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Current inventory approach overestimates the effect of irrigated crop management on soil-derived greenhouse gas emissions in the semi-arid Canadian Prairies

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ABSTRACT

Greenhouse gas (GHG) emissions from agricultural soils in the Canadian Prairie region are generally low and, due to dry, well aerated soil conditions, can be quite variable. Compared to dryland (rainfed) crop production, irrigated cropping has potential to contribute greater quantities of soil derived nitrous oxide (N_2O), carbon dioxide (CO_2), and methane (CH_4) to the atmosphere as producers target higher yields by minimizing soil moisture limitations and applying greater amounts of nitrogen fertilizers. However, the actual GHG dynamics from irrigated soils in this region are not well understood as there have been few field-based studies in the semi-arid prairies of western Canada. The goal of this study was to identify how emissions of soil derived N_2O, CO_2, and CH_4 are influenced by changes in soil temperature, water status, and nitrogen rates brought about by irrigated crop management. This was achieved through continuous, in-situ monitoring of soil conditions and chamber-based measurements of soil GHG flux. The most notable change in soil conditions brought about by irrigation was elevated moisture levels, which appeared to influence the flux dynamics of all three agricultural greenhouse gases—specifically, a reduction in CH_4 uptake and periodic increases in CO_2 and N_2O emissions. Despite the reduced soil moisture limitation, annual N_2O emissions from the irrigated cropping system were much lower than those calculated using the current Canadian National GHG Inventory Reporting. This suggests that annual emissions are limited more by N availability rather than moisture deficits, as the current method for emissions accounting assumes. Consequently, our results indicate that emissions from irrigated cropping systems in the semi-arid Canadian Prairies are overestimated by the current inventory approach. Moreover, because irrigated crop production involves more than just the application of water, our results demonstrate that a more systems-oriented approach to GHG accounting is required to capture the combined effects of water-soil-crop management on GHG emissions from irrigated cropping systems.

1. Introduction

The production of greenhouse gases (GHG) in soils is largely the result of microbial processes; thus, a change in crop management that promotes microbial activity can result in elevated levels of GHG emissions (Butterbach-Bahl et al., 2013). Irrigated crop management involves water applications to supplement natural precipitation and the application of nutrients (especially N) at rates greater than those applied in comparable dryland cropping systems. Thus, by altering soil temperature, moisture, and fertility regimes, irrigated crop management creates the potential for greater emissions of soil-derived GHGs (i.e., N_2O, CO_2, and CH_4) (Trost et al., 2013).

Under dryland conditions in the northern Great Plains, N_2O emissions from agricultural cropping typically follows a pattern that is characterized by persistent, low-magnitude baseline emissions punctuated by episodic, high-emission events (Brumme et al., 1999; Yates et al., 2006a, 2006b). Similar results have been reported for other semi-arid regions including Australia (Barton et al., 2008) and China (Liu et al., 2011). The greatest N_2O efflux is usually observed in the spring during snowmelt and corresponding thawing of the soil (Hao et al., 2001; Lemke et al., 1998; Liebig et al., 2010; Mosier et al., 2006; Nyborg et al., 1997; Rochette et al., 2008). Indeed, up to 60% of the total estimated growing season N_2O losses may occur during spring thaw events (Lemke et al., 1998). Large emissions also are associated

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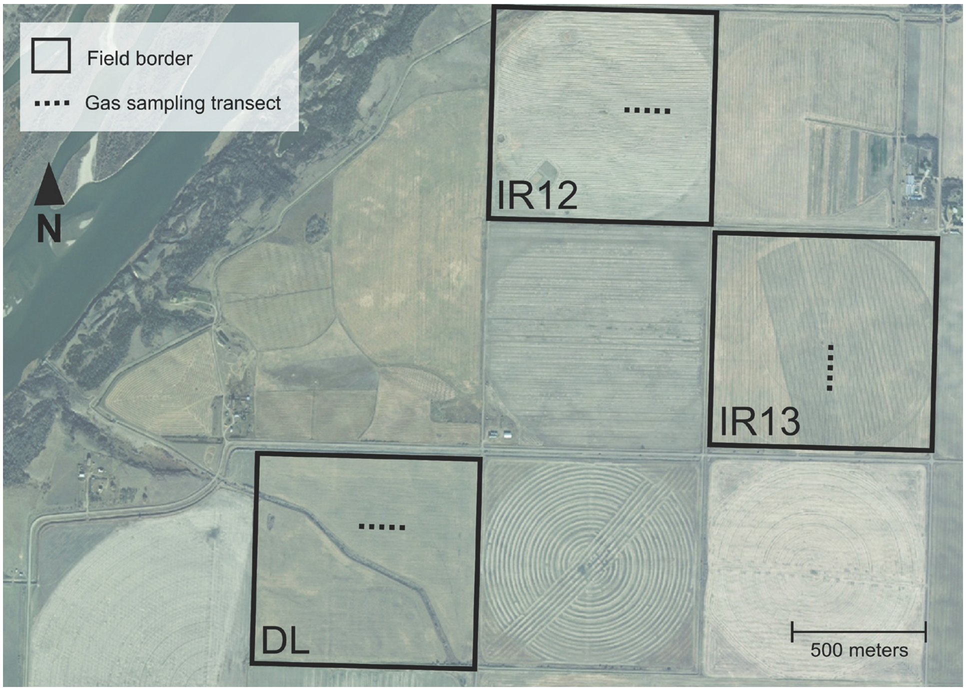

