2011-03-15

Following the fate of 13C-labeled lentil, wheat, canola, and pea in two Chernozemic soils

Following the Fate of ^{13}C-Labeled Lentil, Wheat, Canola, and Pea in two Chernozemic soils

L-P. Comeau[1], A. Bedard-Haughn[1]

[1]Department of Soil Science, University of Saskatchewan, Saskatoon, SK, S7N 5A8

Key Words: Soil density fractionation, root and shoot carbon mineralization.

Abstract

Restoring carbon (C) into the soil is fundamental to improve soil quality, to increase agronomic productivity, to mitigate greenhouse gas emissions and to enhance several ecosystem services. The objectives of this study were to 1) determine the quantity and the fate of C captured during a single growing season of four simple crop rotations in the Prairies and 2) evaluate the quantity and fate of those original residues after a second growing season. To track the progress of C into the different soil organic matter (SOM) pools; plants were grown in intact soil cores and pulse labeled with ^{13}C in hermetic chambers. Results indicated that, at the end of the second growing season (approximately one year after the ^{13}C enrichment), lentil and pea had more new soil C remaining in the soil than canola or wheat. Also at the end of the second growing season, it was found that the roots residues had producer a slightly greater amount of new soil C than the shoots residues. We concluded that ^{13}C-enriched plant material is a versatile and powerful tool to study the C cycle. Longer-term studies with isotopic C residues are required to determine if the trends we observed are temporal or permanent.

Introduction

Since agriculture began in Canada, 15 to 30 percent of the C originally present in A horizon has been lost, estimated as 1.1Pg of C (Hengeveld, 2008). Long term studies are effective to determine which agricultural practices can enhance or decrease the amount of soil organic carbon (SOC). However, there is a gap in the scientific literature about annual gross production of SOC under different agricultural practices. This lack of knowledge is mainly due to the fact that the SOC produced in a given year represents only a very small proportion of the total SOC.

Recent developments in stable isotope techniques in soil science facilitate the tracking of SOC through different SOM pools and through time (Sangster *et al*., 2010). These new isotopic techniques can also be used to quantify root biomass production (Subedi *et al*., 2006). Traditional methods to estimate root production cannot account for those root fragments and rhizodeposits that are quickly mineralized into the soil. An underestimation of rhizodeposit production and root contribution to the SOC would cause an underestimation of the net primary production (NPP), an overestimation of the shoot contribution to the SOC, and an underestimation of the CO_2 emitted from rhizodeposit decomposition.

The three main questions behind this research were:

- Could the inclusion of a pulse crop in rotation with wheat increase the annual gross production of SOC?
- Into which soil pool is new organic carbon is going?
- What is the relative contribution of roots and shoots to the total SOC?

The objectives of this study were to: 1) determine the quantity and the fate of C captured during a single growing season of four simple crop rotations in the Prairies [continuous wheat (*Triticum aestivum*), wheat-canola (T. aestivum - Brassica napus), wheat-lentil (*T. aestivum - Lens culinaris*), and wheat-pea (*T. aestivum - Pisum sativum*)], and 2) evaluate the quantity and fate of those same residues after a second growing season.

Method

This greenhouse study was carried out with 12.5L intact soil cores from Agriculture and Agri-Food Canada Prairie Research Stations at Scott (AAFC-Scott) and at Swift Current (AAFC-Swift) (Saskatchewan, Canada). At AAFC-Scott three crop rotations were selected (continuous wheat, pea-wheat and pea-canola) and two at AAFC-Swift (continuous wheat and lentil-wheat). All rotations had completed a wheat phase of the rotation the previous year. Details on soil and environment of the study sites are presented in table 1.

Table 1. Soil and environmental features at AAFC Scott and AAFC Swift Current (Acton and Ellis 1978; Ayres et al. 1985)

Site	Location	Ecoregion	Soil type	Texture	pH	%C	D_b (0-10 cm)
AAFC Scott	52°23'N 108.50'W	Moist Mixed Grassland	Orthic Dark Brown Chernozem	loamy	5.7	3.4	1.16
AAFC Swift	50°12'N 107°24'W	Mixed Grassland	Orthic Brown Chernozem	sandy loam	6.4	2	1.16

