



UNIVERSITY OF ALBERTA
FACULTY OF AGRICULTURAL,
LIFE & ENVIRONMENTAL SCIENCES
Rangeland Research Institute

Alberta 
Agriculture and
Rural Development

Grassland Carbon Workshop

Agenda and Proceedings

J.G. O'Donaghue Building, Edmonton, Alberta

14 April 2015



Background

Carbon storage in terrestrial ecosystems is increasingly recognized as having value to society, including by western Canadian policy-makers (see: Alberta Offset System). Substantial research evaluating the role of grasslands and other grazing lands in storing carbon has been conducted, or is currently underway, in western Canada. This research can support, directly or indirectly, the valuation of carbon storage over a widespread land base. However, limited activity has taken place to coordinate investigators' efforts, integrate datasets or otherwise maximize research synergies. Making better use of research data and resources is critical to translating research activities into practical and meaningful policy that rewards landowners for this important environmental service. Achieving this outcome will also require greater understanding of how science, economics, and politics interact to inform decision-making processes, and more collaboration among a diverse network of stakeholders.

Expected Outcomes

1. Workshop participants will have an increased understanding of: (a) the status of scientific progress in assessing carbon storage in grasslands; and (b) how science is applied in economic and policy contexts.
2. Science, policy or economic needs, gaps and opportunities related to soil carbon valuation will be identified by participants.
3. Strategies to address needs, gaps and opportunities will be developed.

Morning Session: Research Update

8:30 *Welcome and overview of AM Session*

Edward Bork, Mattheis Chair of Rangeland Ecology & Management, Agricultural, Food & Nutritional Sciences, University of Alberta, and Director, Rangeland Research Institute (Chair)

8:40 *A 'synoptic' approach to carbon benchmarking in Alberta grasslands*

Edward Bork, Mattheis Chair, University of Alberta, and Director, Rangeland Research Institute

8:55 *Effects of disturbances on soil carbon in the Mixed Prairie of southern Alberta*

Walter Willms, Research Scientist (Retired), Agriculture and Agri-Food Canada

9:10 *Province-wide assessment of grassland carbon: challenges, opportunities and potential applications* – Majid Irvani, Research Associate, Alberta Biodiversity Monitoring Institute

9:25 *Responses of greenhouse gas emission and carbon storage to grazing practices on a native rough fescue grassland* – Xiying Hao, Research Scientist, Agriculture and Agri-Food Canada

9:40 *Are soil microbes mediators of carbon storage and greenhouse gas emissions in rangelands?*
Cameron Carlyle, Assistant Professor, Agriculture, Food & Nutritional Sciences, University of Alberta

9:55 *Controls on carbon sequestration in native grassland*

Larry Flanagan, Professor, Biological Sciences, University of Lethbridge

10:10 Break

Morning Session (cont'd)

- 10:25 *Effect of forages in crop rotations on soil carbon levels at the University of Alberta Breton Plots* – Miles Dyck, Associate Professor, Dept. of Renewable Resources, University of Alberta
- 10:40 *Impacts of tame forage management on ecosystem flux and soil carbon stores for black soil in central Alberta* – Vern Baron, Research Scientist, Agriculture and Agri-Food Canada
- 10:55 *Can you C the grassland?*
Emma McGeough, Assistant Professor, Animal Science, University of Manitoba
- 11:10 *Measurement and quantification of SOC stock changes in grasslands*
Brian McConkey, Agriculture and Agri-Food Canada
- 11:25 *What lies beneath: carbon in wetland and buried soils*
Angela Bedard-Haughn, University of Saskatchewan
- 11:40 *Looking at grassland carbon storage: how can remote sensing help?*
John Gamon, Professor, Biological Sciences and Earth & Atmospheric Sciences, University of Alberta
- 11:55 Lunch

Afternoon Session: Valuing Soil Carbon 101

- 12:30 *Introduction and overview of PM session*
Karen Raven, Manager, Land Use, Alberta Agriculture and Rural Development (Facilitator)
- 12:35 *Applying the numbers for credible outcomes*
Sheilah Nolan, Climate Change Specialist, Alberta Agriculture and Rural Development
- 12:45 *Science and policy: issues and scales*
Tom Goddard, Sr. Policy Advisor, Alberta Agriculture and Rural Development
- 1:00 *Risk, rigour and demonstration: how science can address policy needs*
Anish Neupane, Economist, Environment and Sustainable Resource Development
- 1:15 *Economic and institutional drivers of soil carbon valuation*
Brent Swallow, Professor, Resource Economics and Rural Sociology, University of Alberta
- 1:30 *Breakout sessions* – Small groups discuss the following questions (30 min/question):
(1) What is needed to advance soil carbon valuation, from the perspectives of science, economics and policy? (2) What are the key gaps within and amongst these fields that inhibit soil carbon valuation? (3) What synergies and opportunities stem from the needs and gaps that have been identified today?
- 3:00 Coffee
- 3:15 *Round table recommendations* – Groups present key answers for each question (5 min/group)
- 3:45 *Next steps* – Karen Raven and Edward Bork

Grassland Carbon Workshop Proceedings

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A 'synoptic' approach to carbon benchmarking in Alberta grasslands

E. Bork¹, C. Carlyle¹, D. Hewins¹, M. Lyseng^{1,3}, D. Schoderbek¹, S. Chang², B. Adams³, M. Alexander³, D. Thompson⁴, and W. Willms⁴

¹*Department of Agricultural, Food and Nutritional Science, University of Alberta;* ²*Department of Renewable Resources, University of Alberta;* ³*Alberta Environment and Sustainable Resource Development;* ⁴*Agriculture and Agri-Food Canada*

Correspondence: edward.bork@ualberta.ca

Perennial grasslands are widely recognized for their potential to store large amounts of carbon, both in vegetation (root and shoot mass) and soil organic matter. As a large proportion of this C is belowground, it remains relatively stable and resistant to release in the short-term, even with abrupt changes to aboveground vegetation due to grazing or fire. Additionally, C pools in perennial grassland are known to be greater than in cropland, where cultivation has reduced C by 20-60% (Lal 2002). Despite the key role of grasslands in storing C, little is known about the overall size and stability of C pools in Alberta grasslands, including how they vary regionally with agro-climatic conditions, specific soil properties, vegetation composition and productivity, and past land use activities such as livestock grazing. Previous studies have typically examined grassland C at only a few localized sites under a narrow range of experimental conditions, and therefore do not provide a comprehensive regional and provincial accounting of grassland C stores. Furthermore, studies examining the impact of grazing on C are highly variable, with some studies indicating grazing increases grassland C, with others showing the opposite or no effect (Derner and Schuman 2007).

Objectives

In 2012, with support from the Alberta Livestock Meat Agency (ALMA), we initiated an investigation to characterize C pools in grasslands across Alberta. Specifically, we are:

- Quantifying the size and stability of C pools in grasslands across Alberta;
- Characterizing the distribution of C in various ecosystem components, including:
 - Live vegetation (shoots and roots), litter and mulch,
 - Soil organic matter, including various size fractions, and
 - Inorganic mineral sources (where applicable);
- Evaluating the impact of grazing and other land uses (i.e., conversion to tame pasture and annual cropland) on the C pools listed above; and
- Interpreting levels of C based on local agro-climatic, soil and vegetation properties.

Experimental Approach

In 2012, working in partnership with the Range Management Branch of Alberta Environment and Sustainable Resource Development (AESRD), the University of Alberta began sampling an extensive network of Rangeland Reference Area sites currently maintained and monitored by AESRD. A total of 115 sites throughout the Mixed Prairie, Aspen Parkland, Foothills

Fescue, and Montane natural sub-regions were included. Reference sites are well suited to the assessment of C pools because they have existing long-term data on community composition and biomass production, both with and without exposure to cattle grazing in a paired design, the latter situated in fenced exclosures ~10 x 20 m in size. Where available, additional sampling has been done on adjacent tame pasture ($n=15$) and annual cropland ($n=17$) to facilitate comparison of C profiles between contrasting land uses located on the same ecosite and soil type. Working with AESRD staff, we have collected vegetation, litter and soil samples within each plant community from 2012 through 2014.

Within each community ($n=262$), 10 randomly placed soil cores, each 3.25 cm in diameter, have been removed to 30-cm depth below the mineral surface. Cores were separated into 15-cm depth intervals, and then bulked within a class. Sub-sample sizes were determined through preliminary assessments of variation among sub-samples taken in 2012, which showed 8 sub-samples were needed to accurately represent mean C values for each community. An additional 10-cm diameter core was randomly taken in each community to assess soil *in-situ* bulk density, which was needed to adjust C to a volumetric mass basis for the community. Soil samples are being assessed for physical (texture, bulk density) and chemical (pH, electrical conductivity, soil organic matter and total C, and where applicable, inorganic C) properties. Soils are being assessed for the whole soil, and in the case of the top 15 cm depth, also by size fractions (<53 μm or fine, 53-250 μm or medium, and >250 μm or coarse fractions) to assess C stability.

