Assessment of Soil Biological Activity in Northern Aspen Parkland Native and Seeded Pasture Using Bait Lamina

Shawna E. LaRade

Dept. of Agricultural, Food and Nutritional Science, 410 AgFor Center, University of Alberta

Edmonton, Alberta T6G 2P5, Canada

Current address is 1902 Theatre Rd. Cranbrook, British Columbia V1C 7G1, Canada

Tel: 1-250-426-1742 E-mail: Shawna.LaRade@gov.bc.ca

Edward W. Bork (Corresponding author)

Dept. of Agricultural, Food and Nutritional Science, 410 AgFor Center, University of Alberta

Edmonton, Alberta T6G 2P5, Canada

Tel: 1-780-492-3843 E-mail: Edward.bork@ualberta.ca

Walter D. Willms

Agriculture and Agri-Food Canada, Lethbridge Research Center

Lethbridge, Alberta T1J 4B1, Canada

Tel: 1-403-317-2218 E-mail: Walter.Willms@AGR.GC.CA

Received: December 7, 2011 Accepted: December 21, 2011 Online Published: April 1, 2012

doi:10.5539/jas.v4n5p83 URL: http://dx.doi.org/10.5539/jas.v4n5p83

Financial support for this project was provided by the University of Alberta, the Alberta Conservation Association, Agriculture and Agri-Food Canada-Lethbridge, and the Biodiversity Science Fund. The authors thank Drs. Barry Irving, Jim Unterschultz, and Scott Jeffrey for providing comments on earlier versions of the manuscript, and thank Dr. Arthur Bailey for providing the long-term study area within which this study took place.

Abstract

Many native grasslands in the Aspen Parkland of western Canada have been converted to seeded forages. We used bait lamina to test the hypothesis that this change has altered soil biological activity. Bait lamina removal varied with both vegetation type and soil depth ($p=0.03$). Bait removal was 31% in the shallow (0-5 cm) soil profile, and similar between native (32%) and seeded (30%) grassland. Although bait removal was lower at 5 to 10 cm depth (23%), removal in native grassland was greater (26%) than in adjacent seeded pasture (20%). As soils did not differ in organic matter or carbon between vegetation types, differences in removal are attributed to other unknown factors. Bait removal was positively associated with soil temperature ($r \geq 0.58$) in both vegetation types, but negatively to soil moisture ($r \leq -0.33$). Overall, these results suggest replacement of native grassland with seeded forage has altered soil organism activity, and merits further investigation.

Keywords: Grassland conversion, Introduced species, Rangeland health, Soil environment

1. Introduction

Within the same climate, soil is the main factor influencing forage production. Soil organisms and the complex trophic communities they comprise include consumers (i.e. grazers), decomposers (microorganisms, bacteria and fungi) and other organisms. These biota can effect soil development and structure, as well as plant growth through the decomposition of litter and fine roots, and cycling of nutrients from organic matter (Hamel et al., 2007). As a result, the activity of soil organisms can be an important indicator of changes in soil quality

(Dormaar & Willms, 2000a). For example, in agricultural cropping systems, differences in soil quality have been observed between no-till and conventionally tilled fields. Compared to no till areas, tillage has been associated with reduced water holding capacity (Moldenhauer & Wischmeier, 1960), lower organic carbon (Rochette & Angers, 1999), higher respiration rates (Parkin et al., 1996), and reduced populations of springtails and mites (Heisler & Brunotte, 1998) as well as earthworms (Curry, 1998). Less is known however, about the extent to which other agricultural activities such as conversion of native prairie to introduced cropland may alter soil biological activity.

Changes in soil biota and the biological processes they represent are therefore important to understand as they reflect the effect of ongoing changes in land use practices on the capacity of soils to sustain plant and animal productivity (Karlen, 1999). Unfortunately, the direct examination of soil organisms is difficult and expensive to undertake. Consequently, indirect methods have been used to assess soil biotic activity, including the use of bait lamina (von Törne, 1990). Bait lamina have been used in previous investigations in semiarid grassland soils (Hamel et al., 2007) and natural ecosystems (Paulus et al., 1999; Geissen & Brummer, 1999; Rombke et al., 2006) as an indicator of soil organism abundance. Hamel et al. (2007) evaluated the effectiveness of bait lamina and concluded they were a useful tool to assess feeding activity of macro soil organisms including Collembola (spring tails) and Enchytraeidae (worms) responsible for breaking up surface litter. Similarly, Rombke et al. (2006) concluded bait lamina were a promising approach for assessing biological activity in tropical soils.