In July 2009 pea, lentil, canola and wheat (from AAFC-Scott and AAFC-Swift) were germinated and grown in the College of Agriculture Greenhouse (University of Saskatchewan). Each crop was seeded to its respective soil cores based on rotation phase. Labeling was performed in hermetic polymethyl methacrylate chambers, in blocks of four cores per chamber (Sangster et al., 2010). Each block was labeled weekly for 2 h starting 20 days after germination and continuing to the end of embryogenesis (8 label sessions). The soil surface was isolated from the enriched atmosphere during labeling. The atmospheric enrichment during the labeling session was 33 atom% $^{13}CO_2$ and the total CO_2 concentration was maintained around the current atmospheric concentration (380-430 ppm). The CO_2 was devolved into the chamber by injecting a saturated solution of $NaHCO_3$ (33% ^{13}C) into a beaker with 12M HCl. Total CO_2 concentration was monitored with an infrared gas analyzer (IRGA) (S151 Infrared CO_2 Analyzer, Qubit Systems, Kingston, Ontario).

At maturity, plants were dried and harvested to ground level. Shoot residues (10g for lentil, wheat and pea, and 15g for canola) from each core were coarsely ground with a coffee grinder. Ground plant residues from enriched and non-enriched cores were swapped and mixed with the 0-10cm soil. The shoot residues incorporated into the soil was equivalent to 3,225 kg ha^{-1} for lentil, wheat and pea and 4,840 kg ha^{-1} for canola. Those amounts are slightly lower than the average amount incorporated in the field but the mineralization was accelerated by the grinding effect. Samples of roots, stems, leaves, pods/husks and grains, were oven dried at 50°C, finely ground and analyzed for %C, %N and $\delta^{13}C$ with a Costech Elemental Combustion System

(Costech Analytical 191 Technologies, Inc.) coupled to a Delta V Advantage Mass spectrometer (Thermo Fisher 192 Scientific Inc.) in the UofS stable isotope facilities University of Saskatchewan. Half of the cores were destroyed and analyzed at the end of the first growing season; the other half was analyzed at the end of the second growing season. The outcome of the lab design was:

- SOC input from root residues after the 1st growing season
- SOC from root residues remaining after the 2nd growing season
- SOC from shoot residues remaining after the 2nd growing season

Following Gregorich (2008), light and heavy fraction (HF) organic matter were isolated with a dense liquid (sodium iodide solution at 1.7 g cm^{-3}). Then, with deionized water, the light fraction was fractionated into very light (VLF) and light fraction (LF). The materials floating on water (VLF) were mainly fresh plant residues. No plant residues were observed in the LF and HF. For each soil fraction, %C, %N and $\delta^{13}C$ were analyzed with the same system as the plant materials. With the $\delta^{13}C$ results the below ground C mass per hectare for each soil fraction was calculated using the Subedi *et al*. (2006) equation. The calculations for the comparison of CO_2 emitted and stored in the heavy fraction were based on Government of Saskatchewan statistical data (Ministry of Agriculture, 2010; Ministry of Government Services, 2010) Mathematical calculations and descriptive statistical analyses were made with Microsoft Excel XP.

Results

Lentil and pea had slightly higher amounts of newly fixed SOC per hectare remaining after the second growing season (i.e., residual SOC) than canola, and canola had slightly higher amounts than wheat (Fig. 1). Wheat at AAFC-Swift and wheat at AAFC-Scott had similar amounts of residual SOC per hectare. For all crops, except for wheat at AAFC-Scott, the root: shoot ratios were >1 and pea had particularly high root: shoot ratio (Fig. 1).

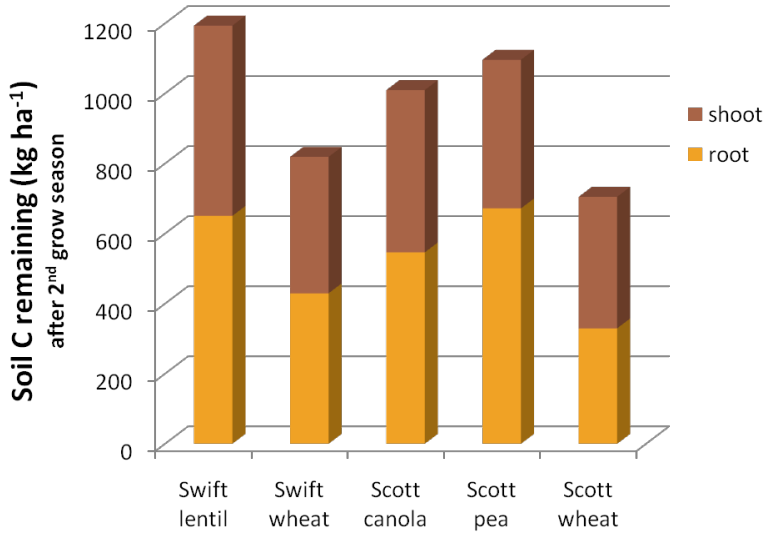

Figure 1. Amount of newly-fixed SOC remaining the end of the second growing season.

