The Effect of Forage Management on Carbon Storage in Pastureland and Rotation

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ABSTRACT

Degraded land with less than 1.5% organic carbon (class 4 and 5 land) in the Parkland of Western Canada has significant potential, from 5 to 15 Mg C ha^{-1} depending on management, for carbon storage with forages in the Parkland. The potential ranges from 5 to 15 Mg C ha^{-1}, over a period from 15 to 20 years, depending on fertility management of forages in pasture and initial levels of soil organic carbon. Nitrogen fertilizer increased organic carbon stored in reseeded pastures at Pathlow and Brandon relative to paddocks without fertilizer. Over a period of 12 years (1978-1989) in the Pathlow study, 21.9 Mg C ha^{-1} (0-15 cm) was stored when N fertilizer was applied at an annual rate of 45 kg ha^{-1} compared to the control treatment, which was attributed to accumulation of plant debris and roots at the surface. Increases in organic carbon did not persist 10 years after N fertilizer was discontinued at the study at Pathlow, Saskatchewan. At Brandon, Manitoba, fertilized grass pasture stored 16.2 Mg C ha^{-1} (0-50 cm) compared to unfertilized bromegrass from 1994 to 1999. Long-term forage rotations at Melfort showed no significant difference in the wheat phase of a F-W-W-H-H-<u>W</u> rotation due to nitrogen fertilizer (147.3 Mg C ha^{-1} 150.7 Mg C ha^{-1}) over a period from 1957 to 1994. This was attributed to the high levels of soil carbon in soils at Melfort. Forages in rotation had no significant effect on organic carbon in a study at Glenlea MB conducted from 1992 to 1999, though a range from 110.8 to 145.7 Mg C ha^{-1} was observed. Significant differences may occur in the long term as organic carbon accumulates in the treatments at Glenlea.

INTRODUCTION

Carbon sequestration, or storage of carbon in the soil as organic matter, is one means of removing CO_2 from the atmosphere. Carbon dioxide (CO_2) is a significant greenhouse gas to which one half of current global warming is attributed (Flach et al. 1997). Carbon dioxide was estimated to be about 353 parts per million by volume (ppmv) in 1990, and was increasing at a rate of about 0.5% CO_2 per year (Flach et al. 1997).

Grazing land in Canada represents a significant land area with considerable potential for carbon storage. In Western Canada, the extent of land in pastureland is a significant proportion of total agricultural lands. Given the acreage of pastureland in Canada there is considerable potential for storage of carbon in the soil. In the Parkland area of Western Canada, degraded land with less than 1.5% organic carbon (class 4 and 5 land) has significant potential (between 5 and 15 Mg C ha-1 depending on management) for carbon storage with forages. Approximately 6 million ha of class 4 and 5 land, currently under annual crops, have the most potential to store organic carbon (R. Eilers personal communication). These soils are often degraded or naturally low in organic carbon, have low potential production for annual crops, and are ideal for conversion to forages or pasture.

Pastureland, defined as agricultural land seeded to forage species, has been cited as an effective system for carbon storage. For example carbon storage averaged 1.1 Mg C ha^{-1} yr^{-1} over a period of five years in a survey of land under the Conservation Reserve Program (CRP) in the United States (Gebhart, D.L. et al. 1994). Although sources and sinks of CO_2 are well known there is little published information regarding the rates of change of soil organic carbon due to pasture management and forages in rotation from long-term studies in Western Canada.

In Western Canada some long-term field trials have shown a significant increase in soil organic carbon due to fertilizer management. Malhi et al. (1991) measured an increase of 20.1 g C kg^{-1} soil in seeded pasture at fertilizer rates of 336 kg N ha^{-1} though forage yield maximized at 224 kg N ha^{-1}. Mass of total C in soil at 168 kg N ha^{-1} was increased by 18.98 Mg ha^{-1} in 0-30 cm and by 43.48 Mg ha^{-1} in the 0-60 cm layer when compared to the treatment with no fertilizer (Malhi et al. 1997). Nyborg et al. (1994, 1998) reported increases of 5.4 and 9.3 Mg ha^{-1} in soil organic carbon (SOC) for two studies in smooth bromegrass grassland.

