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Fertilizer management for seed production of perennial forage crops in the Canadian Great Plains

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Abstract

In the Canadian Prairie Provinces, nitrogen (N) and phosphorus (P) are most commonly deficient nutrients, while potassium (K) and sulphur (S) may also be deficient for certain crop and soil conditions. One or more of these four major nutrients may be limiting for optimum forage seed production. Nitrogen fertilizer application produces the greatest seed yield increase on grasses, but it will not increase seed yield if P, K, or S are limiting in the soil. The best N source for surface-broadcast application is ammonium nitrate, but it may not be widely available in the market. Urea

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is now becoming the most commonly used N fertilizer, but urea and other ammonium-based fertilizers are highly vulnerable to N loss through ammonia volatilization when surface-applied thus diminishing the amount of N that may be available to the crop. So, time of application in relation to rainfall and placement method is important for ammonium-based fertilizers. In general, all N sources can be equally effective when applied properly (e.g., just prior to rainfall or placed below the soil surface). Time of N application is also critical for grass seed production as spring application may stimulate vegetative growth over culm formation. Therefore, autumn application is recommended for many grass species. For legumes, focus should be on correcting P, K and S deficiencies, as these plants have the property of fixing N from the air. Inoculation of seed with the correct strain of Rhizobium or Sinorhizobium becomes then critical for achieving a healthy stand for legume forage seed production. Whenever possible, fertilizers (particularly P, K and urea N) should be banded (or injected) into the soil for most efficient use of the nutrients. Alternatively, higher rates of P and K may be broadcast and incorporated into the soil prior to seedbed preparation to establish forage stands.

Introduction

Perennial forages are a major source of feed for livestock in Canada, where approximately seven million ha of land are dedicated to producing tame hay (Statistics Canada 2001), indicating a great demand for forage seed in this country, and also for export to U.S.A. and northern Europe. The majority of the perennial forage seed crops are grown in western Canada (Statistics Canada 2001). In the three Prairie Provinces of Canada, the total area of perennial forages for seed production is estimated at 280,000 ha, and the majority of the forage seed production area is located in more northern parts where it is an important cash crop for producers. Well-managed forage crops reduce soil erosion (Stinner and House 1989), and improve soil physical properties (Blackwell et al. 1990) and organic matter (Campbell et al. 1990). In addition, perennial legumes grown in rotation provide available N to subsequent crops (Entz et al. 1995; Mohr et al. 1999; Bullied et al. 2002), reduce N fertilizer requirements and enhance the sustainability of agriculture cropping systems. Forage seed crops, especially legume crops, tend to be produced on less fertile soils, and this increases the importance of nutrient management on those crops.

For healthy growth, plants need many essential nutrient elements from the soil (e.g., N, P, K, S, Ca, Mg, Cu, Zn, Fe, Mn, B, Mo, Cl, Co, Na, Si, etc.). The required amounts of these nutrients vary widely from year to year for a given crop and also from one forage crop to another. Forage crops grown for hay production usually remove more nutrients from the soil than those grown for seed, as most of the dry matter produced by forage crops is removed as hay compared to those situations when crop residue is retained on land after harvesting for seed (Ukrainetz 1969). Soil can supply many of the essential nutrients, but N and P are generally deficient under most soil and crop conditions, and K and S may also become deficient in certain areas of the Canadian prairies. Deficiencies of other plant nutrients are not very common. Like most annual crops, perennial forages respond well to the application of fertilizers on nutrient deficient soils. In a field survey, forage seed yields were much lower in “poor” areas than in the “good” areas of the fields surveyed (S. S. Malhi – unpublished results). The soil test results in these survey trials and in an earlier research (Loeppky et al. 1999) suggested that low seed yields were generally due to nutrient deficiencies in the soil in “poor” areas. The purpose of this report is to summarize field research information on fertilizer management for improving seed production of perennial forages in the Canadian Great Plains.

Discussion

A. Nitrogen

1. Grasses

Seed yield improvements with N application have been studied on many forage grass species. The amount of N fertilizer required for optimum seed yield and the magnitude of yield increase from applied N are influenced by many factors such as climatic conditions, soil characteristics, plant species, initial soil test nitrate-N level, timing of fertilizer application and stand age.

Weather conditions, particularly precipitation, are very important in soil fertilization, especially when using fertilizers in a dry form, as these products need moisture to dissolve and be incorporated into the soil solution. In separate experiments at Indian Head, Saskatchewan (Buglass, 1964), seed yield of diploid crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) increased up to 12 fold with increasing N application during a 4-year period with adequate average growing season (May-August) precipitation (285 mm), with an almost linear response to the highest rate of N applied (99 kg N ha^{-1}) (Figure 1). However, during a subsequent 5-year period of relatively drier weather (150 mm growing season precipitation), seed yield of tetraploid crested wheat grass (*Agropyron desertorum* (Fisch) Schult) had only a two fold increase and tended to level at 56 kg N ha^{-1} (Figure 2). Similarly, Loeppky et al. (1999), in a multi-location 4-year study on the response of smooth bromegrass (*Bromus inermis* Leyss.), crested wheatgrass (*Agropyron cristatum* L.), intermediate wheatgrass (*Agropyron intermedium* (Host.) Beauv.) and timothy (*Phleum pretense* L.) to different rates of spring-applied N fertilizer, also reported a significant