Across much of western Canada, agricultural land modification has replaced many native plant communities with either annual crops or seeded forages, a process that can alter ecosystem function (Vitousek, 1990). Changes in soil quality, including soil chemistry and structure, can be partly attributed to the direct effects of cultivation through soil disturbance and admixing (Dormaar et al., 1990; Wu et al., 2006). Additionally, soil quality may change due to alteration of the amount and quality of biomass contributions from the seeded plant community (Dormaar & Willms, 2000a). For example, research in semiarid grasslands has shown that replacement of native plant communities with crested wheatgrass (*Agropyon cristatum* (L.) Gaertn.) and smooth brome (*Bromus inermis* Leyss), both common seeded perennial forages, have led to deleterious effects on soil quality, including reduced soil nitrogen and carbon (Dormaar et al., 1990, 1995; Christian & Wilson, 1999), changes to soil chemistry (Dormaar et al., 1990) and organic matter (Dormaar & Willms, 2000b), and likely soil organisms.

One of the most extensively altered native ecosystems in western Canada is the Aspen Parkland (McCartney, 1993). Although less than 10% of this region remains in an uncultivated state, the long-term impacts of land conversion on soil organisms remain unknown. To assess the impact of converting native Parkland grasslands to seeded forages on soil quality we compared soil characteristics associated with native and seeded grasslands at each of 11 paired sites within the Aspen Parkland of central Alberta. Specifically, we assessed soil biological activity using bait lamina, together with soil organic matter, nitrogen and organic carbon.

2. Materials and Methods

2.1 Study Area

The study area was located in east central Alberta at the 2,700 ha University of Alberta Kinsella Research Station, situated 150 km SE of Edmonton (53°0'N; 111° 31.2' W). Located in the Aspen Parkland natural sub-region at approximately 700 m elevation, the station is comprised of a mix of native (i.e. uncultivated) grassland together with domesticated pastures established following the conversion of native grassland to seeded forages. The area has a continental climate characterized by long cold winters and short warm summers. Average annual precipitation is 430 mm, with more than half occurring during the growing season (May to August) and peaking in July (Environment Canada, unpublished data from 1946-2004). During 2006, summer rainfall from May through August inclusive was 193 mm, 22% below average, although May was relatively moist with 58 mm of rainfall. Average daily temperatures from May through August of 2006 were 1.2^{o}C warmer than normal (15.5^{o}C versus 14.4^{o}C).

Topography of the area is a strongly undulating landscape of glacial moraine knolls and ridges intermingled with kettle depressions. Area soils are classified into three primary orders: Chernozems, Luvisols and Gleysols, associated with upland grasslands, forests and wetlands, respectively. Soils under grasslands on upper slopes range from Orthic Dark Brown to Black Chernozems (Wheeler, 1976), depending on moisture regime. Across the study area, soils were predominantly loamy in texture derived from glacial till.

The landscape supports a diversity of vegetation that provides grazing for livestock. Dominant native plant communities are representative of the Parkland and form a complex mosaic of aspen (*Populus tremuloides* L.) forest in mesic areas, open grasslands on well drained uplands, ecotonal western snowberry (*Symphoricarpos* *occidentalis* Hook) and silverberry (*Elaeagnus commutata* Bernh. ex Rydb) shrublands, and either freshwater or saline riparian meadows (Wheeler, 1976). Common species on native grasslands (i.e. unbroken natural grassland) include dryland sedges (*Carex* spp: 11.1% cover), western porcupine grass (*Hesperostipa curtiseta* (A.S. Hitchc.) Barkworth: 9.1%), and Junegrass (*Koeleria macrantha* (Lebed.) Schult.: 4.0%), with limited amounts of western wheatgrass (*Pascopyrum smithii (*Rydb.) Barkworth & D.R. Dewey: 2.4%), blue grama grass (*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths: 1.8%) and plains rough fescue (*Festuca hallii* (Vasey) Piper: 1.1%). Where uplands had been cultivated and seeded to common agronomic forages in 1980, the dominant plant species included smooth brome (10.3% cover), Kentucky bluegrass (*Poa pratensis* L.: 9.7%) and upland sedges (*Carex* spp.: 8.5% cover). Mean summer herbage production on native and seeded grasslands averaged 2,892 and 2,433 kg ha^{-1}, respectively, during 2006-07 (LaRade, 2010).

