K-State Research and Extension

SEQUESTRATION OF ATMOSPHERIC CO_2 INTO SOILS: HOW AND WHY

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Why

Since the late 1800's fossil fuel use, expansion of cultivated agriculture, and forest clearing have led to an increase in atmospheric CO_2 from 260 ppm to current levels >370 ppm (IPPC, 1995) (Fig. 1). Most of the recent increase in CO_2 has been attributed to combustion of fossil fuels for energy and transportation. This increase in atmospheric CO_2 potentially impacts climate, as it is a greenhouse gas. It has been estimated that 20-40% of targeted emission reductions in the U.S. can be met by carbon sequestration into soils.

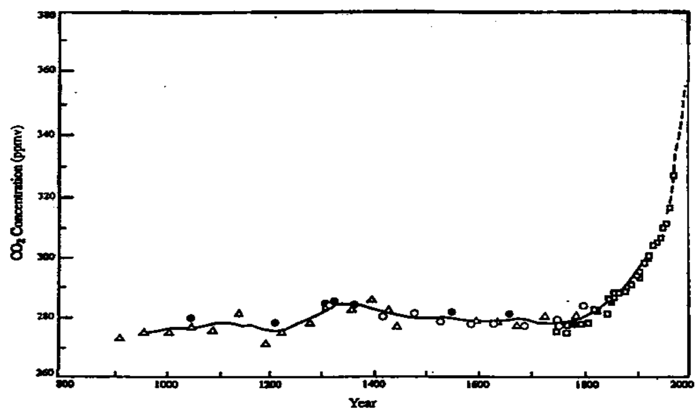


Figure 1. Temporal changes in atmospheric concentration of CO_2 (IPCC, 1995).

How?

Recent models of land use suggest terrestrial systems can mitigate the increase of atmospheric CO_2 by sequestering C into vegetation and soils. The estimated amount of C stored in world soils is about 1100 to 1600 Pg, more than twice the C in living vegetation (560 Pg) or in the atmosphere (750 Pg) (Sundquist, 1993). Hence, even relatively small changes in soil C storage per unit area could have a significant impact on the global C balance. Approximately 50% of the soil organic carbon (soil organic matter) has been lost from the soil over a period of 50 to 100 years of cultivation. However, this loss of soil carbon also represents the potential for storage of C in agricultural soils. Carbon sequestration by soils occurs primarily through plants. Plants convert CO_2 into tissue through photosynthesis. Upon their death, plant tissues decompose, primarily by soil microorganisms, and the carbon in the plant material is eventually released back into the atmosphere as CO_2. However some of the C in plant material forms soil organic matter sometimes referred to as "humus." Some of this carbon in the soil can persist in soils for hundreds and even thousands of years.

	Soil C	Reference
	Mg C ha^{-1}	
Wet Tropical Forest [1]	115	Brown & Lugo, 1982.
Moist Tropical Forest [1]	85	" "
Dry Tropical Forest [1]	71	" "
Guatemalan Tropical Forest [1]	85	" "
Temperate Forest [1]	80	Schleshinger, 1997.
Eastern Kansas Prairie (soil depth 40com)	78	Brennan & Rice, 2001.
Eastern Kansas Prairie (soil depth 15 cm)	53	Rice et al., 2000.
North Central Oklahoma (soil depth 15 cm)	24	Rice et al., 1999.
Western Kansas (soil depth 15 cm)	39	" "