For all native plant communities, vegetation data (composition and biomass) represent average data from the last 10 years. Recently harvested vegetation samples (shoot and root biomass) have been assessed for C and nitrogen concentration, with the same done on litter and surface mulch. While we are not assessing soil C below 30 cm mineral soil depth at our study sites, we are fortunate to have obtained an archived data set from grasslands across a sizeable area of western Canada that documents soil C stored in Mixedgrass and Parkland soils to about 1 m soil depth. These data will enable us to quantify both the size of deeper soil C reserves in grasslands of the region, as well as the contribution of organic and inorganic C across a range of soil depths.

Measures

Vegetation

- Long-term plant composition, richness and diversity, annual net primary production (by growth form), and litter
- Surface mulch and root biomass (to 30 cm depth) from 10 pooled sub-sample cores

Soils

- Soil texture (sand, silt and clay) from the surface (0-15 cm) layer
- Soil bulk density, and volume and mass of rocks (to adjust soil C estimates)
- Soil pH, salinity, organic matter, and total C and nitrogen concentrations, for each soil layer, including the adjusted mass of C in each soil layer
- Carbon stability (i.e. size fractions) by concentration and soil mass within the surface (0-15 cm) layer
- Inorganic C (where applicable; pH > 6.4)

Ancillary Dataset

- Total organic and inorganic C down to 1 m depth

Key Outcomes Expected

Our analysis will provide the unprecedented ability to relate the size and properties of C pools to various soil, vegetation and climatic parameters found across a diversity of grassland environments, essentially representing one of the most 'synoptic' assessments of this important environmental service ever done in Canadian grasslands. Second, C pool sizes and characteristics will be compared among different land uses (cropland, tame pasture, and presence/absence of grazing) to directly test their effects. Last, we will use the collective results of this study to develop an inventory of C pools in grasslands by linking measured C to the provincial Grassland Vegetation Inventory.

Comprehensive information on the size and stability of carbon pools, and how these are affected by the presence of cattle grazing (as well as competing land uses), is necessary to promote the establishment of progressive policies to reward ranchers for C storage in grasslands. Although policy instruments that promote C storage have existed for annual crop producers in Alberta for some time (e.g., C offsets for reduced tillage), no similar instruments are in place to reward livestock producers for storing C in perennial grasslands, in part because studies directly quantifying this service are limited, as are studies addressing the mechanisms behind where and how grazing (or other land use activities) may affect C stores. Ultimately, this research aims to provide the baseline information needed to inform regulators and policy makers on the critical role of perennial grasslands in providing the key ecological service of C storage, retention, and stabilization, and will provide a foundation for developing future strategies valuing new and existing C stored in grasslands.

References

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- Lal, R. 2002. Soil carbon dynamics in cropland and rangeland. *Environ. Pollut.*, 116: 353-362.

Investigating the role of long term grazing on plant litter decomposition

D.B. Hewins¹, E.W. Bork¹, C.N. Carlyle¹, S. Chuan¹, S.X. Chang², B. Adams³, and M. Alexander³

¹*Department of Agricultural, Food and Nutritional Science, University of Alberta;* ²*Department of Renewable Resources, University of Alberta;* ³*Alberta Environment and Sustainable Resource Development*

Correspondence: hewins@ualberta.ca

Perennial grassland ecosystems have the capacity to provide many valuable ecological goods and services (EG&S) (Havstad et al. 2007). In particular, well managed grasslands hold > 30 % of soil organic C globally (Lal 2002) and continue to sequester carbon. Despite the importance of this process in counteracting rising CO₂ levels, clear links between the conversion of plant material to soil carbon (C) as it relates to typical land-uses remain elusive. Presently, detailed estimates of C flux in grasslands under grazing do not adequately capture spatial and temporal variation in abiotic (e.g., climate) and biotic (e.g., plant community) factors. Although it is well known that grazing alters plant assemblages (e.g., by decreasing grazing sensitive plant species, and increasing those that either evade or tolerate grazing) across broad regions, a clear understanding of how these shifts in plant diversity impact the processes that mediate the transformation of C and nutrients in biomass to soil organic matter is not known. To address this uncertainty and improve our ability to estimate C and nutrient transformations, we have undertaken a study in paired long-term grazed and non-grazed exclosures, which span three distinct agro-climatic regions (Aspen Parkland, Foothills Fescue and Mixedgrass Prairie) in Alberta's grasslands.

Our study will quantify leaf litter decomposition of 7 regionally specific increaser/decreaser species, a composite plant community 'mix', and a pure cellulose substrate. Furthermore, we will investigate enzyme activity of microbial decomposers - a key driver of C and nutrient cycling in grasslands, within both surface litter and the surface of the soil (5 cm depth). Our study allows us to investigate the direct (e.g., the physical presence of grazers) and indirect effects (e.g., changes in plant communities) of long-term exposure to livestock grazing on the dynamics of C and nutrient cycling across a broad agro-climatic gradient. Furthermore, studies of soil C and nutrient cycling via microbial enzyme activity will allow us to better understand the fate of belowground C and nutrients relative to grazing and associated changes in plant communities. Ultimately, this work will help expand on results of the 'Carbon Benchmarking in Alberta Rangelands' study to develop a more detailed mechanistic understanding of how grazing may alter decomposition activities in grasslands. In doing so, this work will provide a more complete framework for linking C accumulation in grasslands to nutrient cycling that has the strong potential to inform C offset policy across Alberta.

Objectives

In 2014, with the support of ALMA and Alberta Innovates–Biosolutions, we initiated a litter decomposition study that will:

- Evaluate rates of litter mass loss (i.e. decomposition) of common grasses found across Alberta grasslands and known to be associated with livestock grazing (positive or negative);
- Quantify extracellular enzyme activity (EEA) in litter and soils associated with the breakdown of plant materials; and
- Interpret how grazing may affect C and nutrient cycling in Alberta grasslands.

Experimental Approach

Our nutrient cycling study builds on the carbon benchmarking work by Bork et al. (see pp. 1-3 of these proceedings) by conducting a study on litter decomposition at each of 12 exclosures (4 in each of the Mixedgrass, Parkland, and Foothill sites). This is the ideal experimental setup to make direct comparisons of C and nutrient cycling in the presence or absence of livestock grazing and its associated effects because the exclosures are long-term and have detailed records of plant community composition and productivity over time. Additionally, at 3 other locations, we are comparing areas without livestock grazing to areas grazed under season-long (continuous) or management intensive (rotational) grazing (MIG), in a 3-way comparison.

Within each of the 33 communities, we are assessing comparative decomposition of 6 common grasses [including species with known positive and negative responses to grazing; *Bouteloua gracilis* (+), *Pascopyrum smithii* (-), *Hesperostipa comata* (-), *Festuca hallii* (-), *Festuca campestris* (-), *Koeleria macrantha* (+), and *Poa pratensis* (+)], and a natural 'mixed' litter from the site. Litter bags were installed in May 2014 and are being retrieved over an 18 month period to assess mass loss and remaining litter quality. At each sampling time (0, 1, 3, 6, 12 and 18 months), we are also assessing extracellular enzyme activity (EEA) in soil and litter to further understand C and nutrient cycling patterns in grasslands under varied exposure to grazing and contrasting grazing systems.

Measures

Vegetation

- Composition of the plant community (average cover of plant species, richness, diversity), standing crop, and litter biomass
- Litter quality, including lignin content and C:N ratio

Litter Decomposition

- Mass loss at 0, 1, 3, 6, 12, and 18 months
- Changes in C and N concentration (and mass) as an index of litter quality and grazing treatment, at 0, 1, 3, 6, 12, and 18 months
- Extracellular enzyme activity after being in the field for either 0, 1, 3, 6, 12, or 18 months

Soils

- A variety of data on ecosite conditions (pH, EC, texture, etc.)
- Organic matter, and total C and N concentrations over sequential sampling times
- Extracellular enzyme activity at 0, 1, 3, 6, 12, 18 months

Key Outcomes Expected

Our results will estimate litter decomposition rates in each grassland type, and relate this information to long-term livestock grazing (presence/absence, season-long, or MIG systems). Additionally, observed litter decay (and associated rates of C and nutrient cycling) will be interpreted relative to not only land use, but also associated changes in plant communities across a broad agro-climatic gradient. This process will combine both fixed (grazing) treatment effects and existing environmental conditions (climate, ecosite, and plant composition) in both conventional and multivariate analytical tools.

This novel information will greatly enhance our understanding of C and nutrient cycling by connecting microbial decomposer enzyme activity in above and below ground (i.e., litter and soil) organic pools to the direct effects of grazing and associated shifts in plant community composition and associated litter inputs. In essence, quantifying these linkages will lead to a better mechanistic understanding of how, when and where grazing (i.e., under prescription) may alter the size and stability of C pools, as well as improve/maintain the productivity of grassland ecosystems. In conjunction with the Alberta grassland vegetation index (GVI), we will link results of this study with the 'C benchmarking' study to develop, verify and improve ecosystem models (e.g., CENTURY) to estimate pool sizes and fluxes rates of C in northern temperate grasslands.

References

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- Lal, R. 2002. Soil carbon dynamics in cropland and rangeland. *Environ. Pollut.* 116: 353-362.

Grazing effects and recovery from disturbances on the mixed prairie

W.D. Willms¹

¹Agriculture and Agri-Food Canada, Lethbridge, AB

Correspondence: walter.willms@agr.gc.ca

Summary of:

Smoliak, S., J.F. Dormaar, and A. Johnston. 1972. Long-term grazing effects on *Stipa-Bouteloua* prairie soils. *J. Range Manage.* 25: 246–250.

