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# The Effects of Soil Management Systems on Soil Carbon Dynamics

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**Abstract:** Carbon is the building stone of plant and animals and a major constituent of soil organic matter. Carbon dioxide is the gaseous form of carbon and is a greenhouse gas. The source of atmospheric $CO_2$ is manly fossil fuel combustion, land clearing (removing plant residues from soils and fire or clear cutting of forest areas for cultivation), and soil management systems. Since the beginning of industrial revolution, $CO_2$ levels have risen at a rate of 1.5 percent per year (IPCC, 2001). The increases of atmospheric $CO_2$ concentration could lead to global warming. One possible mechanism for reducing the rise of $CO_2$ concentration in the atmosphere is fixation of $CO_2$ by plant into soil organic carbon. A long-term reduction in atmospheric $CO_2$ levels will require a reduction of fossil fuel use and minimize the amount of $CO_2$ release from soils to the atmosphere.
**Key Word:** Soil carbon, atmospheric $CO_2$, soil management, carbon dynamics

## Toprak Yönetim Sistemlerinin Toprak Karbon Dinamiği Üzerine Etkileri

**Özet:** Karbon, bitki ve hayvanların yapı taşı ve toprak organik maddesinin en önemli öğesini oluşturmaktadır. Karbon dioksit karbonun gaz formu olup bir sera gazıdır. Atmosferdeki $CO_2$'nun başlıca kaynakları fosil yakıtlar, toprak yüzeyinin bitkilerden temizlemesi (bitki hasat artıklarının yakılması ve ormanların yakılarak veya kesilerek tarıma açılması) ve toprak yönetim sistemleridir. Endüstriyel gelişmeden bu yana atmosferdeki $CO_2$ düzeyi yılda 1.5 % düzeyinde artmaktadır (IPCC, 2001). Atmosferdeki $CO_2$ konsantrasyonundaki bu artış küresel ısınmaya yol açabilir. Atmosferdeki $CO_2$ miktarindaki bu yükselişi düşürmenin bir yolu $CO_2$'nun bitkiler tarafından toprak organik karbonuna bağlanmasıdır. Atmosferdeki $CO_2$ düzeyindeki uzun süreli bir düşüş fosil yakıtların kullanımını azaltmayı ve topraklardan atmosfere salınan $CO_2$' nun minimum düzeyde tutulmasını gerektirmektedir.
**Anahtar Kelimeler:** Toprak karbonu, atmosferik $CO_2$, toprak yönetimi, karbon dinamiği

## Introduction

Recent studies have shown a link between increasing atmospheric $CO_2$ concentration and global warming (IPCC, 2001). Atmospheric concentrations of $CO_2$ have increased from pre-industrial revolution of 260 ppm to present levels of 370 ppm (IPCC, 2001) (Figure 1). The greatest portion of this increase can be attributed to burning of fossil fuels, and to a lesser extent changes in land use (Vitousek, 1994; Trumbore, 1997; Stevenson and Cole, 1999). Soils contain the largest active terrestrial C pool on earth, and through soil respiration, annually contribute $CO_2$ to the atmosphere that is 10 times greater than that from fossil fuel combustion; however much of this respired $CO_2$ is reassimilated into new plant growth (Schlesinger, 1997). Because of the size of this pool even a small change in this flux could have a large effect on the atmospheric $CO_2$ concentration. Studies have shown that increased atmospheric $CO_2$ increases the rate of soil respiration (Johnson et al., 1994; Vose et al., 1995; Hungate et al., 1997; Ball and Drake, 1998). Minimizing agriculture's impact on the global atmospheric $CO_2$ requires maintenance of soil organic matter. Soil C levels can be increased in existing agricultural soils by management systems that include production of high residue crops, elimination of summer fallow, and reduction in tillage intensity.

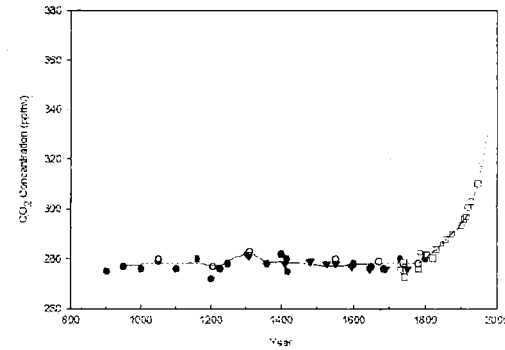


**Figure 1.** Changes in atmospheric carbon dioxide levels. (Note: This graph shows $CO_2$ levels from ice core data from Greenland (Δ,○), and Antarctica (●) (various symbols represent different sampling sites)) + monitoring at Mauna Loa (□) (IPCC, 2001).