From the soil fractionation made at the end of both growing season, the VLF was mainly composed of plant debris; no vegetal debris was distinguished in the LF and HF.

At the end of the first growing season (labeling season), there was more root-derived SOC in the HF than in the LF (Fig. 2). The root-derived SOC in the HF and VLF had decreased at the end of the second growing season but increased in the LF. For both root and shoot residues, at the end of the second growing season, the residual SOC was greatest in the HF and lowest in the VLF. From the end of the first growing season to the end of the second growing season, the average amount of root-derived SOC decreased from 750 kg ha^{-1} to 526 kg of C ha^{-1}. At the end of the first growing season the amount of SOC that had been derived from shoot residues was between 1300 and 2000 kg ha^{-1}. At the end of the second growing season, this had decreased to less than 550 kg of shoot-derived SOC ha^{-1} remaining into the soil.

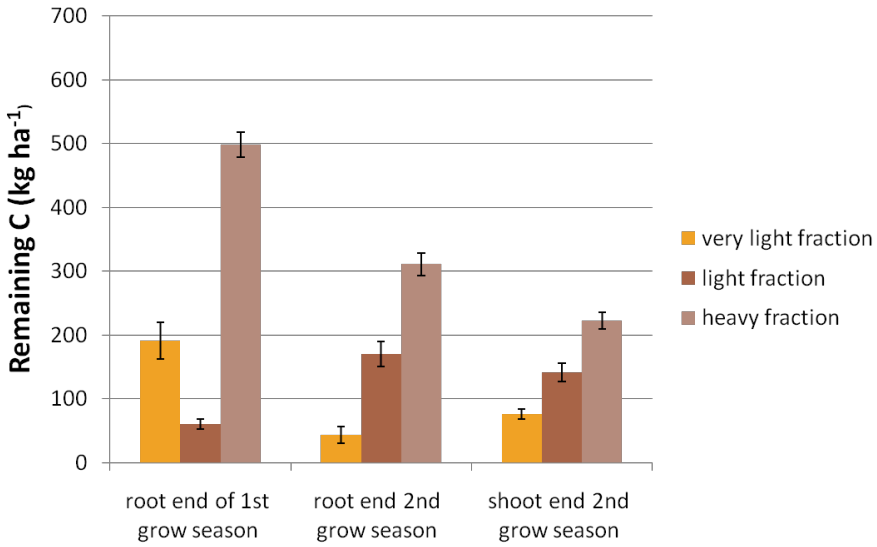

Figure 2. Comparison of the shoot- and root-derived SOC at the end of the first vs. second growing season.

The average amount of C remaining in the HF at the end of the second growing season was 456 kg C ha^{-1} which would be equivalent to 6,835 hundred tonnes of C when extrapolating to the total cropped farm land in Saskatchewan. That in turn corresponds to one third of the reported annual anthropogenic C emission in Saskatchewan (Ministry of Government Services, 2010) (Fig. 3).

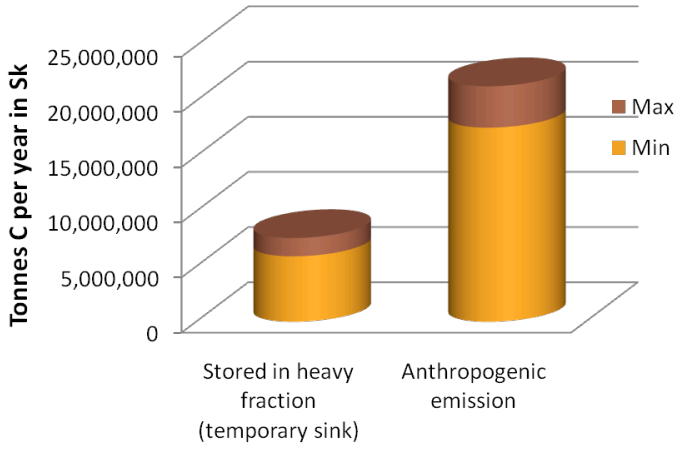

Figure 3. Comparison of the heavy fraction SOC at the end of the second growing season with anthropogenic emissions of C.

