IMPACTS OF CROPPING INTENSITY ON SOIL C AND NET GREENHOUSE GAS FLUXES FOR DRYLAND CROPPING IN NORTHEASTERN COLORADO

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ABSTRACT

In 1985, land that was traditionally used for conventional tillage wheat/fallow cropping was converted to no till alternative cropping systems to investigate soil carbon changes. After 12 years of average to above average precipitation, continuous no till cropping with out summer fallow had stored more than twice the amount of carbon in soil compared to no till wheat/corn/fallow cropping. However, after 18 years, the wheat/corn/fallow system had stored almost 3 times as much carbon in soil as the continuous cropping, primarily due to decreased biomass inputs for the continuous summer cropping system with 3 crop failures associated with drought beginning in 1999. The continuous cropping system had almost 10 times the net greenhouse gas emissions as the wheat/corn/fallow system over an 18 year period which included 6 years of drought. Net greenhouse gas flux included CO_2 emissions from manufacture and transport of fertilizer and farm operations, soil organic C changes, and the CO_2 equivalents of N_2O emissions and CH_4 fluxes. During prolonged drought periods, cropping system rotation as well as the choice of crop within a system can have profound impacts on soil carbon storage and greenhouse gas emissions.

INTRODUCTION

Winter wheat/summer fallow cropping has been, and remains, a common cropping system in semi-arid regions of the US Great Plains. The fallow period conserves water and minimizes the probability of catastrophic crop failure but low residue inputs and conventional tillage lead to losses of soil organic carbon (SOC). In recent years, reduced tillage and cropping intensification have been adopted by some farmers and these practices have slowed SOC loss rates and can even lead to SOC increases in soils that are carbon depleted from decades of conventional wheat/fallow cropping. Land management changes that impact SOC levels also influence soil nitrous oxide (N_2O) and methane (CH_4) fluxes. Nitrous oxide and CH_4 are potent greenhouse gases with global warming potentials that are approximately 310 and 21 times, respectively, greater than carbon dioxide (CO_2) on a mass basis. Cropping intensification is expected to increase N_2O emissions because nitrogen (N) inputs are higher (Bouwman et al. 2002). Compared to conventional tillage, no till cultivation can increase or decrease N_2O emissions, but the impact is usually small. Cropped soils usually consume smaller amounts of CH_4 than uncultivated soils but once land has been converted to cropping, the CH_4 sink strength does not appear to be highly sensitive to tillage and cropping intensity. Our objectives were to quantify the impacts of cropping intensification on SOC levels and net greenhouse gas (CO_2, N_2O,CH_4) emissions over an 18 year time period for dryland systems in northeastern Colorado.

MATERIALS AND METHODS

In 1985, Peterson et al. (2000) set up experimental plots in Sterling, Colorado (lat. 40.6, long. -103.2) in fields that were previously used for conventional tillage winter wheat (Triticum sestivum)/fallow or sorghum cropping for ~50 years. Plots included winter wheat/corn (Zea mays)/fallow, annual cropping, and native range grass (NG) for each of two topographical positions (side slope and toeslope). Continuous annual cropping (CC) involved growing a crop (dryland corn, hay millet [Panicum miliaceum], or winter wheat) every year while avoiding monoculture. No till cultivation was used exclusively for the agricultural plots. Fertilizer was added at the time of planting and the amounts, ranging from 2.2–11.3 g N m^2, were based on measured soil NO_3 concentration and expected crop yield. Grain was harvested for winter wheat and corn and the stover was left on the soil surface.

To quantify SOC changes, a total of fifteen 2.54 cm cores were extracted from each plot and composited for each depth increment (0-2.5 and 2.5-5 cm) with surface residue excluded from the sample. Soils were air dried and ground to pass a 2-mm sieve size with all visible plant material larger than 2-mm sieve size removed. A sub-sample of the 2-mm sieve size sample was powder ground to pass through a 300-um sieve and analyzed for SOC. Nitrous oxide and CH_4 gas fluxes were measured using a static chamber technique (Livingston and Hutchinson 1995) in which headspace samples were extracted four times over a 90 min period from a box placed on a stainless steel collar removed only for agronomic operations. Samples were transported from the field to the laboratory for analysis of N_2O and CH_4 by gas chromatography. Gas samples were collected from four replicate plots of each treatment on the same mornings 2–4 times per month when soils were not frozen (usually March–December).

