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Carbon input to soil from oilseed and pulse crops on the Canadian prairies

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ABSTRACT

The dynamics of carbon (C) in soil is fundamentally affected by crop mix in diverse cropping systems, yet, little is known about C inputs from oilseed and pulse crops. This study determined carbon allocation coefficients in grain, straw, roots, and rhizodeposits for important oilseed and pulse crops in comparison with spring wheat (*Triticum aestivum* L.) under low-water (rainfall only) and high-water (rainfall plus irrigation) conditions. Three oilseeds [canola (*Brassica napus* L.), mustard (*Brassica juncea* L.) and flax (*Linum usitatissimum* L.)], and three pulses [chickpea (*Cicer arietinum* L.), field pea (*Pisum sativum* L.) and lentil (*Lens culinaris* Medik.)], along with a wheat control were tested in Saskatchewan, Canada, in 2006 and 2007. Crops were grown in 15-cm diameter, 100-cm long metal lysimeters pushed into the field of medium-textured Aridic Haploboroll with the soil structure in lysimeters undisturbed. Root mass in the 0–100 cm depth was greater ($P < 0.01$) under irrigation than that under rainfall for wheat (126% greater), flax (54% greater), and mustard (14% greater); there was no difference for dry pea; and was lower ($P < 0.01$) under irrigation for chickpea (−16%) and lentil (−35%). Straw-to-root ratio averaged 4.90 under rainfall conditions and 6.22 under irrigation; the ratio differed among crop species only under rainfall conditions where the ratios for wheat (6.33), dry pea (5.35) and mustard (5.00) were greater than the ratios for canola, chickpea, and lentil. The relative C allocation coefficients in grain (R_g), straw (R_s), roots in the 0–100 cm depth (R_r), and rhizodeposits (R_e), expressed as estimated C input from each plant part in proportion to total C, varied among crop species. On average, the allocation coefficient for pulse crops (R_g:R_s:R_r:R_e) was 0.24:0.46:0.18:0.12 under low-water, and 0.31:0.47:0.14:0.09 under high-water conditions. For oilseeds, the corresponding values were 0.17:0.58:0.15:0.10 for low-water, and 0.19:0.56:0.15:0.10 for high-water conditions. These C allocation coefficients in oilseeds and pulses should provide modellers with essential tools in quantifying C dynamics and soil C sequestration for agricultural systems involving broadleaved crop species.

1. Introduction

Carbon (C) input to soils from crop residues is important because C is the main energy source for heterotrophic organisms that convert organic residues into soil humus and the nutrients required by plants (Coleman et al., 1983). Humus serves to enhance the quality of soil and improve its stability and water holding capacity (Campbell, 1978). Importantly, a net loss of soil C as CO_2 increases atmospheric greenhouse gas concentrations and possibly enhances global warming; conversely a net gain of soil C (via C sequestration) decreases atmospheric CO_2 and increases soil organic matter (Rasmussen et al., 1980; Campbell et al., 1997). This fact has been recognized in models that attempt to quantify soil organic matter dynamics (Kelly et al., 1997; Campbell et al., 2007).

Scientists who are interested in characterizing and predicting soil C dynamics require accurate estimates of the crop residue C entering the soil. These values are a function of the straw (all above-ground plant parts except grains), the roots, and the materials released from the roots as they grow, including root exudates, lysates, sloughed cells, and mucilages (Keith et al., 1986; Bolinder et al., 1997, 2007). Estimates of crop residue C vary with type of crop, weather conditions, nutrient inputs, and how well the difficult-to-measure roots and extra-root materials are determined. Many studies have been conducted throughout the world to provide such data, but most have been on cereal crops, namely wheat, oats (*Avena sativa* L.), barley (*Hordeum vulvare* L.), and corn (*Zea mays* L.). There is a paucity of relevant data for oilseeds and pulse crops, especially for the belowground components. In a

Abbreviation: AG, above-ground plant parts.

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comprehensive review of the subject of C input to soil from agricultural crops that cited 168 studies in North America, Bolinder et al. (2007) listed only one pulse crop (soybean, *Glycine max* L.) and no study on oilseed crops. Consequently, researchers wishing to model changes in soil C for agricultural systems that include oilseed or pulse crops have often assumed that the straw/root ratio of such crops and C allocation in different plant parts is the same as that of cereals (Bolinder et al., 1997; Campbell et al., 2000; Lemke et al., 2007).

The production of pulse and oilseed crops has been steadily increasing on the Canadian prairies during the past two decades (Campbell et al., 2002). Oilseed and pulse crops are playing a significant role in the development of environmentally-friendly, sustainable agricultural systems (Zentner et al., 2001). The use of short-season broadleaved crops to replace conventional summer fallow is having significant environmental benefits (Gan and Goddard, 2008), and potentially, could reduce greenhouse gas emissions from agricultural systems (Lemke et al., 2007). Furthermore, these broadleaved crops have different rooting characteristics and root biomass profiles in the soil compared to cereals (Gan et al., 2009a). These differences will have large impacts on the estimates of C inputs into soil from the roots.