These increases were attributed to increases in biomass production due to N fertilizer. However, P and S greatly increased yield compared to N alone in other studies (Bittman et al. 1997, McCartney et al. 1998). Herbage and SOC respond similarly to N, P and S fertilizer, consequently fertilizer response curves of forages should be considered in predicting carbon storage for fertilized soils. Fertilized perennial grasslands have considerable potential for carbon storage, though fertilizer inputs must be continued to maintain sequestered carbon. Nyborg et al. (1998) also attributed the significant increase of SOC in the light fraction organic matter content of soil (0-37.5 cm), under fertilized bromegrass stands, to increased root growth. Soil organic carbon does not always increase with N fertilizer. Belanger et al. (1999) and Campbell et al. (1991) found no significant increase in soil organic carbon due to fertilizer. This was attributed to the high levels of organic carbon found in soils at these sites prior to addition of N fertilizer.

Forages in crop rotation provide an environment for carbon storage similar to pasture. Below ground production of root biomass in forages is greater than annual crops (Paustian et al. 1997) although tillage related to annual crops may remove soil organic carbon stored by the forages. Rotations with 2-5 years of arable crops and forages did not result in a change in total soil organic carbon in a study in New Zealand. Aggregate structure, carbohydrate content and microbial biomass increased during in the forage phase of the rotation, but decreased when the pasture was plowed (Haynes et al. 1991). Similarly no significant difference in soil organic carbon was observed for forages in rotation with corn, in a soil previously cropped to forages (Baldock and Kay 1987). Campbell et al. (1997) found no increase in soil organic C after thirty years on a soil initially high in soil organic C.

OBJECTIVES

The objectives of this study were: 1) to describe changes in several long-term research studies of pasture management and forages in rotation and 2) assess the potential for management to store carbon in pasture systems under various management systems.

METHODS

Analytical methods

Total, organic and inorganic carbon, and total nitrogen were determined from finely ground samples with an elemental analyzer (Carlo Erba 2500). Soil samples were treated with 2 M HCl to remove inorganic carbon prior to analyses for organic carbon. Soil carbon was calculated without correction for equivalent mass (Ellert and Bettany 1995), as treatments did not significantly affect bulk density. Carbon mass for archived samples was calculated with previously published values for bulk density. All carbon data are reported in mass per unit area to facilitate comparison.

Archived samples, Melfort and Pathlow

Soil carbon was measured in samples archived from the studies at Melfort and Pathlow. The samples were air dried after sampling, ground through a 2 mm mesh screen and stored at room temperature. Carbon mass for samples was calculated with previously published values for bulk density.

Field samples and methods, Glenlea and Brandon

Microsites were located and sampled in the field experiments at Glenlea and Brandon. The microsites were sampled in 1997, 1998 or 1999 depending on the experiment, according to the protocol described by Ellert et al. (2001). The location of each 2 by 5 m microsite was recorded for future sampling. At each microsite plant residue at the surface was removed prior to sampling and six soil cores were collected using a hydraulic sampler. Soil samples were obtained with a coring tube (3.78 cm diameter). Six cores, sampled at 0-5 cm, 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, and 40-50 cm, were then bulked into separate samples by depth increment for analysis.

Sample preparation and analytical methods

Soil samples from each microsite for each depth increment were combined and weighed. A subsample was taken for soil moisture, sieved through a 2 mm sieve and air-dried. Soil samples were first ground through a 2 mm sieve, then a subsample was finely ground in a ball grinder to pass a 100 mesh screen. Light fraction carbon was measured in samples (0-5 cm and 0-10 cm in 1997) following the protocol developed by Janzen et al. (1992). Bulk density was calculated from the volume and total weight of microsite core samples corrected for soil moisture.