**Soil C Dynamics in Agricultural Ecosystems**

Agricultural systems in the past have reduced soil organic C levels and contributed to atmospheric $CO_2$ (Houghton et al., 1983). Decreases in soil C as a result of intensive tillage are well documented (Haas et al., 1957; Greeland and Mye, 1959). Flach et al. (1997) indicated that 50 years of cultivation practices decreased soil C level 53% from the original level (Figure 2). The losses of the soil C over the first half of the 20th century were partlyrecovered in the second half as soil conservation practices improved and cropping intensified. Minimum cultivation and improved hybrids have also played a role building soil organic C levels. The higher yields and greater cropping intensities increased the amount of biomass returned to the soils that can become soil organic carbon. The right-hand side of Figure 2 shows future projection of soil organic carbon levels assuming 1990 tillage and cropping practices. Tillage practices increase C losses to the atmosphere and major gaseous loss of soil C as $CO_2$ occurs immediately after tillage (Reicosky and Lindstrom, 1993). Tillage causes higher fluxes of $CO_2$ compared with no-tillage (Dao, 1998; Lupwayi et al., 1999). Reicosky et al. (1999) determined that cumulative $CO_2$ flux from conventional tillage at the end of 80 h was nearly three times larger than from no-tillage. However, tillage may increase temporarily soil nutrient availability and plant productivity. Tillage can increase aerobic conditions, create a more favorable temperature for biological activity, and enhance nutrient availability. The lower albedo of bare soil increases soil temperature resulting in increased rate of decomposition of organic materials. Changes in nutrient availability and pH status have significant indirect influences on soil C turnover affecting productivity and residue inputs.

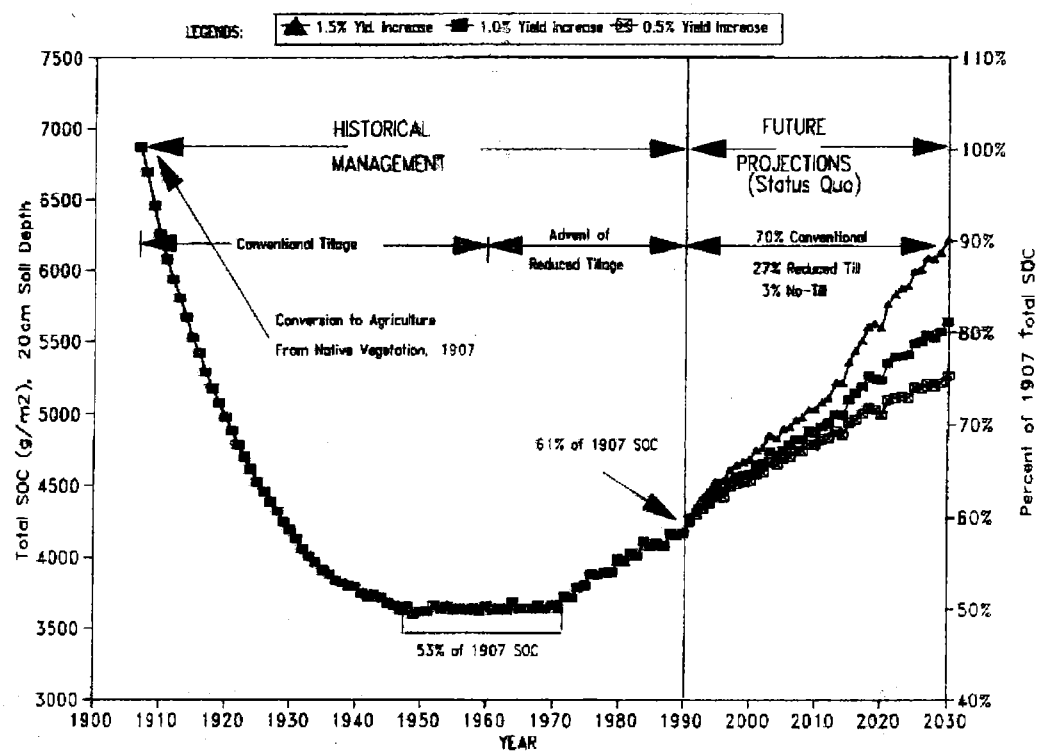


**Figure 2.** Measured and predicted changes in soil organic carbon content of a prairie soil throughout the period of cultivation (Flach et al. 1997).

