Efficient Nutrient Management for Quality Forages

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■ Take Home Message

The yield and nutritive value of forages are affected by climate, soil type, available soil moisture, soil chemical reactions, nutrient status of the soil, cropping history and cultural practices, the species and cultivars, and the final use of the crops – hay, silage or pasture. The highest yields and the best quality forages are produced on soils with high productivity capacity when plant nutrient, soil water and soil chemistry are optimum for plant growth and development. Legumes and grasses are heavy users of plant nutrients. Consequently, effective fertilizer management is a critical component in forage production, not only to improve financial returns, but also to maintain soil quality and reduce the likelihood of damage to the environment. Effective fertilizer management in any cropping system has five components:

Rate: Selected to optimize yield, but not lead to negative effects on crop or environmental quality.

Source: Suited to the time and method of application.

Timing: Selected to ensure that adequate amounts of nutrient are available when required by the crop, losses are minimized and operation is efficient.

Placement: Placed where nutrients are available to the crop when they are required for growth, losses are minimized, damage is avoided and efficiency is optimized.

Balanced nutrient management: Nutrients must be available to the crop in a proper balance to ensure optimal crop growth.

These five components can be combined into many effective management packages. The "best" fertilizer management package for a particular farm will vary, depending on the types of forages grown, environmental conditions and other constraints within the overall production systems

Plant Nutrients

Plants require seventeen nutrients for growth (Table 1). Of these nutrients, only oxygen, hydrogen, and carbon are not obtained directly from the soil. Crops require these nutrients in varying amounts and if one nutrient is lacking, or present in a quantity that is not in "balance" with the other nutrients crop growth, yield and quality will be affected. The macronutrients nitrogen (N), phosphorus (P), potassium (K) and sulphur (S) are the ones most limiting forage production. Few soils can supply adequate N or P to meet a forage crop's full nutrient demand when the demand is not only for yield but also for high protein and/or energy. Although K and S deficiencies are less common, they are often observed on coarse textured well-drained soils, or soils that are severely eroded and may be depleted by successive cropping with limited nutrient replacement. Sulphur may also be deficient on soils formed under an acid environment.

Table 1: Essential Plant Nutrients

Macronutrients		**Secondary Nutrients**		**Micronutrients**			
Nitrogen	(N)	Calcium	(Ca)	Boron	(B)	Chlorine	(Cl)
Phosphorus	(P)	Carbon	(C)	Cobalt	(Co)	Copper	(Cu)
Potassium	(K)	Hydrogen	(H)	Molybdenum	(Mo)	Iron	(Fe)
Sulphur	(S)	Magnesium	(Mg)	Manganese	(Mn)	Zinc	(Zn)
		Oxygen	(O_2)				

Nitrogen: Nitrogen is the most abundant element in the earth's atmosphere (80% by volume). However, the quantity in cultivated soils in a form available to plants is generally insufficient for maximum plant growth. This contradiction of N abundance and scarcity occurs because atmospheric N cannot be used directly by plants. Thus, the N used by plants, other than legumes, comes either from the soil, organic matter, commercial N fertilizers, and organic amendments (manure & crop residues). As the main element in plant protein, plants require more N than the other nutrients. The organic forms of N in organic matter and manure are unavailable to plants. To be used by plants, the N must be converted to "available" forms, mainly nitrates and ammonium forms that are soluble in the soil solution and thus can be taken up by plants. This process of N conversion is called *mineralization* and it continues as long as the soil is moist and warm. Legumes are capable of "fixing" most of their N requirements in symbiotic relationship with *Rhizobium* bacteria. N fertilizer is effective in increasing both the yield and protein content of crops. About 20 to 60 percent of applied N is used in this manner. The remainder of the applied N is generally lost to the crop either by immobilization, leaching and runoff, volatilization or weed growth.

***Immobilization*:** Briefly, this is the conversion of inorganic N (nitrates and ammonium compounds) to organic N. In some sense, it is the opposite of *mineralization*. The process temporarily removes N from the available forms and makes them unavailable to plants.

***Leaching and runoff*:** Leaching is the downward movement of nutrients out of the root-feeding zone of plants; *runoff* is the loss of nutrients as a consequence of water moving over the soil and removing soil particles, organic matter and plant nutrients in solid and liquid states (erosion).