Statistical analyses were calculated with analysis of variance (Steel et al. 1997) with orthogonal contrasts in JMP for randomized complete block designs at Pathlow and Brandon (SAS Institute, 2000 version 4). The split plot design at Glenlea was analyzed with protected least significant differences in Genstat (Genstat 5 1997, version 4.1). Linear regression was conducted with JMP for analysis of trends for data from Melfort (SAS Institute, 2000, version 4). Analysis of variance was conducted based on an assumption of normality and homogeneity of variance for all variables. Homogeneity of variance was assessed with the Brown-Forsythe test (SAS Institute, 2000, version 4) for the study of organic carbon in hummocky terrain, and data transformed with a log transform where required. Significant heterogeneity of variance was observed for some soil properties at Pathlow and Brandon, where the test statistic was likely influenced by the low number of observations (2-3) per treatment. The variables were not transformed for these studies. Analysis of variance is robust, and can operate well even with considerable heterogeneity of variances and non normal distributions, as long as all n equal or nearly equal (Zar 1984).

Rotation study, Melfort

The objective of this study was to determine the relative effects of fertilization and forage (hay) crops in a long-term study initiated at Melfort in 1957 and continued through 1994. Plots were established in 1957 on land broken from aspen and grassland near 1900, and managed in a cereal-cereal-fallow cropping system under conventional tillage (K. Bowren, pers. comm.). The field study included all phases of all rotations in a randomized complete block design with four replicates. The long-term rotations were on land classified as being in the Melfort association (Orthic Black), with a silty clay texture developed on lacustrine deposits and situated on generally level to very gently sloping topography.

During 1960-1971 fertilized rotations received N and P based on general recommendations for the region as provided by the Saskatchewan Advisory Council on Soils. Wheat grown on conventional fallow and wheat grown on partial fallow after plowdown of sweetclover received an average rate of 7 kg N/ha plus 32 kg P205/ha while wheat grown on wheat stubble or after bromegrass-alfalfa hay received only N at an average rate of 27 kg/ha plus P205 at a rate of 23 kg/ha. Hay plots received only N, at an average rate of 75 kg/ha. From 1972 to 1986, N and P fertilizers were applied to fertilized rotations based on soil tests and guidelines for field crop fertilization as prepared by the Saskatchewan Advisory Council on Soils. During this period, wheat grown on fallow and on partial fallow after plowdown of sweet clover received N at an average of 18 kg/ha plus P205 at an average rate of 41 kg/ha; canola grown on fallow received 12 plus 38, wheat grown on wheat stubble 73 plus 42, wheat and canola grown after hay 37 plus 40, and hay plots received and average of 82 plus 28 kg/ha N plus P205 respectively. From 1987 to 1991 canola following fallow received N and P205 at rates of 45.5 and22 kg/ha respectively. Wheat following summerfallow or canola stubble received N and P205 at rates of 26 and 34 kg/ha respectively. Wheat following summerfallow in Fallow-Wheat-Wheat received N and P205 at rates of 45 and 34 kg/ha respectively. Wheat following wheat or canola in Fallow-Wheat-Wheat received N and P205 at rates of 65 and 34 kg/ha respectively.

Total and organic carbon, were measured in archived soil samples, collected in 1970, 1978, 1982, 1986 and 1994 for the sixth phase of the fertilized and unfertilized Fallow-Wheat-Wheat-Brome Alfalfa Hay- Brome Alfalfa Hay-Wheat rotations. Bulk densities used in the calculation of carbon mass were from Campbell et al. (1991) and Beckie et al. (1995). Biomass production was measured in rotations with brome-alfalfa with a forage harvester, while residue production was estimated based on annual crop yield and harvest index for straw and roots. Inputs of carbon from forage and annual crop biomass are based on a carbon content of 45% (Campbell et al. 1991).

Rotation study, Glenlea

The objective of this study was to determine the effect of pea, sweet clover and 2 years of alfalfa in cereal-based rotation on the level of soil organic carbon. A second objective was to evaluate the effect of fertilizer on carbon storage in these systems which were established in 1993. Data collected in this study will provide a baseline for future assessments of carbon storage.

The study area was under conventional tillage with continuous cropping since 1965. Forages were part of the rotation from time to time, main crops were wheat, barley and sunflower. No manure has been applied to the area for 18 years. Soils at the site were classified in the Red River association, and were characterized as a Humic Gleysol solum developed on glacial lacustrine deposits with a clay texture in generally level to very gently sloping terrain.