2.2 Experimental Design and Sampling

Field sampling was conducted within a long-term study area that included a series of replicated and adjacent native and seeded pastures. A series of 11 plots were established in 2006, each of which included native and seeded grasslands as paired subplots, transected by a fenceline. In order to reduce confounding effects of ecosite variability, paired subplots 5 x 5 m in size were established on uplands with internally uniform physical site characteristics (e.g., aspect, slope gradient, soil type and drainage). All pastures that contained plots were grazed annually at a moderate stocking of ~2 animal unit months (AUM) ha^{-1}.

Within each subplot, four soil cores (5 cm wide by 15 cm deep) were randomly collected and bulked, and analyzed for % soil organic matter (OM), nitrogen and carbon. Soil organism activity was assessed within each paired subplot using a bait lamina test (von Törne, 1990). On 9 May 2006, 16 bait lamina strips (16 cm long x 6 mm wide x 1.2 mm thick) were inserted into the soil to 10-cm depth in an equidistant 4 x 4 matrix pattern with 10-cm spacing within each of the 22 subplots. Each lamina strip consisted of 16, 2-mm diameter holes with 5 mm spacing. Holes were filled with a homogenized mix of 6.5 g of cellulose, 1.5 g of agar, 1.0 g of bentonite clay, 1 g of wheat bran, and approximately 25 ml of distilled water. This substrate served as a food source for soil organisms and was reported by Kratz (1998). At installation, a knife was used to pre-cut a vertical slot into the soil equivalent to the length of the bait lamina, the latter of which was then inserted to 10-cm depth, with the top hole just under the soil surface (approximately 3 mm down). After the strip was inserted, the soil surface was pinched closed.

Four additional lamina strips were installed within each subplot for additional monitoring. The extra strips were monitored bi-weekly in order to determine the optimal length of installation so as to capture variation in bait removal relative to the treatments (and avoid saturation of bait use among all laminas). The remaining laminas were subsequently removed on 7 July 2006. Lamina strips were labeled at removal, placed into plastic bags and frozen for later examination. Data were recorded for each bait lamina with readings for each 'hole' placed into one of three categories: full removal (greater than 50% of bait missing), partial removal (less than 50% missing) and no removal.

2.3 Soil Analysis

Soil samples were assessed for organic matter (OM), nitrogen and carbon. Soil OM was determined using the loss on ignition procedure (Ball, 1964). Soil nitrogen and carbon were assessed using a LECO FP-428 auto-analyzer and standard analytical techniques (AOAC, 1995). Additionally, soil moisture and temperature were assessed while the strips were installed. Soil temperature was measured in the top 10 cm within each subplot on 16 May between 11 am and 1 pm using a temperature probe, while percent soil water was measured in the top 10 cm on 1 June using a Delta-T ML2X moisture probe, with 4 replicate readings in each subplot. Estimates of moisture were averaged for each subplot for analysis.

2.4 Statistical Analysis

Bait lamina strips were initially examined to determine the proportion of holes with bait fully intact, partially removed or fully removed. In addition, these data were assessed separately for the top and bottom half of each strip, representing shallow (0-5 cm) and deep (5-10 cm) soil depths. Summary frequency data were then analyzed for the effects of grassland type (native vs seeded), soil depth, and their interaction, using a non-parametric contingency (i.e. chi-square) test with the CATMOD procedure in SAS (SAS Institute, 2003). Significance was set at $p<0.05$.

Soil OM, nitrogen and carbon data from upland native and seeded grasslands were analyzed using a paired t-test between subplots to assess differences in the composition of soils under adjacent vegetation types ($p<0.05$). Additionally, the relationship between the proportion of lamina holes where bait removal was observed was correlated with environmental measures, including soil temperature, moisture, OM, nitrogen and carbon content, using Proc CORR in SAS ($p<0.05$).