Crop residue and how they are managed significantly impact soil physical properties such as bulk density, water infiltration, pore size distribution, and aggregate stability. Residue effects on aggregation and aggregate stability directly affect soil C since aggregates are thought to be a key mechanism in soil C stabilization. Increased retention time of residues generally increases the number and stability of aggregates (Adem and Tisdall, 1984). It has been reported that aggregate stability increases in proportion to the rate of residue addition.

Cultivation destroys macroaggregates and may promote decomposition of physically protected organic matter (Beare et al., 1994). The vulnerability of soil to physical disturbance is greater in coarse-textured soils than fine-textured soils (Aguilar et al., 1988; Burke et al., 1989). Clay promotes organo-mineral complexes which allow aggregates to persist in the soil (Tiessen et al., 1984).

Reduced tillage by decreasing the amount of bare soil and increasing residue inputs, reduces the loss of C and in some cases increases soil C levels (Paustian et al., 1997; Flach et al., 1997; Collins et al., 1999). Residue on the soil surface minimizes the soil – residue contact which results in a lower decomposition rate. The reduced residue decomposition and less soil disturbance usually results in greater amount of soil C in no-tillage than conventional tillage systems.

Soils under tillage and no-tillage management systems have different soil properties. The stratification of no-tillage soil properties occurs not only in the amount, but also in the composition of soil organic matter with depth. Cultivation reduces of total organic C and microbial biomass (Groffman et al., 1993). Several researchers have reported higher microbial biomass C under no- tillage than under conventional tillage (Franzluebbers and Arshad, 1996; 1997; Meyer et al., 1997). The higher microbial biomass under no-tillage is a result of greater quantities of labile C compared with conventional tillage systems. Ajwa et al. (1998) reported that cultivation practices may also alter the distribution and type of mineralizable C in the soil profile. Cultivation translocates organic C and N to the subsurface environment.

Conversion of land from plow tillage to no-tillage management has a positive effect on the quality of agricultural soil (Doran, 1980, 1987; Doran and Linn, 1994; McCarty at al., 1995; McCarty and Meisinger, 1997). The concept of soil quality as it relates to agricultural use requires maintenance of soil properties, such as soil C that are important for soil fertility (Bezdicek et al., 1996). Some studies have proposed that a simple measure of soil organic matter, such as organic C and N, to assess soil quality (Arshad and Coen, 1992), but others have proposed that biological parameters, such as biomass C and N, provide a more sensitive assessment (Visser and Parkinson, 1992).

**Soil C Dynamics in Tallgrass Prairie Ecosystem**

The vegetation of a tallgrass prairie is dominated by warm-season grasses little bluestem (*Schizachyrium scoparium* [Michx.] Nash), blue grama (*Bouteloua gracilis* [H.B.K.] Lag.ex Steud.), big bluestem (*Andropogon gerardii*), and indiangrass (*Sorghastrum nutans*). These grasses can produce large amounts of foliage depending on precipitation (Knapp and Seastedt, 1986). In undisturbed prairie, large amounts of detritus can accumulate as dead vegetation or litter, which may lower the primary production because of the reduction of photosynthetically active radiation and soil temperature (Knapp, 1984). Fire removes the standing dead vegetation and litter thus eliminating photosynthetic limitation (Rice and Parenti, 1978). Research in tallgrass prairie of Kansas found increases in aboveground net primary productivity with burning (Hobbs et al., 1991; Ojima et al., 1990; Ojima et al., 1994). Few studies have examined the response of belowground net primary productivity to fire. Ojima et al. (1990) found a significant increase in roots with annual burning with both long- and short-term burning in tallgrass prairie. Blair et al. (1998) also reported greater root biomass in frequently burned tallgrass prairie than unburned prairie.

