Estimating the Overall Impact of A Change In Agricultural Practices on Atmospheric CO_2

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Introduction

One option for sequestering carbon in the terrestrial biosphere is to increase the carbon (C) stocks in agricultural soils. There is now an extensive literature on the amount of C that has been lost from soils as a consequence of humans disturbing natural ecosystems, and of the amount of C that might be returned to soils with improved management practices. Improvements in management practices could include efficient use of fertilizers and irrigation water, use of crop rotations, and changing from conventional tillage (CT) to conservation tillage (or, more specifically, to no-till (NT)). The Intergovernmental Panel on Climate Change (IPCC) has estimated that 55 x 10^9 Mg of soil C have been lost, globally, largely as a result of cultivating former grasslands, forests, and wetlands (Cole *et al*. 1996). The IPCC estimated further that 22-29 x 10^9 Mg of C could be returned to existing, world, agricultural soils under improved management regimes. Historical losses of soil organic C (SOC) in the U.S., due to cultivation, have been estimated to be $1.3 \pm 0.3 \times 10^9$ Mg (Kern and Johnson 1993). Kern and Johnson projected that by increasing NT practice in the U.S. from 27% in 1990 to 76%, a total of $0.4 \pm 0.1 \times 10^9$ Mg C could be sequestered in the soil during the interval 1990-2020.

These studies tend to focus on increasing the C stocks in soils rather than on the overall effect that changes in agricultural practice would have on C stocks in the atmosphere. Changing agricultural practice can impact net CO_2 emissions to the atmosphere in three fundamental ways: (1) it can lead to an increase in the C held in agricultural soils, (2) it can lead to a change in emissions of CO_2 from fossil fuel burning, and (3) it can change agricultural productivity, and hence the amount of cultivated land needed to meet the demand for agricultural products. Changing agricultural practice can also affect the net emissions of other greenhouse gases, such as N_2O emissions associated with nitrogen (N) fertilizer application. This study focuses on a comprehensive analysis of the first two factors, including N_2O emissions, and inquires into the balance between C sequestered and the change in C equivalent (C_{eq}) emissions associated with a change in agricultural practices. N_2O emissions are converted to C equivalent emissions, based on their time-integrated effect on the global atmospheric energy balance, as suggested by the IPCC (Schimel *et al*. 1996).

Methods of C_{eq} accounting

Estimating the overall impact on net emissions of CO_2 to the atmosphere requires accounting for C fluxes within specific system boundaries. In our analysis, CO_2 emitted to the atmosphere is represented as a positive flux, while C sequestered from the atmosphere into the soil is represented as a negative flux. Carbon dioxide is emitted from the combustion of fossil fuels used to run farm equipment and to manufacture agricultural inputs such as fertilizers and pesticides. Carbon dioxide emitted from agricultural inputs was estimated from energy used to manufacture and transport the inputs (West and Marland 2001a), along with the average amounts of agricultural inputs used in the U.S. (USDA 1997). If, for example, increased C sequestration requires increased use of N fertilizers, the removal of atmospheric C to increase SOC will be, to some extent, countered by increased emissions from fossil fuels used to manufacture fertilizer. On the other hand, if SOC can be increased while using less N fertilizer, there will be additive savings in CO_2 emissions.

Emissions of N_2O from N fertilizer application were based on accounting methodology from the Revised 1996 IPCC Guidelines (IPCC 1996). Accounting for direct and indirect N_2O emissions, using the IPCC Guidelines, results in an average of 2.52 kg C_{eq} (as N_2O) emitted per kg N applied. While it is acknowledged that there is a wide range of uncertainty surrounding the value for N_2O emissions; as a function of time of sampling, type of fertilizer applied, and soil moisture and temperature, etc.; we use this value as a first approximation of the importance of N_2O emissions.

Carbon sequestered in the soil, due to a change in tillage practice, was estimated from data currently being compiled in the U.S. Department of Energy project, Carbon Sequestration in Terrestrial Ecosystems (CSiTE). A change in agricultural practice can be expected to cause SOC to gradually approach a new steady state. Since a chronological analysis has not yet been completed on the CSiTE data base, the duration of sequestration used here is the same as that used by West and Marland (2001a). West and Marland (2001a) assumed that C accumulation continues at the measured average rate for 20 years, from which time it gradually declines until sequestration ceases at year 40. In order to maintain the new level of soil carbon, the new set of management practices will need to be continued. Consequently, the balance between changes in soil C and changes in fossil fuel use will be a function of time, the change in fossil fuel use becoming the dominant component as time passes.