3. Results

Overall levels of bait removal from the strips were relatively low, with less than a third of the lamina experiencing some degree of bait removal. Moreover, partial removal was more common than full removal, at 19% and 8%, respectively. Bait removal differed between native and seeded pastures, as well as between soil depths (Table 1). The proportion of total lamina with evidence of bait removal was 11.1% greater in native grassland (29%) than seeded pasture (26%), largely due to an increase in the number of lamina experiencing partial removal (Table 1). Removal was also 33.6% greater within the shallow (0-5 cm) rather than deep (5-10 cm) soil depth, a trend that remained consistent across both partial and full removal (Table 1).

A treatment by soil depth interaction was also observed in the pattern of bait lamina removed (Figure 1). While the proportion of lamina experiencing any form of bait removal (i.e. full or partial bait loss) in the shallow soil layer remained similar between native (32.%) and seeded (31%) grassland, the native (26%) grassland experienced nearly one-third greater removal of bait than the seeded pasture (20%) at the deeper soil depth.

Although we hypothesized that soil environmental characteristics may differ between vegetation types, this did not occur. Soils in the top 15 cm of native (11.5±2.2%) and seeded (11.2±4.0%) grasslands had similar OM ($p=0.79$), as well as soil N ($p=0.34$; 0.53±0.11% in native VS 0.48±0.17% in seeded) and soil C ($p=0.65$; 6.0±1.5% in native VS 5.7±2.6% in seeded). Similarly, soil temperature ($p=0.16$; 19.1±2.8^{o}C in native VS 20.2±3.0^{o}C in seeded) and soil moisture ($p=0.42$; 20.3±5.9% in native VS 19.1±3.9% in seeded) did not differ between grassland treatments.

Despite the lack of differences in environmental conditions between grasslands, removal of bait from lamina strips was positively correlated ($p\leq0.06$) with soil moisture in both native and seeded grasslands (Table 2). In contrast, bait removal was negatively correlated ($p=0.04$) with soil temperature, but only in native grasslands. Bait lamina removal exhibited no association ($p>0.10$) with soil carbon, nitrogen or organic matter (Table 2).

4. Discussion

Our results support previous studies demonstrating the use of bait lamina for quantifying activity by soil organisms (Gongalsky et al., 2008). Although Hamel et al., (2007) evaluated the effectiveness of bait-lamina for assessing soil biota in more arid Mixedgrass Prairie, the current study is unique in providing a similar assessment within the more northern (i.e. cooler and moister) environment of the Aspen Parkland, but also links this information to grasslands of varying origin and composition (i.e. unploughed native VS seeded pasture of tame forages). Assuming the observed trend in bait lamina removal (i.e. 10-30% greater bait removal in relative terms) reflects soil organism activity as other studies have found, our investigation suggests native grasslands may have either greater populations of soil organisms or greater biotic activity, and that these differences occurred deeper within the soil profile.

Several explanations may account for the observed differences in bait lamina removal at depth between grassland types, including residual differences in soil bulk density arising from greater compaction of seeded grasslands associated with previous cultivation (Pennock et al., 1995), which is known to reduce microhabitat for soil fauna (Li et al., 2002). Many introduced forages including Kentucky bluegrass (Peterson et al., 1979) and smooth brome (Otfinowski et al., 2007), both common species within seeded grasslands of the present study, are known to possess shallow, creeping rooted morphologies, and may reduce the quality of habitat for soil organisms at deeper depths. Conversely, increased rooting in shallow layers may favour those organisms that prefer the shallow soil profile (van Eekeren et al., 2008), and account for the limited difference in bait lamina removal between vegetation types in this soil layer. Notably, seeded grasslands in the current study generally had lower plant species richness and diversity (LaRade, 2010), which in turn, can lead to a simpler trophic community (St. John et al., 2006), results that appear to be supported by the reduced bait lamina removal below 5 cm.