* [1] soil depth 40 cm or greater

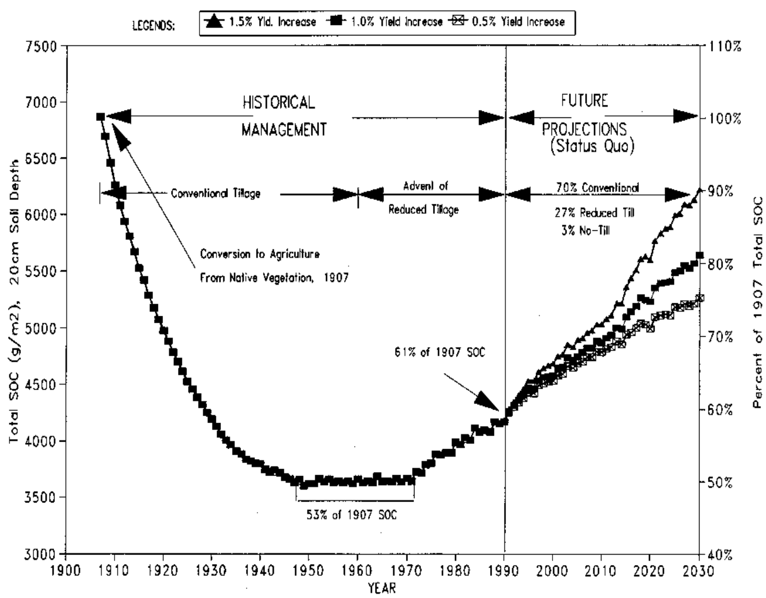
Agriculture's Role

The amount of carbon soils can sequester is dependent on several factors. Inherent factors include climate variables (temperature and rainfall) and clay content. Much of the central United States and Canada, which was once prairie, is now in cultivated agriculture. The grasses of prairies store much of their C belowground, which is eventually converted to soil organic carbon. Previous cultivated agricultural practices have decreased soil C, but advancement in crop and soil management practices have the potential to increase soil C. Table 1 lists several practices affecting the soil's ability to sequester C (Lal et al., 1999).

Table 1. Land Use for C Sequestration (Lal et al., 1999)

Management Strategies		
Land Use	Soil Management	Crop Management
• Cultivation • Forestry • Rangeland	• Tillage • Residue Management • Fertility • Water Management • Erosion Control	• Varieties • Crop Rotations • Cover Crops • CRP

The impact of soil and crop management is illustrated in Fig. 2. As noted earlier, agriculture in the 1800's and early 1900's relied upon the plowing the soil with low crop yields and crop residues were often removed. This combination of agricultural practices resulted in reducing the replenishment of organic material (carbon) to the soil. As a result soil C content decreased by as much as 50% over a 50 to 70 year period. In recent decades, higher yields, return of crop residues, and development of conservation tillage practices have increase soil carbon.



Additional gains in soil C in agricultural soils could be achieved by a reduction in tillage and better management of residues Table 2.

Table 2. Estimates of C sequestration potential of agricultural practices of U.S. cropland (Lal et al., 1999).	
Agricultural practice	(MTC/ha/y)
Conservation Reserve Program	0.3 – 0.7
Conservation tillage	0.24 – 0.40
Fertilizer management	0.05 – 0.15
Rotation with winter cover crops	0.1 – 0.3
Summer fallow elimination	0.1 – 0.3

Comparisons of no-tillage with spring plow have projected 20 to 80% higher soil C with no-tillage after 40 years (Donnigian et al., 1994). Others have reported field studies with approximately 30% increases in soil C due to no-tillage when compared with conventional tillage (Kern and Johnson, 1993). At Kansas State University, we have shown an increase in soil C of approximately 0.2 MT C/ha/y (Fig. 3). This is equivalent to an increase of 1 ton C/acre over a 10-year period. The amount of carbon sequestered is on the lower end of the range given by Lal et al. (1999). Cropping sequences can also affect soil C. In Kansas, intensifying cropping systems by conversion from wheat-fallow rotation to wheat-grain sorghum-fallow rotation in western Kansas increased soil C levels (Havlin et al., 1990). Combinations of high intensity cropping with no-tillage gave maximum benefits modeled for several locations in the North American prairies (Paustian et al., 1998) (Table 3).