Dormaar, J.F., and S. Smoliak. 1985. Recovery of vegetative cover and soil organic matter during revegetation of abandoned farmland in a semiarid climate. *J. Range Manage.* 38: 487–491.

Dormaar, J.F., B.W. Adams, and W.D. Willms. 1994. Effect of grazing and abandoned cultivation on a *Stipa-Bouteloua* community. *J. Range Manage.* 47: 28–32.

The effects of disturbance on soil and its recovery had not been well understood. The process of succession toward a *Stipa-Bouteloua* community appears to be impeded by blue grama, which is sensitive to cultivation but appears to be enhanced by grazing. Knowledge of these processes is of interest in terms of time as a soil-forming factor.

Objectives

- Determine the effects of abandoned cultivation on soil characteristics of a *Stipa-Bouteloua* community with and without the effects of grazing;
- Assess the changes in soil characteristics during the succession of abandoned cropland to native range; and
- Assess long-term effects of grazing by sheep on *Stipa-Bouteloua* prairie soils.

Experimental Approach

The studies depended on existing sites where the history of disturbance was known. Recovery was facilitated with exclosures that protected representative areas from further disturbance. Soil sampling was confined to the Ah or Ap horizons. The treatments were generally unreplicated and estimates of experimental error were obtained by paired sub-sampling across fence lines.

Measures

- Root mass in the Ah/Ap horizon
- Species composition
- Chelating resin-extractable soil carbon (C)
- Soil organic matter; determined as per Walkley and Black (1934) or in two separate fractions, one that is soluble in alcohol:benzene (1:1 EtOH: C₆H₆) and one that is soluble in alkaline solution (0.1 N NaOH)

Key Results

- After 14 years of protection from grazing, needle-and-thread accounted for 79% of foliar cover of the abandoned cultivation and 18% of the untreated range while blue grama occupied 1 and 51% on the same treatments, respectively
- After 60 years, the soil on the abandoned cultivated area showed reduced carbon
 - Grazing increased carbon but cultivation and grazing reduced root mass
- Input of energy, such as cultivation, may well be required to facilitate a rapid transition from blue grama to needle-and-thread stable communities

Total C content increased while chelating resin-extractable C, caloric content of the rootmass decreased in the successional sequence. More than 55 years will be required to allow soil to return to native range standards under moderate grazing by livestock.

Analysis of the soils under the heavy grazing treatment showed lower values for pH and percent spring moisture but higher values for total carbon (C), alcohol/benzene-extractable C, alkaline-soluble C, polysaccharides, and belowground plant material than the soil under light or no grazing. The results were attributed to changes in amounts and kinds of roots due to species changes caused by grazing and to increased amounts of manure deposited by sheep on fields grazed at a higher intensity. Shallow-rooted species replaced the deeper-rooted ones on the drier environment induced by heavy grazing.

Anthropogenic impacts on soil carbon in the mixed prairie

W.D. Willms¹

¹*Agriculture and Agri-Food Canada, Lethbridge, AB*

Correspondence: walter.willms@agr.gc.ca

Summary of:

Willms, W.D., J. F. Dormaar, B.W. Adams, and H.E. Douwes. 2002. Response of the mixed prairie to protection from grazing. *J. Range Manage.*, 55: 210–216.

Willms, W.D., Ellert, B.H., Janzen, H., and H.E. Douwes. 2005. Evaluation of native and introduced grasses for reclamation and production. *Rangel. Ecol. and Manage.*, 58: 177–183.

Wang, X., W.D. Willms, X. Hao, M. Zhao, and G. Han. 2010. Cultivation and reseeding effects on soil organic matter in the mixed prairie. *Soil Sci. Soc. Am. J.*, 74: 1348–1355.

Anthropogenic disturbances on native rangelands may consist of livestock grazing, cultivation and seeding tame forages and, arguably, protection from large herbivores. Understanding their effects is necessary in order to manage these areas for conservation and production-based goals.

Objectives

- To compare the effects that protection from grazing had on soil and vegetation properties on 2 common soil types; and
- To better understand the influence of plant species on grassland productivity and soil carbon.

Experimental Approach

We compared monocultures of introduced and native grasses, as well as simple mixtures of native species. We tested the hypothesis that aboveground net primary production and soil carbon storage were enhanced with native species and increased biodiversity.

We also examined the effects of converting native grassland to perennial monocultures of seeded agronomic grasses and annual crops to better understand the effects that settlement had on the SOC stock on Brown and Dark Brown Chernozemic soils of the Canadian prairie. Our specific objectives in this project were to determine the effects of perennial grass monocultures on SOC, observe the early changes in SOC after cultivating native grassland and cropping with wheat, and assess the effects of haying or cultivating, and abandoning native grassland, which occurred during the drought in the 1920s and '30s.

At Onefour, we compared soil carbon inside 15 exclosures, established in 1927, with moderately grazed areas that were contiguous to the exclosure; of these exclosures, 11 were on Brown Chernozemic soil and 4 on Solonchic soil; only the Ah horizon was sampled.

In 1995, a 5-year study was initiated on Dark Brown Chernozemic (Typic Haploboroll) soil near Lethbridge, Alberta. Ten treatments consisting of monocultures of introduced and selected native species and mixtures of native species were established in a randomized complete block design with 4 replications; 3 or 6 soil cores (6.7 3 60 cm), were taken in increments of 0–7.5, 7.5–15, 15–30, 30–45, and 45–60 cm of soil depth from each treatment plot; winnowing technique to yield macro-organic matter, mineral soil.

The effect of cultivation on SOC was examined in a 7 (treatments) × 4 (replicates) randomized complete block design at each site. Five treatments representing four common production practices, together with a haying, abandoned cultivation, and a native control, were established on previously uncultivated native grassland. The treatments were: cultivated and seeded to monocultures of either (i) Russian wild rye or (ii) crested wheatgrass (iii) cultivated and then abandoned leaving the plot to re-establish thorough succession from residual germplasm (ABA); cultivated and seeded to wheat either (iv) annually (WC) or (v) biannually with summer fallow (chemical fallow) in alternating years (WF); and native grassland that was either hayed (vi) or left undisturbed as a control (vii). All seeded treatments and one native treatment were harvested at about peak standing crop. The soils were sampled in 1995, 1997, and 2006 in early July at 0–7.5, 7.5–15, 15–30, 30–60, and 60–90 cm increments.

Measures

- Total C in the Ah horizon (determined by dry combustion in a Carlo Erba NA 1500 Analyzer)
- Soil organic carbon and macro-organic matter (light fraction) carbon at increments to 60/90 cm depth
- Mineralizable C

Key Results

- The stock of soil carbon in the Ah horizon of the Chernozemic and Solontzic soils was similar in the exclosures as the contiguous grazed areas;
- Organic C in mineral soil, macro-organic matter, and crowns was similar in mixed communities to the average of their respective monocultures; crested wheatgrass and Russian wildrye had more macro-organic matter C than June grass and green needlegrass; treatment effects on soil organic C, total organic C (soil organic C plus macroorganic matter C), and total organic C plus crown C were not detected; in a ranking of treatment means according to mass, crested wheatgrass produced the least SOC and total C; and
- Breaking and immediate establishment of perennial grass monocultures had no effect on SOC, LF OC, or mineralizable C. Wheat cropping (either fallow or continuous) resulted in a 19% loss of SOC after 13 yr. The rate of loss varied from an average of about 1.7 Mg ha⁻¹ yr⁻¹ in the first 4 yr to about 0.32 Mg ha⁻¹ yr⁻¹ in the subsequent 9 yr. These results are consistent with a more rapid loss of SOC in the first decade of cropping virgin soils, a slowing rate of loss, and a new steady state within a few decades.

Province-wide assessment of grassland carbon: challenges, opportunities and potential applications

M. Iravani¹, T. Habib¹, A. Nixon¹, S.R. White², D. Farr¹

¹Alberta Biodiversity Monitoring Institute; ²Alberta Environment and Sustainable Resource Development

Correspondence: iravani@ualberta.ca

Several small scale experimental studies have assessed grassland carbon storage under different management regimes and climate conditions in western Canada. However, a comprehensive, dynamic tool for consistent provincial-scale assessments of grassland carbon remains lacking (Wang et al. 2014). Such tool could support a better understanding of how land management choices and projected climate regimes might impact long-term grassland carbon sequestration, and help identify carbon offset policies that promote carbon storage in grassland soils (Ash et al. 2012).

The Alberta Biodiversity Monitoring Institute (ABMI) is leading a collaborative Ecosystem Services Assessment (ESA) project that is developing an integrated set of ecosystem service models, including a grassland carbon model. The ESA project aims to support a better accounting of the provision and value of multiple ecosystem services and to assess potential changes in ecosystem service provision under alternative land management and future climate change scenarios across the Alberta's landscape. Here we present a general overview of the ABMI's grassland carbon assessment project and the comprehensive carbon dynamics model that is under development for Alberta's native grasslands.