Differences in soil organic matter and carbon were not observed between native and seeded grassland. These results contrast those from more arid regions of western Canada, where seeded forages have been associated with reduced belowground carbon inputs (Dormaar & Willms, 2000) and increased soil bulk densities (Dormaar et al., 1979) relative to native grassland. Similar soil OM and carbon in the current study may be the result of more favourable (i.e. mesic) growing conditions within northern temperate grasslands, which may lead to similar root mass abundance and distribution between vegetation types. For example, seeded grasslands were more productive than native grasslands shortly after seeded pastures were established between 1980 and 1982 (2 833 vs 1 773 kg ha^{-1}, respectively) (Bailey & Irving, 1984). Moreover, although cultivation has been associated with the loss of soil organic matter and N (Dormaar et al., 1990; Wu et al., 2006), cultivation and establishment of the current seeded pastures occurred more than 25 years prior to this study, the effects of which may have dissipated by 2006. Finally, we note that our method of quantifying soil OM and carbon did not differentiate between the shallow and deep soil layers, and therefore our data are not able to conclude that biological activity across soil depths is independent of these factors.

Observed differences in the activity of soil organisms at depth have implications for understanding the impact of native grassland conversion into seeded forages on ecosystem function. Our findings provide further evidence that modification of vegetation composition, in this case of northern temperate native grasslands, can impact ecosystem function (Vitousek, 1990). Reductions in soil organic matter and associated carbon have been linked elsewhere to wholesale conversion of native Mixedgrass Prairie to seeded forages such as crested wheatgrass (Dormaar et al., 1979, 1995; Christian & Wilson, 1999; Whalen et al., 2003), and have raised the possibility that while seeded grasslands are useful for providing forage (Lawrence & Ratzlaff, 1989; Asay et al., 2001), they may not be conducive to the maintenance of critical ecosystem processes necessary to maintain long-term pasture condition and productivity. Soils dominated by seeded forages in the Mixedgrass Prairie have been found to differ not only in chemistry, but also in water holding capacity through decreased infiltration and greater runoff (Murphy et al., 2008).

Although the negative implications of the introduction of crested wheatgrass to arid North American grassland soils have been well documented, the ecological impacts of seeding species such as smooth brome, Kentucky bluegrass and associated species, in mesic areas remain less understood. Jordan et al. (2008) suggested that smooth brome may be dependent on soil biota to aid in self-facilitation, and that smooth brome may condition the soil by creating a hostile environment for native plant species.

5. Conclusions

Soil organisms ultimately play an integral role in the function of agricultural production systems. The current study suggests that while the replacement of native grassland with seeded forages has resulted in similar soil OM and carbon levels, changes in vegetation composition appear to be associated with important changes in the activity of soil organisms, particularly at deeper soil depths. This activity also appears sensitive to environmental conditions, being favored by greater soil moisture and lower spring soil temperatures. As a result, ongoing land management practices that alter these conditions, for example through litter conservation, have the potential to change ecosystem function within northern temperate grasslands (i.e., soil carbon retention and sequestration), the full implications of which remain unknown and merit further investigation.

References

AOAC. (1995). *Official methods of analysis* (16th edition). Association of Official Analytical Chemists, Washington, DC.

Asay, K. H., Horton, W. H., Jensen, K. B., & Palazzo, A. J. (2001). Merits of native and introduced Triticeae grasses on semiarid rangelands. *Canadian Journal of Plant Science*, *81*, 45–52. http://dx.doi.org/10.4141%2FP99-131

Bailey, A. W., & Irving, B. (1984). A comparison of brush control methods for the development and maintenance of grazing lands. *Farming for the Future Final Research Report,* Project #79-0043. Edmonton, Alberta.

Ball, D. F. (1964). Loss-on-ignition as an estimate of organic matter and organic carbon in non-calcareous soils. *Journal of Soil Science*, *15*, 84–91. http://dx.doi.org/10.1111%2Fj.1365-2389.1964.tb00247.x

Christian, J. M., & Wilson, S. D. (1999). Long-term ecosystem impacts of an introduced grass in the northern great plains. *Ecology*, *80*, 2397-2407. http://dx.doi.org/10.1890%2F0012-9658%281999%29080%5B2397%3ALTEIOA%5D2.0.CO%3B2

Curry, J. P. (1998). Factors affecting earthworm abundance in soils. p. 37-64. In: C.A. Edwards (ed.) *Earthworm ecology*. CRC Press, Boca Raton, FL.

Dormaar, J. F., Johnston, A., & Smoliak, S. (1979). Soil changes under crested wheatgrass. *Canadian Journal of Agricultural Research*, 24, 9–10.

