Re-establishment of Native Mixed Grassland Species into Annual Cropping Land

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Summary
Approximately 4.9 to 5.0 M ha of cultivated marginal land in Western Canada is environmentally unsustainable and would benefit from conversion to permanent cover from current annual cropping. Since 2001, re-establishment of native grasslands into marginal cropland has been successfully accomplished using conventional seeding technology and a productive and sustainable pasture grazing system has been achieved. The current native grasslands are providing high quality forage for yearling grazing livestock, consistent biomass production (1100 kg of DM ha^{-1}) and vegetative cover, acceptable average daily gains (0.4 to 0.8 kg d^{-1}), improved biodiversity and additional environmental benefits to soil and water.

Introduction
It is estimated that about 61.5 M ha of Canadian prairie soils were covered by native grassland vegetation prior to their breaking by tillage for crops[5]. It is estimated that only about 11.4 million hectares of native grassland and rangeland remains on the Canadian prairies, of which 10.9 M ha are utilized for grazing by domestic livestock[3]. Alberta, Saskatchewan and Manitoba account for 49%, 41% and 10% of the remaining native grasslands, respectively. Native grasslands are recognized as important resources for producing high quality forage for grazing livestock and wildlife as well as providing many beneficial and essential ecological resources and services e.g., sustainable biomass production, carbon sequestration, biodiversity, habitat, aesthetic value of the landscape, watershed management and soil erosion control[3]. Over the last decade there have been Federal and Provincial government programs such as: Greencover Canada Land Conservation (GCLC) (2005-2009) and Saskatchewan Conservation Cover Program (2001-2003), and organizations like Ducks Unlimited Canada (DUC) and Nature Conservancy of Canada that have encouraged agricultural producers in the re-vegetation of marginal annual cropped land to perennial forage production.

Good quality forage for grazing livestock: Differences in the nutritional content and digestibility among native species (grasses, forbs, shrubs) will vary throughout the growing season due to environmental conditions[1,23]. Several native species are capable of retaining a relatively high nutritive value during late summer and throughout fall and early winter. Many native species are able to preserve their physical form; their stems and particularly leaves do not detach or break-off for some months after senescence[17]. This is often characterized by cattle producers as "curing" and is one of the reasons native pastures can be grazed by cattle later in the grazing season or under moderate winter conditions with little or no supplemental feeding[17]. The ability to extend the grazing season results in economic gains, in terms of reducing animal feed costs, by shortening the winter feeding period. The forage nutritional quality of most diverse native grasslands from June to September is sufficient to meet the nutritional requirements of a beef cow at maintenance and lactating or a growing yearling (0.45 kg gain d^{-1})[10].

Sustainable biomass production and biodiversity: Livestock producers have long recognized that native grasslands are very resilient and able to recover after drought. Well-managed native grasslands (pasture utilization at 40-50%) still grow during drought, while many introduced perennial grasses will go dormant. Numerous research studies have shown that forage production from native grasses compares favorably with introduced species[7,18,22,40]. The biomass productivity advantages that introduced species have over native species appears to depend on soil fertility. Unfertilized introduced species actually yield less than unfertilized native grasslands especially over longer testing periods (> 4 years)[17,20,22]. The native prairie is mostly dominated by cool season (C3) species but warm season (C4) species may be favored under certain environmental and soil conditions[2,8,16]. The C3 species start growing early in the spring and produce about two thirds of their annual production before mid-summer when peak production occurs[17]. The C4 species start growth in June and throughout the hot summer period with peak production occurring by early fall[17]. The inclusion of native forbs (e.g., legumes or herbaceous broadleaf plants) in native grass mixtures has also been shown to improve forage production and quality when compared to unfertilized native grasslands[29]. Cattle producers have long recognized the benefits of grazing native grasslands where the presence of more species allows more choices of nutritious and palatable forages (C3 and C4 grasses, forbs and shrubs) throughout the grazing season and during the dormant season.

Environmental benefits: Most agricultural soils in western Canada have lost 30 to 50% of the pre-existing carbon pool following conversion from native grasslands to annual cropping systems[4]. Therefore, soil organic carbon (SOC) pools in most agricultural soils are well below their potential capacity and conversion from annual cropping to continuous perennial grassland production will result in an increase in SOC levels through increased soil carbon (C) sequestration. It is estimated that in western Canada between 4.9 to 5.0 M ha of cultivated marginal land (Canada Land Inventory: 4, 5, & 6) is environmentally unsustainable and would benefit from conversion to permanent cover[27,37]. The GCLC program that was initiated in 2004 resulted in about 522,000 ha of marginal land converted to perennial cover and after 10 years about 85% of these lands are still in perennial forage cover. The conversion of marginal annual cropland to re-established perennial native grassland could provide an important C sink (i.e., absorbs more C than it releases) and be used as offsets against CO_2 emissions.