Burning removes aboveground biomass in the form of volatile gases. Ojima et al. (1990) found that plant biomass C and N losses to combustion ranged from 63 to 89 % per burn, which represents net losses from the ecosystem.

The increases in the frequency of burning decreases N availability and tissue quality compared to less frequently burned prairie (Blair et al., 1998). Burning removes plant canopy and litter and increases light and temperature at the soil surface (Knapp, 1984; Hulbert, 1988). The change in light intensity and soil temperature will significantly affect plant community, net primary productivity, and nutrient availability.

Increases in soil temperature may influence the rate of litter decomposition in prairie. Ojima et al. (1994) modeled a short-term response of burning as higher microbial C and N and higher in situ net N mineralization rates relative to unburned prairie. However, sites that have been burned for longer periods of time (18 years) showed significant reductions in microbial C and N and net N mineralization rates (Burke et al., 1997). The reduction in microbial activity could decrease aboveground productivity.

## Aboveground Productivity in Prairie and Agricultural Ecosystems

Change in soil C levels partially depends on the amount of C returned to the soil as plant residue. Some agricultural systems can return more C as residue than native prairie, but intensive tillage and residue removal may greatly reduce C returns relative to native ecosystems. The distribution of C inputs may change with a lower proportion of C added belowground in cropped systems compared to native prairie. Buyanovsky et al. (1987) measuring net primary productivity in winter wheat and native prairie reported winter wheat was about 10 % higher than native prairie

whereas, the amount of C allocated belowground was 80 % in the grassland. They also found that the decomposition rate of plant residue was higher for winter wheat, because of incorporation of residues as a result of tillage and higher soil water contents during the summer. Van Veen and Paul (1981) measured the amount of residue production from grassland and wheat as 2000 kg C $ha^{-1}$ $yr^{-1}$ and 1425 kg C $ha^{-1}$ $yr^{-1}$. Rochette et al. (1992) found approximately 1990 kg C $ha^{-1}$ $yr^{-1}$ was added to the soil including roots with barley.

To conclude, prairies are able to maintain higher soil organic carbon due to both higher belowground inputs and slower decomposition rates compared to cultivated lands. The higher decomposition rate and low C input in cultivated lands increase net $CO_2$ flux to the atmosphere.

**References**


Adem, H.H., and J.M. Tisdall. 1984. Management of tillage and crop residues for double-cropping in fragile soils of south –eastern Australia. Soil Tillage Res. 4:577-582.

Aguilar, R., E.F. Kelly, and R.D. Heil. 1988. Effects of cultivation on soils in Northern Great Plains rangeland. Soil Sci. Soc. Am. J. 52:1081-1085.

Ajwa, H.A., C.W. Rice, and D. Sotomayor. 1998. Carbon and nitrogen mineralization in tallgrass prairie and agricultural soil profiles. Soil Sci. Soc. Am. J. 62:942-951.

Arshad, M.A., and G.M. Coen. 1992. Characterization of soil quality: Physical and chemical criteria. Am. J. Altern. Agric. 7:25-31.

Ball, A.S., and B.G. Drake. 1998. Stimulation of soil respiration by carbon dioxide enrichment of marsh vegetation. Soil Biol. Biochem. 30:1203-1205.

Beare, M.H., M.L. Cabrera, P.F. Hendrix, and D.C. Coleman. 1994. Aggregate-protected and unprotected organic matter pools in conventional and no-tillage soils. Soil Sci. Soc. Am. J. 58:787-795.

Bezdicek, D.F., R.I. Papendick, and R. Lal. 1996. Introduction: Importance of soil quality to health and sustainable land management. p. 1-8. *In* J.W. Doran and A.J. Jones (ed.) Methods of Assessing Soil Quality. ASA, Madison WI.

Blair, J.M., T.R. Seastedt, C.W. Rice, and R.A. Ramundo. 1998. Terrestrial nutrient cycling in tallgrass prairie. P 222-243. *In* A.K. Knapp et al. (ed.) Grassland dynamics: Long–term ecological research in tallgrass prairie. Oxford University Press, NY.

Burke, I.C., C.M. Yonker, W.J. Parton, C.V. Cole, K. Flach, and D.S. Schimel. 1989. Texture, climate and cultivations effects on soil organic matter content in U.S. grassland soils. Soil Sci. Soc. Am. J. 53:800-812.

