Re-evaluation of native plant species for seeding and grazing by livestock on the semiarid prairie of western Canada.

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Abstract

There is a growing interest in the re-vegetation of disturbed prairie sites, including annual crop lands, with native species. Previous research from the Mixed Grassland ecoregion, or semiarid prairie region, of western Canada found that introduced forage species, such as crested wheatgrass, produced more spring forage with better nutritive value than native species and concluded that native species exhibited little agronomic merit. However, new research indicates that native species may be useful for extending forage productivity and the grazing season into the late summer, fall and winter. Native species contribute to biodiversity, reduce nonforage invasive species problems, and enhance wildlife habitat in this region. They may also contribute to increased soil carbon sequestration, and increased ecosystem stability despite increasing aridity due to climate change. Future opportunities in native plant research and development include a focus on developing methods of reliable native seed production by either genetic enhancement or agronomic practices or both.

INTRODUCTION

European settlement of the Mixed Grassland ecoregion of southwestern Saskatchewan and southeastern Alberta occurred in two waves. Corporate ranching based on very large tracts of native grasslands leased from the federal government followed the construction of the Canadian Pacific Railway in the 1880's, but inadequate cattle feed during extreme winters resulted in large death losses and subsequent bankruptcies (McGowan 1975). Despite concerns about low and variable precipitation and low organic matter soils that are marginal for annual crop production, the federal government's settlement policy was changed by 1900 to encourage the development of small farms and a supporting rural infrastructure such as railway branch lines. Immigrants farmers or "sod-busters" received 160 acres or a quarter-section of land in exchange for plowing native grass for crop, mainly wheat (*Triticum aestivum* L.), production for export to Europe. This culminated in the plowing of 80% of the native grasslands of this ecoregion in Saskatchewan and Alberta (Selby and Santry 1996). When the unsustainable nature of some homesteads became evident during the major droughts of the 1930s, introduced or exotic forage species, such as crested wheatgrass (*Agropyron cristatum* L. Gaertn. and *A. desertorum* (Fisch. Ex Link) J.A. Schultes), were used for reseeding millions of hectares (Gray 1996). Introduced forage grass species from central Asia have been extensively studied since the 1950's for improved adaptation, forage yield, forage quality and persistence under ruminant grazing pressure. At the same time, *in situ* native species were considered to have low forage yield, poor seed production, low forage quality, and low carrying capacity for grazing by domestic livestock.

Over the last decade, however, there has been a renewed and growing interest in native plant species and this interest has contributed to the formation of the provincial Prairie Conservation Action Plans (PCAP Partnership 2003), the popular Native Plant Summit conferences, and the formation of specialist groups such as the Native Plant Society of Saskatchewan. This revival can be attributed to several emerging trends and changes to the agriculture industry. These trends include increasing demand for wildlife habitat, an increasingly ecological perspective on grassland management by cattle ranchers, greater respect for the role of grasses in soil organic carbon sequestration, and a better understanding of the invasive characteristics of some introduced forage species. Invasion of native rangelands by exotic species has been highlighted as a problem of previous revegetation efforts. The introduction of the *Species at Risk Act 2003* in the federal parliament, an act to promote the preservation of endangered species in Canada, has heightened awareness of the need for the preservation of native mixed prairie rangelands and habitats.

Private and public organizations that manage native prairie landscapes have recognized the importance of re-vegetating disturbed sites with native rather than introduced plant species. For example, Ducks Unlimited Canada has promoted the value of seeded native species for ground-nesting waterfowl habitat on land adjacent to permanent water bodies. In the ecologically sensitive Great Sandhills of southwestern Saskatchewan, the petroleum industry is now re-vegetating pipeline rights-of-way, well-sites, and other disturbed areas with native species. In Alberta, the use of native species has been increasing steadily for public and private land reclamation, resulting in the need for new guidelines (Native Plant Working Group 2001).

Cattle producers' appreciation for native rangelands has increased due to years of range experience and to training in intensive grazing management based on ecological principles.

Native rangelands in the Mixed grassland ecoregion can support good summer weight gains on yearling steers (Karn and Lorenz 1983) and are similar to some introduced grasses (Smoliak and Slen 1974; Hofmann et al. 1993). Stocking rate, grazing rotation among paddocks, and grazing duration can be managed to improve range condition and maximize economic productivity (Hart et al. 1988). Seeded native species will be important forage sources to complement existing native rangelands for improved grazing management and range condition. As changes to transportation and input costs make grain production uneconomical on some soils, the investment in re-seeding native species for summer, fall and winter grazing by cattle has grown. Fall and winter grazing of beef cattle, particularly pregnant non-lactating beef cows, is one strategy to reduce the cost of beef production in this region.

Lessons can be learned from the Conservation Reserve Program (CRP) in the United States which promotes the re-vegetation of land that is marginal for annual crop production and emphasizes native species. One benefit of the CRP is increased soil organic carbon concentration on fragile soils in the Northern Great Plains (Gebhart et al. 1994). A forage seeding program for Canada has been funded and it will support conversion of marginal crop land to perennial vegetative cover but also has an component for re-seeding native species (Agriculture and Agri-Food Canada 2003). Soil re-seeded with native species could be a sink to sequester carbon removed from the atmosphere via photosynthesis and stored as soil organic matter carbon (Christian and Wilson 1999; Janzen et al. 2000). This process could contribute to Canada’s international commitment to reduce greenhouse gas emissions (Environment Canada 2002).

Native prairie has higher floral biodiversity than monoculture cropping systems used in modern agricultural production. Conserving biodiversity on landscapes utilized for ruminant livestock pastures provides many opportunities as well as challenges (Paoletti et al. 1992). Little biodiversity data are available to compare undisturbed prairie ecosystems to agroecosystems (Paoletti et al 1992). Native prairie is one of the most threatened ecosystems because major portions have been converted to annual and perennial crop production for export grains and forage production with introduced species. On a continental scale, there has been a 64% reduction of the mixed-grass prairie region of North America. In the Canadian provinces of Alberta, Saskatchewan and Manitoba, native prairie grasslands have declined 61, 81, and 99%, respectively. The Tall-Grass prairie of Manitoba has been completely converted to crop production and Saskatchewan has lost 6% of its Mixed-Grass prairie (Samson et al. 1998).

Many native plants were used by the first peoples of Canada for medicinal purposes and there is renewed interest in such plants as a source of pharmaceutical and nutritional products (Lewis and Elwin-Lewis 2003). A recent market assessment of native plants in Saskatchewan commissioned by the Native Plant Society of Saskatchewan (Solutions 2000+ 1997) forecasts a 15% yearly increase in market size for native plants including species with medicinal value. In urban settings, there has also been a growing demand for native plants for low-input xeriscaping. The pharmaceutical and landscaping uses of native plant species are beyond the scope of this review.

The purpose of this paper is to review revegetation research involving native plant species of the semiarid prairie region in light of these trends. A second objective is to identify opportunities for further research and development of native plants for seeding on the prairie landscape.

ATTRIBUTES OF NATIVE VS. INTRODUCED FORAGE

Adaptation

Establishment of plant species from seed is key to the re-vegetation of disturbed sites, development of new pastures for livestock grazing, or range improvement. Research results suggest that native grasses are difficult to establish. For example, Kilcher and Looman (1983) reported very low establishment of big bluestem (*Andropogon gerardii* Vitman.) and prairie sandreed (*Calamovilfa longifolia* (Hook.) Scribn.) at Swift Current, Saskatchewan (lat. 50° 16′ N, long. 107° 44′ W, 825 m elevation) (Table 1). However, more recent results (Jefferson et al. 2002; Jefferson unpublished) indicate that varieties of these native grasses from Montana and North Dakota can be successfully established from seed at Swift Current (Table 1) and other sites in western Canada (Jefferson et al. 2002); although cool-season (C_3) grasses established better stands than warm-season (C_4) grasses. Jefferson et al. (2002) have also observed good seedling vigour and excellent stand establishment for other warm-season species (Table 1). The earlier work of Kilcher and Looman (1983) was based on varieties from Kansas, Nebraska and Colorado, whereas recent results were based on varieties from Montana and North Dakota. These states are adjacent to southern Saskatchewan and can provide varieties that are better adapted to western Canada than varieties from further south (Tober and Chamrad 1992).

[insert Table 1 near here]

Lawrence and Ratzlaff (1989) concluded that native grass species were not persistent when seeded at Swift Current, Saskatchewan. The native grasses they tested included five slender wheatgrass (*Elymus trachycaulus* (Link) Gould ex Shinners) varieties, four awned wheatgrass (*Agropyron subsecundum* (Link) Hitchc.) varieties, two northern wheatgrass (*Elymus* *lanceolatus* (Scribn. & J.G. Sm.)) varieties and one streambank wheatgrass (*Elymus lanceolatus* (Scribn. & J.G. Sm.) Gould ssp.*lanceolatus*). The forage yield and plant density of these species were compared to three introduced forages, crested wheatgrass, intermediate wheatgrass (*Elytrigia intermedia* (Host) Nevski) and meadow bromegrass (*Bromus riparius* Rehmann). These authors conclude that slender wheatgrass lacks winterhardiness or persistence as it died in the fifth year after establishment. This conclusion was then extrapolated to all native species relative to introduced grasses for the semiarid region of western Canada. However, these authors failed to recognize that slender wheatgrass and awned wheatgrass are known to be short-lived perennials and die out in three to five years. Thus their primary conclusion, and its extrapolation to all native species, was erroneous. In contrast to the authors' negative conclusion about native grasses, northern wheatgrass exhibited no stand loss in this trial but this result was not acknowledged (Lawrence and Ratzlaff 1989).