Study description

Over the entire ten years of the study there were two phases. The first four years of the study (phase one) evaluated the "Re-establishment of mixed native grasslands in southwest Saskatchewan" and the objectives were:

1. To evaluate animal performance and environmental (e.g., carbon sequestration, improved biodiversity) benefit differences between two native seed mixtures [simple (7 species) and diverse (14 native species) mixtures];
2. Evaluate the impact of grazing cattle (low and high stocking rates) and ungrazed (enclosures) and seed mixtures on native stand establishment and long term stability of the plant community, plants/species diversity, forage production and carbon sequestration potential of perennial native pasture.

Over the next six years the study (phase two) was related to determining the "Effect of different grazing systems on forage and beef production and their contribution to soil and air quality" and the objectives were:

1. Evaluate the effects of two grazing systems [continuous grazing (CG) vs deferred rotational grazing (DRG)] and two native seed mixtures (simple and diverse) on forage and animal production, chemical composition, and forage utilization over a three year period;
2. Evaluate the effect of the different grazing systems and seed mixtures on carbon sequestration with and without grazing.

Studies: 2000-2004 and 2005-2010

Seeding site, seed mixtures and pasture design

Thirty-two ha of land cropped since the 1920's was utilized for the studies and the land was seeded in the spring of 2001. The soils classifications are orthic brown chernozems; predominantly Swinton loam with some Haverhill soils occurring on the knolls and convexities near runways. Prior to seeding, glyphosate was applied the previous fall and prior to seeding at the beginning of May to control weeds. Seeding was done into the weed-free standing stubble using a Bourgault double disk air seedier. The simple and diverse native seed mixes, (Table 1) were formulated by Native Plant Solution - DUC. The seeding rate for the simple mixture was 9.5 kg ha^{-1} using a 22.5 cm row spacing and seeding depth of about 6 mm. To facilitate the seeding, 18 kg ha^{-1} of 11-51-00 fertilizer was used as a seed carrier to prevent seed bridging. The diverse seeding mixture was 9 kg ha^{-1} using the same row spacing and seeding depth and about 34 kg ha^{-1} of 11-51-00 fertilizer was used as a carrier. After seeding no additional nitrogen input were applied to the pastures. Pasture treatments for the 2000-2004 study consisted of a 2 x 2 factorial experimental design with four replications: simple and diverse seed mixes and two grazing utilization levels [low (40-50%) and high (60-75%)]. A total of sixteen pastures, each 2.1 ha in size, were utilized (Fig. 1.). Animal and pasture forage production differences were evaluated between pasture mixtures and utilizations. Pasture treatments for the 2005-2010 consisted of a completely randomized experimental design with two replications: two pasture seed mixes and two different grazing systems (DRG and CG). Each DRG group consisted of four pastures (two simple and two diverse) and there were three groups. Each DRG group started grazing at a different grazing season period (spring, summer or fall) at the start of the study, and over the course of three years all three grazing season periods would have occurred (e.g., of one group: Yr1 = spring, Yr2 = summer and Yr3 = fall) for each pasture type (Fig. 2.). One group of four paddocks (two simple and two diverse) used a CG system. Animal and pasture forage production differences were evaluated between pasture mixtures and grazing systems. More information on the seeding methodology and pasture setup can be found in the referenced publication[15].

Pasture production and grazing performance

Cattle grazing for the 2000-2004 study consisted of generally utilizing 96 commercial Angus yearling steers (343±15 kg). Stocking rates were based on animal unit (AU) and are defined as 450 kg beef cow or the equivalent based upon average daily forage consumption of 11.8 kg. The planned stocking rate for the low utilization was four steers per pasture (1.5 AU ha^{-1}) and the high was eight steers per pasture (3.0 AU ha^{-1}). The higher stocking rate was reduced to six steers per pasture (2.2 AU ha^{-1}) in 2002 due to the previous drought conditions experienced in 2001. In 2003 and 2004, the high stocking rate returned to the original design. Average animal unit month per hectare for phase one study at the 50% utilization rate for simple and diverse pasture mixes were 4.3 and 2.3, and for the 70% utilization rate were 2.6 and 2.9, respectively. Groups of four and six or eight steers were blocked according to body weight, making the average body weights for all groups similar and then randomly allocated to a pasture treatment (i.e., eight simple and eight diverse). For all three years, all steers were initially weighed after a 12 h shrink period before being placed on the pastures. Grazing was initiated at the end of June or beginning of July. Once the pasture utilization levels for each pasture were achieved, the steers were removed from the pasture and weighed after a 12 h shrink period. The entire grazing period generally lasted from June to the end of September. Cattle measurements were average daily gains (ADG) in kg d^{-1} and total live animal production (TLP) in kg ha^{-1}. Available pasture production at the start of grazing was determined using 1/4 m^2 quadrat frames (ten per pasture) and samples were taken randomly over the entire pasture to achieve a uniform distribution. In addition, each pasture also contained a permanent non-grazing enclosure (3.6 x 3.6 m) located near the middle of each pasture. This larger enclosure was totally excluded from any cattle grazing and represented an un-grazed treatment. Forage samples were taken at the end of June and again at the end of July. Forage quality was determined on all forage samples taken.

