the need for fertilizer sulfur. Of the grasses, timothy and bromegrass have shown the most consistent response, and responses appear to increase with repeated application.

Sulfur deficiencies are more likely to occur for forage grasses that receive high nitrogen rates. Generally, annual rates of sulfur range between 20 and 30 pounds of sulfate-sulfur per acre for grasses (Table I in appendix).

The effect of sulfur fertilization on timothy yield was measured in the Mayerthorpe, Alberta area (Table 10). The results show the benefits of sulfur fertilization and a balanced fertility program.

TABLE 10. EFFECT OF SULFUR ON TIMOTHY YIELD AT A NORTH-CENTRAL ALBERTA SITE

Source: Soil & Crop Management Branch, Alberta Agriculture, Food and Rural Development

	Yield (T/ac.)	
	71 lbs./ac. Nitrogen	142 lbs./ac. Nitrogen
N	1.2	1.3
N + S	1.7	1.9

Low nitrogen rates without sulfur exhibited higher protein levels than with sulfur (Figure 8). At the high nitrogen rate, protein levels increased with the addition of sulfur. The low nitrogen rate was not sufficient to maximize yield or protein, and although the addition of sulfur improved yield, there was not enough nitrogen available to increase protein levels. The higher nitrogen rate produced a higher yield level and provided sufficient nitrogen to produce additional protein.

Legume

Forage legumes require large amounts of sulfur to produce maximum yields and optimum forage quality. In fact, alfalfa utilizes about as much sulfur as it does phosphorus. Due to this high requirement, sulfur is often recommended for legumes. Annual sulfur application for the forage legumes increase yield, protein, and sulfur levels in the plant (Table 11).

TABLE 11. EFFECT OF SULFUR FERTILIZATION ON THE YIELD, SULFUR CONTENT, AND PROTEIN CONTENT OF ALFALFA

Source: Agriculture Canada, Brandon, MB

Rate of S (lbs./ac.)	Yield (T/ac.)	Sulfur (%)	Protein (%)
0	1.6	0.1	8.8
15	2.7	0.16	11.3
30	4.2	0.21	18.8
45	5.3	0.23	20.6
60	5.2	0.23	21.3

Generally, rates for annual sulfate-sulfur applications on legumes range between 20 and 40 pounds of sulfur per acre (Table II and III in appendix).

Grass and Legume

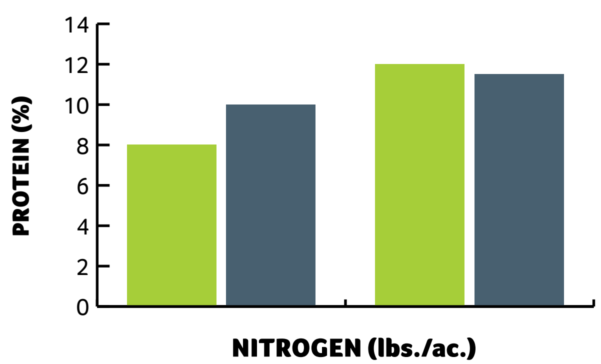
Sulfur fertilization appears to be more important to the legume forages. However, both grasses and legumes benefit from this nutrient and there are no special considerations for sulfur when fertilizing a mixed stand. Sulfur should be applied to a mixed stand at a rate that meets the legume's requirement.

Nitrogen and Sulfur Balance

Nitrogen and sulfur are both used in protein production. If a proper nitrogen to sulfur balance is not maintained, yields can be reduced. Adding nitrogen to soils that are marginally deficient in sulfur can distort the nitrogen to sulfur balance and reduce crop yield.

Nitrogen and sulfur are used in the formation of amino acids, which combine to form protein. When there is insufficient sulfur to convert all of the absorbed nitrogen into protein, an accumulation of non-protein nitrogen (nitrates and amino acids) can occur. Large amounts of non-protein nitrogen will disrupt metabolic functions within the plant, reducing seed production. This ratio is a special concern to cattle producers as feed nitrate levels can affect animal health.

FIGURE 8. EFFECT OF SULFUR FERTILIZATION ON % PROTEIN OF TIMOTHY AT MAYERTHORPE, ALBERTA



Source: Soil & Crop Management Branch, Alberta Agriculture, Food and Rural Development

Application Methods and Timing

The most effective method of application depends on the sulfur source. Sulfate-sulfur products are immediately available to the plant, while elemental sulfur must oxidize to sulfate-sulfur before it can be used by the plant.