Current research projects (Waller et al. 1994; Schellenberg and Jefferson 1998; Banerjee and Schellenberg 2000) have succeeded in establishing various native grass, shrub and forb ecotypes in southern Saskatchewan, although more research is needed to: establish proper seeding and establishment procedures and optimum seeding density; determine the advantages of mixtures versus species monocultures; determine the role that grazing animals play in perpetuating the local plant population; develop proper grazing management strategies; and evaluate the productivity of the stands in the short and long term.

Forage production

Direct comparisons of native and introduced species at Swift Current have generally examined above-ground biomass productivity as the main criteria and conclude that introduced species produce more forage biomass than native species (Lawrence and Troelsen 1964; Lawrence 1978; Kilcher and Looman 1983; Lawrence and Ratzlaff 1989). However, 90% of the variation in forage production among native and introduced species in the report of Kilcher and Looman (1983) are explained by variation in stand establishment. Similarly, forage yield comparison of native versus introduced species was confounded with stand establishment in the intermountain region of the USA (Asay et. al 2001). Other studies (Coupland 1974; Dubbs et al. 1974; Hanson et al. 1976) show native grasses comparing favorably with introduced species. Knowles (1987) reports that western wheatgrass excelled in pasture yields and deserves attention for seeding long-term pastures. He also notes that introduced grasses were less productive during the summer period than native species, which continue to grow. Jefferson et al. (1999) report that sites seeded with an introduced species mixture produced more forage than sites seeded with native species in Manitoba and Alberta, while there was no difference between the two types in Saskatchewan.

In a direct comparison of forage production of native cool- and warm-season grasses with five introduced cool-season grasses, the timing and frequency of forage harvest affected the yield differences. Introduced species produced superior forage yield when harvested in late May in 1991 and 1992 (Table 2) compared to cool-season native grasses at the first of three harvests per year (Jefferson, unpublished data). The native warm-season grasses had not produced measurable forage biomass by the end of May each year. The harvest timing was changed to once (mid-July) per growing season in 1993 and 1994. By 1994, native grasses produced forage yields equivalent to the introduced species (Table 2). These results suggest that previously reported forage yield comparisons may have been biased by harvests that occurred too early and too frequently during the growing season.

(Insert table 2 near here)

The biomass productivity advantage of introduced species over native species appears to depend on soil fertility (Johnston et al. 1968). Introduced species yield more forage than native range only when fertilizer is applied; unfertilized introduced species actually yield less than unfertilized native range (Johntson et al. 1968; Knowles 1987). However, ranchers in the semiarid prairie region find fertilizer application to forages to be economically risky due to variation in rainfall amount and inconsistent responses to fertilizer application. Earlier forage biomass productivity comparisons may reflect the fact that the species were grown on the Swift Current Research Centre where available soil nutrients and weed control are significantly above average. The yield of introduced grasses peaks at 2 to 3 years after seeding and decline thereafter (Knowles 1987) so forage yield comparisons may be biased by short (1 to 3 years) trials. The biomass productivity advantage of introduced species is likely less on semiarid prairie pastures than that reported from research centre trials. Crested wheatgrass may be an exception, as it appears to maintain its above-ground productivity advantage over native rangeland for long periods of time without fertilization (Smoliak et al. 1967). Crested wheatgrass pastures can be two to ten times more productive than adjacent native range (Smoliak et al. 1967; Looman and Heinrichs 1973).

In summary, forage yield production comparisons of native and introduced species are difficult to interpret due to the interaction of soil type, fertility, testing period, harvest management (date), climate and possibly other edaphic factors. We conclude that the advantage in forage productivity of introduced forage species under intensive agronomic management is the primary reason for continued use of these species for hay and spring pasture production in the semiarid prairie region.

Grazing and Forage quality

Native grasses evolved to withstand extreme environmental conditions and buffalo grazing pressures of the original Mixed Grass prairie while introduced grasses evolved in other parts of the globe. Kamstra (1973) reported that individual native grasses each have specific seasonal growth characteristics that can vary their nutritional quality as phenological development proceeds. Therefore, direct comparison of quality components between introduced and native grasses at equivalent maturity stages cannot be made since the usual definitions do not consistently apply to range grasses. For example, many range grasses produce seed only during favorable years. In addition, Knowles (1987) and Coupland (1974) reported that western wheatgrass and northern wheatgrass exhibited a greater degree of senescence compared with cultivated grasses. Although the nutritional contents and digestibility among different native species can be quite variable during the growing season (Abouguendia 1998), cattle producers have recognized that several native species common to the prairies of western Canada retain a relatively high nutritive value during late summer and throughout fall and early winter. In addition, these native species are able to preserve their physical form; stems and particularly leaves do not decompose to any extent for some months after growth has ceased (Table 3). Referred to by cattle producers as “curing”, this remarkable property is one reason why native pastures can be grazed by cattle later in the grazing season or in moderate winter conditions with little or no supplemental feeding. Curing normally occurs during late July but can also take place in mid-June or late August, depending on the season (Pigden 1953). In economic terms, the excellent curing ability of many native species can reduce animal feed costs by shortening the winter feeding period.

(Insert table 3 near here)

Cattle ranchers may not have sufficient land base of native range to exploit summer and fall grazing potential of native species and are interested in seeding native species mixtures specifically for late-season grazing. Based on seeded native-pasture in 1993 and 1994 at Swift Current, calf weight gains on pasture in fall and early winter were nearly as good as those observed in feedlots (Jefferson et al. 1997). Estimates of grazing capacity (grazing days per ha) on the native grasses were similar to those reported for introduced grasses. A monoculture of western wheatgrass exhibited better forage quality for winter grazing than a mixture of northern wheatgrass, western wheatgrass and green needlegrass. In another study, the digestibility of western wheatgrass harvested in September was 14% higher than that of northern wheatgrass (Jefferson et al. 2004). Western wheatgrass maintained good forage quality throughout the grazing season in North Dakota (Frank and Bauer 1991; Hofmann et al. 1993) but can have low quality when harvested at a late phenological stage (Smoliak and Bezeau 1967). However, Jefferson et al. (2004) results agree with Knowles (1987) that western wheatgrass has better forage quality than northern wheatgrass and has good potential for fall grazing.

The quantity and quality of forage produced on native rangelands are highly cyclical, within and between years and one would expect similar variation for seeded native mixtures. Precipitation, plant species, and the proportion of cool- and warm-season species would affect overall forage quality of seeded native pastures at any given point in time and as a result lead to seasonal patterns of livestock gains. In general, diets from dormant native grasses contain 4 to 7% crude protein with higher concentrations occurring from late summer to early fall and lower concentrations occurring from late fall through winter. Plants in a vegetative state and some shrubs such as winterfat can contain over 10% CP (Abouguendia 1998) in late fall or early winter.

Native rangeland consists of a diverse community of forbs and shrubs as well as grasses so forage quality of seeded native species mixtures may be enhanced by their inclusion. Shrub species, such as winterfat (*Krascheninnikovia lanata* (Pursh) Meeuse & Smit syn. *Eurotia lanata* (Pursh) Moq.), have superior forage quality for late fall and winter grazing (Smoliak and Bezeau 1967; Abougendia 1998). Winterfat can be successfully established from seedings (Romo et al. 1997; Schellenberg unpublished data) and could contribute to significant improvements in cattle gains on fall and winter pastures of seeded native species. Gardner's saltbush (*Atriplex gardneri* (Moq.) D. Dietr.) has similar nutritional qualities to winterfat (Smoliak and Bezeau 1967) and could also contribute to cattle nutrition for fall grazing.

