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Lowering carbon footprint of durum wheat by diversifying cropping systems

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ABSTRACT

Improving cropping systems may help mitigate greenhouse gas emissions. This study determined the carbon footprint of durum wheat (*Triticum turgidum* L.) produced in diverse cropping systems. Durum was grown in rotation systems which had different combinations of oilseed, pulse, and cereal crops at five site-years in Saskatchewan, Canada. Total greenhouse gas emissions from the decomposition of crop residues along with various production inputs were used for the estimation of carbon footprint. On average, emissions from the decomposition of crop straw and roots accounted for 25% of the total emissions, those from the production, transportation, storage, and delivery of fertilizers and pesticides to farm gates and their applications 43%, and emissions from farming operations 32%. Durum wheat preceded by an oilseed crop (*Brassica napus* or *Brassica juncea*) the previous year had carbon footprint of 0.33 kg CO_2e kg^{-1} of grain, or 7% lower than durum in cereal–cereal–durum system. Durum preceded by a biological N-fixing crop (*Cicer arietinum* chickpea, *Lens culinaris* lentil, or *Pisum sativum* pea) the previous year lowered its carbon footprint by 17% compared with durum preceded by a cereal crop. Durum produced in a pulse–pulse–durum system had carbon footprint 0.27 kg CO_2e kg^{-1} of grain, 34% lower than durum grown in cereal–cereal–durum systems. Diversifying cropping systems with oilseeds and biological N-fixers significantly lowered carbon footprint of durum wheat.

1. Introduction

Scientific evidences have shown that the Earth's climate is rapidly changing due mainly to increasing anthropogenic greenhouse gas (GHG) emissions (Ruddiman, 2003; IPCC, 2006). Emissions are stemmed from various human activities, farming among them (Janzen et al., 2006). Policy makers, producers, and researchers urge to develop effective farming practices to reduce GHG emissions, while maximizing the potential economic returns from farming. One of the promising strategies in mitigating GHG emissions from farming is to adopt diversified cropping systems where cereal, oilseed, and pulses (i.e., legume) crops are arranged in well-defined crop sequences in crop rotation systems. Such a system has been shown to increase energy use efficiency (Zentner et al., 2004), decrease pest infestation (Krupinsky et al., 2002), improve water use efficiency (Miller et al., 2003a), and increase net productivity of crops (Tanaka et al., 2007). However, little is known about how diversified cropping systems would affect environmental sustainability in terms of GHG emissions.

"Carbon footprint" is a term that was originated from a pioneer academic publication by Rees (1992) where the concept of "ecological footprint" was introduced. Later, Wiedmann and Minx (2008) detailed the perspectives of using carbon footprint to quantify the impact of GHG emissions on environmental sustainability. These authors defined carbon footprint as "a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product". This definition, however, did not emphasize the emissions from GHGs other than CO_2. The fact is that a large amount of GHG emissions associated with farming activities results mainly from nitrous oxide (N_2O) (Janzen et al., 2006), a gas with 300 times global warming potential (Forster et al., 2007). In 2008, for example, agriculture in Canada produced approximately 62 million tones of CO_2 equivalent emissions (excluding emissions from either on-farm energy consumption or the production of agri-chemicals), about 8% of Canada's total emissions (Environment Canada, 2010). Nearly two-third of the total emissions in agriculture occurred as N_2O. Agriculture involves the production of various crops, processing various grain products, and marketing of food products to consumers, and all these generate GHGs (Dyer et al., 2010). A great portion of the emission is related to the inputs of fertilizers, manures, plant litter, as well as those from the interwoven flows of N among several pools (Janzen et al., 2006).

Durum wheat has been widely grown on the northern Great Plains of North America. For example, in 2007, a total of 1.7 million hectares of durum wheat was grown in Saskatchewan, Canada

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(Statistics Canada, 2010). In the semiarid area, wheat crops have been traditionally grown in a cereal-summerfallow or cereal–cereal cropping systems (Campbell et al., 2005), but the cereal-based monoculture practice has been found to have negative impacts to the environment (Gan et al., 2010). In contrast, diversified cropping systems in which cereals are rotated with broadleaf crops (primarily oilseeds and pulses) can not only improve water use efficiency (Miller et al., 2003a), increase grain yield and quality of subsequent crops (Gan et al., 2003; Miller et al., 2003b), but also improve environmental sustainability (Zentner et al., 2001). Moreover, long-term rotations of wheat with pulse crops increase the soil nutrient supply (Campbell et al., 1996), improve soil physical and chemical properties (Campbell et al., 2000), and enhance soil ecological environments (Hamel et al., 2006; Lal, 2008). We hypothesized that the carbon footprint of durum wheat was influenced by the diversity of cropping systems where oilseed, pulse, and cereal crops were arranged in various rotation sequences. This hypothesis was based on the understanding that there were large differences in GHG emissions caused by (a) the decomposition of crop straw and roots, (b) the amount of synthetic fertilizers used in the production of the grain crop, (c) the use of herbicides and fungicides, and (d) various farming operations including sowing the crops, spraying pesticides, harvesting the grain products, and shipping out grain products from farm gates. Therefore, the objective of this study was to determine the effect of diverse cropping systems on the carbon footprint of durum wheat grown on the semiarid northern Great Plains.