Burke, I.C., W.K. Lauenroth, and D.G. Milchunas. 1997. Biogeochemistry of managed grasslands in central North America. p. 85-102. *In* E.A. Paul, K. Paustian, E.T. Elliott, and C.V. Cole (ed.) Soil organic matter in temperate agroecosystems. Boca Raton, FL.

Buyanovsky, G.A., C.L. Kucera, G.H. Wagner. 1987. Comparative analyses of carbon dynamics in native and cultivated ecosystems. Ecology 68: 2023-2031.

Collins, H.P., R.L. Blevins, L.G. Bundy, D.R. Christenson, W.A. Dick, D.R. Huggins, and E.A. Paul. 1999 Soil carbon dynamics in corn-based agroecosystems: Results from carbon-13 natural abundance. Soil Sci. Soc. Am. J. 63:584-591.

Dao, T.H. 1998. Tillage and crop residue effects on carbon dioxide evolution and carbon storage in a paleustoll. Soil Sci. Soc. Am. J. 62:250-256.

Doran, J.W. 1980. Soil microbial and biochemical changes associated with reduced tillage. Soil Sci. Soc. Am. J. 44:765-771.

Doran, J.W. 1987. Microbial biomass and mineralizable nitrogen distribution in no tillage and plowed soils. Biol. Fert. Soils 5:68-75.

Doran, J.W., and D.M. Linn. 1994. Microbial ecology of conservation management systems. p. 1-27. *In* J.L. Hatfield and B.A. Stewart (ed.) Soil biology: Effects on soil quality. Adv. Soil Sci. Lewis, Boca Raton, FL.

Flach, K.W., T.O. Barnwell, Jr., and P.Crosson. 1997. Impacts of agriculture on atmospheric carbon dioxide. p.3-5. *In* E.A. Paul et al. (ed.) Soil organic matter in temperate agroecosystems: Long-term experiment in North America. CRC Press, Boca Raton, FL.

Franzluebbers, A.J., and M.A. Arshad. 1996. Water-stable aggregation and organic matter in for soils under conventional and zero tillage. Can. J. Soil Sci. 76:387-393.

Franzluebbers, A.J., and M.J. Arshad. 1997. Soil microbial biomass and mineralizable carbon of water-stable aggregates. Soil Sci. Soc. Am. J. 61:1090-1097.

Greenland, D.J., and P.H. Mye. 1959. Increases in carbon and nitrogen contents of tropical soils under natural fallows. J. Soil Sci. 10:284-298.

Groffman, P.M., C.W. Rice, and J.M. Tiedje. 1993. Denitrification in a tallgrass prairie landscape. Ecology 74:855-862.

Haas, H.J., C.E. Evans, and E.F. Miles. 1957. Nitrogen and C changes in Great Plains soils as influenced by cropping and soil treatments. Technical Bull. 1164. USDA, State Agriculture Exp. Stns., 111 pp.

Hobbs, N.T., D.S. Schimel, C.E. Owensby, and D.S. Ojima. 1991. Fire and grazing in tallgrass prairie: Contingent effects on nitrogen budgets. Ecology 72:1374-1382.

Houghton, R.A., J.E. Hobbie, J. M. Melillo, B. Moore, B.J. Peterson, G.R. Shaver, and G.M. Woodwell. 1983. Changes in the C content of terrestrial biota and soils between 1860 and 1980: Net release of $CO_2$ to the atmosphere. Ecol. Monogr. 53:235-262.

Hulbert, L.C. 1988. Causes of fire effects in tallgrass prairie. Ecology 69:46-58.

Hungate, B.A., E. A. Holland, R.D. Jackson, F.S. Chapin, H.A. Mooney, and C.B. Field. 1997. The fate of carbon in grasslands under carbon dioxide enrichment. Nature 388:576-579.

Intergovernmental Panel on Climate Change. 2001. Climate Change 2001: The scientific basis. Cambridge University Press, Cambridge, England.

Johnson, D., D. Geisinger, R. Walker, J. Newman, J. Vose, K. Elliot, and T. Ball. 1994. Soil $pCO_2$, soil respiration, and root activity in $CO_2$- Fumigated and nitrogen-fertilized Ponderosa pine. Plant Soil 165:129-138.