Livestock productivity during the grazing season can be predicted from forage quality estimates such as digestibility and protein. The digestibility of most native grasses from May until September (Abouguendia 1998) are able to meet the nutritional requirements of a lactating beef cow or a growing yearling (0.45 kg gain d^{-1}) based on the guidelines developed by Holechek and Herbel (1986). Phosphorus (P) is the most limiting mineral to range livestock production and adequate plant P concentrations for growth or lactation occurs only for a brief period early in the growing season, i.e., vegetative phase. Calcium concentrations of native grasses are adequate for maintenance, growth and lactation throughout the year (Abouguendia 1998). Cattle grazing on only native grasses in late fall, winter and early spring may require additional protein and P supplementation. Phosphorus supplementation may also be needed during the growing season to satisfy the needs of lactating cows and young cattle (Abouguendia 1998). However, including forbs and shrubs in cattle diets improve cattle performance during periods when grasses were dormant and low in quality (Holechek et al. 1989). Several studies reviewed by Holechek et al. (1989) found that leaves from forbs and shrubs contain more protein, P, and cell solubles than do grasses at comparable stages of maturity. Schellenberg and Jefferson (1998) report that two native woody shrubs, winterfat and Nuttall's saltbush (*Atriplex nuttallii* S. Wats.), found in southwest Saskatchewan and southeast Alberta retain their nutritive value well into the fall and early winter (protein concentration was 11.5%). Although information is limited on associative effects between forage species on intake, Milchunas et al. (1978) report that shrub species in the diet may increase digestibility of grasses and increase the overall digestibility of the total diet. During winter, shrubs with a higher protein concentration could improve the intake of grasses with protein levels below 7% by providing rumen microbes with a source of nitrogen (Cordova and Wallace 1975). Arthun et al. (1992) concludes that adding forbs or shrubs with low-quality grass had a similar effect on ruminal digestion kinetics and fermentation process of cattle as including alfalfa hay.

Research by Abouguendia (1998) revealed wide variations in nutrient contents and digestibility both among growth forms and among species in these forms. Therefore, it is important to identify the dominant species and their proportions in each field in order to make efficient use of the available nutrient supply over the entire grazing season and across the landscape. In southern Saskatchewan, the native Mixed Grass prairie is dominated by C_3 species

(Coupland and Rowe 1969); however, some C_4 grasses are found (Budd et al. 1987; Tober and Chamrad 1992). Since C_3 and C_4 forage grasses grow at different rates and patterns throughout the growing season, it is plausible that grazing management could alter their growth response and overall productivity in the field (Waller et al. 1994). Since C_4 grasses grow well in mid-summer, they can support increased grazing livestock production during the summer decline of C_3 forage yield and quality. Currently, a research study started in 2001 at Swift Current is evaluating the nutritional quality, above-ground biomass production and grazing performance of two native mixtures: a simple grasses/forb mixture containing cool-season species and a complex grasses/shrubs/forb mixture containing both cool- and warm-season species. Preliminary results from this study indicate that forage material harvested from the complex native mixture in August and September had protein concentration at 20 to 26% and digestibility concentration at 3 to 8% greater than the simple native mixture, respectively (Iwaasa and Schellenberg 2003). Average daily gains (ADG) of beef steers on the complex native mixtures was consistent during the July to August grazing period, while ADG for the simple native mixture declined rapidly after July. In agreement, other studies (Hall et al. 1982; Ward 1988; Jackson 1999) have concluded that the incorporation of C_4 grasses into a pasture system can improve cattle weight gains during the summer months compared with grazing only C_3 grass pastures. Also, the complex native mixture can provide a forage with higher nutritional value that is better able to meet the nutritional needs of ruminants later in the growing season (Cook 1972).

Selective foraging by cattle (preferring some plants and avoiding others) affects the character and composition of rangelands and nutritional quality of the diet (Wallace et al. 1972) and is a possible explanation for seasonal patterns of livestock gains (Hart et al. 1983). Efficient management of rangelands depends on the identification of plants that are both palatable and nutritious to grazing livestock. Vavra et al. (1977) working in Colorado and Samuel and Howard (1982) in Wyoming reported that blue grama (*Bouteloua gracilis* (H B.K.) Lag. ex Steud.) ranked the lowest in preference compared to western wheatgrass and needle-and-thread (*Stipa comata* Trin. & Rupr.) grass. Even when compared among warm-season grasses (i.e., blue grama, big bluestem, little bluestem, side-oats grama, switchgrass and sandreed grass), blue grama was consistently less preferred (Rogler 1944). However, increased consumption and selection of blue grama was observed as other, more palatable, plants become less abundant in the pasture as the grazing season progressed (Varvra et al. 1977; Samuel and Howard 1982). Some studies (Caswell et al. 1973; Kautz and Van Dyne 1978) have reported that cattle appear to avoid warm-season species and select for forbs and cool-season grasses, but Tomanek et al. (1958) found that cattle prefer big and little bluestem grasses over other warm-season grasses and western wheatgrass during the grazing season (May to August). Some plant species are relatively unpalatable or not prefered by grazing animals, yet were found to have a high nutrient concentration. Hart et al. (1983) reported that the forage quality of blue grama was high in the spring but its quality decreased more rapidly than needle-and-thread. Thus, proper grazing management may enable utilization of such plants (Abouguendia 1998). Bai et al. (1998) reported that moderate stocking rates tended to favor greater plant species diversity. Therefore, increased diversity would improve the productivity of the pasture and the nutritional status of the grazing animal. Additional research in this area is needed to understand the livestock-plant interface and how to best manipulate cattle behavior to improve rangeland forage production, forage quality, and beef production.

Cruz and Ganskopp (1998) found that crested wheatgrass was selectively grazed by beef steers over native grasses at vegetative and anthesis growth stages. Furthermore, some native grass species were more preferred at a mature phenological growth stage than crested wheatgrass while others were similar to it. This preference behaviour was observed both in a pasture where crested wheatgrass made up a large proportion of available forage and in a rangeland site where crested wheatgrass was more limited. These authors concluded that native grasses can provide summer and fall grazing while crested wheatgrass should be used in spring.

The diets of grazing cattle can also be improved by integrating native rangeland into a grazing system. Complementary grazing is currently being promoted in western Canada and may allow pastures to sustain higher stocking rates than continuous season-long grazing. In this system, cattle are moved through a sequence of pastures with forages that mature in sequence over the season. This allows the cattle access to the forage when it has its best quality (Martin and Fredeen 1999). Crested wheatgrass pastures are grazed in spring while native rangeland pastures are grazed in summer and fall. This type of system provides a method of integrating the use of native range plants with seeded pasture to delay grazing of the native range and to improve the nutrient status of grazing cattle over a longer grazing season (Adams et al. 1996). A diverse mixture of seeded-native species exhibiting improved forage quality and palatability combined with managed grazing systems will likely improve livestock performance and provide an alternative to over-grazing and potential degradation of our remaining native rangeland resources.

Seed production

Native grass species exhibit large annual and environmental seed production variation

(Phan and Smith, 2000; Jefferson et al. 2002). Thus, there are inadequate and inconsistent seed supplies of adapted varieties for many native plant species in the northern Great Plains of Western Canada. Phan and Smith (2000) found significant variation for seed yield and seed yield-component traits within collections of blue grama and little bluestem obtained from southern Manitoba. Generally, the most northern collections of both species showed earlier anthesis, produced less biomass, and had lower seed yield than more southern collections when grown at one location. These findings indicate that indigenous plant collections of blue grama and little bluestem show high levels of genetic diversity for seed yield and seed yield components. Genetic diversity is the basis for the development of adapted varieties through directed selection pressure for enhanced seed production capability.

Northern wheatgrass and western wheatgrass plants exhibit strong rhizomatous growth with reproductive tiller density declining over time, as vegetative tillers eventually dominate the sward. Slender wheatgrass seed production has been commercialized in western Canada and high seed yields are reported for this species (Lawrence and Ratzlaff 1989). While high seed yield results in low seed costs for this species, it can contribute to excessive proportions of slender wheatgrass in native species mixtures for revegetation projects. Slender wheatgrass can dominate native stands for several years after establishment due to its rapid establishment and competitive advantage over other grass species (Hammermeister and Naeth 1999).

Shattering of seed is common in most of the native plant species as a method of natural seed dispersal. However, it results in a major reduction in both the quantity and quality of seed harvested. The development of methods to improve seed retention may be the most important requirement to enhance the use of native plant species for seeding by improving both productivity and quality of seed. Consideration must be given to risks of naturalizing native species such as reduced adaptation if seed shattering is reduced in varieties of native species.

Most native species have undergone limited if any selection for agronomic characteristics such as increased germination, improved seed processing and handling, better seedling establishment or reduced seed dormancy (Young and Young 1986). Baskin and Baskin (1998) note that the seeds of forbs and many native grasses are dormant. Most shrubs have varying forms of seed dormancy combined with varying lengths of viability once dispersed from the plant (Baskin and Baskin 1998). For example, winterfat seed remains viable for only a few months at ambient temperatures. Many native seeds have structures which increase difficulty of handling. White prairie (*Petalostemon candidum* (Willd.) Michx.) clover hulls are difficult to remove and inhibit germination. *Stipa* spp. have awns as well as barbs at the tip which result in lodging within seeding and cleaning equipment. Winterfat has hairy bracts which decreases flow of seed within a seeder. Nuttall's saltbush seed is encapsulated within woody bracts that protect the seed but also decrease imbibition and make assessment of seed size difficult.

Recent research efforts have focussed on the collection of a few native plant species in western Canada by government and non-government organizations like Agriculture and Agri-Food Canada (AAFC), Alberta Research Council, Ducks Unlimited Canada, and Prairie Seeds Ltd. Current research efforts at AAFC are focussed on characterization and further selection and development of varieties of a few native plants from collections of ecotypes made within the prairie provinces and was based on a genetic diverse population that captured the maximum genetic diversity from the original ecotypes. While genetically diverse native varieties, called ecovars™, are currently under development (Fig. 1) for large scale revegetation projects (Smith and Whalley 2002), it is unknown whether these varieties have maintained genetic diversity and broad adaptation after selection for seed yield.