Volatilization: *Denitrification* and *ammonification* are the two processes through which N is lost from the soil. *Denitrification* is the process by which nitrate-N is reduced to Nitrogenous gases such as atmospheric nitrogen (N_2), nitrous and nitric oxides. The process may be carried out by bacteria or by chemical reactions. Regardless of the mechanism, the process is most active in the absence of oxygen, for example, under flooded conditions in the fall and spring. *Ammonification* is the changing of nitrogenous compounds to ammonia with the subsequent volatile loss of the ammonia. The process is very rapid when the soil has free calcium carbonates and a pH of 8.0 or greater. On high alkaline soils (calcareous soils), ammonium forms of fertilizers that are left lying on the soil surface are rapidly changed to gaseous ammonia, particularly when the atmospheric temperature is high.

Phosphorus: The functions of P ranges from energy transfer and supply mechanisms to reproduction and encoding of genes. These functions cannot be carried out by other nutrients. Thus, without an adequate supply of P a plant cannot attain its maximum growth potential, nor can it complete its normal reproductive process. To the producer what this means is low yields and poor crop quality. The forms of soil P that are available to plant are those that are soluble in the soil solution. The availability of P from most soils is very low, and maximum crop yields cannot be obtained without the addition of fertilizer P. Phosphorus is unique amongst plant nutrients in that when it is added to a soil it reacts with many soil components to form phosphate compounds of lower solubility. These compounds are relatively immobile and unavailable and are concentrated in an area immediately around the point of fertilizer application. Thus, the ability of plants to feed on fertilizer P depends on the nature of their root system (plant species), the nature of the soil (soil environment), and the nature of the fertilizer. Most forage crops are sensitive to high concentrations of P fertilizer banded with the seed. However, small amounts of P banded with the seeds of several crops have been found to advance physiological maturity and to increase yields.

Potassium: Potassium is required by plants in amounts comparable to N. But, unlike N, it exists in the plant in non-bound forms and is not part of the structural and storage component of the plant. Consequently, crops harvested for seeds remove only a small quantity of K, the bulk of the K is returned to the soil in the crop residue. For forage crops, however, the picture is different. Grazing animals and/or harvesting forage crops for hay or silage removes large quantities of K from the soil. For this, and other reasons, the element requires serious consideration when designing a forage management program. Potassium plays a major role in the physiological and metabolic activities of plants: it regulates the water economy of plants through various mechanisms including the proper regulation of stomata opening and closing; it influences chloroplast formation, thus directly influencing photosynthesis and respiration; it influences the metabolism of carbohydrates and proteins; it enters into the transport of photosynthates and minerals within the plant; in legumes it influences symbiotic N-fixation; it functions in the development of maturity, influences cell senescence, winter survival, disease resistance, and crop quality. Clay soils with large cation exchange capacities (CEC) usually have sufficient plant available K for optimum plant growth, while coarse textured soils (sandy soils) with low CEC are generally deficient in available K. When it is determined that a soil is deficient in K for adequate plant growth, K fertilizer is recommended. For forage crops, however, because of the large amount of K removed from the soil annually, it is essential that continuous monitoring of the soil K and an assessment of the Potential K Supplying Power (PKSP) of the soil be carried out through soil and plant analysis.

Sulphur: Sulphur is often referred to as the “Fourth Major Nutrient”. Most crops contain as much S as P, and it ranks in importance to N and P in protein synthesis. It is an integral part of certain vitamins and enzymes, and is associated with certain enzyme systems that function in the fixation of N by bacteria. The N and S requirements of crops are very closely linked, plant protein contains about 1% S and 17% N. Further, the need for S often depends on the supply of N and other nutrients. If a proper balance of N and S is not maintained, yield and forage quality can be affected. When there is insufficient S to convert all adsorbed N to protein, an accumulation of non-protein N (nitrates and amino acids) can occur. This is of special interest to cattle producers as high feed nitrate levels can affect animal health. The sulphate ion (SO_4^2) is the only form of S in the soil that is totally water soluble and readily available to plants. Like N, sulphate is released from organic matter through mineralization and can be lost from the soil due to immobilization, leaching, runoff, and chemical and microbiological reactions leading to volatilization. For these and other reasons sulphate fertilizers should be applied as close to the time of seeding as possible. On the other hand, because of the time required for the oxidation of elemental S to sulphate-forms, this product should be used not to correct immediate inadequacies but as a long-term S-soil building program, and may be applied several months before seeding.