Cattle grazing for the 2005-2010 study consisted of utilizing 68 commercial Angus yearling steers (354±13 kg) each year. Five yearling steers were placed on each pasture for each DRG group (Fig. 2.) and two yearling steers were placed on each CG pasture. Stocking rate for the DRG was five steers per pasture (1.9 AU ha^{-1}) and the CG was two steers per pasture (0.8 AU ha^{-1}). Average animal unit month per hectare for the phase two study with continuous grazing for simple and diverse pasture mixes were 1.0 and 1.4, and for the deferred rotational grazing were 1.7 and 1.8, respectively. Grazing period started at the end of June and for CG system ended by Aug. and the DRG system lasted until end of Sept. Determination of steer grouping, weighing methodology and collection of animal and forage performances were done the same as was reported for the 2000-2004 study.

Total soil organic carbon

In the fall of 2000, the soils from all sixteen pastures were sampled from five different locations and these sites were permanently marked for future sampling. At each site location, core (6.3 cm cutting edge diameter) samples were taken at six micro-sites and at four depths (0-15, 15-30, 30-45 and 45-60 cm). In 2004, all sixteen pastures were once again soil sampled in the fall, however, after the initial analysis of the 2000 SOC it was determined that overall variations within pastures were low enough that only three of the five sites within each pasture needed to be sampled and each soil depth from each micro-site could be pooled. Thus, at each site location (only three locations per pasture), core samples were taken at five micro-sites and at five depths (0-7.5, 7.5-15, 15-30, 30-45 and 45-60 cm). Core samples from each micro-site depth were pooled. More detailed description of soil processing, storage and analyses can be found in Iwaasa and Schellenberg 2005[15].

Results

Comparing the above ground biomass production between simple and diverse pastures over ten production years showed similar forage production after the first production year (Fig. 3). Year by seed mixes interaction for biomass production was observed and this can be explained by the changing environmental conditions experienced over the ten production years. Higher biomass production and difference between seed mixes was not surprising during the first production year since the release of organic nitrogen after seeding and the abundant moisture received in 2002 would favor forage production especially for the simple mix which contained higher proportions of aggressive and high producing C3 grasses (Fig. 4 & Table 1). It was expected that the simple native mix would dominate the forage production for more than one year but this was not observed. Other studies have also reported mixed results on whether increased plant diversity in grasslands consistently improves primary forage production[11,31]. Recent research found that diversity increased productivity, but that having more than six or eight species in a field did not give additional benefit early in the establishing years. It was only after a 14-year time span that all 16 species in the studies with the most diverse treatments contributed more and more each year to higher soil fertility and biomass production[30]. Thus the effects of biodiversity on forage production are more complex, unpredictable and require long-term research. Western Canadian cattle producers have long recognized the abilities of native pastures to withstand extreme environmental conditions and provide a consistent biomass production and this was clearly observed in this study. Severe drought conditions were experienced in 2007 and 2009, yet average biomass production was similar to long-term averages (Figs. 3 & 4). After 10 production years the average biomass production for the re-established native grassland was greater than 1,100 kg of dry matter ha^{-1} and this compares favorably to long-term Russian wild rye and crested wheatgrass production of about 600 and 780 kg of dry matter ha^{-1} over a 15 and 25 years of production.

The diverse native mixture compared to the simple native mixture had consistently higher crude protein and organic matter digestibility over the entire grazing season from spring to fall which may have contributed to improved animal performances later in the grazing season[14,15]. No differences in ADG and TLP between seed mixes were observed over the three years of the study and the values ranged from 0.4 to 0.8 kg d^{-1} and 40.1 to 92.8 kg of gain ha^{-1}, respectively[15]. Preliminary results from average TLP differences between yearling steers grazing simple vs. diverse native pastures under CG or DRG showed trends of higher gain performances. Total live production of yearling steers grazing diverse pastures were between 11 to 15% higher on the CG and spring and fall DRG, respectively. Having a more diverse range of plant species in a pasture ensures that the forage yield is distributed throughout the grazing season because of the different seasonal growth patterns of C3, C4 and forb species. As a result, livestock are able to make selections among the different plant material to achieve a higher quality of dietary nutrition throughout the grazing season. Research has suggested that incorporation of legume species into native grass pasture would be an effective way to improve the forage quality and increase biomass of native pastures[35]. Purple prairie clover (PPC) was the only forb used in the current study . It is well adapted to the prairie region and is highly palatable to ruminants with higher nutritive value than other native legumes that are common in the east northern central states[33]. Besides the nutritional benefits, PPC also is a nitrogen fixer, extends the grazing season since the majority of its growth occurs from mid-summer to early fall, and it contains condensed tannin which can improve protein utilization by cattle and inhibit growth of various strains of E. coli 0157:H7[19,21,38]. Recent research at Swift Current has shown that PPC forage quality does not decline rapidly after flowering and in a mixture with other native grass specie could improve the nutritional profile of the sward in the late summer to fall grazing period[24].