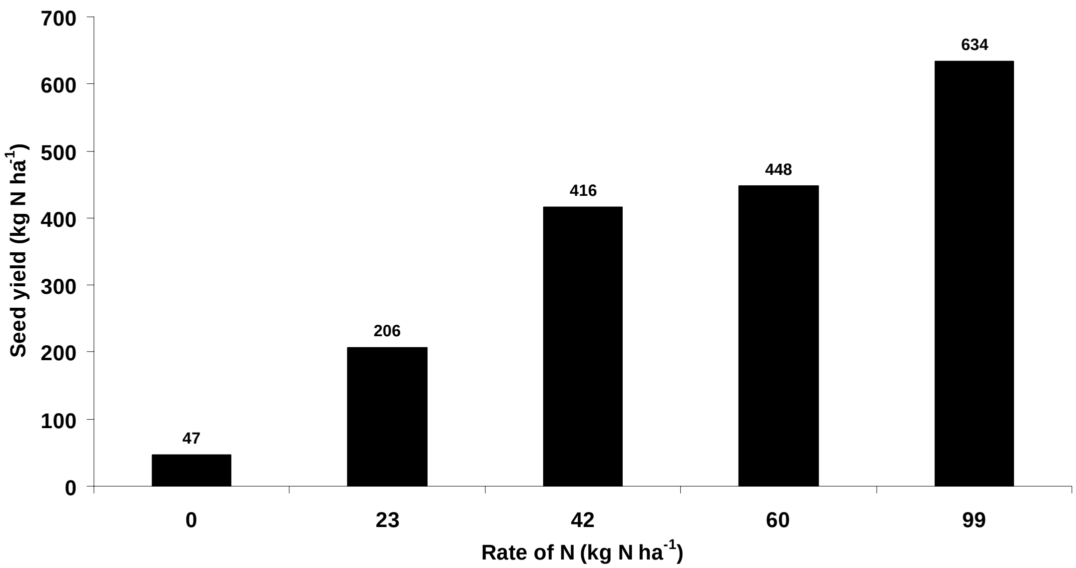

Figure 1. Nitrogen rate effects on seed yield of crested wheatgrass with autumn-applied ammonium nitrate in relatively moist (285 mm May-August precipitation) years (1954-1957) at Indian head, Saskatchewan (prepared from Buglass, 1964).

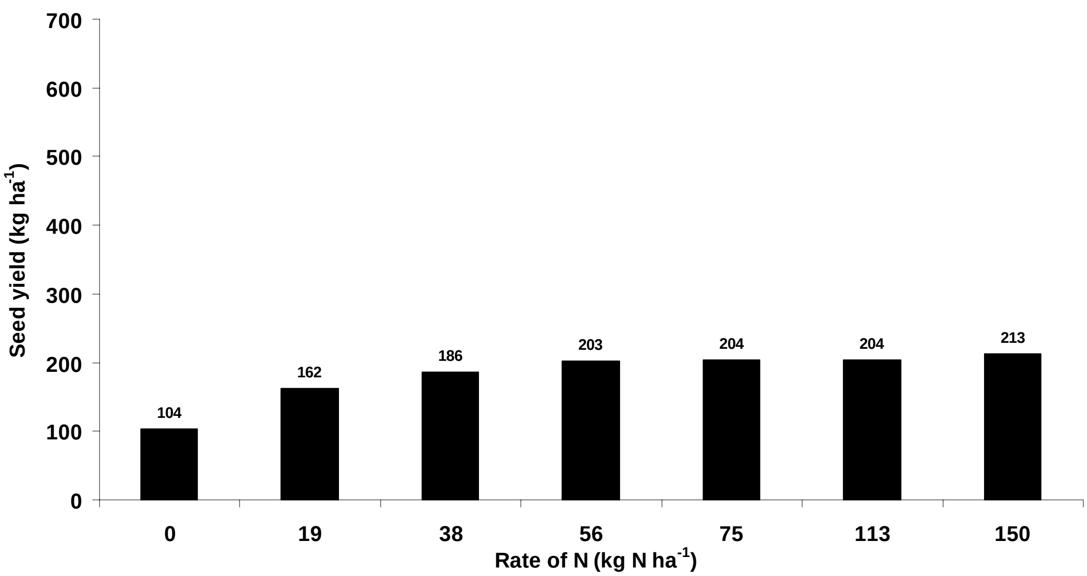

Figure 2. Nitrogen rate effects on seed yield of crested wheatgrass with autumn-applied ammonium nitrate in relatively dry (150 mm May-August precipitation) years (1959-1962) at Indian Head, Saskatchewan (prepared from Buglass, 1964).

year x N interaction for all these crop species, indicating that in a cool moist year their seed yield, and especially of smooth bromegrass, the most productive species, was substantially higher than that obtained by the same species in a dry year at the same N application rate. This was most likely due to the fact that under dry moisture conditions N fertilization increases vegetative growth at the expense of seed yield (Loeppky and Coulman 2002).

Soil characteristics and nutrient level are important considerations that determine the degree of plant response to added fertilization. Thompson and Clark (1989) attributed the difference in response of Kentucky bluegrass (*Poa pratensis* L.) to N application to a combination of differences in stand age and soil drainage in three sites near Teulon, Manitoba (Figure 3). Maximum seed yield was obtained at 50 kg N ha^{-1} in two of the sites, but at the third site, which had both a younger grass stand and good soil drainage, maximum seed yield was reached at 100 kg N ha^{-1}. In a 5-year study on Altai wild ryegrass (*Elymus angustus* Trin.) at Swift Current, Saskatchewan, there was no clear effect of rate and timing of N application on seed yield, most likely due to adequate initial level of plant-available N (57 mg NO_3-N kg^{-1} in 0-60 cm soil depth) (Lawrence et al. 1980). Similarly, in a 2-yr study at four sites near Beaverlodge, Alberta, Fairey and Lefkovitch (1998) did not observe any significant effect of N rates >50 kg ha^{-1} on seed yield of tall fescue (*Festuca arundinacea* Schreb.), with initial soil N of at least 52 kg NO_3-N ha^{-1} in 0-15 cm soil depth.