Fig. 1. An aerial view of the study site. The northwest quarter of section 16-31-07-W3 (IR12; 51°39′34″N, 106°56′31″W) and the southeast quarter of section 16-31-07-W3 (IR13; 51°39′09″N, 106°55′51″W) are managed under irrigated crop production. The dryland (DL) study site is located at the northeast quarter of section 08-31-07-W3 (DL; 51°38′41″N, 106°57′16″W). Photo credit: Saskatchewan Geospatial Imagery Collaborative (2015).

with the first precipitation/irrigation event(s) following spring fertilization (Dusenbury et al., 2008; Guenzi et al., 1994; Halvorson and Del Grosso, 2012; Liebig et al., 2005). The magnitude of precipitation-induced emission peaks are largest early in the growing season and diminish throughout the year (Dobbie et al., 1999; Jabro et al., 2008; Sainju et al., 2012), giving way to a low-level, background emissions pattern as crop growth depletes the pool of available N (Hao et al., 2001). Indeed, the low N_2O emissions occurring during the fall season are likely a result of minimal soil N availability, low soil temperature, and low moisture content (Dusenbury et al., 2008; Liebig et al., 2005; Sainju et al., 2012). Irrigated crop management increases the potential for N_2O emissions through the combination of elevated seasonal soil moisture and high fertilizer-N rates (contributing to high soil N availability) (Bouwman, 1996; Ellert and Janzen, 2008).

The methodology used to estimate fertilizer induced N_2O emissions (FIE) for the Canadian National Inventory Report (CNIR) considers regional climatic moisture trends, using precipitation (P) and potential evapotranspiration (PE) data to estimate emission factors (Rochette et al., 2008). The method assumes that emissions are limited primarily by moisture deficit, and that irrigation removes the stress associated with this deficit (i.e., irrigation + P = PE). Therefore, estimates of annual emissions from irrigated cropping systems are typically much greater than dryland cropping systems, especially in the semi-arid prairie region.

Cropping systems exchange large quantities of carbon, through photosynthesis and decomposition. Highly productive irrigated cropping systems fix large quantities of atmospheric CO_2 in plant biomass that, when returned to the system as crop residues, create potential for carbon sequestration through soil organic matter (SOM) accumulation (Flynn and Smith, 2010; Follett, 2001; Smith et al., 2008). However, realizing this potential depends on the rate of microbial decomposition which, as a result of elevated seasonal soil moisture levels, may be greater in irrigated systems (Jabro et al., 2008; Trost et al., 2013). As decomposition activity increases, SOM is lost, reducing the pool of stored soil carbon by releasing it to the atmosphere as CO_2. A Saskatchewan study that investigated the effects of long-term irrigated crop management on soil properties found that, in spite of consistently high residue returns, the total organic matter content of irrigated soils did not increase, presumably due to rapid organic matter cycling (Bardak-Meyers, 1996).

Soils in the semi-arid prairies are natural sinks for atmospheric CH_4 as a result of oxidation processes facilitated by methanotrophic microbes under aerobic soil conditions (Fowler et al., 2009; Liebig et al., 2005). However, natural rates of soil CH_4 consumption are reduced by agricultural conversion of grasslands (Fowler et al., 2009; Robertson and Grace, 2004). As a result, agricultural soils can vary from being small sinks to minor sources of atmospheric CH_4, with greater uptake occurring under drier soil conditions (Liebig et al., 2010; Mosier et al., 2006). Irrigation is intended to reduce (if not eliminate) water-related crop stress by increasing the plant available water content of the soil, and the accompanying increase in seasonal soil moisture may diminish a soils natural capacity for CH_4 uptake (Liu et al., 2006; Sainju et al., 2012).

A large irrigable land base, substantial freshwater resources, and ever increasing demands for food and fiber, provide strong impetus for the expansion of irrigated crop production in the Canadian Prairies. At the same time, it is important that we improve our understanding of the consequences of converting dryland cropping systems to irrigated production in this region. The factors driving GHG emissions from dryland cropping systems in the Prairies are relatively well studied (Lemke et al., 2009); however, the question remains: how are GHG dynamics altered by irrigated cropping conditions in this region? To address this question, the present study took a "systems" approach; i.e., we compared irrigated and dryland (rainfed) production systems—taking note of the fact that irrigated cropping systems are generally more intensively managed and that differences in GHG emissions between the two production systems will reflect differences in the combined effect of water, nutrient, and crop management. The specific objectives of the study were to (i) measure and compare soil greenhouse gas emissions from irrigated and dryland cropping systems typical of prairie Canada and (ii) determine how observed soil GHG fluxes correspond to soil conditions influenced by irrigated crop management; i.e., annual fertilizer application rate and seasonal soil moisture and temperature trends.