Secondary Nutrients: Prairie soils are adequately supplied with the secondary nutrients, but for problems associated with specific soil and/or plant chemistry, these nutrients present no problem for adequate plant growth. The most frequently encountered problem is the use of lime to correct soil acidity.

Micronutrients: Micronutrients are required by crops in very small quantities relative to macronutrients, but they are as critical in ensuring high quality forages. They seldom limit forage yield, but deficiencies are becoming more common as intensive crop production increases and the soil reservoir is depleted. Boron, copper, manganese, molybdenum, iron and zinc are the nutrients most commonly associated with forage production problems. Selenium is not a required plant nutrient, however it is a critical element in animal nutrition. In recent years there have been reports of selenium deficiencies in the prairies as well as cases of excessive levels, however, research information on the prairies are very limited. Micronutrients pay important roles in the physiological and metabolic processes of the plant and when they are deficient or present in excess quantities may cause severe economic losses to producers. Their greatest benefits are realized not in yield increases but in improvements to forage quality and animal health.

▪ Nutrition of Forage Legumes

Alfalfa comes close to the ideal cultivated crop in not only maintaining but also improving the quality and productivity of soils on which it is grown, and in providing abundant nutritious sustenance as animal and human food. It is the most popular forage crop grown worldwide and in Canada. Other forage legumes such as clovers and birdsfoot trefoil are less important as forage crops, however, like alfalfa they enter into symbiotic N fixing relationship with bacteria and can contribute to improvement in soil quality and productivity. Since very little research has been done with forage legumes other than alfalfa, this section will be devoted to alfalfa nutrition. However, the general technology for alfalfa production can be applied with little change to the other perennial forage legumes.

Inoculation

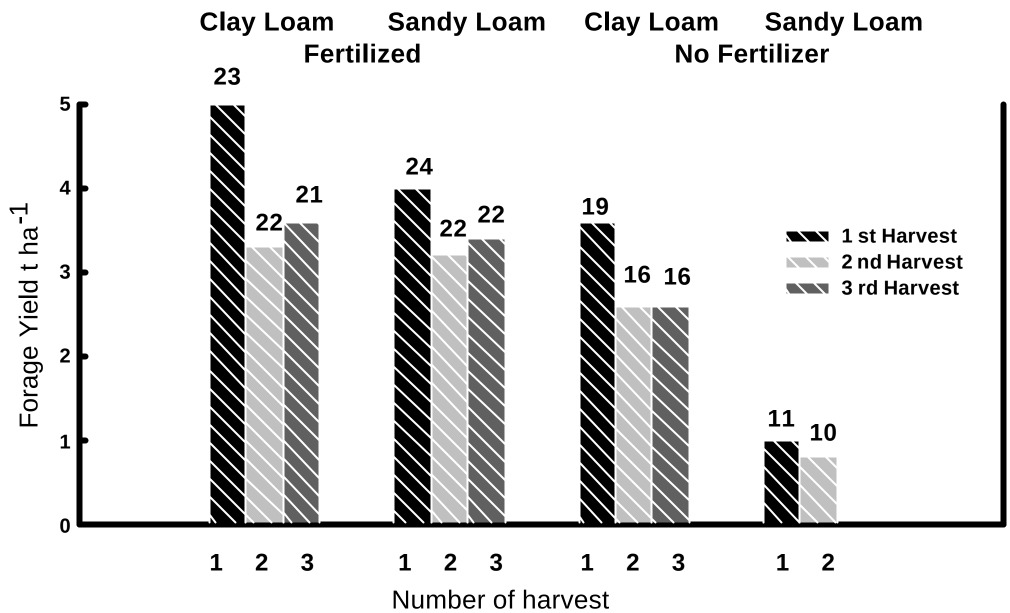
Inoculate seeds with recommended inoculants immediately prior to seeding. Alfalfa is a legume crop and will coexist with *Rhizobium* bacteria in a symbiotic relationship. The bacteria infect the roots and form nodules. These nodules are enlarged plant cells filled with bacteria. In the nodules the bacteria, using energy (carbohydrates) from the plant, convert atmospheric nitrogen (N_2) into forms that the plant can use. The process is called *Symbiotic N-fixation*. Under ideal conditions, an established stand of alfalfa will provide its entire N through N-fixation. The alfalfa roots should be checked periodically for the presence of nodules. Large nodules that are bright pink when cut open are a good indication that N-fixation is occurring.