Dormaar, J. F., Smoliak, S., & Willms, W. D. (1990). Soil chemical properties during succession from abandoned cropland to native range. *Journal of Range Management*, *43*, 260-265. http://dx.doi.org/10.2307%2F3898686

Dormaar, J. F., Naeth, M. A., Willms, W. D., & Chanasyk, D. S. (1995). Effect of native prairie, crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) and Russian wildrye (*Elymus junceus* Fisch.) on soil chemical properties. *Journal of Range Management*, *48*, 258-263. http://dx.doi.org/10.2307%2F4002430

Dormaar, J. F., & Willms, W. D. (2000a). A comparison of soil chemical characteristics in modified rangeland communities. *Journal of Range Management*, *53*, 453-458. http://dx.doi.org/10.2307%2F4003759

Dormaar, J. F., & Willms, W. D. (2000b). Rangeland management impacts on soil biological indicators in southern Alberta. *Journal of Range Management*, *53*, 233-238. http://dx.doi.org/10.2307%2F4003289

Geissen, V., & Brummer, G. W. (1999). Decomposition rates and feeding activities in deciduous forests in relation to soil chemical parameters after liming and fertilization. *Biology and Fertility of Soils*, *29*, 335-342. http://dx.doi.org/10.1007%2Fs003740050562

Gongalsky, K. B., Persson, T., & Pokarzhevskii, A. D. (2008). Effects of soil temperature and moisture on the feeding activity of soil animals as determined by the bait lamina test. *Applied Soil Ecology*, *39*, 84-90. http://dx.doi.org/10.1016%2Fj.apsoil.2007.11.007

Hamel, C., Schellenberg, M. P., Hanson, K., & Wang, H. (2007). Evaluation of the “bait-lamina test” to assess soil microfauna feeding activity in mixed grassland. *Applied Soil Ecology*, *36*, 199-204. http://dx.doi.org/10.1016%2Fj.apsoil.2007.02.004

Heisler, C., & Brunotte, J. (1998). Assessment of tillage with plough and conservation tillage by the bait laminae test after von Torne and by the abundances of springtails and predatory mites. *Landbauforschung Volkenrode*, *48*, 78-85.

Jordan, N. R., Larson, D. L., & Huerd, S. C. (2008). Soil modification by invasive plants: effects on native and invasive species of mixed-grass prairies. *Biological Invasions*, 10, 177-190.

Karlen, D. L. (1999). Opportunities and challenges associated with watershed-scale assessments of soil and water quality. *Journal of Soil and Water Conservation*, *54*, 626-627.

Kratz, W. (1998). The bait-lamina test. *Environmental Science Pollution Research*, *5*, 94-96. http://dx.doi.org/10.1007%2FBF02986394

LaRade, S. E. (2010). Long-term agronomic and environmental impact of aspen control strategies in the Aspen Parkland. *MSc Thesis*, University of Alberta. 170 pp.

Lawrence, T., & Ratzlaff, C. D. (1989). Performance of some native and introduced grasses in a semiarid region of western Canada. *Canadian Journal of Plant Science*, *69*, 251–254. http://dx.doi.org/10.4141%2Fcjps89-033

Li, C. H., Ma, B. L., & Zhang, T. Q. (2002). Soil bulk density effects on soil microbial populationsand enzyme activities during the growth of maize (*Zea mays* L.) planted in large potsunder field exposure. *Canadian Journal of Soil Science*, *82*, 147-154. http://dx.doi.org/10.4141%2FS01-026

McCartney, D. H. (1993). History of grazing research in the Aspen Parkland. *Canadian Journal of Animal Science*, *73*, 749-763. http://dx.doi.org/10.4141%2Fcjas93-079

Moldenhauer, W. C., & Wischmeier, W. H. (1960). Soil and water losses and infiltration rates on Ida silt loam as influenced by cropping systems, tillage practices, and rainfall characteristics. *Soil Science Society of America Proceedings*, *24*, 409-413. http://dx.doi.org/10.2136%2Fsssaj1960.03615995002400050028x