The sum of the positive flux of CO_2 emissions and the negative flux of C sequestration results in a value for Net C flux (NCF). When comparing this value to a baseline (e.g. NT is compared to continuation of CT), a value for Relative Net C flux (NCF_r) is obtained. Cumulative Net C flux (NCF_c) refers to the cumulative sum of NCF_r over time. This analytical approach is described in more detail by West and Marland (2001b). When the analyses include other greenhouse gas emissions, such as N_2O emissions, the result is recorded as a net C equivalent flux ($NC_{eq}F$).

Results and Discussion

Preliminary analyses for the average continuous crop in the U.S. indicate that changing from CT to NT can result in sequestration of 337 ± 108 kg C ha^{-1} yr^{-1} in agricultural soils (Figure 1). Annual crop rotation, with 2 or more crops, can potentially sequester 606 ± 234 kg C ha^{-1} yr^{-1} in the soil following a change from CT to NT. These sequestration rates are for the early years following a change in tillage practice and the rate of sequestration can be expected to decline after a decade or two. Corn crops appear to have a greater potential to sequester C following a change in tillage practice than do either wheat or soybean crops. Analysis of 15 long-term experiments suggests that caution should be used when changing from CT to NT while growing continuous wheat, because in some cases a loss of SOC can occur.

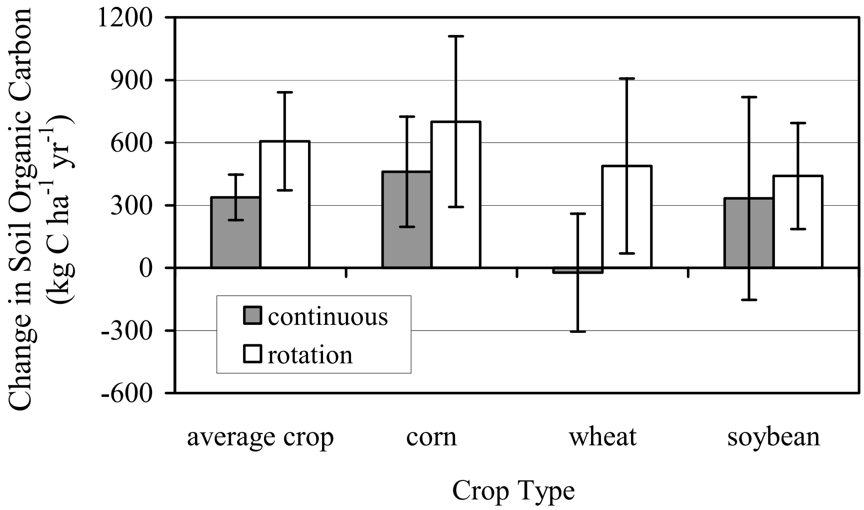

Figure 1. Average annual accumulation of soil organic carbon when changing from conventional tillage to no-till. The rate of carbon increase is for 30 cm depth and for the early years following a change from conventional tillage to no-till.

Adding C emissions from fossil fuel combustion to the amount of C sequestered (Table 1, part A) indicates that there is, on average, a net savings of C emissions over all continuous cropping systems, when changing from CT to NT, although the reasons for the C savings differ between systems. In an average continuous corn system (based on US average values, circa 1995), C emissions from fossil-fuel use are similar between tillage practices for corn, and it is the large accumulation of soil C that contributes to the negative NCF_r. Unlike the corn systems, continuous wheat systems have a potential to release soil C when changing from CT to NT, but the significant decrease in C emissions from fossil-fuel use associated with NT still results in a negative NCF_r.

Including N_2O emissions from fertilizer application in the analysis significantly changes the overall impact on total atmospheric emission of greenhouse gases (Table 1, Part B). In the case of corn, using average U.S. fertilizer application rates for CT and NT and IPCC estimates for the relationship between N fertilizer application and N_2O emissions, accounting for N_2O emissions reduces the net C equivalent savings by more than 100 kg C_{eq} ha^{-1} yr^{-1}. Conversely, in wheat systems the average application rate of N fertilizer decreases with a change from CT to NT and, hence, the C equivalent savings approximately double when N_2O is included in the analysis.