Nutrient Management

The yield, protein and net energy production of alfalfa is superior to that of other forage crops when the crop is properly managed. The crop commences to grow early in the spring and grows through the summer into the late fall. Thus an understanding of climatic as well as edaphic factors must be considered when designing a nutrient management plan for alfalfa.

Soil Type: Alfalfa can be grown on all soils except poorly drained or coarse textured soils too low in moisture. But, coarse textured soils associated with high water table can be as productive as fine textured soils if fertility and moisture conditions are adequate. Alfalfa tolerates saline soils moderately (4 ds m^{-1}) in its establishment stage. But once established, the crop tolerates salts much better (8 ds m^{-1}) if its fertility needs are met. Because soil acidity interferes with N-fixation by *Rhizobium* bacteria, it is difficult to establish alfalfa on highly acid soils. Consequently, soils with pH of 6.5 or lower should be limed to pH 7.0. Most prairie soils have a pH of 7.0 or higher and are suitable for alfalfa production.

Yield potential: Three annual harvests of alfalfa can be taken without any adverse effects on stand density and longevity, provided that the crop is adequately supplied with nutrients (Figure 1). In regions where moisture is generally very low, a two-harvest system may be desirable. Similar, under irrigation, with adequate fertility four or more harvests may be possible. In the three harvest systems, yields in excess of ten tons per hectare of forage with protein content in excess of 18% may be obtained. Research also shows that for optimum yield and protein, harvesting should occur at ‘full bud’ and not later than the 5% bloom stage of growth (Figure 2). Delaying harvest beyond this time will result in minimum increase in forage yield but a significant reduction in protein. Between the 2nd and 3rd harvest there should be at least a six-week period of re-growth so that the crop could prepare for over-wintering by accumulating and storing carbohydrates in its roots.



Numbers above columns = % Protein

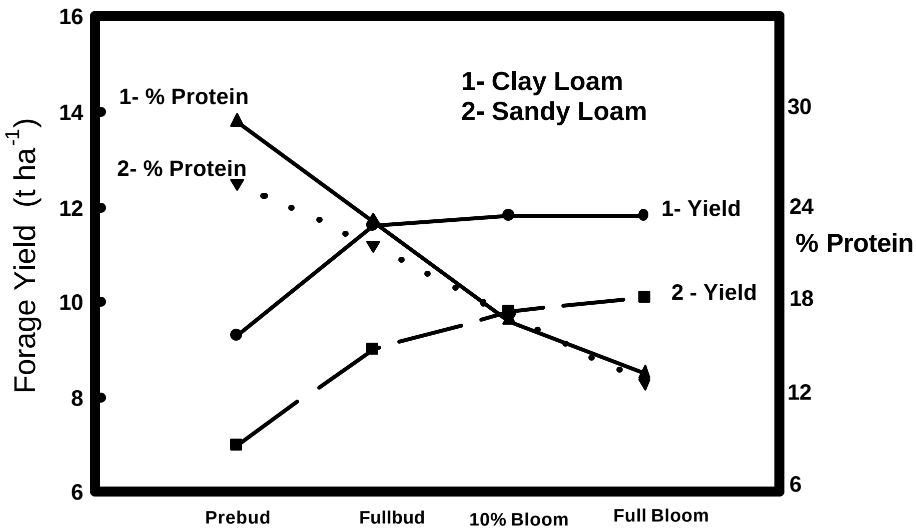
Soil	**Clay loam**				**Sandy loam**		
Fertilize	P_2O	K_2	S		P_2	K_2O	S
Kg ha^{-1}	60	30	30		60	120	30

Figure 1: Alfalfa yield – 3 Harvest System

Fertilizing at establishment: Because it has a small seed, alfalfa needs a readily available supply of P and other plant nutrients right after emergence since by the time a young plant has attained about 25% of its total dry weight, it may have already accumulated as much as 75% of its total P. However, high rates of fertilizer placed with the seed may damage the seedlings. Thus, when P and S are recommended, they should be broadcast and worked into the soil or drilled prior to seeding to a depth of 7.5 to 10 cm. The best response to P fertilizer as measured by P utilization and seeding vigor is obtained when the P placed either 2.5 cm directly below the seed or 2.5 cm below and 2.5 cm to the side of the seed.