(Insert Figure 1 near here)

Additional research is needed to confirm the genetic diversity of the resultant populations, evaluate their range of adaptation across the region, and develop seed production technologies to ensure their commercialization.

Soil fertility and carbon

Perennial forages are usually grown on low productivity soils, and ranchers seldom manage fertility for them with the care they do for their annual grain crops (Follett and Wilkinson 1995). The use of chemical fertilizers on rangelands may not be desirable because sustainable production systems are those that rely on minimal inputs of resources, such as chemical fertilizer, to achieve long-term productivity and environmental compatibility (Poincelot 1987). Consequently, any sustainable production system must depend on efficient nutrient management. Improved nutrient utilization requires greater understanding of the role of biological processes in the release of nutrients from soil organic matter.

Soil organic matter concentration is fundamental to maintenance of soil fertility because nutrients are critical to plant growth. The rate at which nutrients are released from soil organic matter is influenced by the chemical composition of the organic matter (including crop residues and root biomass), landscape position, and climate (Gregorich et al. 1995). Plant litter, a layer of dead leaf and stem tissues found at the soil surface, is an important source of carbon input to the soil. In addition, litter is essential in sustaining the prairie ecosystem as an energy inputs for soil microbes and as a sink for plant nutrients (Wilms et al. 1994). Thus, characterization and manipulation of soil organic matter (including forage residues and root biomass) concentration and nutrient mineralization rates in forage fields in the prairies is an integral part of sustainable forage production.

When soils are cultivated for crop production, particularly annual crops, the natural plant-soil system is modified (Gregorich et al. 1995) and soil organic matter concentration decreases. This is due to increased decay of existing soil organic matter as a result of tillage and alterations in soil temperature, water, and aeration as well as changes in the nature of crop residue (straw and root) additions (Swift et al. 1979). The planned conversion from arable agriculture to continuous grass production, either as an introduced species pasture or as a reseeded-native pasture, will result in an increase in soil organic matter levels (Dormaar and Carefoot 1996), and thereby enhance soil carbon (C) sequestration. Sequestration of current carbon in soil by enhancing soil organic matter (which is mostly carbon) has been proposed as a carbon "sink" in Kyoto protocol negotiations. In the inital implementation years of the protocol, carbon sequestration in sinks can be used as "offsets" against CO_2 emissions (Environment Canada 2002). Efforts to meet national targets to decrease carbon emissions for Kyoto could be aided by planting perennial native plants on land that is marginal for annual crop production. The Conservation Reserve Progam land in the USA has greater soil organic carbon concentration compared to land that was in annual crops (Follett et al. 1999). Soil microbial biomass levels in the 0-60 cm depth were 28% higher in CRP soils and 81% higher in native rangeland soil compared to soils from cropland. Janzen et al. (2000) noted that soil organic carbon in rangeland soil may exceed all above-ground portions of a temperate forest and this amount can be increased by returning previously-cultivated land back into grassland.

Bremer et al. (1994) found crested wheatgrass accumulated more total organic soil C and light fraction C than wheat. Soil from a long-term (23 years) stand of crested wheatgrass had less soil organic carbon than adjacent native rangeland (Smoliak and Dormaar 1985). Frank et al. (1999) found that native mixed prairie had greater potential as a carbon sink than a monoculture of western wheatgrass. This may have been due to increased root mass and greater exploration of different soil strata by various species. Christian and Wilson (1999) suggested that since total C was less in soils under crested wheatgrass than under native prairie, the planting of crested wheatgrass on millions of hectares of the Great Plains may have left 3.3 - 4.8 $x10^8$ tonnes of C in the atmosphere that otherwise would have been stored as soil organic matter by native grass. Thus, if C sequestration is a management goal, then native species should be preferred to introduced forage species for sequestration projects on the prairies.

Grazing stimulates aboveground production, increases tillering, and rhizome production, and may stimulate root respiration and root exudation rates (Schuman et al. 2002). All of these factors can result in a change in the amount of C or N being released or stored in the soil system. Several studies (Schnabel et al. 2001; Schuman et al. 2002) have concluded that some grazing management strategies (i.e., grazing intensity) can assist in the rapid incorporation of C into the soil, leading to increased soil organic carbon (SOC) levels. The study by Schnabel et al. (2001) further concluded that the SOC sequestration potential was considerably higher for lightly and heavily grazed pastures if they were hayed monthly (1.5 and 1.8 MT C ha^{-1} yr^{-1} vs 0.3 MT C ha^{-1} yr^{-1}, respectively). Henderson (2000) measured SOC storage in grazed and ungrazed areas at nine native grassland sites on the southern Canadian prairies and found soil C tended to be higher under grazing than in ungrazed exclosures at semi-arid sites (mean annual precipitation of 328 to

390 mm). However, at sub-humid sites (mean annual precipitation of 476 mm) the trend was reversed, suggesting that SOC sequestration depends on factors, such as climate, soils, previous management and potential net primary productivity (Follett 2003). In Canada, it is estimated that about 22 M ha of land is rangeland and improved forage lands while about 5 M ha of land is cultivated marginal land (CLI 4, 5 & 6) that is economically and environmentally unsustainable across the three western provinces (Smith and Hoppe 2000). Through the potential reseeding of native forage species, this large land resource, could greatly contribute towards decreasing greenhouse gases by sequestering more C into the soil sink.

ECOLOGICAL CONSIDERATIONS

Biodiversity

Biodiversity is essential for livestock production on native prairie. By increasing the number of species present, there are more choices of nutritious and palatable forage resources for grazing ruminant livestock (Smoliak and Bezeau 1967). As described above, later maturing forb or shrub species can improve nutritional quality. Ecosystem productivity increases as biodiversity increased on Tall-Grass prairie in Minnesota (Tilman et al. 1996). Tilman and Downing (1994) also found primary production was more resistant to drought stress with increased biodiversity. Current research suggests that a more diverse and complex mixture of cool and warm season grasses combined with shrub and forb species produced more steer gains in late summer compared to a simple mix of cool-season grasses (Iwaasa and Schellenberg 2003). Mixed prairie was the forage of choice in August and September as opposed to monoculture crested wheatgrass (Schellenberg et al. 1999). The proportion of shrub species, including winterfat, in revegetation seed mixtures was higher when biodiversity and habitat restoration were primary objectives compared to mixtures seeded for watershed protection and soil erosion control in Nevada, USA (Richards et al. 1998). These authors concluded that the cost of diverse native species seed mixtures frequently restricts their use, even by government agencies or NGOs whose own policies promote the use of natives.

Increased plant biodiversity can decrease resource limitations such as N through biological N fixation (Schellenberg and Banerjee 2002) thus increasing forage productivity. Wilson (2000) found that increased biodiversity can also increase heterogeneity of abiotic resources. Heterogeneity of nutritional resources often vary over time as well as space and small differences may have impacts on plant physiology and competition (Bakker 2000). Increased biodiversity can result in several levels of competition for soil nutrient resources (Wilson 2000). Davis (2003) suggests the available soil nutrient resources is often the deciding factor in the success of invasive species. There exists the possibility then that diverse mixtures of re-seeded native species may be less susceptible to invasion by exotic weeds but this hypothesis needs to be examined with additional research.

The decision between native or introduced species in rangeland seeding is a multiple component process that includes philosophy, objectives, site potential and limitations, availability and cost of plant materials, weed invasion, desired community seral stage, and economic limitations (Jones and Johnson 1998). Critics of varieties developed from native species suggest that they introduce undesirable genetic change in natural landscapes (Jones and Johnson 1998). However, Jones and Johnson (1998) document several known, naturally-occurring interspecific hybrids on grasslands to support their position that genetic change and intra-specific diversity can occur without human intervention. While genetically diverse populations or localized varieties of native species would be ideal for re-vegetation, such ideals are often unavailable or too expensive for large scale projects. Knowledge of an individual species' genetic variation in relation to its ecological adaptation and their interactions with other ecosystem components is needed to make the best decisions.