The cumulative sum of NCF_r over time, not including N_2O emissions (Figure 2), shows a continuous and growing C savings in all systems following conversion from CT to NT. For most systems, the largest annual C savings occur in the early years when soil C sequestration rates are at their highest. Continuing savings past year 40 are attributed to smaller emissions from fossil fuel use for NT than for CT. This trend is not seen in wheat systems. In wheat systems the potentially small or negative changes in SOC that occur when changing tillage practice are balanced by savings in fossil fuel emissions, and the curve becomes more steep as soil C reaches a steady state and fossil fuel savings continue.

Table 1. Carbon fluxes from agricultural systems over three crop types and two tillage practices (**A**) not including N_2O emissions and (**B**) including N_2O emissions.

	Average crop		Corn		Wheat		Soybean	
	CT	NT	CT	NT	CT	NT	CT	NT
	Carbon flux to atmosphere (kg C ha^{-1} yr^{-1})							
A.								
C sequestration	0	-337	0	-460	0	23	0	-333
CO_2 emissions from fossil fuels	171	137	228	225	173	115	112	71
Net C flux	171	-200	228	-235	173	138	112	-262
Relative net C flux		-371		-463		-35		-374
B.								
N_20-C_{eq} emissions	160	200	271	379	178	147	31	73
Net C_{eq} Flux	331	0	499	144	351	285	143	-189
Relative net C_{eq} flux		-331		-355		-66		-332

Note: CT and NT refer to conventional tillage and no-till, respectively.

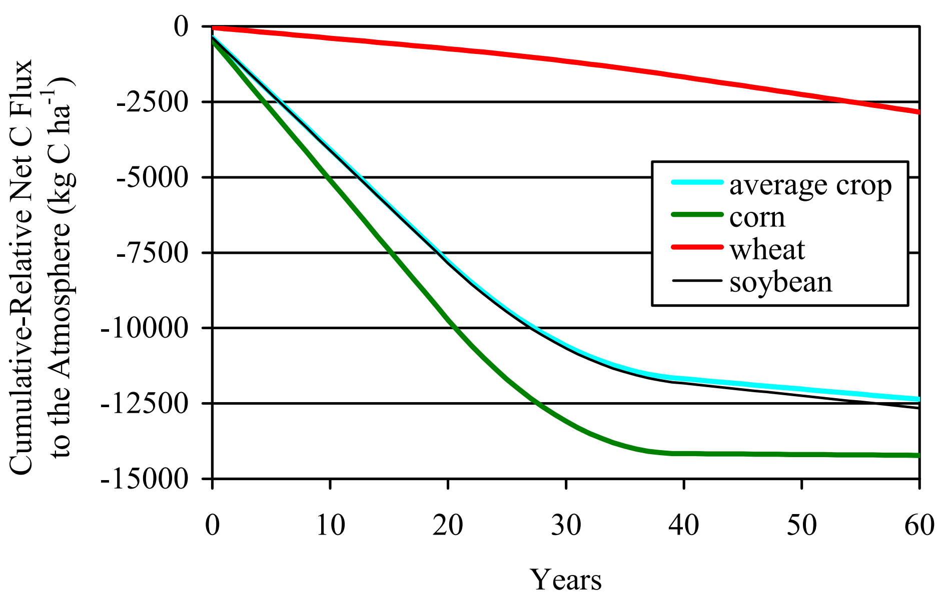

Figure 2. Cumulative Net C flux for no-till cropping systems, relative to conventional tillage systems, not including N_2O emissions.

The trends of cumulative savings in emissions of C_{eq} change when N_2O is included in the analysis (Figure 3). The effect of increased emissions of N_2O becomes increasing apparent after changes in soil carbon cease in the 40th year. An increase in N fertilizer application when moving from CT to NT results in a continual C_{eq} loss to the atmosphere over time, and this loss will continue as long as the practice continues. For wheat, the decreased use of N fertilizers leads to higher savings in net greenhouse gas emissions.