The factorial experiment has crop rotation as main plots, and fertilizer and herbicide use as subplots. Crop rotations include 1) wheat-pea-wheat-flax (W-P-W-Fl); 2) wheat (under seeded to sweet clover)-wheat-flax (W.Cl-W-Fl); 3) wheat- alfalfa (two years)-flax (W-Al-Al-Fl); and 4) a restored native tallgrass prairie (mixture of indigenous cool and warm season grass species; plots successfully established in summer of 1993). All treatments are replicated three times in a split plot design.

The flax crop phase of rotations 1, 2, and 3 was sampled in 1999 for all fertilized and unfertilized rotations with pesticides. Native grass plots were also sampled. One microsite was located in each plot.

Pasture study, Pathlow

The objective of this study was to determine the impact of nitrogen, phosphorus and sulphur fertilizer on carbon storage in brome alfalfa. The study site was located in an area, which was cleared of aspen (*Populus tremuloides* Michx.) in 1973 and seeded to bromegrass alfalfa (D. McCartney, pers comm.). The site has been continuously grazed since clearing. In 1978 nitrogen fertilizer was applied at rates of 0, 45, and 90 kg N ha^{-1} with P fertilizer at rates of 0 and 20 kg P ha^{-1} to plots in bromegrass and alfalfa on an annual basis. Sulphur fertilizer was applied as a treatment combination of 90 kg N + 20 kg P + 23 kg S ha^{-1} and 90 kg N + 20 kg P + 45 kg S ha^{-1} on an annual basis. An additional treatment of 180 kg N + 80 kg P ha^{-1} was applied every 4 years to compare with the annual treatment of 45 kg N + 20 kg P ha^{-1}. The N source was ammonium nitrate, the P source, monoammonium phosphate, and the S source, elemental S (Agri-Sul). Fertilizer was broadcast each spring from 1978 to 1989 on plots 7.3 by 11.0 m in size. Soils are classified as being in the Waitville association (Gray Wooded), which is a Luvisol developed under aspen (*Populus tremuloides* Michx.) on undifferentiated medium to moderately fine textured soil in hummocky terrain. The experimental site is located at Pathlow, 30 km south west of Melfort, Saskatchewan.

Soil carbon was measured in archived samples that had been bulked across all replicates in a randomized complete block design from selected treatments in 1983 and 1984, and in individual replicates for all treatments in 1989. Plant residue at the surface was included in the soils sampled for the 0-15 cm depth increment during 1978 to 1989. A constant value for bulk density (1.01 Mg m^{-3}) was used in the calculation of carbon mass (0-15 cm) based on previous calculations from McCartney et al. (1998). Due to missing values only three replicates were used in the analysis of 1989 data. Forage production was measured in 1 exclosure (0.9 * 2.7 m) per plot (Nuttall et al. 1991).

Soil carbon was also measured in 1999 from bulked samples (0-15, 15-30, 30-60 cm) from two locations per plot. Bulk density was calculated from the total mass corrected for soil moisture measured in subsamples. Plant residue was not included in the soil samples collected in 1999.

Pasture study, Brandon

The objective of this study is to determine carbon storage in fertilized and unfertilized brome-alfalfa in a grazed system established in 1994. Effects of fertilizer and alfalfa are evaluated. Data collected in this study will provide a baseline for future assessments of carbon storage. The study site was continuously cropped with cereals, predominantly wheat, under excessive tillage management. Under this management, soils were observed to be prone to wind erosion due to reduced crop residue cover and low levels of organic matter in the surface soil (P. McCaughey pers. comm.). The study was initiated in 1994 and has two forage types (meadow bromegrass and meadow bromegrass-alfalfa mix), two levels of fertilizer with two replicates in a randomized complete block design. Pastures are grazed with the objective of leaving approximately the same amount of residual biomass in each pasture at the end of the grazing season. Fertilizer was applied based on soil test recommendations (Table 1). Soils are classified as being in the Souris association (Orthic to Regosolic Black) on sandy (fine sandy loam) glacio-lacustrine deposits in generally level to very gently sloping terrain (Manitoba Land Resource Unit 1996). The experimental site is located 2 km north east of Brandon, Manitoba.