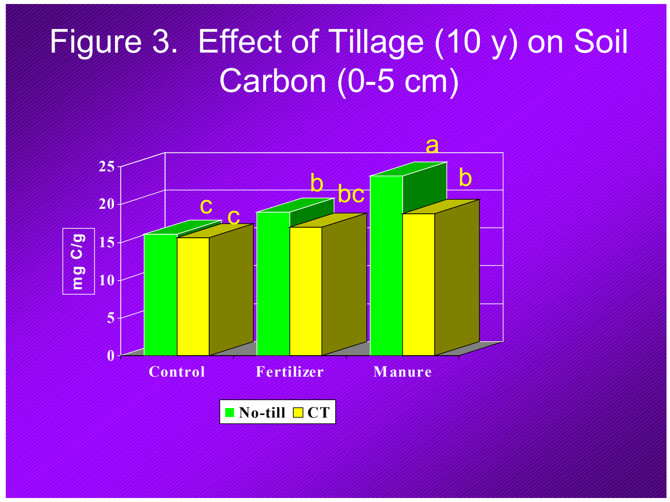


Figure 3. Effect of Tillage (10 y) on Soil Carbon (0-5 cm)

Table 3. Change in soil C due to cropping intensity and tillage (g C m^{-2}) (Adapted from Paustain et al., 1998)

	Cropping intensity/tillage			
	-----High----		-------Low------	
Site	CT	NT	CT	NT
Wisconsin	1300	1400	-30	260
Kansas	2000	2300	980	1100
Canada	290	450	-90	100
Nebraska	1170	1320	140	230
Colorado	810	970	-80	30

Grassland systems also can contribute to C sequestration when properly managed. Research at Kansas State University has shown that under elevated atmospheric CO_2 the soil contained 6% more C to a depth of 15 cm compared with ambient conditions (Rice et al., 1999) (Fig. 5). The increased in soil C was due to increased plant production followed by incorporation into the soil. The amount of C sequestered over the 8-year experimental period was equivalent to 2 tons C/acre. Proper fire management also increases soil C. We have reported a 5 % increase with annual burning compared to unburned tallgrass prairie (Rice et al., 1999).

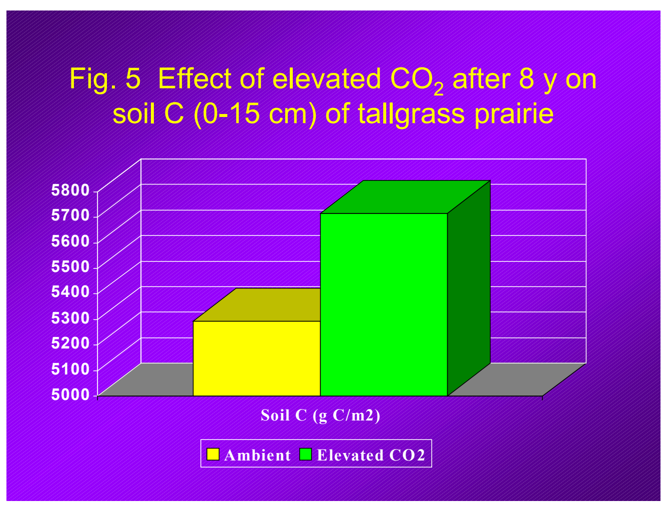


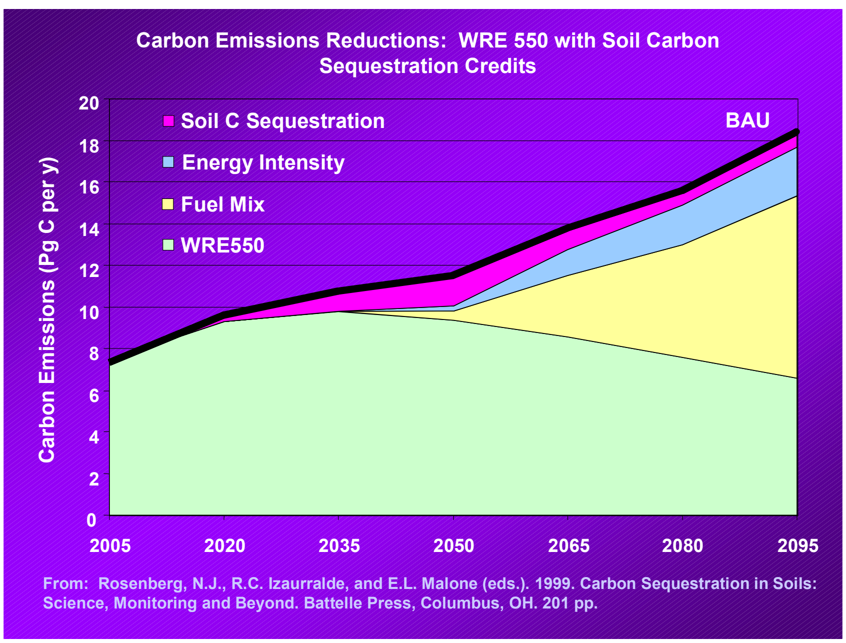
Fig. 5 Effect of elevated CO_2 after 8 y on soil C (0-15 cm) of tallgrass prairie