Objectives

- Establish a carbon dynamics model for Alberta's native grasslands:
 - Regionalize, parameterize, calibrate and validate the spatially-explicit provincial carbon model of Alberta's native grasslands;
 - Assess uncertainties in the model estimates to evaluate the level of precision in simulating grassland carbon storage across different regions; and
- Predict future carbon storage of Alberta's native grasslands:
 - Determine how land management practices affect grassland carbon storage across different regions;
 - Predict how grassland carbon storage might be changed under the most widely accepted climate change scenarios for Alberta's native grasslands; and
 - Identify grazing management practices that mitigate potential negative impacts of climate change on carbon storage in various grassland regions.

Experimental Approach

Model setup

We used the Agricultural Region of Alberta Soil Inventory Database (AGRASID version 3.0) to build a soil database for native grasslands of Alberta. We extracted soil polygons associated with native grassland areas, as determined from the ABMI's Wall to Wall Land Cover (v 1.0; ABMI 2012a) and Human Footprint maps (v 1.1; ABMI 2012b). This resulted in 25,093 soil polygons comprising 1491 soil types associated with seventeen grassland soil correlation areas (SCAs; distinct grassland sub-regions with unique soil and climate conditions). SCAs that were comparable in terms of soil zone, ecoregion and agroclimatic zone were combined to reduce the number of regions to nine. To account for regional variations in climate and vegetation across the province, we performed independent regional parameterization and calibration of the carbon dynamics model for these nine newly defined grassland SCAs.

We used the widely applied ecosystem carbon model CENTURY (Parton 1988), with the AGRASID polygons serving as the spatial units. Historic monthly climate data (1901-2011) for each AGRASID polygon were extracted from ClimateWNA (Wang et al. 2012), which provides gridded (approx. 4 x 4 km) monthly, seasonal and annual climate data based on interpolated historical weather station records.

We used available literature to adjust input parameters related to nitrogen to represent the role of soil and plant nitrogen content in overall turnover rates of grassland OC in our model. Vegetation parameters suggested for temperate C3 vegetation were modified for Alberta's grasslands, based on consultations with other CENTURY users. For the initial run, these values were kept consistent across all SCAs. The remaining parameters were left to default values or, in the case of initial soil organic matter, established through equilibrium.

We first used 1901-1990 climate averages to run a 4900 year equilibrium period, specifying a fire event every six years and a two-month bison grazing event (shifting annually by two months) out of every year. The monthly climate data were then used to run a 110 year period (1901-2011), specifying cattle grazing (during the months of June, July and August) under a low-to-moderate grazing intensity regime (40% offtake of above-ground biomass).

Model evaluation

A lack of geo-referenced, consistently measured and harmonised data on soil carbon content is a major challenge for broad-scale modeling of grassland carbon storage. Through its ongoing monitoring program, ABMI has completed OC measurement in the top mineral soil layer (0-5 cm depth) at approximately 400 terrestrial monitoring sites systematically spaced throughout native grasslands of the province. We used AGRASID's OC data for native soil types to calculate regional OC conversion factors to extrapolate ABMI's OC measurements (i.e., 0-5 cm to 0-20 cm depth), which were then used in comparison with model estimates of soil carbon storage to calibrate carbon model across grassland regions.

Calibration of the regionalized carbon model is necessary to represent most of the actual processes in each region. We are currently conducting calibration and parameterization (i.e., repetitive runs with several sets of the most sensitive input parameters) to generate the most relevant physically and biologically meaningful ranges for model parameters and to estimate parameter uncertainty.

The availability and quality of data for model parameterization and calibration are limited. In addition to ABMI's OC measurements, we will use long-term biomass and forage production data provided by Alberta Environment and Sustainable Resource Development (ESRD) and remotely-sensed vegetation data based on MODIS NDVI, derived and compiled by ABMI. Finally, we will validate model estimations using measured above- and below-ground plant biomass and soil carbon data provided by the Rangeland Research Institute at University of Alberta. Regionalized evaluation of carbon model will more accurately represent carbon dynamics throughout Alberta's native grasslands. It also will enable an assessment of the uncertainties in the model estimates so that we can evaluate the level of precision achieved in our simulations of grassland carbon across different regions.

Preliminary results

In general, our initial model sufficiently captured the spatial pattern of soil OC measurements. However, our preliminary analysis revealed unexplained variability among and within regions that requires further investigation. This underscores some limitations of the currently available data (e.g., land management history and grazing intensity) and

scientific knowledge (e.g., overall grazing impacts on grassland carbon, appropriate ranges for sensitive model parameters such as optimum temperature for plant growth and OC decomposition) that, if addressed, could improve the accuracy of the model and extend its application.

Measures

We focus on two types of grassland organic carbon (OC), including OC stored in the soil (top 20 cm of soil profile) and OC stored in aboveground plant biomass.

Key Outcomes Expected

As the first province-wide assessment of its kind, the regionalized carbon model of Alberta's native grasslands will provide a foundation to:

- Assess the current status of carbon storage across grassland regions;
- Predict potential impacts of alternative land management practices on grassland carbon storage and the uncertainties associated with these predictions;
- Predict potential impacts of future climate change on grassland carbon storage and the uncertainties associated with these predictions;
- Identify alternative adaptive strategies and management scenarios that might mitigate potential negative impacts of climate change on grassland carbon storage; and
- Support a more complete cost-benefit analysis of potential climate change adaptation strategies and provide a baseline to assess whether such strategies will lead to resilience of socio-ecological systems in Alberta's rangeland.

We are seeking advice from stakeholders and experts on defining appropriate adaptive strategies and management scenarios. Finally, we will share our findings with stakeholders and experts to support the further development of carbon offset policies in Alberta.

Acknowledgements

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Response of greenhouse gas emission and soil carbon storage to cattle grazing practice on a rough fescue grassland

X. Hao¹

¹*Agriculture and Agri-Food Canada, Lethbridge, AB*

Correspondence: xiying.hao@agr.gc.ca

Cow-calf grazing on rangeland generates an estimated 80% and confined feeding operation 20% of total greenhouse gas emissions from the beef industry in Western Canada. However, there has been little research on the potential for reducing GHG (CH₄, CO₂ and N₂O) emissions from the cow-calf portion of the beef production cycle.

Objectives

- Determine how GHG emission from cow-calf production on rangeland is influenced by management practices;
- Determine GHG emission from cattle dung and urine patches; and
- Assess the potential for managing rangeland to increase soil C sequestration and storage.

Experimental Approach

Four experiments were planned and conducted with the experimental period ranging from one to three years.

Experiment 1: Effect of long-term cattle stocking on GHG emission and soil C storage

This three-grazing season (May-Oct) field experiment (2013-2015) was superimposed onto an existing long-term grazing study started in 1949 near Stavely AB. Briefly, cow-calf pairs have been stocked at four annual rates, 0, 1.2, 2.4 and 4.8 AUM ha⁻¹, since spring 1949. In April 1998, three permanent exclosures (upper, middle and lower slope) were installed in the fields with 2.4 and 4.8 AUM ha⁻¹ stocking rates to assess the rangeland recovery after 49 years grazing.

Experiment 2: GHG emission from producer grazing site

This two-year field experiment (2014-2015) was conducted at the Little Bow watershed in a Lethbridge community pasture where cattle were stocked at 1.3 AUM ha⁻¹. Four transit lines were selected near the cattle water trough, and GHG flux chambers were placed at 10, 17.5, 25, 40, 60 and 85 m away from the water trough. Gas sample collected was on a weekly schedule during the grazing season (May-October) and less frequent off the grazing season (November-April)

Experiment 3: Effect of soil texture on GHG emission under a rotational grazing system

This one-grazing season (May-Oct) field experiment (2014) was conducted at Duchess on the University of Alberta Mattheis Ranch. Eight chambers at E3NE (sandy texture) and eight chambers at E5E (loamy texture) were installed.

Experiment 4: Contribution of dung and urine to GHG emission from rangeland

This one-year study (June 2014-June 2015) was conducted at the Lethbridge Research Center on a tame pasture populated by broom grass and crested wheatgrass. Urine was applied at rate of 750 kg/ha and dung at 65.4 tonne (DM) /ha.

Measures

- Weekly GHG flux, temperature and soil moisture content during the grazing season (May-October)
- Monthly surface soil (0-15 cm) sampling from May to September for soil available N and P contents
- Monthly surface soil (0-15 cm) sampling from May to September for the abundance of methanogens, methanotrophs, ammonia oxidizing bacteria, nitrite oxidizing bacteria and denitrifying bacteria
- One-time soil profile (0-15, 15-30 and 30-60 cm) sampling in summer 2014 included measures of:
 - Bulk density
 - pH, EC and water-extractable C and N
 - Available N and available P
 - TC, OC, TN, ¹³C, ¹⁵N, TP
- Annual herbage sampling at peak production time (early July) included measures of:
 - Herbage yield
 - Nutrient and mineral concentration (N, P, K, Na, Ca, and Mg)

Key Outcomes Expected

- Data set of GHG emissions from rangeland under cow-calf production; and
- Relations of GHG emission to environmental and livestock management practices.

Are soil microbes mediators of carbon storage and greenhouse gas emissions in rangelands?

C.N. Carlyle¹, E.W. Bork¹, D.B. Hewins¹, S.X. Chang², B.P. Willing¹, M. Alexander³

¹Department of Agricultural, Food and Nutritional Science, University of Alberta; ²Department of Renewable Resources, University of Alberta; ³Alberta Environment and Sustainable Resource Development

Correspondence: cameron.carlyle@ualberta.ca

Project funding from: Alberta Livestock and Meat Agency, Ltd.