Researchers at Swift Current found that different native species mixtures (simple and diverse) can be successfully established using traditional air seeding technology and by seeding into weed free stubble or a firm fallow field[12,15]. Research found that grazing disturbance is a benefit in maintaining species diversity in re-established native grass stands and seeded native plants produced relatively stable forage under grazing over the four years[34,36]. Native grasslands have evolved under grazing and grazing can stimulate above ground production by increasing tillering and rhizome production[32]. Native species have a more extensive root system than introduced species and thus more root biomass below ground[6,9]. Studies have reported higher SOC levels associated with existing and re-established native grasslands compared to introduced grasslands[25,39]. Average annual C sequestration rates on newly established native pasture onto annual cropland in its first four years was 530 kg ha^{-1} yr^{-1} which was similar to the dark Brown and Black soils in Saskatchewan[13, 26]. We also found an important interaction between seed mixes and pasture grazing utilization affecting SOC levels. The SOC changes were 3.59, 2.03, 1.47 and 0.94 ± 0.68 Mg C ha^{-1} for simple (S) seeded pasture under a high (H) stocking rate and pasture utilization, diverse (D) + low (L), S+L and D+H, respectively. Therefore, the S had higher mean SOC values than D seeded pastures (2.53 and 1.48 ± 0.83 Mg C ha^{-1}, respectively). Since the highest mean pasture forage production was observed for the S native mix during the first four years of the study (Fig. 3.), it was not unexpected to see higher SOC levels. There was an interaction between seed mixes and grazing pasture utilizations that are not easily interpreted over the first four years. Although accumulated SOC levels from the 2004 sampling of SOC on re-established native pastures was promising the preliminary results from the 2008 SOC sampling for the next four years showed little C sequestration occurring. A study reviewing grazing versus non-grazing effects on C concluded that SOC levels were higher under the driest and wettest environmental conditions but lower at intermediate precipitation (400 to 800 mm), thus environmental conditions can greatly affect SOC levels[28]. Work is under way to compare the SOC levels of the 2004 to the 2008 and 2011 sample years and in order to provide a clearer indication how SOC levels are affected by environment and net primary pasture production of re-established prairie grasslands.

Future

Currently the research being conducted on the re-established native grasslands under grazing will continue in the future with emphasis being placed upon the development of sustainable productive and environmental grazing systems for western Canada. This research shows the importance of doing long-term research since factors affecting biodiversity and productivity of native pastures and C sequestration potential are more complex and unpredictable than previously thought.

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Table 1. Species name of two native plant mixtures and seeding rate of each species.

Mixture	Species name	Seeding rate (PLS m^{-2})
Simple (7 species)	Western wheatgrass (*Pascopyrum smithii* (Rydb.) Barkworth & D.R.)	14
	Northern wheatgrass *(Elymus macrourus (*Turcz. *ex* Steud.*)* Tzvelev)	14
	Awned wheatgrass (*Elymus trachycaulus* (Link) Gould & Shin. ssp *subsecundus* (Link) A.&D. Love.)	14
	Slender wheatgrass (*Elymus trachycaulus* (Link) Gould subsp. *trachycaulus*)	14
	June grass (*Koeleria macrantha* (Ledeb.) Schult.)	14
	Green needle grass (*Nassella viridula* (Trin.) Barkworth)	14
	Purple prairie clover (*Dalea purpurea* Vent.)	14
Diverse (14 species)	Western wheatgrass (*Pascopyrum smithii* (Rydb.) Barkworth & D.R.)	8
	Northern wheatgrass *(Elymus macrourus (*Turcz. *ex* Steud.*)* Tzvelev)	8
	Awned wheatgrass (*Elymus trachycaulus* (Link) Gould & Shin. ssp *subsecundus* (Link) A.& D. Love.)	8
	Slender wheatgrass (*Elymus trachycaulus* (Link) Gould subsp. *trachycaulus*)	8
	June grass (*Koeleria macrantha* (Ledeb.) Schult.)	8
	Green needle grass (*Nassella viridula* (Trin.) Barkworth)	8
	Purple prairie clover (*Dalea purpurea* Vent.)	8
	Needle and thread grass (*Hesperostipa comata* (Trin. & Rupr.) Barkworth)	8
	Little Bluestem (*Schizachyrium scoparium* (Michx.) Nash)	8
	Prairie sandreed (*Calamovilfa longifolia* (Hook.) Scribn.)	8
	Saltbush (*Atriplex canescens* (Pursh) Nutt.)	8
	Winterfat (*Kraschennikovia lanata* (Pursh) A. Meeuse & Smit)	8