Grass species do not respond equally to additional N fertilization. Loeppky et al. (1999) observed that, for most grass species studied, seed yield increased but gains decreased at the higher N rates, but in the case of smooth bromegrass, which was the highest yielding species, seed yield was maximized at 50 kg N ha^{-1}, and then tended to decline at higher N rates (Figure 4). Similarly, in a central Saskatchewan study with nine grass species, Crowle (1966)

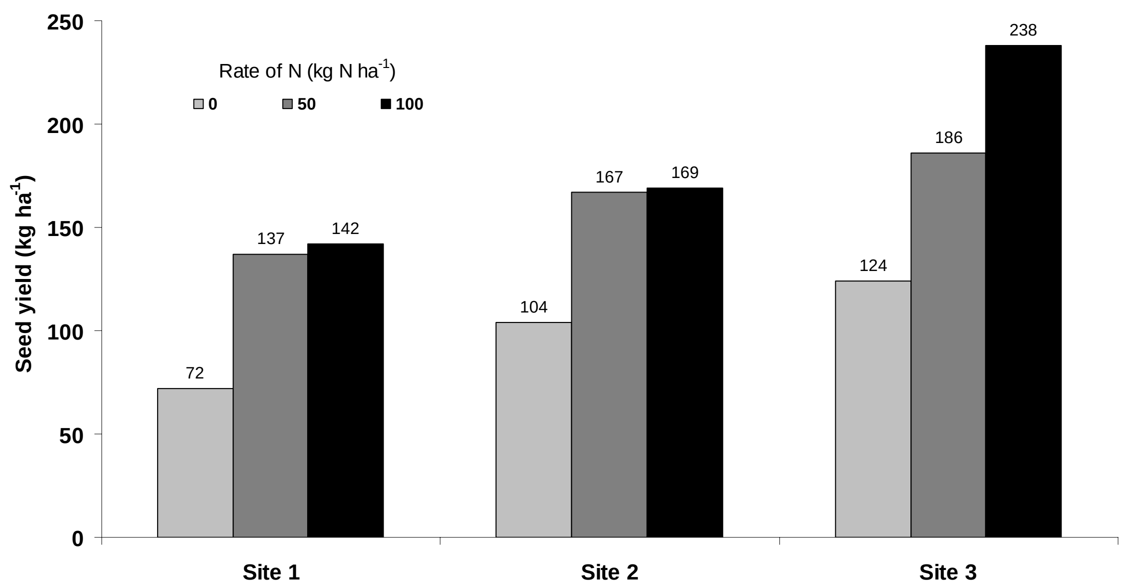

Figure 3. Nitrogen rate effects on seed yield of Kentucky bluegrass at three sites near Teulon, Manitoba (prepared from Thompson and Clark 1989).

observed that for some species seed yield increases were substantial after autumn application of 56 kg N ha^{-1}, especially under irrigation, while for others there was no response or even negative response to N fertilization.

Several studies involving many grass species have concluded that autumn applications of N fertilizers result in higher seed production than spring applications (Knowles and Cooke 1952; Lawrence and Kilcher 1964; Buglass 1964; Ukrainetz 1969). Buglass (1964) also observed that an early spring (mid April) application, although not as effective as either of two (early and late) autumn applications, resulted in much higher seed yield of crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) than a late spring (early May) application (Figure 5). He concluded that, in order for the N fertilizer to be effective on seed production, it must be in the soil solution before spring growth starts, otherwise vegetative growth is stimulated over culm formation. In an irrigated 3-year study, using Russian wild ryegrass (*Elymus junceus* Fisch) at Swift Current, Saskatchewan, Lawrence and Kilcher (1964) did not find as much difference between early (mid September) or late autumn (mid October) and early spring (April) fertilizer (56 kg N ha^{-1}) applications, as between mid-summer (July, immediately after seed harvest), when best seed yields were obtained, and other applications in the autumn or spring, especially in the first two years of seed production. Similarly, in a 2-yr study at four sites near Beaverlodge, Alberta, Fairey and Lefkovitch (1998) did not observe any significant effect of timing of N fertilizer application (September, October and April) and placement method (surface-broadcast of granular and soil-injection of ammonium nitrate