The results reported in this paper are based on data collected in1986, 1997, and 2003 for SOC changes and from 2002-2004 for N_2O and CH_4. Changes in SOC were assumed to represent net soil CO_2 fluxes. Net greenhouse gas fluxes (GHG) for each system considered included soil N_2O and CH_4 fluxes, SOC changes, emissions from farm operations (e.g., planting, harvesting, pesticide application), and emissions from manufacture and application of N fertilizer. Emissions from farm operations were based on information in West and Marland (2002). Emissions from the energy used to produce (0.82 kg CO_2-C kg^{-1} N) and apply (45.5 kg CO_2 ha^{-1}) the N fertilizer were estimated according to Follett (2001) and West and Marland (2002). Soil N_2O and CH_4 fluxes were converted to CO_2-C equivalents by using the respective global warming potentials (N_2O=310, CH_4=21) and accounting for molecular stoichiometry (EPA 2007).

RESULTS AND DISCUSISION

During the first 12 years after converting from conventional tillage wheat/fallow cropping to alternative land use, the continuous cropping system gained the most SOC followed by the NG and WCF plots (Figure 1). However, almost all of the carbon gained under CC cropping from 1986-1997 was lost during 1998-2003, while SOC levels changed little for the WCF system and continued to increase for the NG (Figure 1). Minimal crop residue inputs from

3 crop failures due to drought beginning in 1999 are responsible for the loss of SOC from the CC system. Mean annual SOC gains for the entire 18 years compared to the first 12 years of the experiment were a little lower for WCF, much lower for CC, and slightly higher for NG (Figure 2).

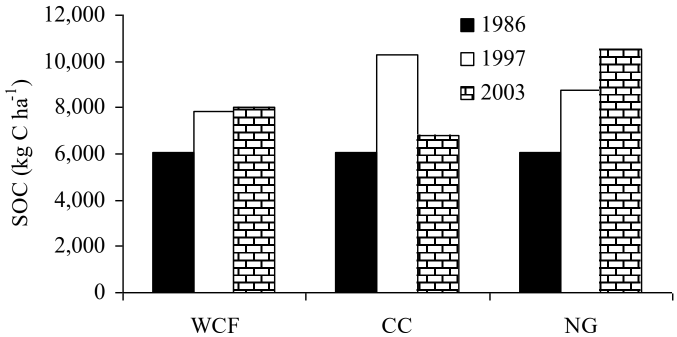

Figure 1. Soil organic carbon (0-5cm depth) for winter wheat/corn/fallow, continuous cropping, and native grass systems in northeast Colorado.

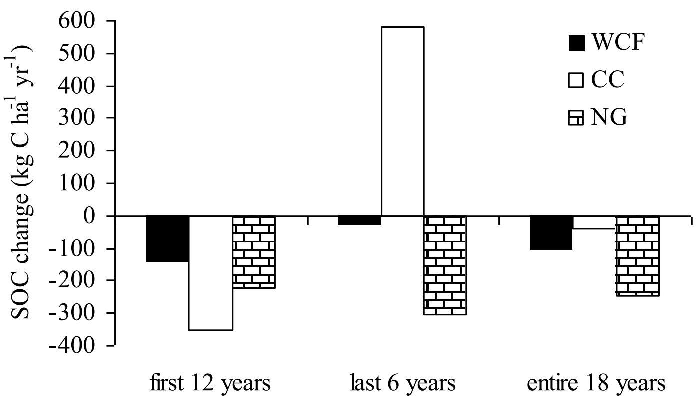

Figure 2. Mean annual soil organic carbon changes (0-5cm depth) over different time periods of an 18 year experiment for winter wheat/corn/fallow, continuous cropping, and native grass systems in northeast Colorado. Negative values imply carbon storage in soil.