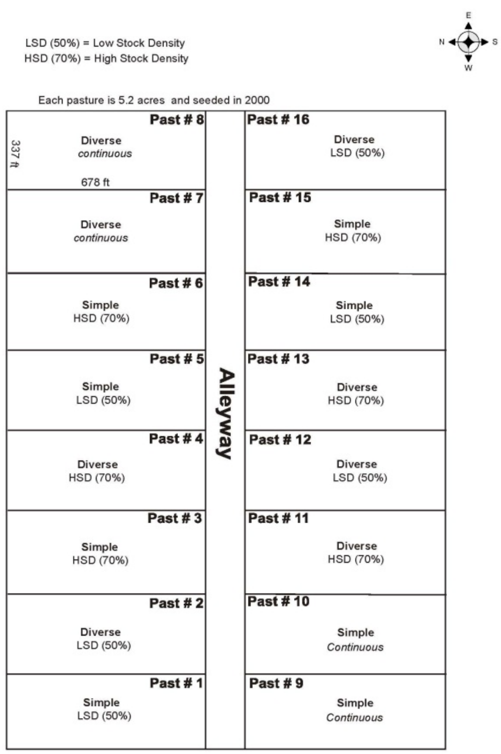

Figure 1. Pasture design of re-established mixed native grassland (simple or diverse) at AAFC-SPARC.

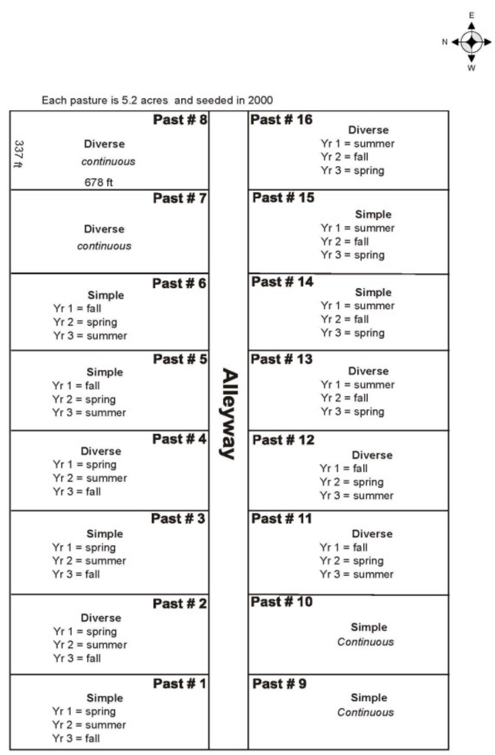

Figure 2. Pasture design of different grazing grazing systems (continuous vs. deferred) on simple or diverse mixed native grassland at AAFC-SPARC.

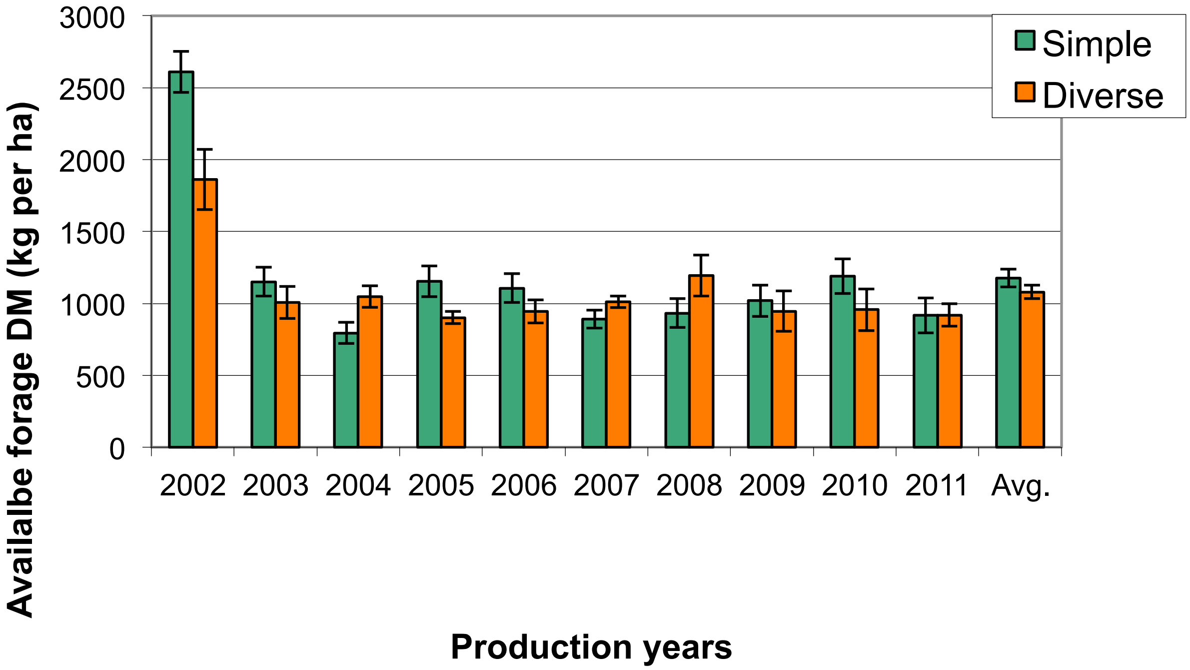

Figure 3. Available above ground biomass dry matter production from simple and diverse pastures harvested at the beginning of the grazing season (beginning of July) over ten years with no N inputs at AAFC-SPARC (Bar = SEM).