Murphy, S. R., Larney, J. F., Willms, W. D., DeMaere, P. R., & Harden, S. (2008). Surface runoff response of native and introduced grasses under simulated rainfall in southern Alberta. *Canadian Journal of Soil Science*, *88*, 337-348. http://dx.doi.org/10.4141%2FCJSS07045

Otfinowski, R., Kenkel, N. C., & Catling, P. M. (2007). The biology of Canadian weeds: *Bromus inermis* Leyss. *Canadian Journal of Plant Science*, *87*, 183-198. http://dx.doi.org/10.4141%2FP06-071

Parkin, T. B., Doran, J. W., & Franco-Vizcaino, E. (1996). Field and laboratory tests of soil respiration. p. 231-246. In: J. W. Doran and A. J. Jones (ed.) *Methods for assessing soil quality*. Soil Science Society of America Special Publication 49. SSSA, Madison, WI.

Paulus, R., Rombke, J., Ruf, A., & Beck, L. (1999). A comparison of the litterbag-, minicontainer- and bait-lamina-methods in an ecotoxicological field experiment with diflubenzuron and btk. *Pedobiologia*, *43*, 120–133.

Pennock, D. J., Anderson, D. W., & de Jong, E. (1995). Landscape-scale changes in indicators of soil quality due to cultivation in Saskatchewan, Canada. *Geoderma*, *64*, 1-19.

Peterson, L. A., Newman, R. C., & Smith, D. (1979). Rooting depth of Kentucky bluegrass sod as measured by N-absorption. *Agronomy Journal*, *94*, 421-428. http://dx.doi.org/10.2134%2Fagronj1979.00021962007100030027x

Rochette, P., & Angers, D. A. (1999). Soil surface carbon dioxide fluxes induced by spring, summer, and fall moldboard plowing in a sandy loam. *Soil Science Society of America Journal*, *63*, 621-628. http://dx.doi.org/10.2136%2Fsssaj1999.03615995006300030027x

Rombke, J., Hofer, H., Garcia, M. V. B., & Martius, C. (2006). Feeding activities of soil organismsat four different forest sites in Central Amazonia using the bait lamina method. *J. Trop. Ecol., 22*, 313-320. http://dx.doi.org/10.1017%2FS0266467406003166

SAS Institute, Inc. (2003). SAS user's guide: Version 9.1. SAS Institute, Inc. Cary, NC.

St. John, M. G., Wall, D. D., & Behan-Pelletier, V. M. (2006). Does plant species co-occurrence influence soil mite diversity? *Ecology*, 87, 625-633.

van Eekeren, N., Bommelé, L., Bloem, J., Schouten, T., Rutgers, M., de Goede, R., Reheul, D., & Brussaard, L. (2008). Soil biological quality after 36 years of ley-arable cropping,permanent grassland and permanent arable cropping. *Applied Soil Ecology*, *40*, 432-446. http://dx.doi.org/10.1016%2Fj.apsoil.2008.06.010

Vitousek, P. M. (1990). Biological invasions and ecosystem processes:towards an integration of population biology and ecosystem studies. *Oikos*, *57*, 7-13. http://dx.doi.org/10.2307%2F3565731

von Törne, E. (1990). Assessing feeding activities of soil-living animals. Bait-lamina-tests. *Pedobiologia, 34*, 89-101.

Whalen, J. K., Willms, W. D., & Dormaar, J. F. (2003). Soil carbon, nitrogen and phosphorus in modified rangeland communities. *Journal of Range Management*, *56*, 665–672. http://dx.doi.org/10.2307%2F4003944

Wheeler, G. W. (1976). Some grassland and shrubland communities in the parklands of central Alberta. MSc Thesis. Dept of Plant Science, University of Alberta, Edmonton,AB. 95 pp.