Oxidation of elemental sulfur requires time, warm, moist soil, and microbial activity. The most important factors affecting the rate of conversion are particle size and temperature. Small particles (150 microns or less) convert to sulfate-sulfur much faster than larger particles. It is critical to consider this when choosing the timing and method of elemental sulfur applications. Warm temperatures promote bacterial activity and hasten conversion to the sulfate form.

Generally, if an elemental form is used, it should be applied six to 12 months prior to the crop's actual need, and attention should be paid to product characteristics. Some products should be broadcast and incorporated, while others are best broadcast without incorporation. If an elemental sulfur product is considered, discuss its management with an agronomist.

Some sulfur fertilizers affect soil pH. In areas of low pH, ensure that pH is not reduced to levels that affect Rhizobia survival. Additions of lime can reduce the effects of low pH on forage growth.

Seed Placement

Seed placement of sulfate-sulfur is an efficient and agronomically sound practice. However, care should be taken to ensure that application rates do not exceed safe levels.

The application of sulfur fertilizer with the seed of the various forages is not a practice that is normally recommended or followed by growers when using seed equipment that places seed and fertilizer material in a narrow space. However, special circumstances do exist when a floater or spreader system is used to apply fertilizer and seed. In this case, the spreading action of the equipment separates the seed and fertilizer. This separation reduces the potential for seed placed fertilizer causing seed or seedling injury.

Banding

Sulfate-sulfur can be band applied prior to establishment of the forage crop. The effectiveness of the application is dictated by weather conditions. Under dry spring conditions, fall banding can produce a better seedbed for establishment. If fall or spring conditions are wet, some leaching of the sulfate-sulfur can occur on coarse-textured soils. Banding is not usually practical in established perennial forages, and fertilizers will need to be broadcast on the soil surface.

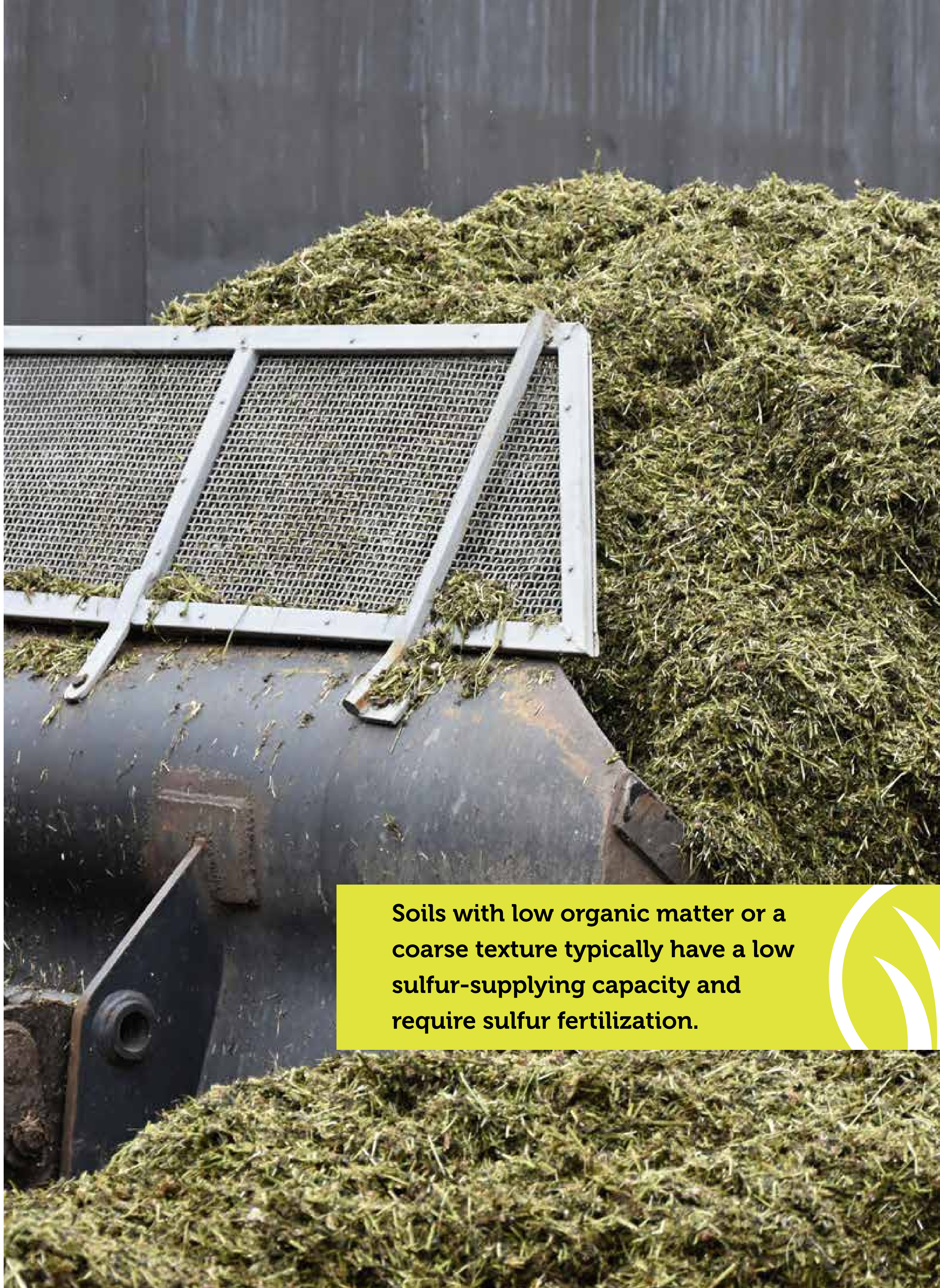
Banding elemental forms of sulfur is not usually recommended if a response is desired in the year of application. Banding reduces physical dispersion of elemental sulfur into small particles, slowing the conversion to sulfate-sulfur. With traditional elemental sulfur products, it is not uncommon to find elemental sulfur granules intact after periods of three to six months when applied in a band.