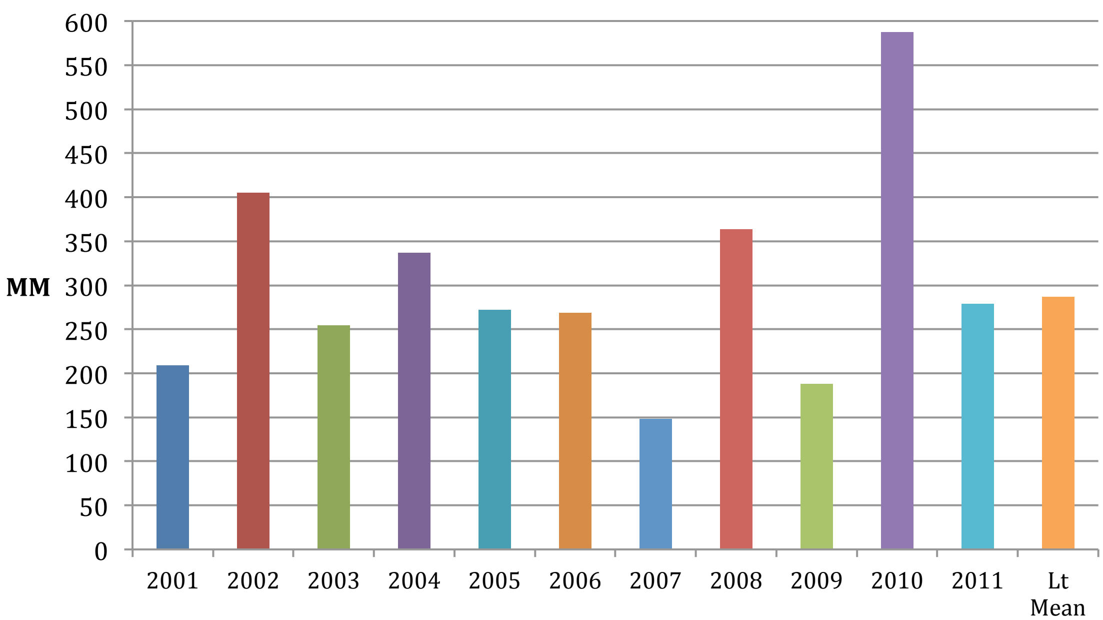

Figure 4. Precipitation received at AAFC-SPARC from April to October from 2001 to 2011 and long term average (based over 125 years).

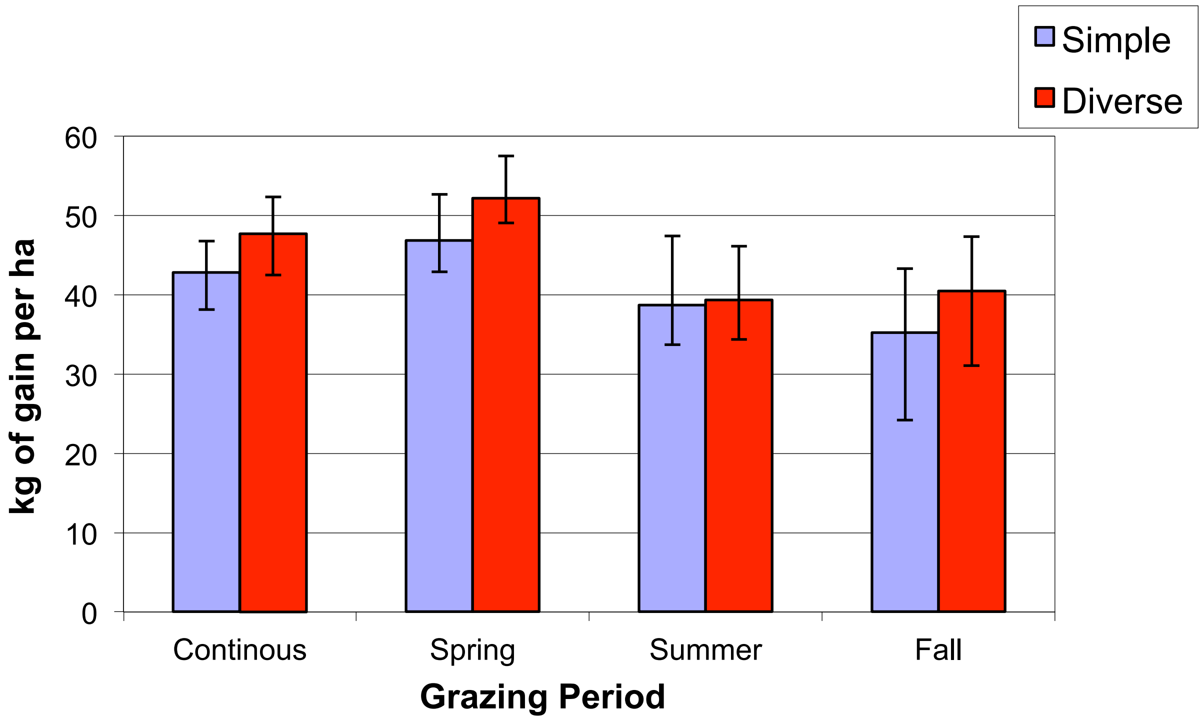

Figure 5. Average total live production differences between simple and diverse native pastures under continuous or deferred rotational grazing system over a six year period (2005 to 2010) at AAFC-SPARC (Bar = SEM).