Discussion

At the end of the first growing season the root (0-10cm): shoot ratio was notably < 1; by the end of the second growing it increased to >1. This suggests that plants are producing more shoot biomass than root biomass but that roots are more recalcitrant and/or that at the end of the first growing season a significant amount of root already have been respired by microorganisms. In order to generate accurate estimations of root biomass production, an evaluation of the amount of rhizodeposits that are respired before the quantification of root biomass is needed. Our root quantifications were made in the 0-10cm; following Gan *et al*., (2009) the values would have been 20 to 80% for the 0-20 cm increment.

At the end of the second growing season, lentil and pea had greater total residual SOC than canola and wheat. However, we believe that the in the subsequent stage of SOM decomposition pulse crops will have higher mineralization rate than canola and wheat due to differential amounts of silicon, lignin, cellulose and C:N ratio in the plant tissues. Sangster (2010) found that field pea has lower % of acid detergent fiber and acid detergent lignin than canola and therefore would be more readily degradable.

It was expected that at the end of the first growing season the VLF would have the highest value of residual SOC and the HF would have the lowest. This hypothesis was made with the assumption that the HF was an older and more recalcitrant pool than the LF and that the VLF would require more than one season to start decomposing. This hypothesis has been rejected. At the end of the first growing season the majority of the labeled SOC was already in the HF, indicating that the VLF decomposed quickly into the soil, and that probably some of the C in the VLF fraction is incorporated directly into the HF. At the end of the second growing season, the amount of C in the VLF and HF fraction had decreased but the amount of C in the LF had increased. It is probable that some of the C that was contained into the HF had moved to the LF. The decrease of the total residual SOC between the end of the first and second growing season is presumably due to soil microbial respiration.

When comparing the amount of C stored in the HF with the amount of anthropogenic emission of C it is important to mention that the HF is a temporal sink. In a system at equilibrium, the amount of SOC input from NPP is equal to the amount of SOC lost by microbial respiration.

Conclusion

At the end of the second growing season, pulse crop-wheat rotation had increased the amount of SOC remaining comparing with continuous wheat. Also at the end of the second growing season, it was found that the root residues had generated a slightly greater amount of remaining SOC than the shoot residues. Our results indicate that in the second stage of decomposition the fate of the ^{13}C-labeled crop residues is possibly the LF. However, studies that follow the fate of labeled C residues for more than two year are needed to confirm or refute those tendencies.

References

Gan, Y.T., C.A., Campbell, H.H. Janzen, R.L. Lemke, P. Basnyat, C.L. McDonald. 2009. Agriculture, Ecosystems & Environment, 132:290-297.

Hengeveld, L. H., 2008. An overview of the background science and goals of Canadian research activities relevant to enhancement of greenhouse gas sinks in Canada. in: Hengeveld, H., S.L. Braithwaite, R.L., Desjardins, J. Gorjup, and Hall. (eds.) Enhancement of greenhouse gas sinks: a Canadian science assessment. perd pol 6.2.1 final report. Torono: Environment Canada.

Ministry of Agriculture, Saskatchewan Agricultural Statistics Pocket Reference, December 2010, Saskatchewan Ministry of Agriculture 3085 Albert St. Regina Sk Canada ISSN 1924-6110

Ministry of Government Services, Province of Saskatchewan 2009-2010 Annual Report p10, Available in electronic format from the ministry's web site at http://www.gs.gov.sk.ca/Default.aspx?DN=23425680-6003-4a0b-887b-3158953e84a6

Sangster, A, D. Knight, R. Farrell, and A. Bedard-Haughn. 2010. Repeat-pulse $^{13}CO_2$ labeling of canola and field pea: implications for soil organic matter studies. Rapid Communications in Mass Spectrometry. 24: 2791–2798

Sparks, D. 2003. Chemistry of soil organic matter. In C. Crumly ed., Environmental Soil Chemistry. Adademic Press, Elsevier Science, USA.

Subedi, K.D, B.L. Ma, B.C. Liang. 2006. New method to estimate root biomass in soil through root-derived carbon. Soil Biology & Biochemistry 38:2212-2218.

VandenBygaart A.J., and D.A. Angers. 2006. Towards accurate measurements of soil organic carbon stock change in agroecosystems. Can. J. Soil Sci. 86:465–471.

Waksman, S.W. 1936. Humus: origin, chemical composition and importance in nature. The Williams & Wilkins Company Volume 41 Issue 5 - p 395.

Whitehead, D. C., J. Tinsley. 1963. The biochemistry of humus formation. Journal of the Science of Food and Agriculture . 14:849-857.