Simulated changes in soil organic carbon pools with different tillage scenarios in the Northwest Great Plains

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Abstract Tillage practices greatly affect carbon (C) stocks on agricultural lands. Quantification of the impacts of tillage on carbon stocks at a regional scale has been challenging because of the spatial heterogeneity of soil, climate, and management conditions. We evaluated the effects of tillage management on the dynamics of soil organic carbon (SOC) on croplands in the Northwest Great Plains ecoregion, using the General Ensemble Biogeochemical Modeling System (GEMS), coupled with a block sampling protocol. The tillage management scenarios included: conventional tillage (CT), no-till (NT), and actual tillage management (ATM) which in 1998 consisted of CT (23.5%), NT (38.4%), and reduced tillage (RT) (38.1%). Model simulations indicated that the average amount of C released from croplands in the region to the atmosphere between 1972 and 2000 was 261 (± 31) kg C $ha^{-1}yr^{-1}$ under CT and 210 (± 27) kg C $ha^{-1}yr^{-1}$ under NT. The decrease in total SOC stock was predominantly a result of the reduction in the slow C pool at the study's time scale. Results suggest that the response of SOC to tillage management depends significantly on the baseline SOC level: soils having higher SOC levels tend to lose more C under CT but have a higher potential to reduce C emissions with NT.

1. Background and Objectives

Sequestering carbon (C) in cultivated soils by converting from conventional tillage (CT) to no till (NT) is being advocated by many as a measure to assist in meeting the demands of an international C credit system (Bernacchi et al., 2005). However, the potential of croplands with such conservation management to mitigate CO_2 emissions from grass-crop mixed ecosystems at a regional scale needs to be understood.

This study evaluated the effects of tillage on soil C budgets by simulating the dynamics of soil organic carbon (SOC) with the tillage management scenarios of CT, NT, and actual tillage management (ATM) at an ecoregion scale.

2. Materials and Methods

2.1. The Study Area

The study area is the Northwest Great Plains ecoregion which covers a total surface area of 33,718 km^2 in Montana, Wyoming, North Dakota, South Dakota, and Nebraska. The ecoregion was dominated by grassland (77%), and cropland (15%) in 2000 (Fig. 1).

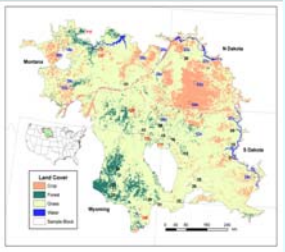

Fig. 1. The Northwest Great Plains (Ecoregion 43) and locations of sample blocks (After Tan et al., 2006).

2.2. Data Sources and Model Simulations

Model simulations and analyses of results were based on sample blocks. There were forty 10 km x 10 km sample blocks that were previously selected within the ecoregion by Loveland et al. (2002) (Fig. 1) for identifying changes in land cover using Landsat data obtained in 1973, 1980, 1986, 1992, and 2000.

Data used in this study primarily consisted of climate, land cover/land use change, soil properties (as initial soil values from STATSGO), and ATM data obtained from the Conservation Technology Information Center (CTIC). These data layers were overlaid to produce a Joint Frequency Distribution (JFD) table. The SOC dynamics on croplands were simulated with the General Ensemble Biogeochemical Modeling System (GEMS) at a 60-m spatial resolution and monthly time step (Liu et al., 2004).

The tillage information derived from CTIC data was integrated into model simulations by random allocation to cropped areas, proportionally between 1972 and 2000. We assumed that the tillage type in 1972 and before was CT over all croplands.

The outputs associated with cropland were analyzed and discussed for the sample blocks in which the percentage of cultivated area was greater than 10%.

3. Results and Discussion

3.1. Tillage Management History

The croplands devoted to row crops, small grain, and fallow were mainly for spring wheat (*Triticum aestivum*), maize (*Zea mays* L.), soybean (*Glycine max* (L.) Merr.), and alfalfa (*Medicago sativa*). The proportion of cropland to total land area in our 40 sample blocks was 41.2, 21.4, 8.7, and 4.7% in North Dakota, Montana, South Dakota, and Wyoming, respectively. The areal proportions of croplands under ATM are presented in Fig. 2.

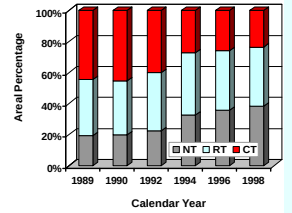

Fig. 2. Areal proportions in the total planted area under of each tillage management across the ecoregion (RT: reduced-tillage; CT: conventional tillage; NT: no-till).