Fertilizing established stands: Increased use of fertilizer, use of improved varieties, pesticides, and improved management, and in some areas use of irrigation have resulted in increased yield of high quality alfalfa forage. This has resulted in increased removal of soil nutrients. Therefore, established stands of alfalfa require annual applications of plant nutrients to maintain high forage yield and quality. A soil test and/or chemical analysis of the plants is used to determine the quantities of the various nutrients required.

Figure 2: Forage Yield and Protein Content of Alfalfa



Alfalfa Growth Stage at Harverst

Response to fertilizer: Alfalfa is very responsive to applications of balance nutrients, both in terms of forage yield and protein content (Figure 2). Response is best on clay loam soils, where because of superior nutrient and moisture holding capacity, the crop suffers little stress. On sandy loam soils, with high moisture table and balanced fertility, increases in the order of 100 to 300% are possible. In spite of research that has shown responds to good fertilizer management only about 15 to 25% of the alfalfa on the Prairies is fertilized.

Nutrient removal: Harvesting alfalfa forage results in a continuous depletion of nutrients from the soil. Under a three-cut management system, a high yielding crop of alfalfa uses a tremendous amount of plant nutrients (Table 2). Nutrient removal from the clay soil with its superior water supplying capacity was higher than on the sandy loan soil, but on both soil without fertilizer there was a significant mining of plant nutrients. Although applications of micronutrients did not boost yields significantly, foliar spray or soil applications increased the uptake of plant nutrients. For example, the plant produced more crude protein when fertilized with copper and molybdenum on some soils, and also increased the concentration of minerals in the forage.

Table 2: Nutrient Removal by Alfalfa – 3 Harvest System (kg ha^{-1})

A. Clay Loam Soil

Cut	Fertilized*				Unfertilized			
	N	P	K	S	N	P	K	S
1 st	185	13	175	12	108	7	88	8
2 nd	116	8	100	8	83	5	52	6
3 rd	122	9	90	8	55	5	42	6
Total	423	30	365	28	256	17	180	20

* Annual Application: 60 kg ha^{-1} P_2O_5; 30 kg ha^{-1} K_2O; 30 Kg ha^{-1} S

B. Sandy Loam Soil

Cut	Fertilized*				Unfertilized			
	N	P	K	S	N	P	K	S
1 st	152	10	104	10	18	2	11	2
2 nd	112	7	74	8	13	1	6	2
3 rd	119	8	68	8		No Harvest		
Total	383	25	246	26	31	3	17	4

* Annual Application: 60 kg ha^{-1} P_2O_5; 120 kg ha^{-1} K_2O; 30 kg ha^{-1} S

Nitrogen: Nitrogen is required for protein synthesis. Properly inoculated alfalfa will fix large quantities of atmospheric nitrogen and when conditions are adequate for optimum fixation, the crop needs no additional N-fertilizer. However, low rates of N applied at the time of seeding will hasten and improve establishment and increase yield in the establishment year. But, the presence of large quantities of soil N and/or fertilizer N has a depressive effect on stand establishment. Response to N on established stands has been reported under dry-land and irrigated conditions, which probably Indicates relatively low efficiency of N-fixation. On acid soils, where nodulation and N-fixation may be poor alfalfa responds to N application. Because of the large quantity of N required by a high yielding, high protein crop, application of large rates of N, intended to meet the complete requirement of alfalfa is not recommended.

Phosphorus: The majority of Prairie soils are deficient in plant available P. Determining the phosphate requirement of alfalfa is a difficult due to the complexity of soil and environmental factors governing the availability of soil P to plants - low recovery of P from fertilizer (about 35%), and the low concentration of P in the forage (0.2% to 0.4%). Because of the low concentration of P and the relatively small amount of P removed from the soil by alfalfa forage, it is generally interpreted that alfalfa does not require and will not respond to P fertilizers. However, both yield and protein content of alfalfa will respond to fall or spring applications of P fertilizer when the P is applied in balance with other nutrients (Table 3).