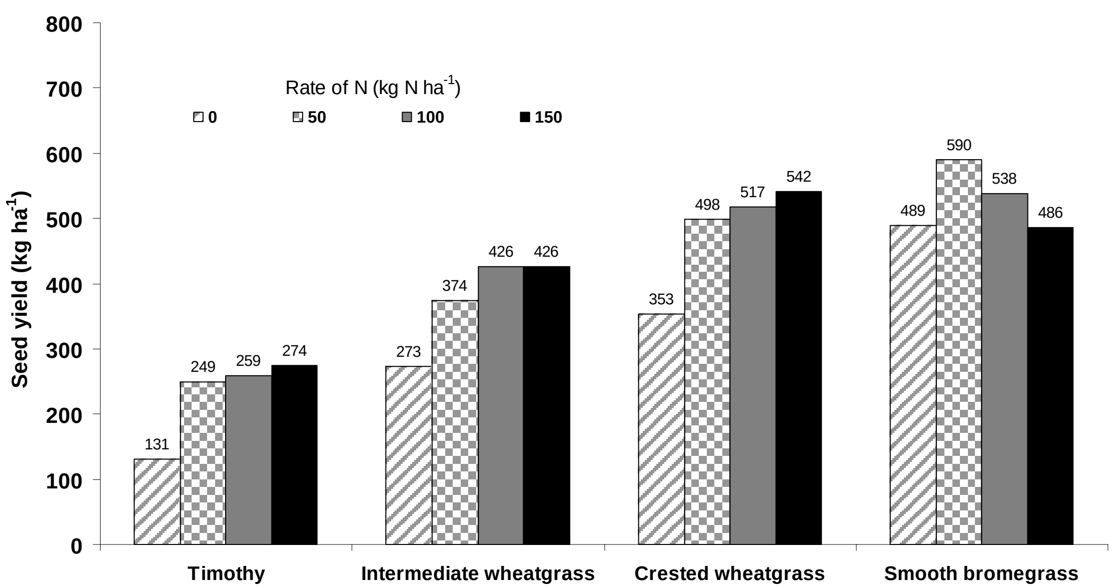

Figure 4. Nitrogen rate effects on seed yield of timothy, intermediate wheatgrass, crested wheatgrass and smooth bromegrass in northeastern Saskatchewan (averaged across P rates from 1989-1991) (prepared from Loeppky et al. 1999).

on seed yield of tall fescue (*Festuca arundinacea* Schreb.). No consistent effect of time and/or method of N (68 kg N ha^{-1}) application on seed yield of creeping red fescue (*Festuca rubra* L.) have also been reported (Fairey and Lefkovitch 2000, 2002).

The form of N can have a major impact on the grass seed yield increase if surface-broadcast application method is used. The best N source for surface-applied fertilizer is ammonium nitrate (34-0-0), because it is highly soluble in water and moves readily with soil moisture into the root zone for rapid and effective uptake by the plants (Malhi et al. 1992a; 1995; Malhi 1995). On the other hand, although urea (46-0-0) or other ammonium-based N fertilizers are highly soluble in water, they are vulnerable to N loss through ammonia volatilization and thus surface-applied N in this form becomes less available to plants (Volk 1959; Fen and Hossner 1985) However, N sources can be equally effective when applied just prior to a significant precipitation event or below the soil surface (Malhi 1995). In a study at Melfort, Saskatchewan, seed yield of smooth bromegrass was greater with spring-applied ammonium nitrate than ammonium sulphate (21-0-0-24), especially at higher N rates (Figure 6; Knowles and Cooke 1952). Ammonium nitrate was also found superior to ammonium sulphate in a study at Unity, Saskatchewan, using the same grass species, when these two sources of N were compared in autumn and spring applications (Figure 7; Knowles and Cooke 1952). On the other hand, Lawrence and Kilcher (1964), in a similar study, found no consistent difference in the seed yield of Russian wild ryegrass due to the use of either ammonium nitrate or ammonium sulphate as the N source.

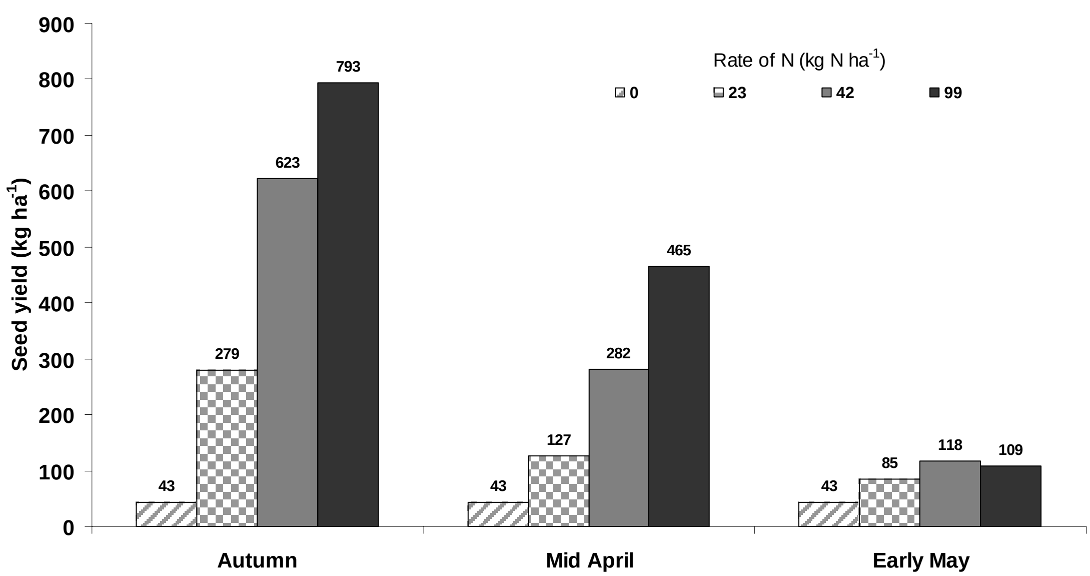

Figure 5. Effect of time of N application on seed yield of crested wheatgrass at Indian Head, Saskatchewan (prepared from Buglass 1964).

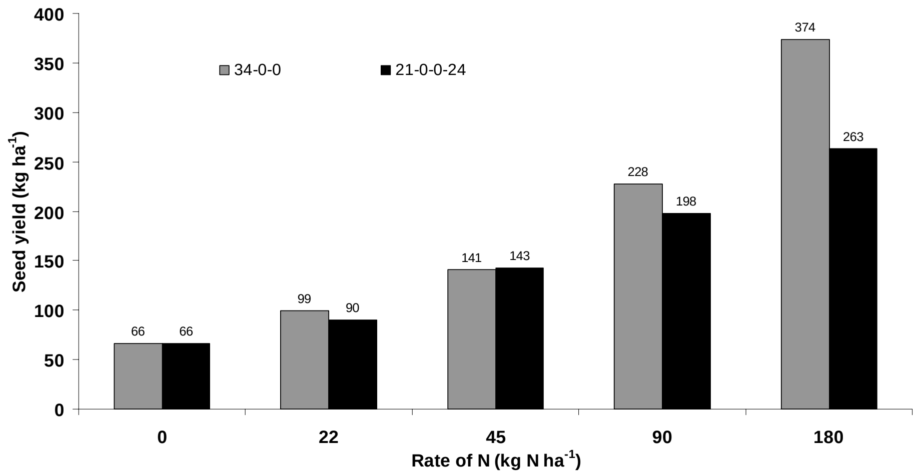

Figure 6. Seed yield response of smooth bromegrass to N source (1950-1951) at Melfort, Saskatchewan (prepared from Knowles and Cooke 1952).