Rangelands provide many ecosystem goods and services (EG&S). They store as much as twice the carbon in cultivated land [2] and are sinks for greenhouse gasses (GHG) under appropriate management [3]. While there are policies in place to pay carbon offsets for agricultural practices in cultivated land in Alberta, policies to reward cattle producers using perennial grassland do not exist. Alberta has 9 M ha of grassland, so the identification of grazing management practices capable of increasing soil carbon storage could significantly reduce GHG levels.

While the beef industry is criticized for methane emissions that come directly from cattle there is evidence that cattle grazing can alter ecosystem processes in a way that reduce GHG emissions from the soil or even increase GHG uptake. Three significant GHG are carbon dioxide, methane and nitrous oxide. Management that enhances carbon storage in soils will offset and potentially reduce carbon dioxide and methane emissions at regional and global scales. Appropriate grazing can increase soil carbon anywhere from 0.3 tons/year [6] to 1.5 tons/year, but this varies spatially and is highly variable [4]. Similarly, it has been demonstrated that cattle can reduce nitrous oxide emissions because of the ecosystem changes initiated by grazing [8] and management can alter soil microbes that remove methane from the atmosphere [9].

Soil microbes represent a significant amount of biomass in grasslands (~2000 kg/ha) and are critical to carbon cycling in general, as they exchange carbon dioxide and emit or consume other GHG; in comparison, cattle biomass is ~70 kg/ha under moderate stocking. It is therefore critical to evaluate the microbial community when examining the effect of land use on GHG emissions, but little is known about microbial abundance, diversity or response to grazing, globally or in Alberta. Until recently these organisms have not been characterized despite their importance in supporting plant productivity [7] and GHG because they were difficult to observe, but new technology is verified and affordable for accomplishing this. Different microbial species are important for organic matter breakdown and GHG fluxes. For example, some fungi are proficient at breaking down lignin while certain bacteria cycle cellulose [1]. The ratio of fungi to bacteria can alter carbon sequestration and stability [5] and are shown to respond to grazing [10].

Objectives

In the spring of 2015 we are beginning a study that will:

- Measure GHG emission in grasslands across Alberta in adjacent grazed and non-grazed sites;
- Measure the abundance and community composition of the microbial community; and
- Integrate data from this study and others to model carbon cycling in Alberta's grasslands and in particular understand the role of grazing.

Experimental Approach

This study builds on two other studies outlined in these proceedings: 'A 'synoptic' approach to carbon benchmarking in Alberta grasslands' (Bork et al.; pp. 1-3) and 'Investigating the role of long-term grazing on plant litter decomposition' (Hewins et al.; pp. 4-6). Study sites are at 12 long-term grazing exclosures, 4 in each of the Mixedgrass, Parkland and Foothills grassland regions. Additionally, in each region there is one more location that includes a 3-way comparison of no grazing, rotational grazing and continuous grazing. In total there are 33 plant communities. In each plant community two subplots will be established where GHG emissions will be measured throughout the growing season and more intensively during spring. The microbial community will be determined in litter samples (from the Hewins et al. study) and newly collected soil samples using molecular methods and will include fungi, bacteria and archaea (collected three times per year). The study will continue for 2 years and then a second phase of this study will be undertaken integrating data from all three studies through modelling.

Measures

GHG

- Carbon dioxide, methane and nitrous oxide emissions from soil

Microbial community

- Biomass estimates of fungi, bacteria and archaea in litter and soil
- Diversity of fungi, bacteria and archaea in litter and soil

Vegetation

- Composition of the plant community (average cover, diversity), standing crop, and litter biomass
- Plant traits likely related to decomposition rates: lignin, C:N

Soils

- A variety of data on ecosite conditions: pH, EC, OM, texture, carbon and nitrogen, organic matter
- Continuous soil temperature and moisture

Key Outcomes Expected

Our research goal is to understand where, when and how grazing (presence/absence, and grazing system) and associated ecosystem conditions alter greenhouse gas (GHG) flux from rangeland soils. We will quantify GHG emissions in grazed and non-grazed grasslands in Alberta's major grassland types and quantify the role of grazing in altering GHG emissions. By examining the microbial communities in soils at these locations - the primary source of GHG from soils - we hope to understand the mechanisms through which cattle grazing can be used to manage (including reduce) GHG emissions. Our long-term objective is to distribute this information to the public, industry and policy makers so the cow-calf industry can be recognized for the beneficial role perennial grasslands play in offsetting GHGs, including the development of policy that rewards producers for doing so.

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Controls on carbon sequestration in native grassland

L.B. Flanagan¹

¹*Department of Biological Sciences, University of Lethbridge*

Correspondence: larry.flanagan@uleth.ca

Grassland productivity and net carbon sequestration are controlled by growing season precipitation and temperature, both of which are expected to vary under climate change. However, the response of grassland carbon sequestration to climate change remains poorly understood.

Objectives

- Measure ecosystem net carbon exchange in response to environmental variation;
- Study moisture-temperature interactions that control ecosystem carbon sequestration;
- Compare local case studies with regional-scale variation in carbon sequestration; and
- Model ecosystem response to projected changes in temperature and precipitation.

Research Approaches

A. Ecosystem observational studies

- Eddy covariance studies of CO₂ flux in response to annual environmental variation
- Repeat-photography (PhenoCam) studies of annual changes in plant canopy greenness

B. Ecosystem manipulation experiments

- Exposure of grassland plots to warmer temperatures using infrared heater arrays

C. Modeling

- Development and use of models to predict ecosystem response to environmental change

Key Outcomes

- A. Net carbon sequestration (NEP) in grasslands varies to a large extent on an annual basis. However, native grassland has the potential to sequester significant amounts of carbon for extended periods of time.
- B. Variation in moisture and moisture-temperature interactions are major factors controlling grassland net carbon sequestration. If moisture remains near “normal” conditions, carbon sequestration can increase significantly in response to warmer conditions.
- C. Despite projected increases in aridity, modeled responses predict higher grassland leaf area and productivity under climate change. Shifts in vegetation growth to earlier spring emergence can compensate for drought-induced reduction in growth in summer time, particularly in northern regions of the Great Plains.

Effect of forages in crop rotations on soil carbon levels at the University of Alberta Breton Plots

M. Dyck¹, D. Puurveen¹, and J. Robertson¹

¹*Department of Renewable Resources, University of Alberta*

Correspondence: mdyck@ualberta.ca

Long-term soil experiments have shown long-term management practices such as rotation, tillage and fertilization affect soil C and nutrient reservoirs and soil C and nutrient cycling. The objective of this paper is to present the long-term, mixed annual-perennial rotations at the Breton Plots and the effects of these rotations on total soil carbon and nutrient levels over the long-term.

The University of Alberta Breton Plots

The University of Alberta Breton Classical Plots are the longest running long-term agricultural soil experiments on grey and dark grey wooded soils in North America. These soils currently occupy 15% of the cultivated area in Alberta, but could potentially occupy up to 40%. Gray Wooded soils will be focal points of future expansion of agricultural production on the Canadian prairies.

Soils in the gray soil zone in Alberta were originally called Gray Wooded, but the current name is Gray Luvisol. The old, Gray Wooded name lingers perhaps because it is such a good adjective of these soils: they are gray and they developed under forests. Thus it is not surprising to see that the gray soil zone in Alberta coincides with forested regions within and east of the foothills of the Rocky Mountains, the Peace River, and the Boreal forest.

Gray Wooded (Luvisolic) soils in the Breton area are developed on glacial till material. Glacial till is a mixture of sand, silt and clay (generally 20 to 30% clay) deposited by advancing or retreating glaciers. The most obvious characteristic of these soils is the gray colour of the topsoil. This gray colour is the result of two processes that occur in forested ecosystems: 1) organic acids released into the soils from leaf litter bleach the natural colour of the soil minerals creating a gray surface horizon 5 to 15 cm thick; and 2) above ground organic plant material (leaves, deadfall, etc) is not mixed into the surface soil horizons because, over the course of soil formation, there were no organisms such as earthworms to mix it in and tree and shrub roots are coarse and sparsely distributed in the soil. Many of the Gray Wooded soils in the Peace River areas in north-western Alberta were developed on much different water-lain sediments associated with glacial lakes and generally have higher amounts of clay. Best management practices for these soils may be different from the till soils at the Breton Plots.

Descriptions of long-term agricultural experiments at the Breton Plots

Within the Breton Plots site, a number of long-term agricultural experiments have been established over the years. The word “plots” is used in the names of the experiments, as well

as the whole site, which may cause some confusion. The Classical Plots and Hendrigan Plots are two long-term rotation experiments within the Breton Plots site.

The Classical Plots (1930 – Present)

The Classical Plots are the flagship of the Breton Plots and represents the longest on-going experiment at the site, set up to address some of the challenges faced by producers on these soils. The original treatments of the Classical Plots were intended to test which nutrients were deficient in these gray soils. and to gain better understanding of which rotations would perform better on these soils.