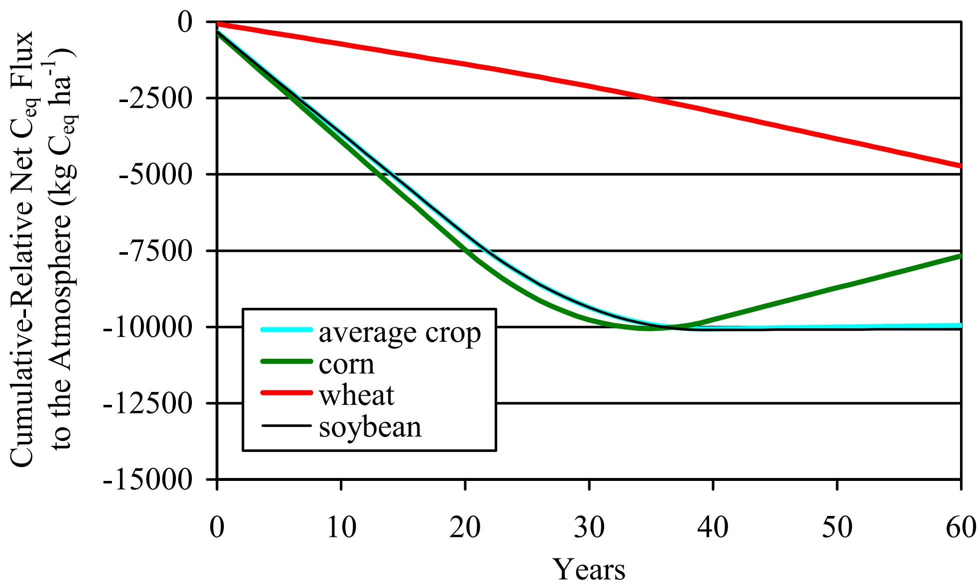

Figure 3. Cumulative Net C_{eq} flux for no-till cropping systems, relative to conventional tillage systems, including N_2O emissions.

Conclusions

Corn, wheat, and soybean collectively account for over 60% of harvested area in the U.S. All of these crops could potentially be managed to decrease the net amount of C lost to the atmosphere as CO_2, i.e. if a change from CT to NT were to occur. When emissions of N_2O from application of N fertilizer are included, the long term effect on net emissions of total greenhouse gases might be quite different. High rates of fertilizer application on NT corn might permit savings of net greenhouse gas emissions over the short term, but lead to increased net greenhouse gas emissions over a longer time period (Figure 3). This result is based on current U.S. trends of N application with changes in tillage practices (USDA 1999). Presumably the increase in N fertilizer is necessary to maintain crop yield with changes in tillage. In this analysis, we have not considered any changes in yield that might accompany changes in tillage practice. One would expect that changing yield on land used to produce crops would lead to changes in the area in tillage, and hence to changes in land use. Changes in land use can be expected to yield additional changes in net C flux to the atmosphere.

As of 1995, harvested area of corn, wheat, and soybean in the U.S. was 26.3, 24.6, and 24.9 million ha, respectively. The percentage of area in corn, wheat, and soybean using conventional tillage practices in 1995 was 59, 78, and 57, respectively. If tillage practices on all lands currently using CT were changed to NT, and the dynamic relationships of soil C sequestration illustrated in Figure 2 could be maintained for the additional lands, there is potential for an improvement of cumulative net C flux of -0.35×10^9 Mg C over a 40-year period. That is, the net C flux to the atmosphere could apparently be decreased by a total of 0.35×10^9 Mg C over 40 years if all lands producing corn, wheat, or soybean by CT were converted to NT. Since conversion of all CT land to NT is highly unlikely, we have made a similar estimate for the hypothetical case that the amount of land in NT, as of 1995, is doubled. In 1995, the percentage of area in corn, wheat, and soybean using NT practices was 17, 7, and 28, respectively. Doubling the application of NT practices on lands grown for corn, wheat, and soybean can potentially result in an improvement of cumulative net C flux by -0.06×10^9 Mg C over 40 years. During the initial years of soil C sequestration, if all CT corn, wheat, and soybean systems changed to NT, the potential relative net C flux would be -0.012×10^9 Mg C yr^{-1}.

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