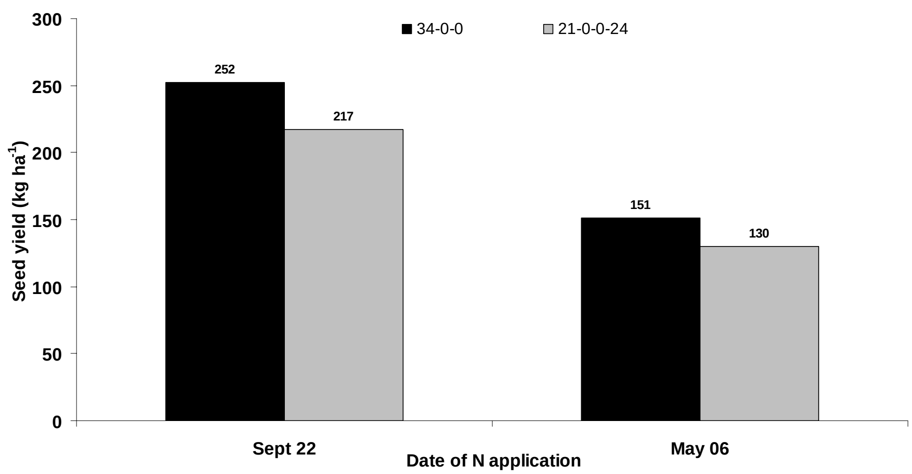

Figure 7. Effect of N form and date of application at 45 kg N ha^{-1} on seed yield of smooth bromegrass at Unity, Saskatchewan (prepared from Knowles and Cooke 1952).

2. Legumes

Legumes coexist with *Rhizobium* or *Sinorhizobium* bacteria in soil that can induce nodulation and convert N_2 from the air to a form that is available to plants. Consequently, no N fertilizer is required for legumes, provided legumes are inoculated with appropriate *Rhizobium* or *Sinorhizobium* bacteria (specific to each plant type) when this bacteria is absent from the soil The results of separate field experiments conducted at 2 and 3 sites in northeastern Saskatchewan (Horton 1991, Loeppky et al. 1999) showed that there was no significant increase in seed yield of alfalfa (*Medicago media* Pers.) from N fertilization, irrespective of soil type and climatic conditions. It has been reported that, in some legume grain crops, the application of N fertilizer may reduce nodulation (Williamson and Diatloff 1975; Sundaram et al. 1979; Clayton et al. 2004). However, biological nitrogen fixation (BNF) in alfalfa was observed to continue at high rates even at very high levels of N application (Lamb et al. 1995).

B. Phosphorus

1.Grasses

When more than one element is deficient in the soil the addition of an isolated element does not usually result in higher seed yield. Application of phosphorus (P) to dryland Altai wildrye grass at Swift Current, Saskatchewan in 25-25 and 50-50 kg ha^{-1} combinations of N and P increased seed yield over application of N alone (Figure 8; Lawrence 1980). In this trial, N application of 25 kg N ha^{-1} increased seed yield by 30 kg ha^{-1} when applied in combination with 25 kg P ha^{-1}, but seed yield increased by only 23 kg ha^{-1} when 25 or 50 kg N ha^{-1} were applied alone. In earlier studies, with Russian wildrye grass (Lawrence and Kilcher 1964) and crested wheatgrass (Buglass 1964), there was no consistent difference in the seed yield from either ammonium nitrate (33.5-0-0) or ammonium phosphate (16-20-0) fertilizers, when both provided 55 kg N ha^{-1}.

Field experiments to study the response of smooth bromegrass, crested wheat grass, intermediate wheat grass and timothy to 0, 9 and 18 kg P ha^{-1} fertilization were conducted at 7 sites in northeastern Saskatchewan from 1988 to 1991 (Loeppky et al. 1999). The seed yields of timothy and crested wheatgrass were significantly increased (though small) by P application (Figure 9).