Three microsites were located in each pasture and soils were sampled in 1997 and 1999. Averages of two microsites were used in statistical analysis, as the third microsite in each pasture was located in poorly drained soils, which were not typical of the rest of the pasture. Soils were sampled in locations unaffected by urine or manure deposits. Total forage production was measured in 0.25 m^{-2} quadrats prior to and after grazing in each rotation. Grass and alfalfa production, were determined separately in 4 quadrats per pasture.

RESULTS

Carbon storage in alfalfa in rotation, Melfort

No significant linear trend was observed in soil organic carbon for soils sampled in the sixth phase of a forage rotation (Fallow-Wheat-Wheat-Hay-Hay-Wheat) from 1970 and 1994 in Black silty clay soils at Melfort (Fig. 1). Although the study was initiated in 1957, a significant decrease in soil organic carbon was recorded from 1970 to 1978. No significant differences were observed between treatments in succeeding years. Soil organic carbon (0-15 cm) in the sixth (Wheat) phase of hay rotations was 64.4 Mg C ha^{-1} in fertilized compared to 58.2 Mg C ha^{-1} for unfertilized plots in 1994 ($P=0.0506$). Campbell et al. (1991), reported no significant ($P=0.10$) relationship between biomass inputs of carbon and soil carbon. No significant ($P=0.5446$) difference was observed for the comparison of soil organic carbon (0-60 cm) between fertilized (150.7 Mg C ha^{-1}) and unfertilized rotations (147.3 Mg C ha^{-1}) in 1994.

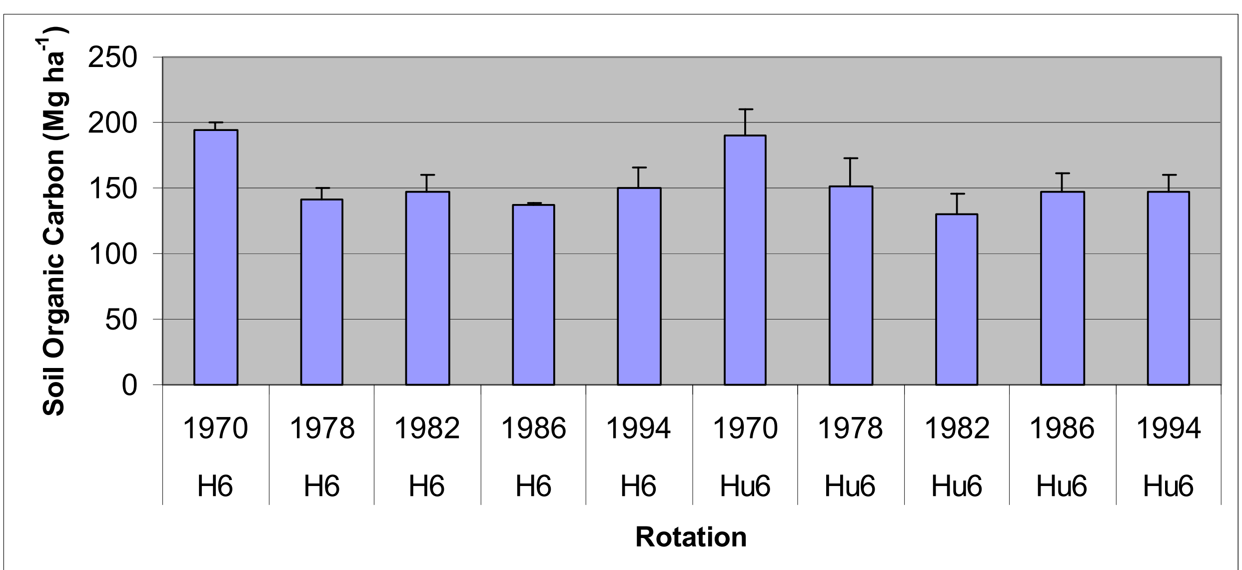

Figure. 1 Carbon storage in alfalfa in rotation 1970-1994, Melfort. Error bar represents one standard error.

Carbon storage in forage rotations, Glenlea

No statistically significant differences were observed in the mass of organic carbon at the 0-50 cm depth (Fig. 2), due to alfalfa in rotation (P=0.110), or addition of fertilizer (P=0.461) over the period from 1992 to 1999. Mass of organic carbon was highest in rotations containing alfalfa though the difference was not significant. Bulk density (0-10 cm) ranged from 1.1 to 1.3 Mg m^{-3} and did not vary significantly between treatments.