Therefore, the objectives of this study were to (i) provide quantitative estimates of carbon allocation in grain, straw, roots, and rhizodeposits for important oilseed and pulse crops, and (ii) compare the allocation coefficients with that of spring wheat for conditions like those in western Canada. Crop growth in western Canada is prominently influenced by varying degrees of drought, thus our study examined a range of moisture regimes.

2. Materials and methods

2.1. Experimental design

Field experiments were conducted at the Agriculture and Agri-Food Canada Semiarid Prairie Agricultural Research Centre, near Swift Current (50°15′N, 107°44′W), Saskatchewan, Canada, during two growing seasons (2006 and 2007). The soil was an Aridic Haploboroll soil in US soil classification, and a Swinton loam, an Orthic Brown Chernozem in Canadian soil classification (Ayers et al., 1985). Seven crops (three pulses, three oilseeds, and spring wheat) (Table 1) were grown in 15-cm diameter, 100-cm deep, 24-gauge iron lysimeters pushed into the soil at planting time using a hydraulic system (Gan et al., 2009b). Lysimeters were withdrawn and subsampled at five growth stages (Gan et al., 2009b) but we only discuss those taken at maturity in this paper. Water conditions and crop species (along with fallow control) were arranged in a factorial, randomized complete block design with two replicates. Four extra lysimeters were installed and sampled for initial values of soil water, C, and nutrients. Thus, the experiment had 164 lysimeters (7 crops and 1 fallow × 2 water conditions × 5 stages × 2 replicates + 4) in each year.

Table 2
Precipitation for the rainfed-treatments and rainfall plus irrigation for the irrigated-treatments received by various pulses and oilseed crops, at Swift Current, Saskatchewan, Canada, in 2006 and 2007.

Year and conditions[a]	Wheat	Canola	Mustard	Flax	Chickpea	Dry pea	Lentil
				mm			
2006, rainfed	180	180	180	180	180	180	180
2007, rainfed	135	135	121	121	135	120	135
2006, irrigated	281	293	280	280	293	280	280
2007, irrigated	286	285	258	258	258	259	286

[a] Irrigation was applied five times (22–30 mm each) during the growing season. Initial available soil water in the 120-cm depth at planting was 122 mm in 2006 and 117 mm in 2007.

2.2. Seeding and plot management

Seed was pretreated with fungicides to minimize seed- and soil-borne diseases, and the legume seeds were inoculated with an effective *Rhizobium* strain applied in a liquid emulsion to seed. Crops were planted in the lysimeters with the rates of seed corresponding to the area of the lysimeters (Table 1). In 2006, the seedbed was very dry therefore 125 mm of water was added to each lysimeter 2 days before planting. On the date of planting 20 mm of the top soil was removed, the seeds were placed on the firm seedbed and then the soil returned and packed. Two weeks after plant emergence, the seedlings were thinned to the desired plant population (Table 1). Oilseeds and wheat received 80 kg N ha^{-1} (fertilizer 46-0-0) and 27 kg P ha^{-1} (superphosphate 0-45-0) at seeding; pulse crops only received P. All crops were grown using recommended crop management practices. For irrigated treatments, tap water was applied as deemed necessary based on weather conditions. On average, irrigated-treatments received 75% more water during the growing season than rainfed-treatments (Table 2).

2.3. Sampling and data collection

At maturity, the plants were cut off at ground level and dry weight of above-ground (AG) biomass and grains were determined by oven drying at 50 °C for 7–10 days. The lysimeters were lifted from the field positions, transported to the laboratory and stored at 2 °C until the soil was processed. Lysimeters were sampled destructively with cross-sectioned slices of soil made at 10 cm intervals to the depth of 60 cm, and at 20 cm intervals for the 60–100 cm depths. The soil–root matrix was dispersed in a dilute $NaHCO_3$ solution overnight in containers and the roots separated by washing out the soil using an in-house root washing system (Gan et al., 2009b). The soil–root matrix was first placed on a 4-mm diameter sieve under running water to wash out the soil, and then the rooting systems were placed in containers full of tap water with a 0.8-mm diameter sieve mounted just below water level in the containers. This ensured that all crop roots were best captured

Table 1
Crop cultivars and seeding information for lysimeter experiments conducted at Swift Current, Saskatchewan, Canada, 2006–2007.

Crop	Cultivar	Seeds per lysimeter	Plants per lysimeter	Seed treatment
Oilseeds				
Canola	45H21	11	3	Thiamethoxam 153 mg 100 kg^{-1}
Mustard	Cutlass	11	3	Thiamethoxam 153 mg 100 kg^{-1}
Pulses				
Chickpea	CDC Anna	5	2	Carbathiin 55 g and thiabendazole 35 g 100 kg^{-1}
Dry pea	Eclipse	5	2	Metalaxyl 50 g 100 kg^{-1}
Lentil	CDC Glamis	7	3	Carbathiin 55 g and thiabendazole 35 g 100 kg^{-1}
Cereal				
Wheat	Lillian	7	3	Carbathiin 51 ml and thiram 44 ml 100 kg^{-1}