2. Materials and methods

2.1. Data sources

The data used in the calculation of carbon footprint was originated from a field experiment conducted from 1996 to 2000 at Swift Current (50.2°N, 107.4°W) and Stewart Valley (50.6°N, 107.4 °W), Saskatchewan, Canada. The soil at Swift Current was an Aridic Haploboroll with silt loam texture and a saturated-paste pH of 6.5 in the 0–15 cm depth. The soil at Stewart Valley was a Vertic Cryoboroll with heavy clay texture and a saturated-paste pH of 6.8. In the study, three pulse crops (chickpea, lentil, and dry pea), one oilseed crop (oriental mustard), and one cereal crop (hard red spring wheat) were planted in the first-year. The five crops were arranged in a randomized, complete block design with four replications, and plot size was 16 m × 4.5 m. All crops were grown using recommended agronomic practices in terms of seeding date and depth, plant density, pest control, and fertilizer application. In the second year, spring wheat, an oilseed (mustard or canola), and a pulse (lentil or dry pea) crop were no-till planted on the fields with standing stubble of the five previous crops. The re-cropped oilseed and spring wheat were fertilized to supply 70 kg N ha^{-1} and 7.5 kg P ha^{-1}, based on previous fall soil test results in the 0–120-cm depth, and pulses received P only. All crops were grown using recommended agronomic practices as did for the year 1 crops. In the third year, a durum wheat crop (cv Kyle) was no-till planted on the field of 15 types of standing stubbles from the previous two years (5 crops in year 1 × 3 crops in year 2). Durum wheat was fertilized at the rate of 13–83 kg N ha^{-1} (ammonium nitrate); the varying rates were based on the amount of residual soil N tested the previous fall and a yield target of 2400 kg ha^{-1} (average durum wheat yield). Therefore, all durum wheat plots received an equal amount of N (fertilizer N plus residual soil N). The crop also received 7.5 kg P ha^{-1} (mono-ammonium phosphate) and 6.5 kg S ha^{-1} (ammonium sulfate). The crop was managed using recommended farming practices in terms of seeding, plot management, and pest control. At maturity, the center eight rows (19.2 m^2) of the crop plot were harvested using a plot combine. The grain samples were air-dried, cleaned, and weighed. Straw was harvested from a 1-m^2 area in each plot. The N concentrations in the grain and the straw were measured using the standard micro-Kjeldahl method. Root mass was estimated using a mass allocation model developed by Gan et al. (2009).

At both sites, the 3-year cropping sequences were duplicated for three cycles, staggered one year apart. Three cycles of the crop sequences were completed in 1996–1998 (1st cycle), 1997–1999 (2nd cycle), and 1998–2000 (3rd cycle). The effect of cropping sequences on crop yield (grain and straw), soil water and nutrient use efficiencies, and the benefits of crop rotation have been discussed in previous publications (Gan et al., 2003, 2010; Miller et al., 2003a,b). In the present paper, the total GHG emissions from the decomposition of crop residues along with various production inputs were used for the estimation of carbon footprint of durum wheat produced in the various cropping systems.

2.2. Factors in carbon footprint estimation

When a crop is harvested, straw and roots are left in the field to decompose. The remaining crop residue is an N source for nitrification and denitrification, contributing directly and indirectly to N_2O emissions (Forster et al., 2007). The amount of N_2O contributed by the decomposition of crop straw and roots is highly related to their N concentrations (Janzen et al., 2003) and biomass yields (Gan et al., 2009). Therefore, the straw and root N concentrations have been considered in the estimate of C footprint. Total emissions from crop straw and roots include direct emission and the emission due to leaching; these were estimated using the Intergovernmental Panel on Climate Change (IPCC) methodology (IPCC, 2006) adapted for Canadian conditions (Rochette et al., 2008). This same method is also used for the annual Canadian submission of greenhouse gas inventory to the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. The IPCC method involves estimates of N_2O emissions directly on farmland as a result of N that has entered the soil from synthetic fertilizers and crop residues, and indirectly offsite through volatilization of NH_3 and NO_x and nitrate leaching (IPCC, 2006). Using a large number of observations on measured N_2O fluxes from Canadian farmland, Rochette et al. (2008) developed a simple method for determining N_2O emission factors based on the growing season moisture deficits. The direct emissions from crop residue decomposition and synthetic N application were a function of the ratio of precipitation to potential evapotranspiration, as described by Rochette et al. (2008):

$$\mathrm{EF} = \frac{0.022\ \mathrm{P}}{\mathrm{PE}} - 0.0048 \quad (1)$$

where EF is the emission factor with a unit of kg N_2O–N kg^{-1} N; P/PE is the ratio of precipitation to potential evapotranspiration during the growing season (1 May–31 October) based on long-term data. The direct soil N_2O emissions (N_2O_{Direct}) from the application of synthetic N fertilizer (N_{SNF}) and crop residue N (N_{CR}) were estimated as follows:

$$\mathrm{N_2O_{Direct}} = (\mathrm{N_{SNF}} + \mathrm{N_{CR}}) \times \mathrm{EF} \times \frac{44}{28} \times 310 \quad (2)$$

where 44/28 is a coefficient converting N_2O–N into N_2O, and 310 is the global warming potential. The fraction of N subject to leaching ($FRAC_{Leach}$) was estimated to be proportional to P/PE (Rochette et al., 2008) as follows:

$$\mathrm{FRAC_{Leach}} = \frac{0.3247\ \mathrm{P}}{\mathrm{PE}} - 0.0247 \quad (3)$$