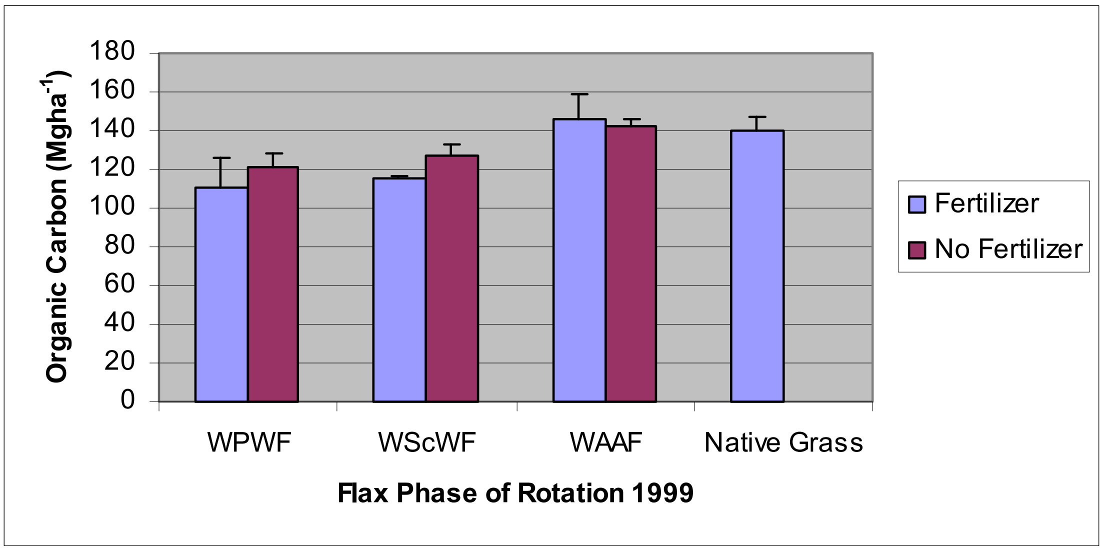

Figure. 2 Carbon storage in alfalfa in rotation 1999, Glenlea. Error bar represents one standard error.

Carbon storage in fertilized pastures, Pathlow

Soil organic carbon (0-15 cm) increased (P=0.0583) in fertilized grazed brome-alfalfa pasture over a period of 12 years from 1978 to 1989 (Fig. 3). Carbon was stored at rates of approximately 21.9 Mg ha^{-1} over this period due to fertilizer treatments with 45 kg ha^{-1} N fertilizer and 20 kg ha^{-1} P. A nonlinear (P=0.0583) response to N is present, with a contrast (P=0.0641) between 0 kg ha^{-1} P and 20 kg ha^{-1} P for 45 and 90 kg ha^{-1} levels of N fertilizer. The increase in soil carbon was a slow process, with approximately half of the carbon stored in 1984 after 6 years. Surface plant residue mixed with root biomass at the soil surface was included in the soil samples collected between 1978 and 1989, and may have increased the levels of soil organic carbon measured in the samples.

Organic carbon measured in soil samples (0-15 cm) collected at Pathlow in 1999, was not significantly different between treatments, with a mean of 11.48 Mg C ha^{-1} (Fig. 4). Bulk density measured in 1999 did not vary significantly between treatments or from values used in the calculation of mass of organic carbon in 1989. Levels of organic carbon measured in 1999 (Fig 5) represent a decrease from levels measured in the control plots in 1989, which did not receive fertilizer from 1978 to 1989. The decrease in control plots is attributed to a reduction of carbon stored due to removal of nitrogen from all treatments through gazing, and to the difference in sampling protocol for the archived samples and 1999. Plant residue at the surface was not included in the soil samples collected in 1999, in contrast to those collected from 1978 to 1989. In 1999, fertilizer treatment had no significant effect (P=0.30) on plant residue at the soil surface with a mean for the experiment of 0.17 Mg C ha^{-1}.