Average cropped area in the Northwest Great Plains between 1989 and 1998 was about 4.06 million ha. The CT area was 44.7% in 1989 and decreased to 23.5% in 1998. Meanwhile, the NT area increased from 19.2% to 38.2%, and little change happened to the RT area. The percentages of NT- and CT-managed areas for each state are presented in Fig. 3.

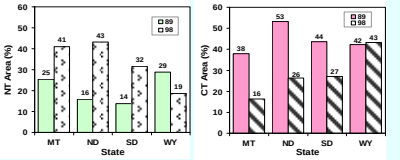

Fig. 3. Changes in conventional tillage (CT) and no-till (NT) areas for each state between 1989 and 1998.

3.2. Temporal Trends of SOC Pools

The total SOC stock in cropped areas generally tended to decrease from 1972 to 2000, but the reduction in SOC stock was smaller under NT (210±33 kg C $ha^{-1}yr^{-1}$) than under either CT (261±36 kg C $ha^{-1}yr^{-1}$) or ATM (256±38 kg C $ha^{-1}yr^{-1}$). Compared to CT, NT reduced SOC loss by about 51 kg C $ha^{-1}yr^{-1}$ during the study period. We attributed the difference to the changes both in labile and slow C pools. As indicated by Fig. 4, NT likely led to more reduction in the labile pool and a lower rate of decrease in the slow pool, compared to either CT or ATM.

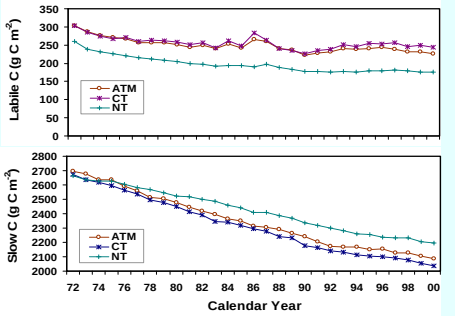

Fig. 4. Temporal trends in soil labile C pool and slow C pool in association with conventional tillage (CT), no-till (NT), and actual management practice (ATM) within the sample blocks where cropped area was greater than 10%.

3.3. Change Rate of SOC in Relation to Initial SOC Level

The simulation results in Fig. 5 indicate that crop production, regardless of tillage practices, tended to reduce SOC from the topsoil (0 – 20 cm in depth). The response of SOC to tillage management, especially in the slow C pool, depended significantly on the initial or baseline SOC levels. Generally, soils with higher baseline SOC content tend to lose more C over time. However, the simulation results presented in Fig. 6 suggest that the conversion from CT to NT might lead to little C emission from or C sequestration by soils with low initial SOC stocks.

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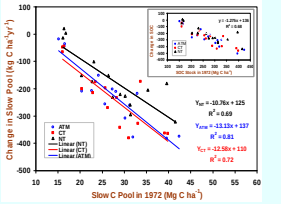

Fig. 5. Magnitude of the change in the slow pool over the period from 1972 to 2000 in relation to the initial slow pool in 1972 for the sample blocks in which the cropped area portion was greater than 10%. The embedded graph was made in the same way to illustrate the relation of the changed magnitude of the total SOC stock to the baseline level.

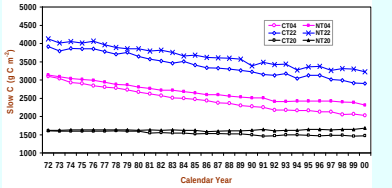

Fig. 6. Temporal trends of slow C pools under CT and NT in association with initial slow C levels for selected sample blocks. (The digits following CT and NT in the legend are the sample block numbers)

4. Conclusions

There are many studies on the dynamics of SOC stock with tillage practices on experimental plots. Our study focused on the cropped areas within grassland ecosystems. We used a block sampling protocol and a biogeochemical modeling approach to spatially integrate tillage management inventory data at a county level with other multi-source data sets.

The potential to reduce C emissions with the conversion of CT to NT at the sample block and regional scales as presented here is smaller than those reported from some experimental plots in North Dakota. However, our results suggest that the effects of tillage management on SOC budgets and the potential mitigate CO_2 emissions with the conversion of CT to NT depend significantly on the initial SOC levels. This will help farmers and policy-makers to manage C sequestration programs, based on both land cover/land use and soil inventory information.

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