While much of the discussion of carbon sequestration has been directed to forests, global estimates for C sequestration for different ecosystems indicate the agricultural lands are 45 to 90 % of forests (Metting et al., 1999) (Table 4). If grasslands and rangelands are considered, then managed lands contributions to carbon sequestration are greater than forests. Thus all ecosystems must be considered in any plan to increase C sequestration.

Table 4. Global terrestrial C sequestration potential (adapted om Metting et al., 1999)

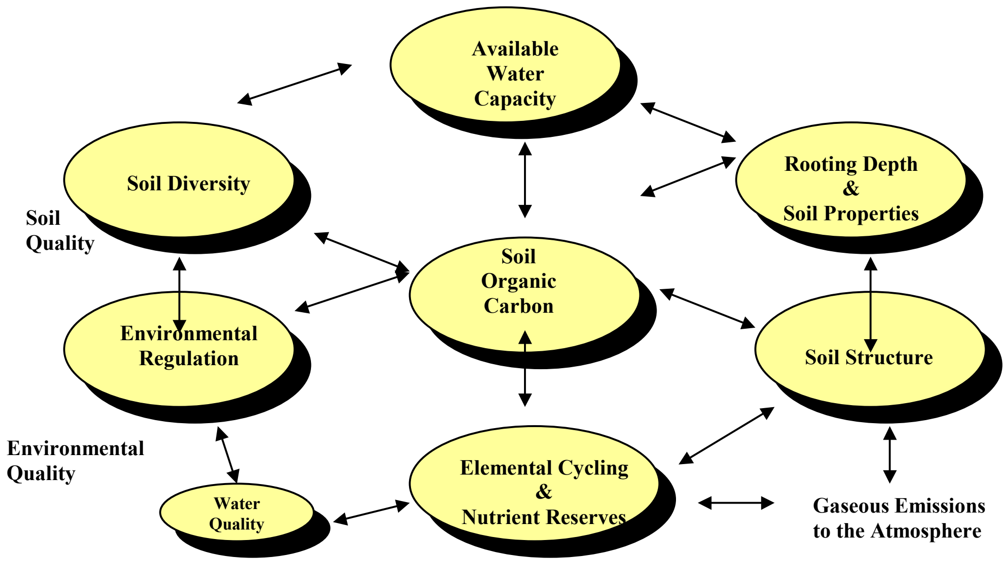
Ecosystems	Potential (Gt C/y)[2]
Agricultural lands	0.85 – 0.90
Biomass crops for biofuel	0.5 – 0.8
Grasslands	0.5
Rangelands	1.2
Forests	1 – 2

Economic analysis suggest that soil carbon sequestration is among the most beneficial and cost effective options available for reducing greenhouse gases, particularly over the next 30 years until alternative energy sources are developed and become economic feasible. Recent estimates of the potential for U.S. agriculture, using existing technologies, are on the order of 75-200 MMT C per year (Lal et al., 1998; Bruce et al., 1998). The figure below illustrates a scenario in which carbon sequestration is allowed. Under this scenario, soils achieve the necessary net carbon emissions until 2050 (Rosenberg et al., 1999). After 2050 reductions in carbon emissions must come from changes in energy technologies.



Additional benefits

Managing agricultural soils for sequestering C will result in additional benefits.



The benefits of increasing soil organic C include increased crop productivity and enhanced soil, water, and air quality. In addition, management practices that increase soil C also tend to reduce soil erosion, reduce anthropogenic energy inputs into the soil, and improve soil resources.

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