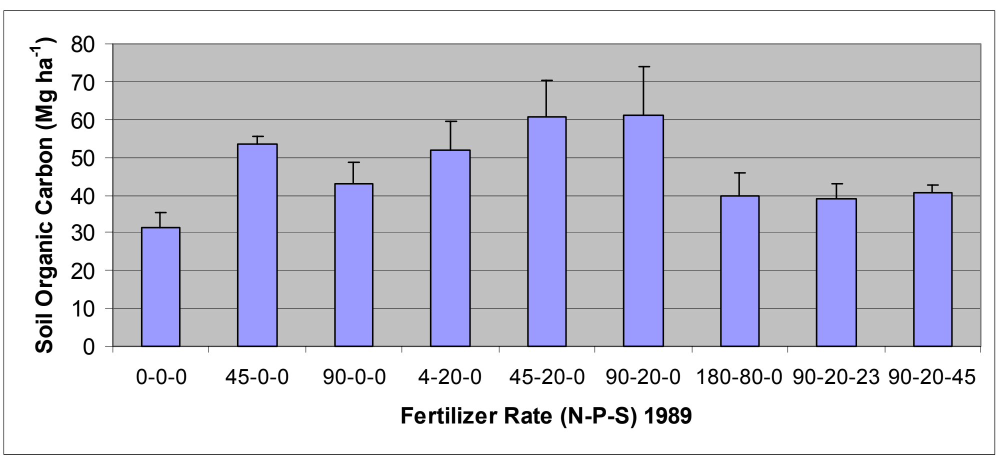

Figure. 3. Carbon storage in alfalfa in rotation 1989, Pathlow. (0-15 cm). Error bar represents one standard error.

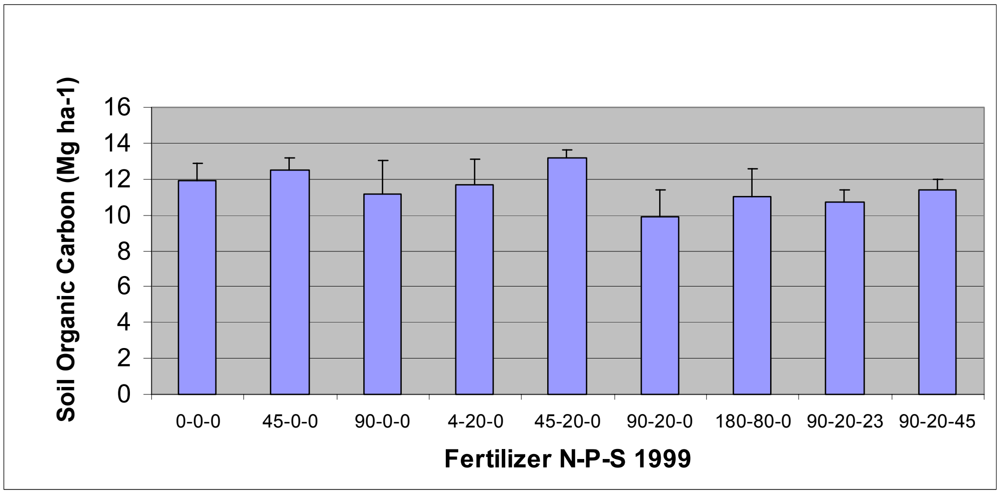

Figure. 4. Carbon storage in alfalfa in rotation 1999, Pathlow. (0-15 cm). Error bar represents one standard error.

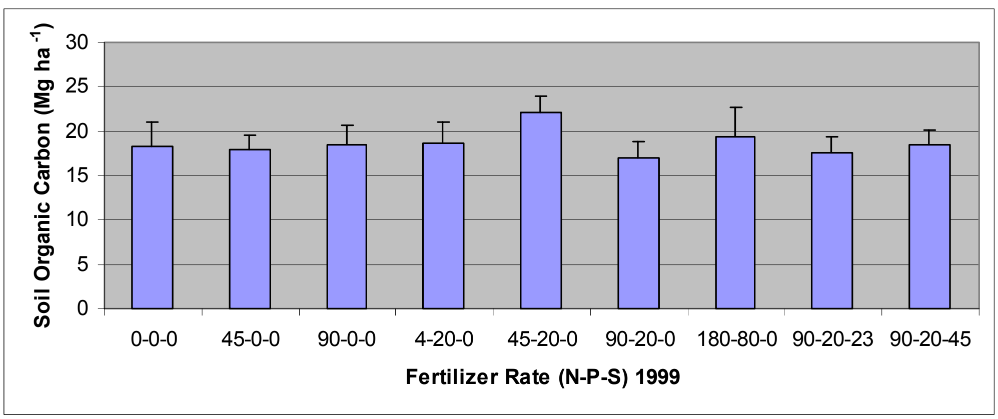

Figure. 5. Carbon storage in alfalfa in rotation 1999, Pathlow. (0-60 cm). Error bar represents one standard error.