References

1. Abouguendia, Z. 1998. Nutrient content and digestibility of Saskatchewan Range Plants: A summary report. GAPT (July), 3.
2. Adams, B.W., Poulin-Klein, L., Moisey, D., and McNeil, R.L. 2005. Rangeland Plant Communities and Range Health Assessment Guidelines for the Dry Mixedgrass Natural Subregion of Alberta. Rangeland Management Branch, Public Lands Division, Alberta Sustainable Resource Development, Lethbridge, Pub. No. T/040 106 p.
3. Bailey, A.W., McCartney, D., and Schellenberg, M.P. 2010. Management of Canadian prairie rangeland. AAFC Pub., No. 10144.
4. Bhatti, J.s., Apps, M.J., and Lal, R. 2006. Anthropogenic changes and the global carbon cycle. IN. J.S. Bhatti, R. Lal, M.J. Apps and M.A. Price (eds.) Climate Change and Managed Ecosystems, CRC Taylor & Francis Group, Boca Raton, FL.
5. Clayton, J.S. Ehrlich, W.A., Cann, D.B., Day, J.H., and Marshall, I.B. 1977. Soils of Canada, Vol. 1, Canada Department of Agriculture, Research Branch, Ottawa, 243 p.
6. Coupland, R.T. 1992. Mixed Prairie. IN R.T. Coupland (ed), Ecosystems of the World 8A. Natural Grasslands Introduction and Western Hemisphere,
7. Coupland, R.T. 1974. Matador Project. Technical Rep. No. 62. Can. Comm. For the Int. Biol. Progr. University of Sasktchewan, Saskatoon, Sask.
8. Coupland, R.T. 1973. A theme study of natural grasslands in western Canada. Report for the National and Historic Parks Branch, Canada Dept. of Indian Affairs and Northern Development. 177 p.
9. Dormaar, J.F., Naeth, M.A., Willms, W.D. and Chanasyk, D.S. 1995. Effect of native prairie, crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) and Russian wildry (*Elymus junceus* Fisch.) on soil chemical properties. J. Range Manage. 48:258-263.
10. Holechek, J.L., and Herbel, C.H. 1986. Supplementing range livestock. Rangelands 8:29-33.
11. Huston, M.A., Aarssen, L.W., and Austin, M.P. 2000. No consistent effect of plant diversity on productivity. Science (Washington, D.C.), 289, 1255.