The Classical Plots consist of 8 fertility treatments super-imposed on two rotations: a two-year wheat-fallow (WF) rotation and a 5-year wheat-oats-barley-hay-hay rotation. Some of the original fertility treatments were modified in 1980, but they have been managed consistently since then. Table 1 summarizes the fertility treatments.

Table 1. Treatment descriptions in the Breton Classical Plot Study

Treatments, 1980 onward						
Plot	Treatment	kg ha ⁻¹				
		N	P	K	S	
1	Control	0	0	0	0	*N amounts depend on the crop and its place in the rotation: - wheat on fallow: 90 kg N ha ⁻¹ - wheat after forage: 50 kg N ha ⁻¹ - oats or barley after wheat: 75 kg N ha ⁻¹ - barley underseeded to hay: 50 kg N ha ⁻¹ - legume-grass forages: 0 kg N ha ⁻¹
2	Manure	#				
3	NPKS	*	22	46	5.5	
4	NSK(-P)	*	0	46	5.5	
5	Control	0	0	0	0	# N application via manure depends on the rotation.
6	Lime	0	0	0	0	
7	NPK(-S)	*	22	46	0	- wheat-fallow: 90 kg N ha ⁻¹ during cropped years
8	PKS(-N)	0	22	46	5.5	- cereal crops in WOBHH rotation: 175 kg N ha ⁻¹ every 5 years applied in two equal applications
9	NPKS†	*	22	0	5.5	
10	NPS(-K)	*	22	0	5.5	† subsoiled in 1983
11	Control	0	0	0	0	

The Hendrigan Plots (1980 – Present)

The Hendrigan Plots were established in 1980 to compare 3 different rotations: 1) continuous grain (CG) with N, P, K, and S fertilization and straw returned to the Plots; 2) continuous forage with N, P, and S fertilization (CF fescue and white “Dutch” clover) and 3) an 8-year “agro-ecological” rotation of barley, faba beans and grass-legume forages. The CG and CF rotations are meant to represent two extreme cropping systems that could be implemented on gray wooded soils.

The continuous forage system consists of a creeping red fescue, tall fescue and white “Dutch” clover. This was conceived by a farmer from Winfield, AB, Mr. Lou Hendrigan. Mr. Hendrigan was an advocate of growing perennial forages on Gray Wooded soils and was quoted as telling farmers in the area: “Don’t spend money on expensive equipment – put power in the soil not on it.” The system is based on nitrogen supply through N-fixing legumes (white clover) and low amounts of added P and S fertilizers.

The 8-year agro-ecological crop sequence was designed as a mixed farming rotation that is self-sufficient for nitrogen fertility. Nitrogen is supplied to this cropping system by a combination of manure and biological fixation (faba beans, alfalfa and red clover). Grazing is “simulated” by removing hay and returning manure.

The CF and CG rotations are meant to simulate strict cropping systems that aren’t grazed and no manure is introduced into the soil. Thus, nitrogen fertilizer is used as the primary N source for these rotations. A complete nitrogen balance of the three rotations included in the Hendrigan Plots is presented later in this article along with the fertilizer N rates used.

Key Results

- Mixed annual-perennial cropping rotations are the most productive rotations at the Breton Plots in terms of grain and forage yields;
- Total soil C and nutrient levels in the mixed annual-perennial cropping rotations were much higher than rotations with only annual crops because of much higher root biomass and return of crop residues to the soil; and
- Some of this sequestered C (perhaps eventually all of it), however, is offset because a portion of the biologically fixed N in the alfalfa (and likely clover) is lost as nitrous oxide (N₂O) – a potent greenhouse gas.

Impacts of tame forage management on ecosystem flux and soil carbon stores for black soil in central Alberta

V.S. Baron¹, R. Lemke², A.C. Dick¹ and D.G. Young¹

Agriculture and Agri-Food Canada, ¹Lacombe, AB and ²Saskatoon, SK.

Correspondence: vern.baron@agr.gc.ca

Beef-cow herds require approximately 90% of their feedstuffs from forage and grazing systems. Tame forage and pasture in Alberta have traditionally supplied about 60% of the annual forage production and utilize approximately 2.5, 2.2 and 0.32 million ha for pasture, hay and annual green feed and silage. Grasslands per se represent the larger percentage of soil organic carbon (SOC) stores in agriculture since they occupy the same total area as all cultivated crops and are more permanent by nature, requiring the least tillage of any crop type. Because the perennial lands occupied by tame forage have been broken at some point they may be classified as being in the process of conversion of cropland to grasslands and lands occupied by annual forages may be classified as the reverse, conversion from grasslands to croplands. Using the Century model, the Canadian National Inventory Report (2011) estimates for conversion of cropland to grassland on black soils in the Prairie Parkland a linear sequestration rate of 0.55 Mg ha⁻¹yr⁻¹ SOC over the first 20 yr. of conversion and a mean rate of 0.2 Mg ha⁻¹yr⁻¹ SOC over 100 years; a land management change from grassland to cropland or the reverse results in SOC loss of the same magnitude. Some research (Bremer et al. 2008) has indicated that the duration of SOC accumulation after conversion to grassland is much shorter than 10 years, after which further accumulations are barely significant, without applications of fertilizer-N.

Many farms in the Parkland of the Prairie Provinces have land devoted to some or all of long-term grassland (old grass pastures or hay lands), short-term hay and pasture lands and annual forage used as green feed and silage. However, a recent survey of central Alberta dairy farms indicated that few dairy farms in this region have a large perennial feed component, using mostly barley silage, and 50% have tried or use corn silage in their operations. Thus, forage management may result in complete soil cover of vegetative material and substantial return of vegetative C-inputs or intermittent vegetative cover and small C-inputs after crop harvest is considered. Forage crop lands as a whole are a collection of C-sources and sinks in any year and their status as sources and sinks is dependent on many factors including fertilizer inputs, stand age, previous cropping history and current organic carbon content.

Objectives

1. Follow ecosystem carbon dynamics through the life cycle of a meadow bromegrass stand (establishment to breaking) from 2002 until 2010 using the Bowen Ratio Energy Balance (BREB) method; and
2. Determine short-term effects of pasture, hay and barley silage production systems compared to an “Old Grass” baseline on harvested-C, root and residue-C inputs and SOC stores.

Experimental Approach

All of the research was conducted on sandy-loam soil at the Lacombe, Research Centre at Lacombe Alberta. The SOC content in the 0-5 cm and 5 -15 cm depth ranged from 4.6 to 5.5% and 3.5 to 4.5%, respectively, typical of Ecodistrict 737 (Bowden to Wetaskawin).

Ecosystem carbon dynamics over a meadow bromegrass life-cycle were determined from 2002 until 2010. The BREB method was used to follow the year-round assimilation of CO₂ in a 20-ha crop and the concurrent respiration of CO₂ from establishment under canola until chemical desiccation and direct seeding to barley for silage harvested in 2010. Net ecosystem CO₂ exchange (NEE) was determined annually and Net Biome-C determined after taking crop removal into account. In a second experiment, a study comparing impacts of perennial and annual pasture management on soil properties had been set up in a replicated study beginning in 1993 in 9 m x 30 m fenced paddocks (Baron et al. 1999). In 1993 the land was broken from perennial grassland, then half immediately seeded back to Meadow bromegrass or smooth bromegrass and the other half to cereals. All treatments were grazed and utilized, originally, from 1994 until 1997. From 1998 until 2006 the perennial paddocks received no inorganic-N inputs and were grazed or treated as hay. The cereal treatments were retained as chemical-fallow or planted to barley which was harvested as hay, also with no inputs. From 2006 until present the annual paddocks were direct seeded to barley for silage with 100 kg-N ha⁻¹ and 30 kg-P₂O₅ ha⁻¹ broadcast. A portion of the original annual paddocks were planted to meadow bromegrass controls, meadow bromegrass with Fertilizer-N and meadow bromegrass-alfalfa mixtures and utilized as either hay or rotational grazing. Measurements were taken from 2008 until 2012.

Measurements

In the first experiment CO₂ flux was determined daily for 365 days of each year from April 2002 until the end of March 2011 using the BREB technique. We will present annual NEE determined from the BREB and net Biome-C. Daily night time, day time and net C flux accumulated monthly, averaged over years will be shown for the 12-month periods. We have determined annual gross primary photosynthesis and respiration from this experiment. Attendant SOC and vegetative-C input data were taken. In the second experiment SOC and light fraction soil-C data were taken in the spring and fall of each year as well as vegetative-C inputs of roots, residue and vegetative-C removed.

Key Outcomes

Experiment 1

Carbon sequestration is the difference between carbon accumulated in the system through net photosynthesis and loss through respiration, which occurs due to microbial respiration of organic matter in soil residue and crop residue. Three very dry years reduced the number of days in which there was a net uptake of CO₂. The two dry establishment years averaged 80 days of uptake compared to 130 days for production years of 2004 to 2009. The bulk of the accumulation of NEE-C occurred during the periods of first growth prior to hay cut. Net uptake was initiated when the leaf area index reached 2.0 or twice the ground area. During years of high uptake it was initiated in April and carried on until October. During 2010 when barley silage was produced net CO₂ uptake only occurred on 61 days. CO₂ loss appeared large in springs following the drought years and also appeared large in the breaking year, but may have been due to the decaying root mass of the perennial crop.