Table 3: Alfalfa Response to Fertilizer – P, K and S (Yield and Protein)

P_2O_5 Annual Rate (kg ha^{-1})	**0**	**23**	**45**	**67**	**112**
Yield (kg ha^{-1})	5.0	6.1	10.2	12.5	11.2
Phosphorus (%)	0.08	0.15	0.20	0.22	0.25
Protein (%)	11.3	12.5	13.8	20.0	18.8
K_2O Annual Rate (kg ha^{-1})	**0**	**56**	**84**	**112**	**224**
Yield (kg ha^{-1})	3.3	6.4	8.3	10.6	10.0
Potassium (%)	0.8	1.2	1.8	2.5	3.2
Protein (%)	9.4	12.5	17.5	20.0	21.2
S Annual Rate (kg ha^{-1})	**0**	**17**	**34**	**51**	**67**
Yield (kg ha^{-1})	3.6	6.2	9.6	12.2	11.7
Sulphur (%)	0.10	0.16	0.21	0.23	0.23
Protein (%)	8.8	11.3	18.8	20.6	21.3

Potassium: It is generally believed that the majority of Prairie soils contain sufficient plant available K for alfalfa production. However, studies have shown that initial exchangeable K level of some soils may not be an adequate criterion for determining the availability of soil K to alfalfa. It is suggested that an assessment of the Potential Potassium Supplying Power (PKSP) of a soil may be a more useful tool. Soils with low PKSP and low exchangeable K required an annual application of K in balance with other nutrients to produce maximum yield (Table 3). Significant responses to K were also obtained on soils that tested in the medium and high ranges of exchangeable K. At maximum yield, taken at full bud, K concentration in the forage exceeded 2.0% and represented a large removal of soil and fertilizer K. Spring or fall broadcast application of K on established alfalfa is an effective treatment. The element may also be applied at anytime during the growing season with good efficiency of use, particularly when it is applied immediately after a harvest and under an irrigation system. Alfalfa stand life depends greatly on soil fertility (Table 4). Plants receiving no K on soils testing less than 292 kg K/ha suffered winterkill. Their K content generally were 1% or less. Plants receiving no P_20_5 and S on soil testing less than 10 kg P/ha and 6 kg SO_4-S/ha also suffered winterkill. Their P and S content were 0.15% or less. To guarantee top yield, quality and stand life of 12 to 15 years, the alfalfa crop should be managed so that the plants contain more than 3.0% N, 0.2% P, 2.0% K and 0.2% S.

Table 4: Potassium fertilizer prevents winterkill of alfalfa (sandy loam soil)

Year	Potassium*		No Potassium	
	Density**	Yield*** (t ha^{-1})	Density**	Yield*** (t ha^{-1})
1970 (seeded)	-	-	-	-
1971	98	2.6	102	2.2
1972	102	3.2	90	2.5
1973	97	4.5	82	2.5
1974	98	4.2	51	1.4
1975	102	4.6	35	0.9
1976	100	4.4	15	0.5
1977	95	4.4	15	0.5

* Annual Application = 112 kg ha^{-1} K_2O
** Number of plants in May expressed as a % of the count taken previous September
*** First harvest yield
Initial soil test: 260 kg ha^{-1} exchangeable K (0-15 cm)

Sulphur: Plant protein contains about 1.0% S and 17.0% nitrogen. There is a close relationship between the N and S nutrition of alfalfa, for optimum forage yield, the ratio of total N to total S in the plant is 14, and for maximum yield of forage, the concentration of S in the herbage at full bud should be in excess of 0.20%. Thus, the annual broadcast application of S on S-deficient soils will increase both forage yield and protein (Table 3).

Micronutrients: Isolated cases of response to boron, copper and manganese have been reported in Saskatchewan and Manitoba. Micronutrients are not generally associated with increase yields but function as “triggers” for symbiotic N-fixation and as such contribute to forage quality. For example, plant produced more crude protein when fertilized with copper and molybdenum on some soils, and also increased the concentration of minerals in the forage.

▪ Nutrition of Forage Grasses

Nitrogen is the major determining factor in the production of quality grass herbage both for hay and pasture. Because of the increasing cost of land, labour and energy, maximizing production per unit area of land is an effective technique for optimizing farm profits. This fact has prompted increased use of high rates of high analysis fertilizer on farms. But, unfortunately only about 7% of the fertilizer used in the Prairies is used for forage production with N being the dominant nutrient. Although the other plant nutrients are not as effective as N in increasing yield and protein content of grasses, these plant nutrients must be available in adequate quantities before the full benefits of N can be obtained.