Climate change

In the near future, climate change will alter crop species and their productivity in the current agricultural regions of the USA (Antle 1997). World Resources Institute (1990) predicted that the mean May-August temperatures will rise by 3.5 °C, and the frost-free growing season would lengthen by four to nine weeks with increased frequency of drought in July and August on the Northern Great Plains of North America. Environment Canada (2001) projects a similar 3 °C annual temperature increase for the prairie region of western Canada. As the climate warms up, plant communities would shift in favour of species that tolerate water and high temperature stress. Cutforth et al. (1999) examined long term (50 y) weather records of an area 15,000 km^2 of semiarid prairie southwest of Swift Current, Saskatchewan and found that winter and spring maximum and minimum temperatures have increased and precipitation has decreased. Climate change has been linked to plant species migration (Root et al. 2003) and to shifts in species ranges (Higgins et al. 2003). Pastures and rangelands are thought to be very sensitive to climate change (Gregory et al. 1999). These changes in species composition may have large impacts on livestock production capabilities due to possible changes in nutritional quality and time of availability (Gregory et al. 1999). Species richness has declined with climate warming (Sala et al. 1999). Climate warming over several centuries in southwestern Saskatchewan has favoured C_3 species over C_4 species at Grasslands National Park located in the semiarid prairie region near

Val Marie, Saskatchewan (Peat 1997). Perhaps this result should not be surprising given the biochemical advantage of C_3 photosynthesis compared to C_4 photosynthesis at ambient CO_2 concentrations. Analysis of long term vegetation data in Colorado (Alward et al. 1999) found a similar shift in production in favour of C_3 species over several decades. Native species may provide useful genetic resources to respond to future climates of the Northern Great Plains. Further research is required to elucidate the potential economic of climate change on livestock production and society's appreciation of grassland landscapes.

Bio-invasion

Re-seeding native species for forage and grazing may be preferable to seeding introduced forage species because some introduced forage species have contributed to bio-invasion of neighbouring native plant communities. Bio-invasion involves the replacement of native species by exotic species, which were usually introduced to the environment through human activity. As many as 80% of the world's endangered species are threatened due to the competitive pressures of introduced or exotic species (Armstrong 1995). However, Davis (2003) states that no introduced plant species has caused extinction of another plant species but may have contributed to extinction via competition-mediated reduction in fitness. The primary cause of extinction is habitat loss which can be associated with climate change and bio-invasion working together with human development pressure. Sala et al. (1999) found that the invasion of exotic species into natural systems is a powerful driver of global change. Both climate change and exotic plant invasion contribute to habitat fragmentation and decline in biodiversity.

Bright (1998) provides the following example from Australia's attempt to identify superior forage species. During European settlement of Australia 466 plant species were introduced for hay and/or pasture production but only 21 species showed merit. Seventeen of these 21 forage species were deemed to be invasive of adjacent native rangeland. Thus, only four out of the 21 species with merit were deemed non-invasive.

Davis (2003) concluded that 4000 plant species have been introduced into North America. Most were introduced for food, fibre and ornamentals for humans (Pimental et al. 2000). Further introduced species account for 98% of the food production in the U.S.A. Among the introduced forage species, D'Antonio and Vitousek (1992) conclude that alien grass species invasion is most severe in the arid and semi-arid west of the U.S.A. Annual grass invasions were largely unplanned, while many perennial invasive grasses were purposely introduced for livestock forage or to prevent soil erosion (D'Antonio and Vitousek 1992). This use of introduced forage grass species throughout North America for pastures and erosion control led to the widespread distribution and dominance of several species (Haber 1996). Smoliak and Dormaar (1985) estimated that 1,000,000 hectares have been seeded to crested wheatgrass alone in the Canadian prairie provinces and this area has undoubtedly increased in the 20 years since 1985. White et al. (1993) consider smooth bromegrass (*Bromus inermis* Leyss.), yellow sweetcclover (*Melilotus officinalis* (L.) Pall.), and white sweetclover (*Melilotus alba* Medic.) moderately invasive and alfalfa, crested wheat grass, and Kentucky blue grass (*Poa pretensis* L.) minor invasive species of uplands. It is noteworthy that all these species were introduced for pasture or hay production in Canada.

The proportion of exotic flora on the prairies of western Canada was estimated to be 16% (Haber 1996) and Davis (2003) estimated that it was 20% for North America In Saskatchewan, smooth bromegrass and crested wheatgrass were deemed invasive in native fescue grassland

(Romo and Grilz 1990). Crested wheatgrass pasture weas not invaded by native plant species until stands were more than 15 years old (Looman and Heinrichs 1973). Even when native species were found in old crested wheatgrass stands, their contribution to above ground biomass did not exceed 10% of the total annual forage production. Thus, crested wheatgrass monocultures seedings appear to resist successional species change even under heavy grazing utilization. Similar results were found in crested wheatgrass pastures of southern Alberta (Smoliak et al. 1967). The bio-invasive risk of introduced forage plant species has not been systematically evaluated for most introduced forage species of the semiarid prairie.

Caution must be used in recommending restrictions on the use of these introduced forage grass species. A large proportion of the range livestock industry of the Northern Great Plains depends on these introduced species and economic losses could occur if a wholesale move to natives only was forced by legislation or government policy. Firstly, there is not sufficient seed for such action. Secondly, more research is necessary to assess the capabilities of native species varieties. To date only a relative few native species have been examined and some lack even the basic agronomic information. One must also realize that many of these lands were seeded to reduce erosion (Gray 1996) and removal of the introduced species and the vegetative cover they provide without an adequate plan for replacement native species could result in environmental disaster.

The issue of exotic bioinvasion in Canada lacks practical action on the Government's part (Commissioner of the Environment and Sustainable Development 2002) . Efforts are being made to address the issue within Agriculture and Agri-Food Canada's research portfolio. Management of invasive introduced species, their impact on native plant communities in the agricultural context, and the environmental context as well as invasive potential of native species require further research.

Management Implications

The controversy over the relative advantages and disadvantages of using native versus introduced species for forage production and grazing has raged for decades in the Northern Great Plains region. A new paradigm for selecting plant species was proposed by Brown and Amacher (1999). They suggested that introduced or exotic species are those which dominate early in ecological succession (early seral) and are characterized by high biomass yield, fast growth rates, high seed production, aggressive growth habit, and responsiveness to soil fertility. Native species can be characterized as those which dominate late successional (late seral) stage communities and exhibit slower growth rate, variable seed production, compatibility with other species, and adaptation to low soil fertility. Brown and Amacher (1999) present a model where all species would be considered depending on the goals and objectives of the restoration project. Our review has shown that both native and introduced species have distinct advantages depending on the intended use.

Native plant species will contribute to sustainable agricultural systems of the new century in the semiarid prairie. We conclude that more research is needed on several topics. The genetic diversity of new native plant varieties needs to be established and the value of intra-variety genetic diversity compared to intensively selected varieties confirmed. In addition, the geographic range of adaptation of native varieties and their role in summer and fall grazing by beef cattle needs to be determined. Seed production technology to permit efficient commercialization of these species needs to be studied. For some species, this may be as simple as documenting techniques developed by individual producers, while for other species, research into seed dormancy will be required. The establishment of shrub species to improve rangelands for fall and winter grazing also needs further study. Changes in soil organic carbon after seeding native species on previously cropped land need to be quantified, including the impact of species type and grazing management on the rate and extent of carbon sequestration.

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Literature Cited

Abouguendia, Z. 1998. Nutrient content and digestibility of Saskatchewan range plants a summary report. GAPT July, 1998.

Adams, D.C., R.T. Clark, T.J.Klopfenstein, and J.D. Volesky. 1996. Matching the cow with forage resources. *Rangelands* 18:57-62.

Agriculture and Agri-Food Canada. 2003. Greencover Canada. Online: www.agr.gc.ca/env/greencover-verdir [accessed 16 March 2004]

Alderson J., and W.C. Sharp. 1994. *Grass varieties in the United States*. USDA-ARS. Handbook No. 170 Washington, DC. 296 pp.

Alward, R.D., J.K. Detling, and D.G. Milchunas. 1999. Grassland vegetation changes and nocturnal global warming. *Science* 283:229-231.

Antle, J.M. 1997. Climate Change and Economic Constraints Facing Great Plains Agriculture. Briefing Document for Great Plains Regional Climate Change Workshop. Loveland, CO. May 27-29, 1999. In *Proceedings Climate Change Impacts on Rangeland Systems* Symposium and Workshop, SRM Meeting, Feb. 25-26, 1999. Omaha, NE.

Armstrong, S. 1995. Rare plants protect Cape's water supplies. *New Scientist* (11 Feb):8.

Arthun, D., J.L. Holechek, J.D. Wallace, M.L. Gaylean, and M. Cardenas. 1992. Forb and shrub effects on ruminal fermentation in cattle. *J. Range Manage*. 45:519-522.

Asay, K.H., W.H. Horton, K.B. Jensen, and A.J.Palazzo. 2001. Merits of native and introduced Triticeae grasses on semiarid rangelands. *Can. J. Plant Sci*. 81: 45-52.

Bai, Y., Z. Abouguendia, and R.E. Redmann. 1998. Effect of grazing on plant species diversity of grasslands in Saskatchewan. Proc. Of *5th Prairie Conservation and Endangered*

Species Conf. Feb. 19-22, Saskatoon, SK.

Bakker, J.P. 2000. Environmental heterogeneity : effects on plants in restoration ecology. p. 379-400. In: *The ecological consequences of environmental heterogeneity*, ed. M.J. Hutchings, E.J. John and A.J.A. Stewart. Blackwell Science, Oxford.

Banerjee, M.R. and M.P. Schellenberg. 2000. Legume and native shrub mixtures for potential optimum forage production. *Proc. Soils and Crops Workshop.* Feb. 24-25, 2000. Saskatoon, SK.