Wu, T., Shoenau, J. J., Li, F., Qian, P., Malhi, S. S., & Shi., Y. (2006). Influence of tillage and rotation systems on distribution of organic carbon associated with particle-size fractions in Chernozemic soils of Saskatchewan, Canada. *Biology and Fertility of Soils*, *42*, 338-344. http://dx.doi.org/10.1007%2Fs00374-005-0032-y

Table 1. Comparison of the proportion (%) of bait lamina exhibiting no, partial, or full removal in relation to vegetation type and soil depth, based on a maximum likelihood Chi-Square analysis (X^2)

Response	Grassland	X^2	P-value	No Removal	Partial Removal	Full Removal
Vegetation Type	Native	15.1	p=0.0005	70.4 %	20.7 %	8.0 %
	Seeded			75.4 %	17.0 %	8.5 %
Soil Depth	Top	67.1	p<0.01	69.0 %	20.0%	11.0 %
	Bottom			76.8 %	17.7%	5.5 %

Table 2. Summary of Pearson correlations (r) between the proportion of all bait lamina removed and associated soil environmental characteristics

	Bait Removed in Native Grassland	Bait Removed in Seeded Grassland
Moisture	+ 0.576 *	+ 0.621 **
Temperature	- 0.588 *	- 0.328
Organic Matter	- 0.131	+ 0.166
Carbon	+ 0.160	+ 0.224
Nitrogen	+ 0.017	+ 0.153

*, ** Significant at $P = 0.06$ and $P = 0.04$, respectively.

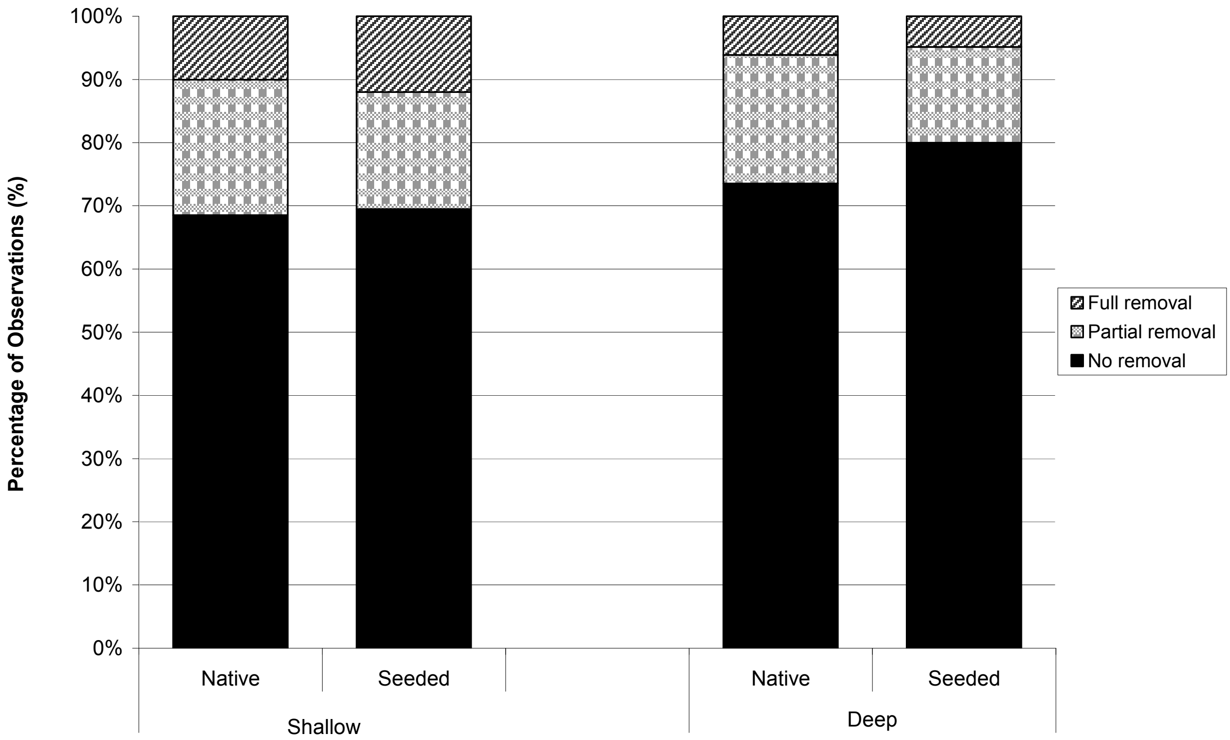

Figure 1. Proportion of bait lamina exhibiting partial, full and no removal within soils under native and seeded grassland, further stratified by shallow (0-5 cm) and deep (5-10 cm) soil depths. Removal was effected by vegetation x soil depth based on a Maximum Likelihood contingency test (X^2 = 6.81; p=0.03)