New fertilizers combining monoammonium phosphate and elemental sulfur, such as Nutrien's MAP+MST containing micronized elemental sulfur, have been introduced in recent years. In Nutrien's MAP+MST, the micronized sulfur particles are much smaller in size (averaging about 15 microns) than traditional elemental sulfur fertilizers to promote rapid sulfur oxidation. While banding traditional elemental sulfur products is not usually recommended, banded phosphorus is much preferred over broadcast phosphorus. Combining micronized sulfur with a water-soluble phosphorus granule improves sulfur availability. Initial research with banded placement of MAP+MST in canola indicates sulfur oxidation is sufficient for most crop needs. Additional research on MAP+MST performance is in progress. If immediate sulfur need is greater than MAP+MST provides, some sulfate-sulfur can be added to the blend.

Broadcasting

Sulfate-sulfur can be broadcast and incorporated in the fall or spring prior to establishment. Fall sulfur application may result in leaching and immobilization. Broadcasting sulfate-sulfur in the spring can be as effective as banding when there is adequate rainfall to move the sulfur into the rooting zone. Broadcasting is the most practical method for annual application on established stands. The application should be made in the spring to avoid potential late fall or early spring loss conditions. Spring applications should be timed such that the fertilizer is in place at, or shortly prior to, the spring green up of the crop.

Broadcasting is the method most commonly recommended for applying elemental sulfur. Breakdown of the fertilizer granule is essential in order to promote oxidation of the elemental sulfur to the sulfate-sulfur form used by the plant. Fall applications are best as this provides over winter freeze-thaw actions which aid in breaking up the granule. Nutrien's MAP+MST is an ideal product for broadcasting both phosphorus and sulfur on established forages. The slow-release nature of the micronized sulfur reduces potential for over-winter or early spring leaching losses while providing a steady sulfur supply to the forage crop.



Soils with low organic matter or a coarse texture typically have a low sulfur-supplying capacity and require sulfur fertilization.

Micronutrients

Micronutrients are required in relatively small amounts; however, these nutrients are essential to forage growth and quality.

Micronutrient Requirement

The extent of micronutrient deficiency on forage land is unknown. The existence of a deficiency may only be diagnosed when it is severe enough to be noticed, not necessarily when yield is affected. Deficiencies in elements such as boron (B), copper (Cu), and zinc (Zn) have been documented for specific forages. Information on manganese (Mn), iron (Fe), chloride (Cl), and molybdenum (Mo) is limited and few responses have been recorded. Selenium (Se), cobalt (Co), molybdenum, copper, and sulfur interactions in grass and legume forages have recently become a greater concern.

The majority of the micronutrient issues focus on seed yield and feed quality. Yield responses are erratic or nonexistent, and further study often exposes quality benefits that may not be visually apparent.

Crop scouting, soil and plant analyses, and the input of an agronomist will help determine the need for micronutrients.