Species and Varieties: In Canada, several grass species and varieties are recommended based on use (hay vs pasture) suitability for various soil types, environmental conditions and adaptability. To maximize yield and quality of grass herbage it is essential that the right species and varieties for the environment be selected and that a balance nutrient program is in place.

Nutrient Management

Grasses for hay or pasture, are generally established on summer fallow or partial fallow. The nutrient requirement at seeding is determined by soil analysis as for cereals. But grass seeds are not as tolerant to high rates of fertilizer placed with the seed, as are cereals. Rates of P up to 30 kg P_20_5/ha can be safely placed with the seeds, but it is recommended that all other fertilizers be broadcast and worked into the soil 5 to 10 cm deep prior to seeding.

Nitrogen: The plant available nitrogen under an established grass sward is generally very low, often zero. But, response to applied N depends on the time, rate and source of N, and on the age of the sward. All N should be broadcast on established grass swards prior to commencement of re-growth. The nearer the application is to the start of re-growth, the more effective is the N in increasing yield. Consequently, spring applied nitrogen is more effective than fall applied nitrogen (Table 5). Also, split-rate application of N (applying equal increments of nitrogen in the spring and immediately after each harvest except the final) is comparable to a single spring application. The split-rate technique has the added advantages of equalizing the production of herbage with a relatively higher protein content throughout the growing season and is particularly useful for pasture production where rotational grazing is practiced. Annual applications of N are required for continuous high yields of quality herbage since the residual effect of N on subsequent crops is negligible. Also the response of old grass stands to applied N is greater than new stands when fertilized for the first time, but with continued annual application similar responses are obtained on all stands.

Table 5: Source of N (120 kg $^{ha-}$1) on Yield and % Protein of Brome and Russian Wild Rye (3 Harvest System)

Brome Grass							
		Check		NH_4NO_3		Urea	
Fertilized	Harvest	Yield t ha^{-1}	Protein %	Yield t ha^{-1}	Protein %	Yield t ha^{-1}	Protein %
April	June	2.5	9	4.2	18	3.5	19
	August	0.4	6	1.2	13	1.1	14
	October	0.6	7	1.6	16	2.0	17
	Total	3.5		7.0		6.6	
October	June	2.5	9	4.1	18	3.5	19
	August	0.4	6	1.0	13	1.0	14
	October	0.6	7	1.5	16	1.8	17
	Total	3.5		6.6		6.3	
Split Rate	June	2.5	9	3.5	18	3.0	19
	August	0.4	6	1.5	13	1.3	14
	October	0.6	7	1.9	16	2.3	17
	Total	3.5		6.9		6.6	
Russian Wild Rye							
		Check		NH_4NO_3		Urea	
Fertilized	Harvest	Yield t ha^{-1}	Protein %	Yield t ha^{-1}	Protein %	Yield t ha^{-1}	Protein %
April	June	0.7	7	2.3	15	2.0	16
	August	0.4	6	1.1	12	1.8	14
	October	0.6	7	1.2	13	1.9	16
	Total	1.7		4.6		5.7	
October	June	0.7	7	2.4	15	1.8	16
	August	0.4	6	1.1	13	1.5	14
	October	0.6	7	1.3	13	1.7	16
	Total	1.7		4.8		5.0	
Split Rate	June	0.7	7	2.2	15	1.9	16
	August	0.4	6	1.1	12	1.9	14
	October	0.6	7	1.4	14	1.9	16
	Total	1.7		4.7		5.7	

Phosphorus: Most prairie soils are deficient in P for optimum hay production. Consequently, it is essential that adequate levels of P be applied to optimize yield of quality forage. The yield increases obtained when P is applied is not generally as great as that obtained for similar units of applied N, however, research has shown that P prolongs stand life, particularly when the stand is subjected to intensive grazing. The element also increases the efficiency of plants in utilizing other nutrients and water, and thus promotes rapid re-growth. Unlike nitrogen, phosphorus can be applied in the spring and/or fall with equal effectiveness. In the prairies, 30 to 50 kg P_20_5/ha is considered adequate for annual production of hay and pasture. The objective is to produce herbage containing 0.2% P or greater.