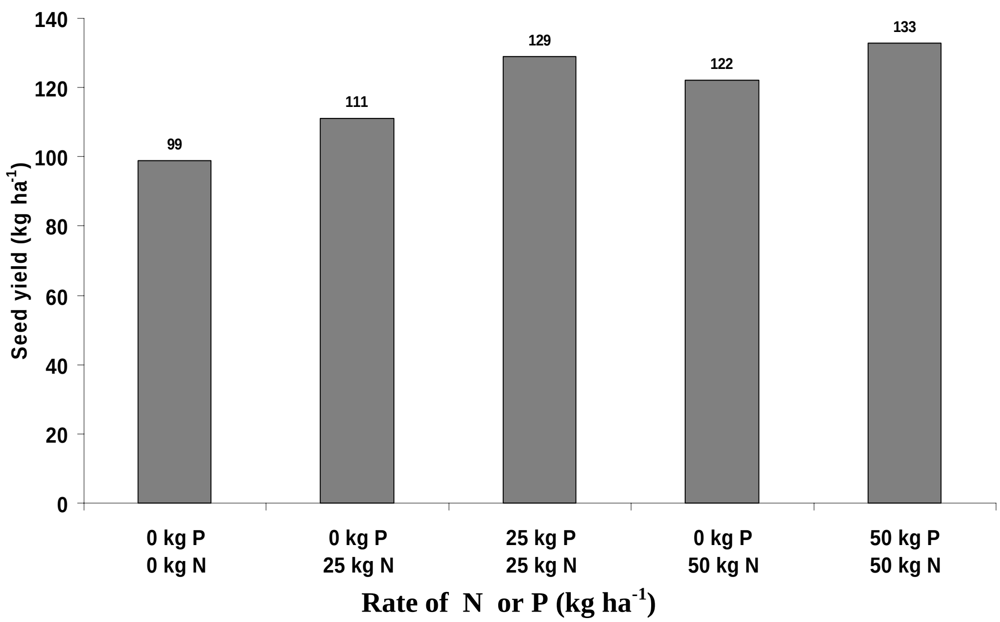

Figure 8. Interaction effect of N and P fertilizer on seed yield of dryland Altai wild ryegrass at Swift Current (prepared from Lawrence 1980).

In the study of Loeppky et al. (1999), seed yield response of smooth bromegrass to N and P fertilizers was also affected by the amount of available N and P in the soil Seed yield in the control plots increased with increasing level of soil test N and P (Figure 10). Relative to the control, percentage increase in seed yield from applied N and P fertilizers decreased with increasing soil test N and P levels (Figures 11, 12). The high correlation of seed yield to soil test N and P data (R^2 = 0.93) clearly established the significance of nutrient status of the soil in making more precise fertilizer recommendations

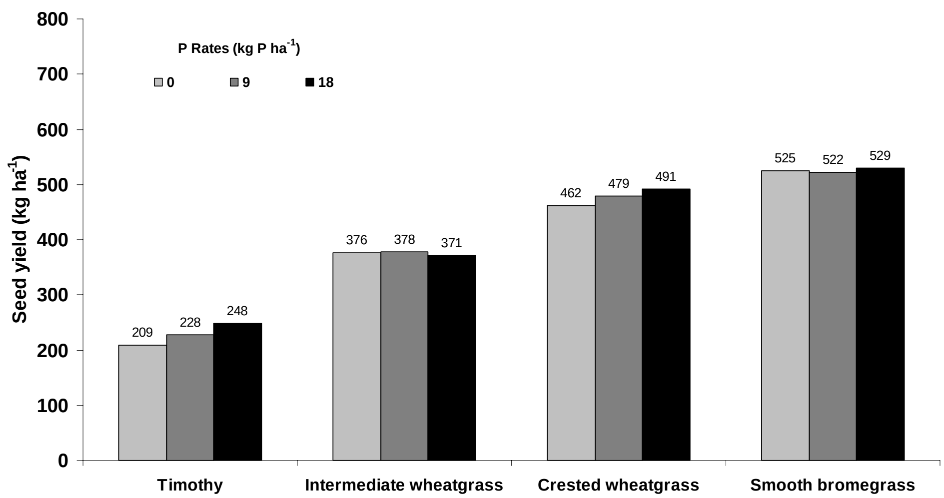

Figure 9. Phosphorus rate effects on seed yield of timothy, intermediate wheatgrass, crested wheatgrass and smooth bromegrass (averaged over N rates, years and sites) in northeastern Saskatchewan (prepared from Loeppky et al. 1999).

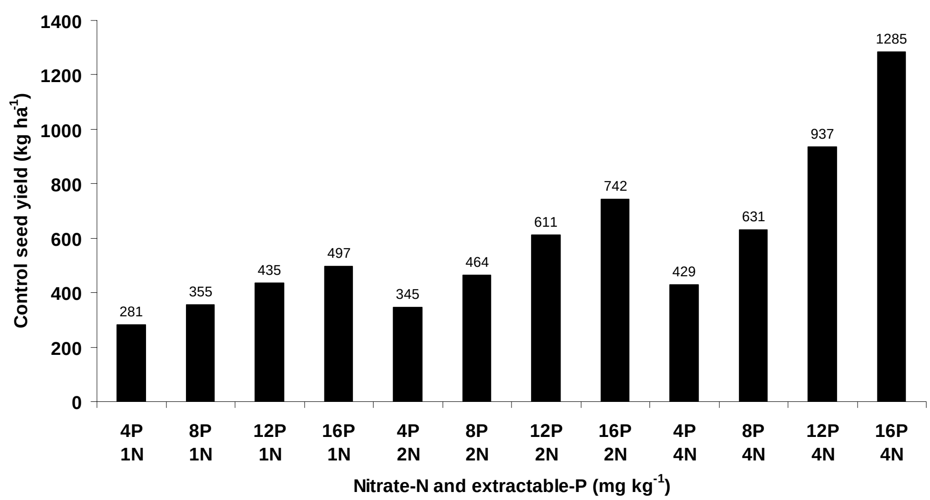

Figure 10. Seed yield of smooth bromegrass in the unfertilized control plots in relation to soil test nitrate-N (NO_3-N) and sodium bicarbonate ($NaHCO_3$) extractable-P levels at various sites in northeastern Saskatchewan (prepared from Loeppky et al. 1999).