Copper (Cu)

Forage grasses have shown little response to copper application. There have been isolated reports of increased seed yields for some of the grass crops with copper application. When deficiency symptoms occur, they appear as yield reductions, loss in dry matter production, reduced seed-set, reduced seed quality, or increased susceptibility to disease. The focus on copper fertility has come largely from the feed-quality aspect and attempts to raise feed copper levels rather than supplement animal diets.

Copper problems often occur on peat soils, but the extent of deficiencies on mineral soils has increased in recent years. Problems are more prevalent in dry years, on soils with a pH greater than 7.5, or in areas applying high rates of poorly spread manure, or in eroded soils.

Copper is not mobile within the plant, therefore, symptoms appear on the upper plant parts. Copper deficiency symptoms on forages are not well defined.

The majority of the micronutrient issues focus on seed yield and feed quality.

Boron (B)

Boron deficiencies can occur on coarse-textured soils. Soils under irrigation can test low in boron, but this is not a certainty as some waters used for irrigation contain boron. Research information documenting forage response to boron is limited and producers are cautioned to only apply recommended rates as excessive levels will result in boron toxicity. Forage grasses have shown limited responses to boron, although there have been reports of increased dry matter production and seed yield for alfalfa.

Forage legumes such as alfalfa and clover have relatively high boron requirements, sometimes two to three times that of other field crops. Care should be used when applying boron fertilizers, because even a small excess can be toxic. When rotating from a forage legume to a boron-sensitive crop, such as a small grain, it is often recommended to forego boron application the last year before rotating in order to reduce the potential for boron toxicity.

Zinc (Zn)

Zinc deficiency is not considered to be a widespread problem. Deficiencies are usually localized to specific areas, soil types, or management practices. Severely eroded soils, soils that have been leveled for irrigation (both cases where the subsoil has been exposed), calcareous soils, soils with pH levels above 7.5, and peat soils are frequently low in zinc.

Research regarding forage crop response to zinc is limited and zinc deficiency symptoms on forage crops are not well defined. Misdiagnoses can occur since deficiency symptoms may be confused with disease symptoms or other nutritional disorders.

Selenium (Se)

Selenium is not thought to be required by plants for normal growth and development; however, selenium is of critical importance in animal nutrition and feed selenium levels are an important consideration. Selenium fertilization of forage is not a well researched topic, nor has it been a major issue. There have been reports of selenium deficiency in some soils, but high selenium soils are known to exist throughout North America.

Forages well fertilized with nitrogen may have lower total selenium levels than unfertilized forages. This is a result of the dilution effect, whereby a larger plant is produced, and that plant material has a limited selenium supply for its size. Heavy sulfur use is also known to result in a dilution effect. Sulfur may also be antagonistic to selenium uptake and use in some way. Selenium fertilizers are currently difficult to obtain due to their low demand.

Other Micronutrients

Colbalt (Co) – Cobalt deficiency reduces the rate of infection of the root by bacteria and also impairs the formation of nodules (O'Hara et al. 1988). Increasing Co supply can improve nodule and nitrogen fixation capacity which, in turn, increase legume yield (Riley and Dilworth 1985).

Molybdenum (Mo) – The nitrogen fixing enzyme, nitrogenase, is composed of molybdenum and therefore, legumes have a high relative demand for molybdenum compared to most crops. A reduced supply of molybdenum will limit the formation and activity of nitrogenase, which reduces the overall nitrogen fixation capacity of the crop. Low nitrogen fixation capacity generally leads to lower yields in a typical legume fertilizer program (Sulas et al. 2016). Furthermore, it has been noted that molybdenum deficiency decreases population growth rates of nitrogen fixing bacteria (O'Hara 2001), which reduces the probability of an infection event occurring, which lowers overall nitrogen fixation capacity.

Iron (Fe) – Along with molybdenum, Iron is a major component of the nitrogen fixing enzyme – nitrogenase (Marschner et al. 2012). The nitrogenase complex consists of two iron containing proteins:

- The homodimeric iron protein, a reductase which has a high reducing power and is responsible for the supply of electrons used in the step below.
- The heterotetrameric molybdenum-iron protein, a nitrogenase which uses the electrons provided to reduce N_2 to NH_3.

Increasing iron supply can improve nodule population density and increases the overall nitrogen fixation capacity which, in turn, increases legume yield (Abdelmajid et al. 2008).