Baskin, C.C. and J.M. Baskin. 1998. *Seeds: Ecology, Biogeography, and Evolution of Dormancy and Germination*. Academic Press, San Diego.

Bremer, E., H.H. Janzen, and A.M. Johnston. 1994. Sensitivity of total, light fraction and mineralizable organic matter to management practices in a Lethbridge soil. *Can J. Soil Sci*. 74:131-138.

Bright, C. 1998. *Life out of bounds: Bioinvasion in a borderless world*. Worldwatch Environmental Alert Series (ed) L. Starke. W.W. Norton & Company, New York.

Brown, R.W. and M.C. Amacher. 1999. Selecting plant species for ecological restoration: a perspective for land managers. p. 1-16 *In:* Holzworth, L.K. and Brown, R.W., *Revegetation with native species*: proceedings, 1997 Society for Ecological Restoration annual meeting; PMRS-P-8, United States Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT.

Budd, A.C., J. Looman, and K.F. Best. 1987. *Budd's flora of the Canadian prairie provinces.* Research Branch, Agriculture Canada Publication 1662, Ottawa ON. 863 pp.

Caswell, H., F, Reed, S.N. Stephenson, and P.A.Werner. 1973. Photosynthetic pathways and selective herbivory: a hypothesis. *American Naturalist* 107:465-481

Christian, J.M. and S.D. Wilson. 1999. Long-term ecosystem impacts of an introduced grass in the Northern Great Plains. *Ecology* 80:2397-2407.

Commissioner of the Environment and Sustainable Development. 2002. Annual Report: Ch. 4 Invasive species. Http://www.oag-bvg.gc.ca/domino/reports.nsf/html/c2002004ce.html (accessed 30/05/2003).

Cook, C.W. 1972. Comparative nutritive values of forbs, grasses and shrubs. In C.M. McKell, J.P. Blaisdell, and J.R. Goodin, eds. *Wildland Shrubs: Their Biology and Utilization*. USDA Forest Service GTR INT-1. Pp 303-310.

Cordova, F.R. and J.D. Wallace. 1975. Nutritive value of some browse and forb species. Proc. *West. Sec. Amer. Soc. Anim. Sci*. 26:160-162.

Coupland, R.T. 1974. Matador Project. Technical Rep. No. 62. *Can. Comm. For the Int. Biol. Progr*. University of Saskatchewan, Saskatoon, Sask.

Coupland, R.T. and J.T. Rowe. 1969. Natural vegetation of Saskatchewan. p. 73-78. In: J.H. Richards and K.I. Fung eds. *Atlas of Saskatchewan, Univ. of Saskatchewan*. Modern Press.

Cruz, R. and D. Ganskopp. 1998. Seasonal preferences of steers for prominent northern Great Basin grasses. *J. Range Manage*. 51:557-565.

Cutforth, H.W., B.G. McConkey, R.J. Woodvine, D.G. Smith, P.G. Jefferson, and O.O. Akenremi. 1999. Climate Change in the semiarid prairie of southwestern Saskatchewan: Late winter-early spring. *Can.J. Plant Sci*. 79:343-350.

D'Antonio, C.M. and P.M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/fire cycle and global change. *Annual review of ecology and systematics* 23:63-87.

Davis, M.A. 2003. Biotic globalization: Does competition from introduced species threaten biodiverity. *Bioscience* 53:481-491.

Dormaar, J.F. and J.M. Carefoot. 1996. Implications of crop residue management and conservation tillage on soil organic matter. *Can. J. Plant Sci*. 76: 627-634.

Dubbs, A.L., R.T. Harada, and J.R. Stroh. 1974. Evaluation of thickspike wheatgrass for dryland pasture and range. *Montana State University Bulletin 677*.

Environment Canada 2001. The science of climate change. Online: www.ec.gc.ca/climate/overview_science-e.html [accessed 31 March 2004].

Environment Canada 2002. Climate change plan for Canada. Achieving our commitments together. F. Agriculture, Forestry and Landfills. Online: www.climatechange.gc.ca/plan_for_canada/plan/chap_3_6.html [accessed 16 March 2004].

Follett, R.F. 2003. Pasture management systems: impact on soil carbon and greenhouse gases. Proceeding of *2003 CSAS Annual Meeting, June 10-13, 2003.* University of Saskatchewan, Saskatoon, Saskatchewan

Follett, R.F., E.G. Pruessner, J.M. Kimble, S.E. Samson-Liebig, and S.W. Leavitt. 1999. Soil-C Storage Within Soil Profiles of the Historical Grasslands of the USA. Briefing Document for Great Plains Regional Climate Change Workshop. Loveland, CO. May 27-29, 1999. In Proceedings *Climate Change Impacts on Rangeland Systems Symposium and Workshop,* SRM Meeting, Feb. 25-26, 1999. Omaha, NE.

Follett, R.F. and S.R.Wilkinson. 1995. Nutrient management of forages. p. 55-82. In: R.F.

Barnes, D.A. Miller, and C.J.Nelson, eds. *Forages Vol. II: The Science of Grassland Agriculture.* Iowa State University Press, Ames, Iowa.

Frank, A.B. and A. Bauer. 1991. Rooting activity and water use during vegetative development of crested and western wheatgrass. *Agron. J.* 83:906-910.

Frank, A.B., W.A. Dugas, J.F. Karn, and H.S. Mayeux. 1999. Carbon dioxide fluxes over grazed grasslands. p. 214-215. In: D. Eldridge & D. Freundenberger, eds. Proceedings of the *VI International Rangeland Congress; People and Rangelands: Building the Future*. Townsville, Australia, July 19-23, 1999.

Gebhart, D.L., H.B. Johnson, H.S. Mayeux, and H.W. Polley. 1994. The CRP increases soil organic carbon. *J. Soil and Water Cons.* 49: 488-492.

Gray, J.H. 1996. *Men against the desert.* Western Producer Prairie Books, Saskatoon, SK.

Gregorich, E.G., D.A. Angers, C.A. Campbell, M.R. Carter, C.F. Drury, B.H. Ellert, P.H. Groenevelt, D.A. Holmstrom, C.M. Monreal, H.W. Rees, R.P. Voroney, and T.J. Vyn. 1995. Changes in soil organic matter. In: D.F. Acton and L.J. Gregorich, eds. *The Health of Our soils: toward Sustainable Agriculture in Canada.* Agriculture and Agrifood Canada Publication #1906/E

Gregory, P.J., J.S.I. Ingram, B. Campbell, J. Goudriaan, L.A. Hunt, J.J. Landsberg, S. Linder, S.S. Smith, R.W. Sutherst, and C. Valentin. 1999. Managed production systems. p. 229-270. In: B. Walker, W. Steffen, J. Canadell and J. Ingram, eds. *The terrestrial biosphere and global change: implications for natural and managed ecosystems*. Cambridge University Press, Cambridge.

Haber, E. 1996. Invasive Exotic Plants of Canada Fact Sheet No. 1. Online:_____

infoweb.magi.com/~ehaber/fact1.html. (Accessed 17 Feb 2000).

Hall, K.E., J.R. George, and R.R. Riedl. 1982. Herbage dry matter yields of switchgrass, big bluestem and indiangrass with N fertilization. *Agronomy J.* 74:47-51.

Hammermeister, A. and A. Naeth. 1999. An ecological approach to seed mix design and native prairie revegetation. p.55-60 *in*: Proc. of *Fifth Prairie Conservation and Endangered Species Conference*, J. Thorpe, T.A. Steeves, and M. Gollop, eds., Provincial Museum of Alberta, Natural History, Occasional Paper No. 24, Edmonton, AB.

Hanson, C.L., G.A. Schumaker, and C.J. Erickson. 1976. Influence of fertilization and supplemental runoff water on production and nitrogen content of western wheatgrass and smoothbrome. *J. Range Manage.* 29:406-409.

Hart, R.H., O.M. Abdalla, D.H. Clark, M.B. Marshall, M.H. Hamid, J.A. Hager, and J.W. Waggoner Jr. 1983. Quality of forage and cattle diets on the Wyoming high plains. *J. Range Manage.* 36:46-51.

Hart, R.H., M.J. Samuel, P.S. Test, and M.A. Smith. 1988. Cattle, vegetation, and economic responses to grazing systems and grazing pressure. *J. Range Manage*. 41:282-286.

Henderson, D.C. 2000. Carbon storage in grazed prairie grasslands of Alberta. M.Sc. thesis, University of Alberta, Edmonton, AB, Canada.

Higgins, S.I., J.S. Clark, R. Nathan, T. Hovestadt, J.M. Schurr, J.M.V. Fragoso, M.R. Aguiar, E. Ribbens, and S. Lavorel. 2003. Forecasting plant migration rates: managing uncertainty for risk assessment. *J. Ecology* 91:341-347.

Hofmann, L., R.E. Ries, J.F. Karn, and A.B. Frank. 1993. Comparison of seeded and native pastures grazed from mid-May through September. *J. Range Manage*. 46:251-254.