The meadow brome grass stand was an NEE source during 2002 and 2003. Taking the accumulated NEE into account the meadow brome grass averaged a net gain of 0.51 Mg C ha⁻¹ yr⁻¹ from 2002 to 2009. During the production years under a hay-graze system the perennial stand was a NEE-sink in 5 of 6 years. However, when we take harvested carbon into account the stand was a Biome-C source in 4 of the 6 years. This doesn't include years when the Biome-C loss was less than 0.5 Mg ha⁻¹ yr⁻¹.

Therefore it is difficult to believe that the perennial grass stand could accumulate-C under the weather and management regime that occurred. The question remains: Could a net carbon gain or balance occur had the perennial not been broken, had drought not occurred and the land been managed as pasture? Further the barley silage system projects to be one of the poorest forage practices for C-sequestration.

Experiment 2

When SOC mass from the "Old Grass" (meadow brome grass) from 1993-97 was compared to 2008-12 there was essentially no change. However, there was a loss of 22% of SOC mass in the 0-5 cm depth and a loss of 16% in the 0-15 cm depth for the annual or barley silage treatment. It is important to note that the new meadow brome grass hay and pasture stands were planted into some of the barley ground in 2006. When the average of 2008 to 2012 treatment means were compared, the new stands' SOC mass was similar to the barley baseline at the 0-5 cm depth, but as the depth was increased to 0-30-cm the difference between "Old Grass" baseline and the meadow brome grass pasture, in particular, diminished and they were similar. The SOC content for the meadow brome grass pasture was similar to the "Old Grass" baseline at 5-15 cm and 15-30 cm depths, but was less at the 0-5 cm depth. The MB hay was lower in SOC content than the old grass at the upper depths, but similar at the 15 - 30 cm depth. SOC content for all perennials was greater than the Barley silage. The light fraction C-mass of the barley silage treatment was less than half of the "Old Grass" baseline and was significantly less than all perennial treatments at all depths. Generally, the light fraction C-mass for meadow brome grass pasture was greater than the meadow brome grass hay and averaged 81% of the "Old Grass" baseline. Thus the light

fraction carbon for the meadow brome grass pasture accumulated rapidly. Further, light fraction carbon mass for the pasture and hay systems where N-fertilizer was applied was greater than meadow brome grass controls and treatments including alfalfa. The root mass for all perennial treatments was similar and double that of the barley silage. The residue left after pasture was twice that of barley silage and meadow brome grass hay and three times the “Old Grass” baseline.

Conclusion

The studies indicate that a perennial grass cover *per se* is not sufficient to cause C-sequestration, annually, for a long duration on black soils in central Alberta. Carbon stores may be lost rapidly during spring time if green leaf area is not available to counter respiration loss with higher rates of net photosynthesis. On the other hand removal of C-inputs in an annual forage system such as a barley on barley silage sequence may result in substantial loss of SOC. It appears that systems which maximize C-inputs such as rotational pasture may allow recovery from sub-optimal management to close to perennial baseline levels, but at first light fraction carbon may account for the SOC increase. This fraction is susceptible to microbial respiration and may be highly vulnerable after dry years. Fertilizer-N appears to enhance accumulation of light fraction-C as shown in previous research. This research does not indicate the effect that N-inputs would have on the SOC accumulation for the “Old Grass” baseline. Further: Does increasing productivity always result in net SOC accumulation if the above ground biomass is removed, limiting organic C inputs? Increasing yield requires increased photo-assimilate-energy to maintain increased or higher above ground biomass and root mass.

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Net CO₂ exchange and carbon budgets of a three-year crop rotation following conversion of perennial lands to annual cropping in Manitoba, Canada

B. Amiro¹

¹Department of Soil Science, University of Manitoba

Correspondence: brian.amiro@umanitoba.ca

Summary of:

Taylor, A.M., Amiro, B.D., and T.J. Fraser. 2013. Net CO₂ exchange and carbon budgets of a three-year crop rotation following conversion of perennial lands to annual cropping in Manitoba, Canada. *Aggr. Forest Meteorol.*, 182: 67–75.

Experimental Approach

Flux towers were used to measure net ecosystem production over three adjacent agricultural fields in Manitoba, Canada, from 2009 to 2011 as 30-minute averages. Two fields were converted from long-term perennial hay/pasture to annual cropping, while the third field served as a control field that was maintained as hay/pasture. One converted field had a rotation of oat-canola-oat crops, while the second was hay-oat-fallow. Weather affected inter-annual variability, with poor yields on all fields in 2011 because of dry conditions in summer, with the summer-fallow condition on one field caused by excess spring moisture not allowing planting.

Key Results

Cumulative net ecosystem production over the 30-month study period was:

- Oat-canola-oat field lost 100 g C m⁻²;
- Hay-oat-fallow field lost 500 g C m⁻²; and
- Hay field gained 550 g C m⁻².

The hay field had the highest cumulative gross primary production of 2500 g C m⁻², whereas the oat-canola-oat and hay-oat-fallow fields had only about 1400 g C m⁻². The perennial field had the advantage of both early- and late-season growth when crops were absent on the other fields. The hay and hay-oat-fallow fields had comparable cumulative ecosystem respiration (1400 g C m⁻²). Manure additions contributed 300 g C m⁻² on the two converted annual-crop fields.

With harvest exports and manure additions included over the 30-month period:

- Oat-canola-oat field lost 240 g C m⁻²;
- Hay-oat-fallow field lost 415 g C m⁻²; and
- Hay/pasture field gained 120 g C m⁻².

Quantifying C change over time on re-established pasture of native species mixes

B. McConkey¹, and A. Iwaasa¹

¹*Agriculture and Agri-Food Canada, Swift Current, SK*

Correspondence: brian.mcconkey@agr.gc.ca, alan.iwaasa@agr.gc.ca

Depending on expected returns differentials between grain farming and cattle raising, there can be considerable interest in converting marginal cropland in the semiarid Brown soil zone to permanent perennial pasture. Aside from the importance that native grasslands play as a repository for biodiversity, wildlife habitat and a grazing resource, the restoration and maintenance of native grasslands can provide an important opportunity to mitigate greenhouse gas concerns through soil organic carbon (SOC) sequestration. Native grasses have more extensive rooting system than tame species, and higher species richness can result in higher SOC potential.

Objectives

- Determine the effect of on native species mix, grazing, and grazing regime on production and grazing duration; and
- Determine the effect of native species mix, grazing, and grazing regime on SOC sequestration.

Experimental Approach

Sixteen pastures (2 ha ea) were randomly set up in a factorial design involving two native mixtures [7 species simple (S) or 14 species complex (C)] seeded in spring 2001 on long-term cropland. In each pasture a permanent enclosure (3.6 x 3.6 m) was used as the non-grazing treatment. From 2002 to 2004 there were four replicates and two grazing utilization levels [low (40-50%) and high (60-70%)]. From 2005 to date, there has been two replicates and four grazing regimes based on timing (continuous, spring only, summer only, and fall only).

Measures

- Pentagonal microsites designed for repeated soil sampling were established
 - SOC to 60 cm in 15 cm increments in fall 2000, 2004, 2008, 2011, 2014 (not all microsites were measured to full depth in all years)
- C in litter
- C in surface fecal deposits
- C in above ground pasture growth (in cage)
- Grazing duration
- Species abundance (annual)

Key Results

From 2000 to 2004, there was overall increase in SOC of 3Mg ha⁻¹ to a depth of 30 cm. However, for 2008 and 2011 sampling there was few hundred kg ha⁻¹ more SOC than 2000 including C in litter and fecal matter at soil surface. There were no clear treatment differences although the non-grazed tended to have more SOC than the grazed. Nearby evaluation of SOC on cropland over the same period showed that SOC dropped over this period, indicating that loss of SOC from decomposition exceeded C input on cropland. Thus, relative to what the SOC would have been without native establishment, there was likely a C gain. Absolute SOC change can be positive or negative; it is preferable to have a check treatment that follows historical management to gain better understanding of SOC change in relative sense. We look forward to analysis of 2014 sampling that was more intensive regarding number of microsites measured and to depth of measurement.

Guidance for designing measurement strategies for quantifying carbon stocks on grassland at one time, over time, and/or over space based on global literature review

B. McConkey¹, É. Maillard², and D. Angers²

Agriculture and Agri-Food Canada, ¹Swift Current, SK and ²Ste Foy, QC

Correspondence: brian.mcconkey@agr.gc.ca, emilie.maillard@agr.gc.ca, denis.angers@agr.gc.ca

Worldwide and in Canada, carbon stocks in permanent grasslands are important. To manage this grassland carbon, we need to be able to quantify its amount and how it is being affected by management and climate. However, carbon stocks in grasslands are generally more heterogeneous in space than cropland due to interactions between vegetation community patterns, accumulation of C in perennial vegetation and litter, livestock behaviour and management, and/or variation in underlying soil landscapes. Consequently, efficiently and effectively quantifying carbon stocks on grassland is a challenge and applying methods developed for more homogenous cropland may not be appropriate.

Objectives

- Summarize current state of knowledge on detection ability of general measurement strategies based on experience in scientific literature; and
- Use the experience to develop guidance to assist designing appropriate measurement strategies for quantifying carbon stocks in one pasture at one time, carbon stock changes over time, and/or carbon stock differences over space.