Potassium: Coarse textured and well-drained soils are generally deficient in K for optimum production of high quality forages. The quantity of K required by various grasses differs. However, for grasses grown on the Prairies, a level of 2.0 to 25% K in the forage should be the goal of a fertilizer program. When forage is grown without K fertilizer, on soils low or deficient in potassium, stand life and forage quality decrease, particularly when grazing is practiced; further, the element has been shown to increase carbohydrate accumulation in the roots thus enhancing winter hardiness and early spring re-growth. Annual spring and/or fall broadcast application of 60 to 200 kg K_20/ha is adequate for production of grass forage on soils low in potassium. Although application of K fertilizer may not result in large yield increases, the benefit obtained from crop quality, winter hardiness (stand longevity), disease resistance and water use efficiency generally more than compensates for the cost of the fertilizer.

Sulphur: Sulphur is generally low or deficient for crop production on coarse textured and well-drained soils. Sulphur is used in the manufacture of certain essential amino acids and proteins. It is generally recommended that, for grass forage production, the level of soil available S should be higher than is required for optimum plant growth, since the increased concentration of S in the forage is beneficial to animals. The use of S fertilizer does not generally result in dramatic yield increases, but rather in increased protein and efficiency in the use of N and other plant nutrients. Good quality forage contains 0.20 to 0.25% S. Sulphur can be broadcast in the spring and/or fall with equal effectiveness. In general 20 to 35 kg $S0_4$-S/ha applied annually is adequate to maintain production on most Prairie soils that may be low or deficient in the element.

Micronutrients: The need for micronutrients is best diagnosed by leaf or tissue analysis. Deficiencies are corrected by either foliar sprays or soil incorporation of the deficient element(s). Micronutrients may be applied to forage not only to correct deficiencies but also to increase the levels of the nutrient(s) in the forage to meet the requirement of livestock feed. Because this field of research is still new, if micronutrients are suspected as a problem, it is advisable to contact a professional agronomist.

■ Nutrition of Forage Legume-Grass Mixtures

The nutrient requirement of a mixed forage stand is determined by its composition. The legume component has a high N demand that is met by N-fixation; the grass component also has a high N demand that must be met by soil N, N contribution from the legume and fertilizer N. In established stands, legumes with well-developed active nodules will fix enough N to satisfy their requirements. However, only a very small fraction of the N required by the grass will be obtained from the legume, this mainly through decomposing nodules and plant parts and small amounts of root exudates. This quantity of N is not generally sufficient to maximize production of the grass; consequently, it must be supplied with added N. In general, if the stand has less than 25% grass it is recommended to follow the fertilizer practices outlined for pure legume stands. Similarly, if the stand has less than 25% legume then it is recommended to treat it as a grass stand. For pastures, a higher proportion of grass to legume is generally recommended, particularly in the case of alfalfa-grass mixtures, because of the incidence of bloat. For hay, 60% legume to 40% grass is desirable. As a rule mixtures do not yield as well as pure stands. Also, legume and grass seeds are very sensitive to fertilizer placed with the seed. Severe reduction in emergence may occur where high rates of fertilizers are placed with the seed. No N and not more than 20 kg P_20_5/ha should be placed with the seeds. If more phosphate and other plant nutrients are needed then they should be side-banded, or broadcast.

A general rule for fertilizing mixed stands is (1) determine the percent legume and grass in the stand, (2) determine the quantity of nitrogen that would be added if the stand was 100% grass, (3) multiply the percentage of grass in the stand by the nitrogen required for a 100% grass stand, this is the nitrogen that is required for the mixture.

For example: % grass in mixture 40%,

Nitrogen required for 100% grass = 100 kg N/ha (soil test)
Nitrogen to be added to mixture = 100 x .40 = 40 kg/ha

Legumes in mixed stands generally show a greater response to K than grasses. It is likely that the K is required for carbohydrate synthesis that supports N-fixation by the legume, thus low K results in low N-fixation which is reflected in poor stand performance. Grasses and legumes are effective and efficient feeders of broadcast fertilizers applied either in late fall or early spring. A general recommendation for grass-legume mixtures is 40 N, 40 P_20_5, 30 K_20 per hectare applied in late fall or early spring. Sulphur must be applied if the soil has low levels. It must be remembered that the previous discussion for pure stands of grasses and legumes with respect to secondary and micronutrients requirements apply equally to mixed stands.