Net GHG fluxes calculated using SOC changes over the entire 18 years showed that the WCF system was a small source, CC cropping was a substantial source and NG was a strong sink (Figure 3). The primary GHG sources were from N fertilizer manufacture and application and soil N_2O emissions (Figure 3). Soil N_2O emissions were highest from CC, which received the most N fertilizer, and lowest from NG, which was not fertilized. SOC storage varied substantially while all the systems were small sinks for CH_4. During the first 12 years after land use change, all the systems were net GHG sinks, but during the last 6 years the cropped systems became net sources (Figure 4). This was due to last 6 years of the experiment representing a drought period which led to SOC losses for the CC system and minimal SOC gains for the WCF cropping (Figure 2). Interestingly, the native grass continued to store carbon even during the drought years.

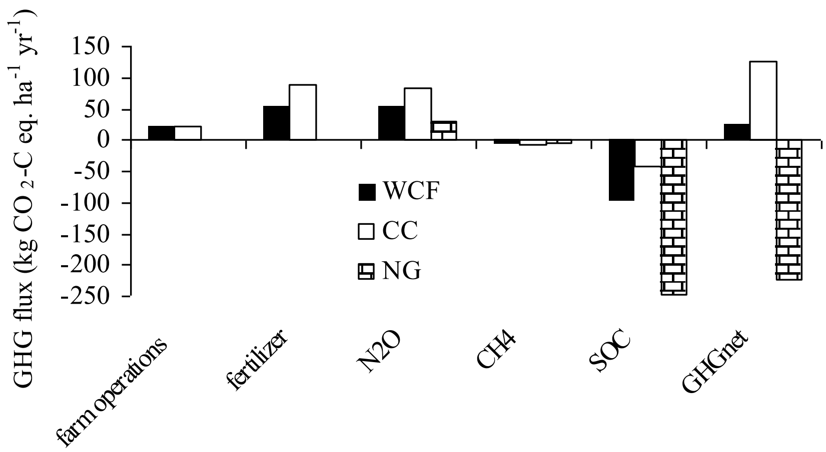

Figure 3. Components of net greenhouse gas flux for wheat/corn/fallow, continuous cropping, and native grass systems in northeast Colorado. Negative values imply carbon storage in soil.

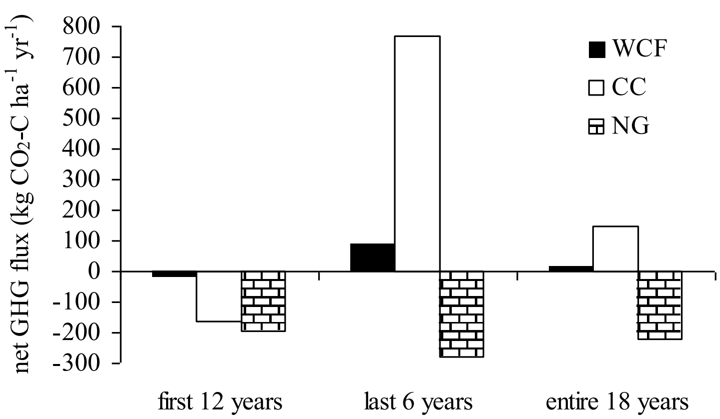

Figure 4. Mean annual net greenhouse gas flux over different time periods of an 18 year experiment for winter wheat/corn/fallow, continuous cropping, and native grass systems in northeast Colorado. Negative values imply a net GHG sink.

CONCLUSIONS

SOC gained from cropping intensification is highly vulnerable to loss during drought years and the full suite of GHG must be considered to fairly compare different land management strategies. Soils that are depleted in SOC from years of conventional tillage wheat/fallow cultivation can sequester C upon land use change. However, there are interactions between choice of cropping system and weather that strongly influence SOC changes. Cropping system and weather also control N_2O emissions and management choices intended to increase SOC levels can lead to higher N_2O emissions, and increase the net GHG source. We emphasize the importance of conducting long term studies that include sufficient climate variability because after the first 12 years of land use change the CC system stored much more C than the WCF system but after 18 years, SOC storage in the CC was minimal and this system had almost 10 times the net GHG emissions of the WCF rotation. Increasing cropping intensity can increase SOC levels during years of normal or greater precipitation but a relatively small number of drought years can quickly reverse SOC gains. Native grass systems can be a net GHG sink, even during drought periods.

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