Approach

Review worldwide scientific literature on quantifying C stocks on heterogeneous landscapes. Two thousand (2000) citations were identified for evaluation. Of these, 795 have been identified that characterize and/or discuss SOC variability and measurement strategies.

Measures

- Develop typology of C stock measurement strategies and situations for measurement;
- Determine SOC stock detection ability of different strategy-situation type combinations; and
- Identify techniques that provide good detection ability with effective use of measurement resources.

Key Outcomes Expected

Several scientific papers that summarize current state of scientific knowledge will be published. An international committee brought together through the Global Research Alliance on Agricultural Greenhouse Gases will develop guidance to assist design of effective measurement strategies to meet desired detection ability for grasslands.

What lies beneath: carbon in wetland and buried soils

A. Bedard-Haughn¹, D. Pennock¹, and B. Helgason^{1,2}

¹*Department of Soil Science, University of Saskatchewan;* ²*Agriculture and Agri-Food Canada, Saskatoon, SK*

Correspondence: angela.bedard-haughn@usask.ca

The Prairie Pothole Region (PPR) spans 800,000 km² and encompasses millions of freshwater mineral soil wetlands. It also encompasses some of the most fertile agricultural land in North America. Over the past century, the PPR landscape has been dramatically altered by agriculture, including tillage and drainage. Despite the potential importance of wetland soils for accurate inventory of soil C stocks, they often fall between the cracks: too wet for soil scientists and too dry for wetland scientists. Over the past decade, much more recognition of their significance, but there is still room for improvement!

Redistribution of soil across the landscape changes lateral and vertical distribution of SOC. In those landscape positions where tillage redistribution has resulted in inverted profiles (i.e., the original A horizon is buried by low SOC material from eroding knolls), we may actually underestimate SOC stocks. Furthermore, these buried A horizons are thought to be protected from further decomposition, and therefore represent potential C sinks. Interestingly, eroded knolls are also potential sinks through “dynamic replacement” with newly sequestered C, especially when restored to grassland.

Objective

Quantify SOC in PPR soils with different management histories, with emphasis on wetland soils and soils that have evidence of substantial soil redistribution.

Experimental Approach

Wetland C

- Quantifying C in cultivated wetland soils of the Black soil zone with different drainage histories: never drained, recently drained (≤ 15 yr), medium-term drained (15-35 yr), and long-term drained (≥ 35 yr) (2015, unpublished data)
- Quantifying C in wetland soils of the Dark Brown soil zone with different management histories: native (never-tilled), uncultivated (tilled in the past, but not currently), and cultivated (annual cropping) (Bedard-Haughn et al., 2006)
- Quantifying C in restored wetland soils across the Prairie provinces: recently (< 5 yr) vs. long-term restored (≥ 5 yr) (Badiou et al., 2011)

Buried C

- VandenBygaart et al. (2012) examined SOC concentrations/stocks with depths at six sites across Canada. They also used ^{137}Cs and A horizon thickness to evaluate amount and timescale of C redistribution over past 50 years
- Helgason et al. (2014) considered microbial activity in buried profiles at one of VandenBygaart's sites, examining microbial abundance and C mineralization
- Other studies have noted buried profiles with potentially much longer redistribution histories (e.g., Bedard-Haughn and Pennock, 2002)

Key Results

- Preliminary results suggest that drainage may not drive SOC loss from wetland soils in the Black soil zone; there may even be a slight increase in SOC in some drained wetland soils compared to cultivated wetlands that had not been drained, perhaps due to improved plant growth under drainage (2015 unpublished data);
- Cultivation, of course, *does* have a significant impact on wetland SOC levels in the Dark Brown soil zone, with cultivated wetlands having about half of the SOC of uncultivated or native wetlands (Bedard-Haughn et al., 2006);
- Across the Prairies, wetland restoration has the potential to sequester up to $2.7 \text{ Mg C ha}^{-1} \text{ year}^{-1}$, equivalent to $9.9 \text{ Mg CO}_2 \text{ eq. ha}^{-1} \text{ year}^{-1}$. Even after accounting for increased CH_4 in restored wetlands due to prolonged saturation, the net sequestration is up to $3.3 \text{ Mg CO}_2 \text{ eq. ha}^{-1} \text{ year}^{-1}$ (Badiou et al., 2011);
- Within-field tillage redistribution led to redistribution of approximately 200 Mg ha^{-1} SOC (to 60-cm depth) in Alberta (Mundare) and Saskatchewan (St. Denis) study sites, with estimated deposition rates of about 4 Mg/ha/yr (VandenBygaart et al., 2012);

- At the St. Denis site, buried SOC was found to be associated with an abundant microbial community, as indicated by phospholipid fatty acid (PLFA) analysis (Helgason et al., 2014). However, a follow-up mineralization study found that despite the presence of high levels of SOC and associated microbial biomass, the C mineralization rates for the buried soils were 76% lower than surface soils, suggesting the buried SOC is unavailable for decomposition (even under comparable environmental conditions; manuscript in preparation); and
- Not all buried soils are due to management history; 3-m deep paleosols found at another site in the St. Denis area were attributed to historical periods of climate instability during the Holocene (Bedard-Haughn and Pennock, 2002). Interestingly, this buried profile and that used for the PLFA study above were not in depression centers, but rather in concave positions just upslope from the depression, suggesting very different landscape morphology pre-redistribution.

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Looking at grassland carbon storage: how can remote sensing help?

J. A. Gamon¹

¹*Departments of Biological Sciences and Earth and Atmospheric Sciences, University of Alberta*

Correspondence: gamon@ualberta.ca

Increasing atmospheric carbon dioxide levels are changing the climate and altering the metabolism of the Earth, all of which threaten the sustainability of current human economic activities. Proposed mitigation measures include voluntary and regulated carbon markets that would encourage reductions in anthropogenic carbon emissions and encourage carbon sequestration efforts. Given the large exchanges of carbon between the biosphere and atmosphere, opportunities exist for enhanced biospheric carbon sequestration. Such biosequestration provides a feasible way to begin to reduce net carbon emissions while other, long-term policy and technical solutions are still being developed. Biosequestration also offers several potential co-benefits involving a number of ecosystem goods and services that offer additional economic benefits.

Measuring biospheric carbon uptake and putting a value on carbon are fundamental steps to calculating the costs and benefits of biosequestration. Such measurements can provide a foundation for developing effective and realistic carbon policy. Fortunately, we now have the technology and ability to measure biospheric carbon sequestration. Currently, remote sensing combined with field measurements in a modeling framework provides ongoing estimates of biospheric carbon uptake for the entire planet. These methods and the information they provide are not effectively utilized in current carbon policy. Incorporating these methods can provide the opportunity for Alberta to develop an effective and realistic carbon policy that includes biosequestration.

This presentation will briefly review current carbon monitoring methods with a particular focus on the advantages and challenges of remote sensing and coupled ground validation of carbon exchange for Albertan rangelands. A vision of an operational carbon monitoring system (a “Biospheric Carbon Network”) will be presented. Such a system could demonstrate actual carbon sequestration levels, inform carbon policy, certify emerging carbon markets, and provide new opportunities for a diversity of industries and economic activities.

Applying the numbers for credible outcomes

Sheilah Nolan¹

¹Alberta Agriculture and Rural Development

Correspondence: sheilah.nolan@gov.ab.ca

The capacity of soils to sequester carbon is becoming increasingly valued as a means of lowering greenhouse gas emissions in Alberta, the United States and internationally. However, using highly variable measurements of soil carbon to quantify impacts of management changes on rates of carbon sequestration is a challenging process. The International Organization for Standardization (ISO) 14064-2 provides good practice guidance for developing factors that quantify management changes for use in offset protocols - based on sound science, a conservative approach and technical reviews. An example will illustrate how measurements of soil carbon were used to estimate regional management change factors for a protocol that generated over \$132 M in offset sales. High quality measurements, expertise, collaboration and peer review were essential components of this success.

Resources

i) *Soil Quality Benchmark Study - Methodologies for Site Selection, Soil Sampling, Monitoring, Science Development*

<http://www.agric.gov.ab.ca/soilquality>

ii) *Conservation Cropping (Carbon Sequestration) Protocol*

<http://esrd.alberta.ca/focus/alberta-and-climate-change/regulating-greenhouse-gas-emissions/alberta-based-offset-credit-system/offset-credit-system-protocols/documents/ProtocolConservationCropping-Apr2012.pdf>

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Risk, rigour and demonstration: how science can address policy needs

A. Neupane¹

¹*Alberta Environment and Sustainable Resource Development*

Correspondence: anish.neupane@gov.ab.ca

Abstract

Sound research and science is critical to informing the development of robust approaches to address resource and environmental issues. Needed also are accompanying institutional and regulatory systems and processes that confer and validate actions taken to address the issues. For example, Alberta has developed an objective to reduce carbon emissions and created a regulatory infrastructure where emission reduction activities are recognized as carbon offset. Alberta is building on this approach by articulating system design elements for offset. These elements articulate Alberta's intent on how offset fits within Alberta's various regulatory processes and identifies a set of requirements that will be common to an offset program developed to address a given issue. This presentation provides an overview of the interaction between science and its application to policy implementation.