Carbon storage in fertilized pastures, Brandon

Organic carbon for soils sampled in 1999, was higher by 16.1 Mg ha^{-1} (0-50 cm) in fertilized bromegrass compared to unfertilized bromegrass (P=0.012) (Fig. 6). Carbon storage was higher by 15.8 Mg ha^{-1} in unfertilized alfalfa/bromegrass relative to unfertilized grass (P=0.013). No significant difference was observed for organic carbon between fertilized grass and unfertilized alfalfa/bromegrass. Organic carbon was significantly (P = 0.023) lower in fertilized alfalfa/bromegrass compared to unfertilized alfalfa/bromegrass. This is attributed to the decrease in alfalfa root biomass due to fertilizer in previous years, though root biomass data are not available to confirm this observation.

The majority of the organic carbon was in the 0-20 cm depth (59.6-66.1%) though significant (P=0.0294) differences were recorded in the 30-40 cm depth increment with an increase of 2.92 Mg C ha^{-1} between fertilized and unfertilized bromegrass.

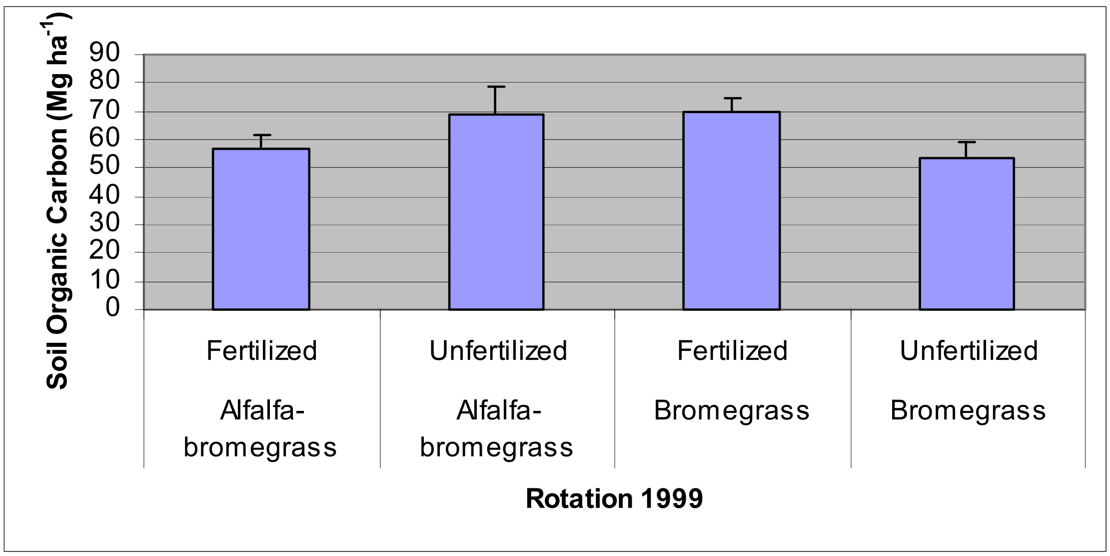

Figure. 6. Carbon storage in pasture systems 1999, Brandon. (0-50 cm). Error bar represents one standard error.

Conclusions

- Pasture and forage management have the potential to store carbon in soil, particularly in combination with fertilizer management on degraded soils or luvisols initially low in soil organic carbon.
- Soils high in organic carbon, such as glaciolacustrine deposits in the Black soil zone have less potential for carbon sequestration.
- Alfalfa and nitrogen inputs must be continued to maintain significant amounts of carbon in pasture and forage systems,

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