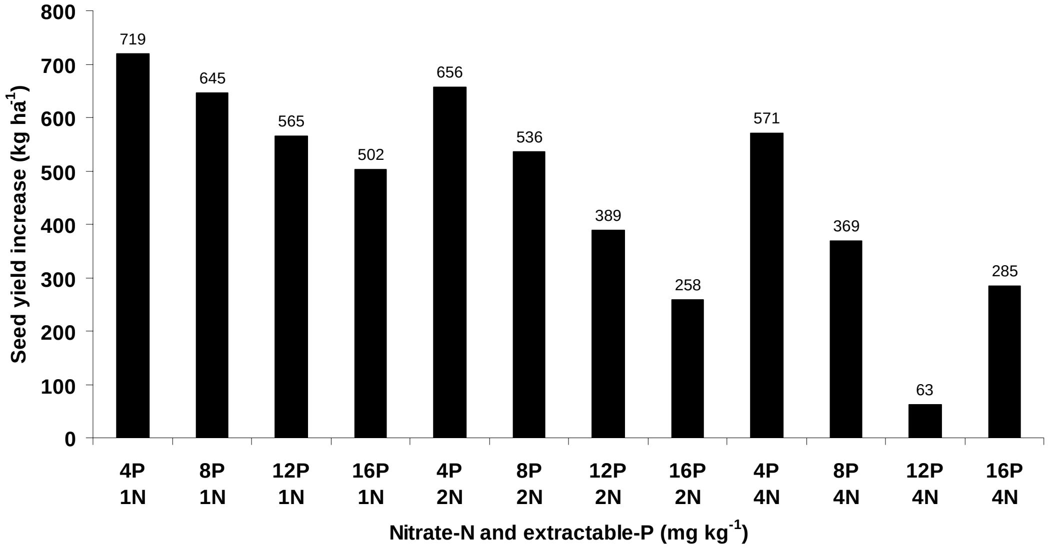

Figure 11. Estimated seed yield increase of smooth bromegrass from N and P fertilizers in relation to soil test nitrate-N (NO_3-N) and sodium bicarbonate ($NaHCO_3$) extractable-P levels when 50 kg N ha^{-1} plus 9 kg P ha^{-1} were applied at various sites in northeastern Saskatchewan (prepared from Loeppky et al. 1999).

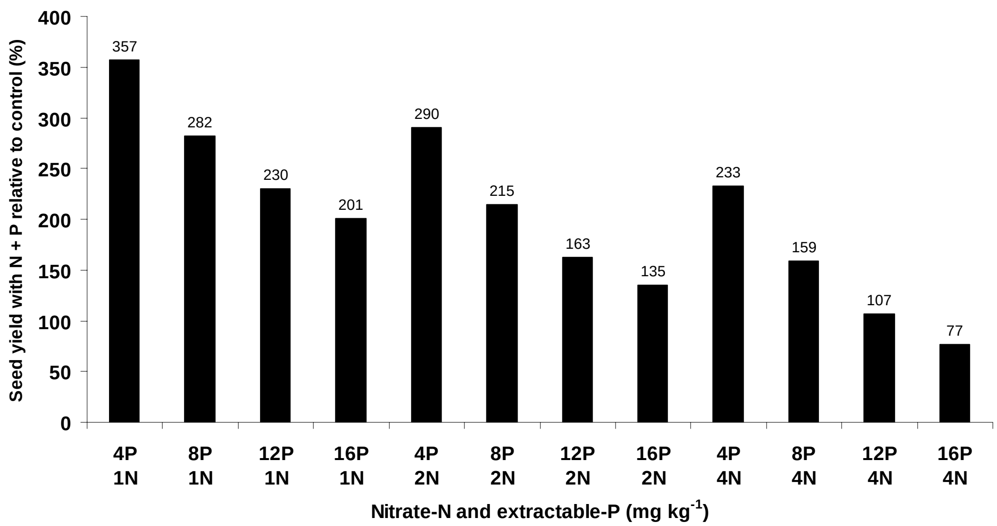

Figure 12. Estimated seed yield of smooth bromegrass in the N and P fertilized plots relative to control (%) in relation to soil test nitrate-N (NO_3-N) and sodium bicarbonate ($NaHCO_3$) extractable-P levels when 50 kg N ha^{-1} plus 9 kg P ha^{-1} were applied at various sites in northeastern Saskatchewan (prepared from Loeppky et al. 1999).

Unlike N, which moves relatively freely with water in soil, P is relatively immobile (Malhi et al. 1992b, 2003), and tends to have a more lasting residual effect, when compared with N fertilizer forms (Lawrence 1980). For this reason, placement of P fertilizer in the soil where it will be directly intercepted by roots is very important (Malhi et al. 2001). However, research information on appropriate method of P application is lacking in perennial forages grown for seed production.

2. Legumes

Under poor soil P conditions, alfalfa can not compete with weeds and maintain its original productivity. Under improved soil P fertility alfalfa can be more competitive with weeds and increase the longevity of stands by several years (Oohara et al. 1981). In field experiments at three sites in northeastern Saskatchewan to determine the response of alfalfa seed yield to the application of 0, 9, 18, 26 and 53 kg P ha^{-1} from 1988 to 1991, the application of P produced a significant increase in seed yield of alfalfa, although the response varied with site (Figure 13; Loeppky et al. 1999). The estimated increase of alfalfa seed yield from 18 kg P ha^{-1} was 31 kg ha^{-1} on a Black soil with 11 mg extractable P kg^{-1} in the 0-15 cm depth. Similarly, in a study in northeastern Saskatchewan (S. S. Malhi – unpublished results), seed yield of alfalfa increased with P fertilization on a P-deficient soil. In the study of Loeppky et al. (1999), there was little or no increase in seed yield of alfalfa at sites where soils had 19 mg or more extractable P kg^{-1}. In another study in Saskatchewan (Gossen et al. 2004), application of P fertilizer had little or no influence on seed yield of alfalfa due to adequate initial soil P fertility (41 mg extractable P kg^{-1}). Weather can also interact with soil fertility and result in lower seed production, even under adequate soil fertility, as insect pollinators have reduced activity under wet, cloudy and cool conditions (Gossen et al. 2004).