Holechek, J.L. and C.H. Herbel. 1986. Supplementing range livestock. *Rangelands* 8:29-33.

Holechek, J.L., R.D. Pieper, and C.H. Herbel. 1989. *Range management principles and practices.* Regents/Prentice Hall, Englewood Cliffs, N.J.

Iwaasa, A.D. and M.P. Schellenberg. 2003. Progress report on re-establishment of a mixed native grassland in Southwest Saskatchewan ADF Project #20010042.

Jackson, L.L. 1999. Establishing tallgrass prairie on grazed permanent pasture in the upper midwest. *Restoration Ecology* 7:127-138.

Janzen, H.H., B.H. Ellert, and J.F. Dormaar. 2000. Rangelands and the Global Carbon Cycle. In: Proceedings of *The Range: Progress and Potential*, Jan. 23-25, 2000, Lethbridge, AB.

Jefferson, P.G., N.W. Holt, and E. Birkedal. 1997. Use of seeded native grasses for beef production. Saskatchewan Agriculture Development Fund Project no. 95000086.

Jefferson, P.G., W.P. McCaughey, K. May, J. Woosaree, and L. McFarlane. 2004. Forage quality of seeded native grasses in the fall season on the Canadian Prairie Provinces. *Can. J. Plant Sci*. 84: [in press].

Jefferson, P.G., W.P. McCaughey, K. May, J. Woosaree, L. McFarlane, and S.M.B. Wright. 2002. Performance of American native grass cultivars in the Canadian prairie provinces. *Native Plants Journal* 3:24-33.

Jefferson, P.G., L. Wetter, and B. Wark. 1999. Quality of deferred forage from waterfowl nesting sites on the Canadian prairies. *Can. J. Anim. Sci*. 79:485-490.

Johnston, A. 1987. *Plants and the Blackfoot.* Graphcom Printers Ltd., Lethbridge, AB.

Johnston, A., A.D. Smith, L.E. Lutwick, S. and Smoliak. 1968. Fertilizer response of native and seeded ranges. *Can. J. Plant Sci*. 48:467-472.

Jones, T.A. and D.A. Johnson. 1998. Integrating genetic concepts into planning rangeland seedings. *J. Range Manage.* 51:594-606.

Kamstra, L.D. 1973. Seasonal changes in quality of some important range grasses. *J. Range Manage.* 26:289-291.

Karn, J.F. and R.J. Lorenz. 1983. Supplementation of yearling steers grazing fertilized and unfertilized Northern plains rangeland. *J. Range Manage.* 36:41-45.

Kautz, J.E. and G.M. Van Dyne. 1978. Comparative analyses of diets of bison, cattle, sheep and pronghorn antelope on shortgrass prairie in northeastern Colorado. p. 438-443. In: D.N. Hyder ed. Proc. *First International Rangelands Congress*, Denver, CO.

Kilcher, M.R. and J. Looman. 1983. Comparative performance of some native and introduced grasses in southern Saskatchewan, Canada. *J. Range Manage.* 36:654-657.

Knowles, R.P. 1987. Productivity of grass species in the dark brown soil zone of Saskatchewan. *Can. J. Plant Sci*. 67:719-725.

Lawrence, T. 1978. An evaluation of thirty grass populations as forage crops for southwestern Saskatchewan. *Can. J. Plant Sci.* 58:107-115.

Lawrence, T. and C.D. Ratzlaff. 1989. Performance of some native and introduced grasses in a semiarid region of western Canada. *Can. J. Plant Sci*. 69:251-254.

Lawrence, T. and J.E. Troelsen. 1964. An evaluation of 15 grass species as forage crops for southwestern Saskatchewan. *Can. J. Plant Sci.* 44:301-310.

Lewis, W.H. and M.P.F. Elvin-Lewis. 2003. *Medical Botany. Plants affecting human health.* John Wiley & Sons, Inc. Hoboken, NJ.

Looman, J. and D.H. Heinrichs 1973. Stability of crested wheatgrass pastures under long-term pasture use. *Can. J. Plant Sci.* 53:501-506.

Martin, R. and A. Fredeen. 1999. Effect of management of grasslands on greenhouse gas balance. Agriculture and Agri-Food Canada Report Sept. 1999.

McGowan, D.C. 1975. *Grassland settlers: the Swift Current region during the era of the ranching frontier.* Canadian Plains Research Centre, University of Regina. Regina, SK.

Milchunas, D.G., M.I. Dyer, O.C. Wallmo, and D.E. Johnson. 1978. *In vivo-in vitro* relationships of Colorado mule deer forages. Colorado Div. Wildlife Spec. Rep. 40, Fort Collins, CO.

Native Plant Working Group. 2001. Native Plant Revegetation Guidelines for Alberta. H. Sinton-Gerling, ed., Alberta Agriculture, Food, and Rural Development and Alberta Environment, Edmonton, AB.

Paoletti, M.G., D. Pimental, B.R. Stinner, and D. Stinner. 1992. Agroecosystem biodiversity: matching production and conservation biology. p. 3-24. In: *Biotic Diversity in Agroecosystems* M.G. Paoletti and D. Pimental, eds., Elsevier, Amsterdam.

Peat, H. 1997. Dynamics of C_3 and C_4 productivity in northern mixed grass prairie. M.Sc. thesis, University of Toronto, Toronto, ON.

PCAP Partnership. 2003. *Saskatchewan Prairie Conservation Action Plan 2003-2008.* Canadian Plains Research Centre, University of Regina, Regina, SK.

Phan, A. T. and S.R. Smith, Jr. 2000. Seed yield variation in blue grama and little bluestem plant collections in Southern Manitoba, Canada. *Crop Sci.* 40:555-561.

Pigden, W.J. 1953. The relation of lignin, cellulose, protein, starch and ether extract to the curing of range grasses. *Canadian J. Agricultural Science* 33:364-378

Pimental, D., L. Lach, R. Zuniga, and D. Morrison. 2000. Environmental and economic costs associated with non-indigenous species in the United States. p. 285-306. In: *Biological Invasions:Economic and environmental costs of alien plant, animal and microbe species.* D. Pimental, ed. CRC Press, Boca Raton, FL.

Poincelot, R.P. 1987. *Toward a more sustainable agriculture*. AVI Publishing Co., Inc., Westport, CT.

Richards, R.T., J.C. Chambers, and C. Ross. 1998. Use of native plants on federal lands: policy and practice. *J. Range Manage.* 51:625-632.

Rogler, G.A. 1944. Relative palatabilities of grasses under cultivation on the northern great plains. *J. Amer. Soc. Agronomy* 36:487-497.

Romo, J.T., D.T. Booth, and C. Zabek. 1997. Seedbed requirements and cold tolerance of winterfat seedlings: An adapted forage for the Canadian Prairies. Final ADF Report, Regina, SK.

Romo, J.T. and P.L. Grilz. 1990. Invasion of the Canadian prairies by an exotic perennial. *Blue Jay* 48:131-135.

Root, T.L., J.F. Price, K.R. Hall, S.H. Schneider, C. Rosenzweig, and J.A. Ponds. 2003. Fingerprints of global warming on wild animals and plants. *Nature* 421: 57-60.

Sala, O.E., F.S. Chapin III, R.H. Gardner, W.K. Laurenroth, H.A. Mooney, and P.S. Ramakrishnan. 1999. Managed production systems. p. 304-328. In: *The terrestrial biosphere and global change: implications for natural and managed ecosystems*. B. Walker, W. Steffen, J. Canadell and J. Ingram, eds. Cambridge University Press, Cambridge, UK.

Samson, F.B., F.L. Knopf, and W.R. Ostlie. 1998. Grasslands. p. 437-472. In: *Status and trends* *of the nation's biological resources*, Vol. 2. M.J. Mac, P.A. Opler, C.E. Puckett, and P.D. Doran, eds. U.S. Department of the Interior, U.S. Geological Survey. Reston, VA.

Samuel, M.J. and G.S. Howard. 1982. Botanical composition of summer cattle diets on the Wyoming high plains. *J. Range Manage.* 35:305-308

Schellenberg, M.P. and M.R. Banerjee. 2002. Looking for a legume-shrub mixture for optimum forage production: A greenhouse study. *Can. J. Plant Sci.* 82:357-363.

Schellenberg, M.P. , N.W. Holt, and J. Waddington. 1999. Effects of grazing dates on forage and beef production of mixed prairie rangeland. *Can. J. of Anim. Sci*. 79:335-341.

Schellenberg, M.P. and P.G. Jefferson. 1998. Forage for late season grazing. SPARC, Research Newsletter No. 5., March 27, 1998.

Schnabel, R.R., A.J. Franzluebbers, W.L. Stout, M.A. Sanderson, M.A., and J.A. Studemann. 2001. The effects of pasture management practices. p. 291-322. In: R.F. Follett, J.M. Kimble and R. Lal, eds. *The Potential of US Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect*. Lewis Publishers. Boca Raton, FL.