12. Iwaasa, A.D., Lennox, T. and Jensen, R. 2008. Management techniques required for establishing native grass stands in combination with various tame and native legumes. Greencover Canada TAC Project Fair in Regina, SK., Feb. 27-28, 2008.
13. Iwaasa, A.D., McConkey, B. and Schellenberg, M. 2008. Effect of grazing and re-establishment of native species on soil organic matter sequestration for the semiarid central grasslands of Canada. Joint Meetings: IGC - IRC, Hohhot, China, June 29 to July 5th, 2008
14. Iwaasa, A.D. and Schellenberg, M.P. 2006. Effect of increase biodiversity on grazing performance of different native pasture mixtures seeded in southwest Saskatchewan in 2001. 59th Society for Range Management Annual Meeting, Vancouver, BC., Feb. 12-17, 2006.
15. Iwaasa, A.D. and Schellenberg, M.P. 2005. Re-establishment of a mixed native grassland in southwest Saskatchewan. Saskatchewan ADF Final Report #20010042, 132 p.
16. Jefferson, P.G., McCaughey, W.P., May, K., Woosaree, JU., McFarlane, L., and Wright, S.M.B. 2002. Performance of American native grass cultivars in the Canadian prairie provinces. Native Plants Journal 3:24-33.
17. Jefferson, P.G., Iwaasa, A.D., Schellenberg, M.P. and McLeod, J.G. 2005. Re-evaluation of native plant species for seeding and grazing by livestock on the semiarid prairie of Western Canada. P. 85-106. IN Todd A. Radenbaugh and Glenn C. Sutter (eds), Prairie Forum 30, No. 1 (Spring 2005), Canadian Plains Research Centre.
18. Jefferson, P.G., Wetter, I., and Wark, B. 1999. Quality of deferred forage from waterfowl nesting sites on the Canadian prairies. Can. J. Anim. Sci. 79:485-490.
19. Jin, L., Xu, Z., Iwaasa, A.D., Schellenberg, M.P., Zhang, Y.G., McAllister, T.A. and Wang, Y. 2011.Nutrient and tannin contents of purple prairie clover (Petalostemon purpureum) harvested at different growth stages. J. Anim. Sci. Vol. 89, E-Suppl. I/J Dairy Sci. Vol 94, E-Suppl. 1 pp 48.
20. Johnston, A. Smith, A.D., Lutwick, L.E., and Smoliak, A. 1968. Fertilizer response of native and seeded ranges. Can. J. Plant Sci. 48:467-472.
21. Klabi, R., Hamel, C., Iwaasa, A.D. and Raies, A. 2010. Nitrogen fixation of native and tame forage stands. Soils and Crops 2010, University of Saskatchewan, Saskatoon, SK., Feb. 25-26, 2010.
22. Knowles, R.P. 1987. Productivity of grass species in the dark brown soil zone of Saskatchewan. Can J. Plant Sci. 67:719-725.
23. Kusler, J. 2009. Comparing simple and complex native forage mixtures for grazing cattle in southwestern Saskatchewan. University of Saskatchewan, Dept. of Animal and Poultry Sci., M.Sc. Thesis, Dec. 2009, 142 p.
24. Li, Y. Iwaasa, A.D., Birkedal, E. and Han, G. 2012. Forage quality constituents of purple prairie clover (*Dalea purpurea*) and white prairie clover (*Dalea candida*) harvested at different phenological stages in southwest Saskatchewan. Soils and Crops 2012, Prarieland Park, Saskatoon, SK., Mar. 13-14, 2012.
25. McConnell, S.G. and Quinn, M. L. 1988. Soil productivity of four land use systems in southeastern Montana. Soil Sci. Soc. Am. J., 52:500-506.
26. Mensah, F., Schoenau, J.J. and Malhi, S.S. 2003. Soil carbon changes in cultivated and excavated land converted to grasses in east-central Saskatchewan. Biogeochemistry 63:85-92.
27. Paragon Soil and Environmental Consulting Inc. 2009. Technical Background Document for Conversion to Perennials Protocol-Phase I.
28. Pineiro, G., Paruelo, J.M., Oesterheld, M., and Jobbagy, E.G. 2010. Pathways of grazing effects on soil organic carbon and nitrogen. Rangeland Ecology & Manage. 63:109-119.
29. Posler, G.L., Lenssen, A.W. and Fine, G.L. 1993. Forage yield, quality, compatibility, and persistence of warm-season grass-legume mixtures. Agronomy Journal 85:554-560.
30. Reich, P.B., Tilman, D. Isbell, R., Mueller, K., Hobbie, S.E., Flynn, D.F.B., and Eisenhauer, N. 2012. Impacts of biodiversity loss escalate through time as redundancy fades. Science 236:589-592.
31. Sanderson, M.A. 2006. Plant species diversity: Management implications for temperate pasture production. IN. J.S. Bhatti, R. Lal, M.J. Apps, and M.A. Price (eds), Climate Change and Managed Ecosystems, CRC Taylor & Francis Group, Boca Raton, FL.
32. Schuman, G.E., Janzen, H.H. and Herrick, HJ.E. 2002. Soil carbon dynamics and potential carbon sequestration by rangelands. Environmental Pollution 116:391-396.
33. Sheaffer, C.C., Wyse, D.L. and Ehlke, N.J. 2009. Palatability and nutritive value of native legumes. Nat. Plants J. 10:224-231.
34. Schellenberg, M.P., Biligetu, B., and Iwaasa, A.D. 2012. Species dynamic, forage yield, and nutritive value of seeded native plant mixtures following grazing. Can. J. Plant Sci. (in Press)

35. Schellenberg, M.P. and Banerjee, M.R. 2002. Looking for a legume-shrub mixture for optimum forage production: A greenhouse study. Can. J. Plant Sci. 82:357-363.
36. Schellenberg, M.P. and Iwaasa, A.D. 2008. Grazing disturbance a benefit to species diversity in re-established native grass stands. Joint Meetings: IGC - IRC, Hohhot, China, June 29 to July 5th, 2008.
37. Smith, D.G. and Hoppe, T.A. 2000. Prairie Agricultural landscapes: A Land Resource Review. Regina: Agriculture and Agri-Food Canada, Prairie Farm Rehabilitation Administration.
38. Wang, Y., McAllister, T.A., Acharya, S.N. and Iwaasa, A.D. 2009. Condensed tannins from purple prairie clover inhibit growth of Escherichia coli O157:H7. ADSA - CSAS - ASAS Joint Annual 2009 Meetings, Montreal, Quebec, July 12-16, 2009.
39. Wedin, D.A. and Tilman, D. 1996. Influence of nitrogen loading and species composition on the carbon balance of grasslands. Science 274:1720-1723.
40. Willms, W.D., Ellert, B.H., Janzen, H.H. and Douwes, H. 2005. Evaluation of native and introduced grasses for reclamation and production. J. Range Manage. 58:177-183.