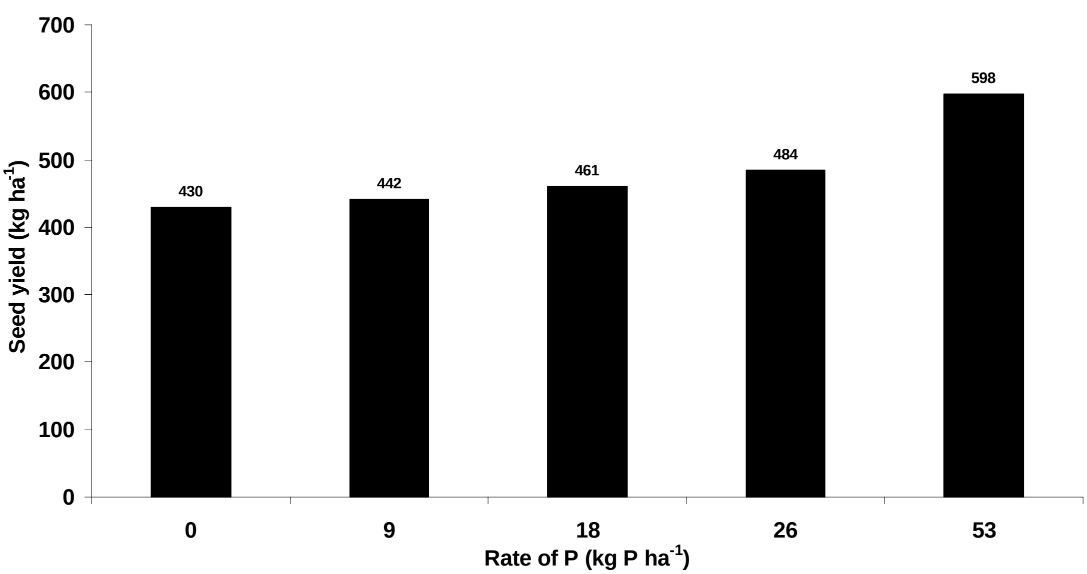

Figure 13. Estimated seed yield of alfalfa at various P fertilizer rates in northeastern Saskatchewan (averaged over 1989 to1991 – prepared from Loeppky et al. 1999).

C. Potassium

Potassium (K) stimulates N fixation and decreases the incidence of winter injury in legume stands by increasing the accumulation of carbohydrates in the root system (Bailey 1983). Under K-deficient conditions, plant density declines in the legume component of long-term stands (Anonymous 1982; Goplen et al. 1982), thus potentially reducing seed production. Alfalfa is less competitive with companion crops under poor K conditions, but high soil K fertility can increase the alfalfa stands and thus longevity of the crop (Oohara et al. 1981; Burmester et al. 1991). Potassium is a nutrient that is used in large quantities by most crops, especially when perennial forages are grown for hay production. The majority of Saskatchewan soils contain adequate amounts of K for perennial forages, but some coarse-textured (loamy sand and sandy loam) and organic soils are likely to be K deficient. On these soils, perennial forages may benefit from K fertilization, but field research information on the seed yield responses of perennial forage grasses and legumes to K fertilization on various soils is lacking. When applying K fertilizer, banding is the preferred method of application, and K can be banded with a blend of P fertilizer.

D. Sulphur

Sulphur (S) is an essential nutrient for N-fixing bacteria, and it affects both yield and quality of seed in legumes and other crops. Sulphur is likely to be deficient in many Gray and Dark Gray Luvisol (Boralfs) soils and some coarse-textured Black Chernozem (Borolls) soils in northeastern Saskatchewan. Both legume and grasses will respond to S fertilizer (sulphate form) when soil is deficient in plant-available S (sulphate-S). Increases in forage seed yield (especially for legumes because of their higher requirements for S than grasses) can be expected from relatively small annual additions of sulphate-S fertilizers. In northeastern Saskatchewan, S. S. Malhi (unpublished results) observed an increase in seed yield of alfalfa with application of sulphate-S fertilizer on an S-deficient soil.

E. Miconutrients

Most soils in Saskatchewan are adequately supplied with micronutrients and deficiencies of micronutrients are rare for growing perennial forages. In few field studies conducted in Saskatchewan (Gossen et al 2004), forage seed yield responses to micronutrient fertilizers have been small and inconsistent, mainly due to adequate levels of micronutrients in the experimental sites. Therefore, no general conclusions can be drawn regarding the response of forage seed yield to micronutrient fertilizers. In order to determine which micronutrient is limiting in soil, soil and tissue testing is suggested. In addition, it is important for producers to try on-farm testing in small areas to determine seed yield responses to micronutrient fertilizers before making major changes in overall fertilizer programs.

Conclusions

For grasses, N fertilizer application increased seed yield when other nutrients were not limiting in the soil, and magnitude of seed yield increase was much higher under cool moist conditions than dry conditions in the growing season. Surface-applied ammonium nitrate was more effective than other ammonium-based fertilizer. Autumn-applied N usually produced higher grass seed yield than spring-applied N. For legumes, focus should be on correcting P, K and S deficiencies, as these plants have the property of fixing N from the air when properly inoculated. Whenever possible, fertilizers (particularly P, K and urea N) should be banded (or injected) into the soil for most efficient use of the nutrients, but there is very limited research information on forage seed stands. In addition, research information is also lacking on the feasibility of the use of micronutrient fertilizers on forage seed production.

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