Knapp, A.K. 1984. Post-burn differences in solar radiation, leaf temperature and water stress influencing production in a lowland tallgrass prairie. Am. J. Bot. 71:220-227.

Knapp, A.K., and T.R. Seastedt. 1986. Detritus accumulation limits productivity of tallgrass prairie. Bioscience 36:662-668.

Lupwayi, N.Z., W.A. Rice, and G.W. Clayton. 1999. Soil microbial biomass and carbon dioxide flux under wheat as influenced by tillage and crop rotation. Can. J. Soil Sci. 79:273-280.

McCarty, G.W., J.J. Meisinger, and F.M.M. Jenniskens. 1995. Relationships between total-N, biomass-N and active – N in soil under different tillage and N fertilizer treatments. Soil Biol. Biochem. 27:1245-1250.

McCarty, G.W., and J.J. Meisinger. 1997. Effects of N fertilizer treatments on biologically active N pools in soils under plow and no tillage. Biol. Fertil. Soils 24:406-412.

Meyer, K., R.G. Joergensen, and B. Meyer. 1997. The effects of reduced tillage on microbial biomass C and P in sandy loess soils. Appl. Soil Ecol. 5:71-79.

Ojima, D.S., W.J. Parton, D.S. Schimel, and C.E. Owensby. 1990. Simulated impacts of annual burning on prairie ecosystem, in proceedings of a symposium: Fire in North American Grasslands, S.L. Collins and L.L. Wallace (eds.). Ecological Society of America and Botanical Society of America, University of Oklahoma press, Norman, OK.

Ojima, D.S., D.S. Schimel, W.J. Parton, and C.E. Owensby. 1994. Long- and short-term effects of fire on nitrogen cycling in tallgrass prairie. Biogeochemistry 26:67-74.

Paustian, K., H.P. Collins, and E.A. Paul. 1997. Management controls on soil carbon. p. 15-50. *In* E.A. Paul et al. (ed.) Soil organic matter in temperate agroecosystems: Long –term experiments in North America. CRC Press, Boca Rotan, FL.

Reicosky, D.C., D.W. Reeves, S.A. Prior, G.B. Runion, H.H. Rogers, and R.L.Raper. 1999. Effects of residue management and controlled traffic on carbon dioxide and water loss. Soil Till. Res. 52:153-165.

Rice, E.L., and R.L. Parenti . 1978. Causes of decreases in productivity in undisturbed tallgrass prairie. Amer. J. Bot. 65:1091-1097.

Rochette, P., E.A. Gregorich, and R.L. Desjardins. 1992. Comparison of static and dynamic closed cambers for measurement of soil respiration under field conditions. Can. J. Soil Sci. 72:605-609.

Schlesinger, W.H. 1997. Biogeochemistry: An analysis of global change. 2nd ed. Academic Press, San Diego, CA.

Stevenson, F.J., and M.A. Cole. 1999. Cycles of soil: Carbon, nitrogen, phosphorus, sulfur, micronutrients. Wiley and Sons, New York, NY.

Tiessen, H., J.W.B. Stewart, and W.H. Hunt. 1984. Concepts of soil organic matter transformations in relation to organo-mineral particle size fractions. Plant Soil. 76:287- 290.

Trumbore, S.E. 1997. Potential responses of soil organic carbon to global environmental change. Proc. Natl. Acad. Sci. USA. 94:8284-8291.

Vitousek, P. M., 1994. Beyond global warming: Ecology and global change. Ecology 75:1861-1876.

Visser, S., and D. Parkinson. 1992. Soil biological criteria as indicators of soil quality. Am. J. Altern.Agric. 7:33-37.

Van Veen, J.A., and E.A. Paul. 1981. Organic carbon dynamic in grassland soil. I. Background information and computer simulation. Can. J. Soil Sci. 61:185-201.

Vose, J.M., K.J. Elliot, D.W. Johnson, R.F. Walker, M.G. Johnson, and D.T. Tingey. 1995. Effects of elevated $CO_2$ and N fertilization on soil respiration from ponderosa pine (*pinus ponderosa*) in open top chambers. Can. J. For. Res. 25:1243-1251.