Manganese and chloride have potential for concern in certain soil types and conditions. At the present time, documented responses to these nutrients are limited.

Appendix

TABLE I. GENERAL FERTILITY GUIDELINES FOR FORAGES (LBS./AC.)

Source: Nutrien Agronomy Group, adapted from various U.S. State and Canadian Prairie Province Extension Bulletins

		Low-Medium Yield Potential Soils		Medium-High Yield Potential Soils				High Yield Potential Soils			
CROP		Nitrogen	Phosphorus (P_2O_5)	Nitrogen	Phosphorus (P_2O_5)	Potassium (K_2O)	Sulfur	Nitrogen	Phosphorus (P_2O_5)	Potassium (K_2O)	Sulfur
Grass	Seed	30-60	10-25	30-70	10-30	30-50	0-10	45-100	30-50	40-60	0-15
	Forage 20% Legume	40-90	10-30	60-100	10-30	50-60	10-15	60-200	30-50	40-60	0-15
Grass-Legume	20-40% Legume	30-65	20-30	40-90	20-40	50-70	15-30	60-80	40-60	60-80	15-20
	40-60% Legume	10-30	20-40	20-40	30-40	50-80	15-30	0-60	40-80	80-150	15-30
Legume	Greater than 60% Legume	0-30	30-50	0-30	40-70	60-150	15-30	0-50	60-100	80-200	20-30

** Residual response to the higher rates may persist for two years, particularly when the year of application is dry and production is low. Therefore annual application may not always be necessary.*

TABLE II. NUTRIEN: GENERAL FERTILITY GUIDELINES FOR GRASSES

	General Fertility Guidelines for Grasses (lbs./ac. of nutrient)			
	Nitrogen	Phosphorus (P_2O_5)	Potassium (K_2O)	Sulfur
New stands on fallow	0-50	30-50	(2)	(3)
New stands on stubble	40-100	20-40	(2)	(3)
Established stands	(1)	20-35	(2)	(3)

(1) An economic return to the application of nitrogen fertilizer onto established grass stands is questionable when the selling price of hay is low and the yield potential is low due to dry soil moisture conditions. When the prices are high and soil is moist, apply 60 to 200 pounds of nitrogen per acre.

(2) Sands, sandy loam and organic soils are frequently low in available potassium. On these soils, apply 30 to 60 pounds of potash (K_2O) per acre for established stands and 45 to 90 pounds of potash (K_2O) per acre for new stands.

(3) Low sulfur levels can occur in any soil. When required, apply a minimum of 15 pounds of sulfate-sulfur per acre.

TABLE III. NUTRIEN: GENERAL FERTILITY GUIDELINES FOR LEGUMES

	General Fertility Guidelines for Legumes (lbs./ac. of nutrient)			
	Nitrogen	Phosphorus (P_2O_5)	Potassium (K_2O)	Sulfur
New stands	0-30	50-90	(1)	(2)
Established stands	0-30	40-60	(1)	(2)

(1) Sandy, sandy loam, and organic soils are frequently low in available potassium. On these soils apply 60 to 150 pounds of potash (K_2O) per acre at the time of establishment or 100 to 200 pounds of potash (K_2O) per acre for established stands.

(2) 25 pounds of sulfate-sulfur per acre are recommended on well-drained sandy soils and high yield potential soils.

(3) If the mixed stand contains more than 25 percent legume, fertilize as for a pure legume stand. If there is less than 25 percent legume in the stand, use the recommendation for pure grass stand.

Conclusion

Fertility management for forage is exceptionally important due to the high nutrient demand and residue removal levels of these crops. The fertility program is integral to the success and profitability of the forage crop.

Other Management Factors to Remember

- Select a variety that is suited to area and end use.
- Use quality seed to ensure a quick and strong establishment.
- It is desirable to have a firm, weed-free seedbed.
- Packing should be avoided on soils that have a tendency to crust over.
- Companion cropping is generally not a recommended practice. Companion crops can reduce seedling vigor, increase seedling mortality, and compete for nutrients and moisture. However, they can help to reduce erosion and wind damage in high-rainfall areas.
- If a companion crop is used, companion crop seeding rate should be 1/4 to 1/3 the normal rate.
- The use of a suitable, good quality inoculant is recommended when seeding a forage legume.
- Seeding should coincide with favorable moisture conditions. Depending on the species, successful seedings can be accomplished during three different times of the year (i.e., early spring, summer, and late fall).
- Seeding depth is critical; the greatest error is to seed too deep.

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