Schuman, G.E., H.H. Janzen, and J.E. Herrick. 2002. Soil carbon dynamics and potential carbon sequestration by rangelands. *Environmental Pollution* 116:391-396.

Selby, C.J. and M.J. Santry. 1996. *A National Ecological Framework for Canada: Data model, database, and programs*. Agriculture and Agri-Food Canada and Environment Canada, Ottawa, ON.

Smith, D.G. and T.A. Hoppe. 2000. Prairie agricultural landscapes: A land resource review. Agriculture and Agri-Food Canada, Prairie Farm Rehabilitation Administration, Regina, SK.

Smith, S.R. Jr., and R.D.B. Whalley. 2002. A model for expanded use of native grasses. *Native Plants Journal* 3: 38-49.

Smoliak, S. and L.M. Bezeau. 1967. Chemical composition and *in vitro* digestibility of range forage plants of the *Stipa-Bouteloua* prairie. *Can. J. Plant Sci*. 47:161-167.

Smoliak, S. and J.K. Dormaar. 1985. Productivity of Russian Wildrye and Crested Wheatgrass and their effect on prairie soils. *J. Range Manage*. 38:403-405.

Smoliak, S., A. Johnston, and L.E. Lutwick. 1967. Productivity and durability of crested wheatgrass in southeastern Alberta. *Can. J. Plant Sci*. 47:539-548.

Smoliak, S. and S.B. Slen. 1974. Beef production on native range, crested wheatgrass and Russian wildrye pastures. *J. Range Manage*. 27:433-436.

Solutions 2000+. 1997. Market Assessment of Native Plant Materials in Saskatchewan. Native Plant Society of Saskatchewan and Northwest Saskatchewan Grasslands Association.

Swift, M.J., O.W. Heal, and J.M. Anderson. 1979. *Decomposition in Terrestrial Ecosystems*. University of California Press, Berkeley, CA..

Tilman, D. and J.A. Downing. 1994. Biodiversity and stability in grasslands. *Nature* 367:363-365.

Tilman, D., D. Wedin, and J. Knops. 1996. Productivity and sustainability influenced by biodiversity in grassland ecosystems. *Nature* 379:718-720.

Tober, D.A. and A.D. Chamrad. 1992. Warm-season grasses in the Northern Great Plains. *Rangelands* 14:227-230.

Tomanek, G.W., E.P. Martin, and F.W. Albertson. 1958. Grazing preference comparisons of six native grasses in the mixed prairie. *J. Range Manage*. 11:191-193.

Vavra, M., R.W. Rice, R.M. Hansen, and P.L. Sims. 1977. Food habits of cattle on shortgrass range in northeastern Colorado. *J. Range Manage.* 30:261-263.

Wallace, J.D., J.C. Free, and A.H. Denham. 1972. Seasonal changes in herbage and cattle diets on sand hills grassland. *J. Range Manage.* 25:100-104.

Waller, S.S., Moser, L.E. and Dill, T.O. 1994. Warm-season grasses for a cool climate. p. 206-215. In: F.K. Taha, A. Abouguendia, P.R. Horton and T.O. Dill, eds. *Managing Canadian Rangelands for Sustainability and Profitability.* The First Interprovincial Range Conf. Western Canada, Saskatoon, SK., Jan. 17-20,1993, Grazing and Pasture Technology, Saskatchewan Stockgrowers Association, Regina, SK.

Ward, J.K. 1988. Optimizing beef production grazing cool-season and warm-season pastures. Proc. Nebraska Forage and Grassl. Counc. Winter Meeting.

White, D.J., E. Haber, and C. Keddy. 1993. Invasive plants of natural habitats in Canada: An integrated review of wetland and upland species and legislation governing their control. Report prepared for the CWS, Environment Canada. Cat. No. CW66-127/1993E.

Wilms, W.D., D.J. Major, and B.W. Adams. 1994. The role of litter on forage production in the mixed prairie. p.169-174. In: F.K. Taha, A. Abouguendia, P.R. Horton and T.O. Dill, eds. *Managing Canadian Rangelands for Sustainability and Profitability.* The First Interprovincial Range Conf. Western Canada, Saskatoon, SK., Jan. 17-20,1993, Grazing and Pasture Technology, Saskatchewan Stockgrowers Association, Regina, SK.

Wilson, S.D. 2000. Heterogeneity, diversity and scale in plant communities. p. 53-69. In: The ecological consequences of environmental heterogeneity. M.J. Hutchings, E.J. John and A.J.A. Stewart, eds. Blackwell Science, Oxford, UK.

World Resources Institute. 1990. World Resources 1990-1: A Report by the World Resources Institute in collaboration with United Nations Environment Programme and The United Nations Development Programme. Oxford University Press, New York, NY.

Young, J.A. and C.G. Young. 1986. *Collecting, Processing and Germinating Seeds of Wildland Plants.* Timber Press, Portland, OR.

Table 1. Establishment of native grasses in three studies.

Common name	Latin name[1]	Kilcher and Looman 1983	Jefferson et al. 2002	Jefferson unpublished data
<u>Introduced species</u>		----------------------------------	%	----------------------------------
Crested wheatgrass	*Agropyron desertorum* (Fisch. ex Link) J.A. Schultes	100	--	100
Russian wildrye	*Psathyrostachys juncea* (Fisch.) Nevski	100	--	100
<u>Native species</u>				
Northern wheatgrass	*Elymus lanceolatus* (Scribn. & J.G. Sm.)	90	98	--
Western wheatgrass	*Pascopyrum smithii* (Rydb.) A. Love	80	94	--
Green needlegrass	*Nasella viridula* (Trin.) Barkworth	90	98	96
Big bluestem	*Andropogon gerardii* Vitman.	5	89	94
Little bluestem	*Schizachyrium scoparium* (Michx.) Nash	3	44	--
Prairie sandreed	*Calamovilfa longifolia* (Hook.) Scribn.	5	68	95
Indiangrass	*Sorghastrum nutans* (L.) Nash	11	32	80
Switchgrass	*Panicum virgatum* L.	--	86	100
Sand dropseed	*Sporobolus cryptandrus* (Torr.) Gray	6	--	23
$LSD_{0.05}$		NR[2]	7	21

[1] Nomenclature after Alderson and Sharp 1994

[2] NR- Not reported.

Table 2. Forage yield (kg ha^{-1}) of introduced and native forage grass species clipped 3 times per season for 1991 and 1992 and once per season for 1993 and 1994 at Swift Current, Saskatchewan. Least significant difference (LSD) values and probability of contrasts between groups of species are shown.

Species	1991			1992			1993	1994
	May 30	Jul 9	Aug 20	May 28	Jul 15	Oct 22	Jul 16	Jul 14
Introduced Grasses								
Crested wheatgrass	3810	2800	700	840	560	500	920	4430
Intermediate wheatgrass	2500	3370	2050	270	1670	100	960	4050
Russian wildrye	1740	1950	850	960	710	270	1220	3910
Tall Fescue	1740	4240	1470	720	1250	650	760	4210
Tall Wheatgrass	2030	4690	1150	700	1530	610	1070	4540
Native cool-season								
Beardless wildrye	400	1080	410	50	670	160	460	4130
Green needlegrass	650	1730	1160	460	920	410	1120	5400
Junegrass	280	20	--	240	0	--	150	3300
Native warm-season								
Big Bluestem	--	200	220	--	660	100	410	4830
Blue grama	240	280	280	--	800	430	400	4690
Indian ricegrass	--	--	--	--	70	60	230	3110
Indiangrass	--	230	780	--	590	280	--	3590
Prairie sandreed	190	560	270	--	600	180	660	5400
Sideoats grama	--	190	580	--	260	300	--	3150
Switchgrass	--	560	460	--	1340	310	650	4900
Sand dropseed	--	--	--	--	--	--	500	3200
LSD	720	900	920	600	560	350	NS	1200
P>F Introduced vs Native	<0.001	<0.001	0.001	0.007	<0.001	0.024	--	0.75
P>F cool- vs warm-season	0.487	0.013	0.228	N.A.	0.519	0.669	--	0.565

Table 3. Native grass and shrub species that exist in the prairie areas of Saskatchewan and Alberta that demonstrate the ability to cure to a greater or less degree (Pigden 1953)

Common name(s)	Latin Name
Speargrass, Needle-and-thread	*Stipa comata* Trin. & Rupr. [2]
Blue grama grass	*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths[1]
Western wheatgrass	*Pascopyrum smithii* [1]
Northern wheatgrass	*Elymus lanceolatus* [1]
June grass	*Koeleria gracilis* Pers. [2]
Rough fescue	*Festuca hallii* (Vasey) Piper [2]
Porcupinegrass	*Stipa spartea* Trin. [2]
Salt sage	*Atriplex nuttallii* S. Wats. [2]
Winterfat	*Krascheninnokovia lanata* (syn. *Eurotia lanata* (Pursh) Moq. [2]

[1] Nomenclature after Alderson and Sharp 1994
[2] Nomemclature after Budd et al. 1987

Figure 1. Scheme for development of varieties or ecovars™ of native plant species (adapted from Smith and Whalley 2002).