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 CO₂ is mainly 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, CO₂ levels have risen at a rate of 0.15 percent per year (IPCC, 2001). The increases of atmospheric CO₂ concentration could lead to global warming. One possible mechanism for reducing the rise of CO₂ concentration in the atmosphere is fixation of CO₂ by plant into soil organic carbon. A long-term reduction in atmospheric CO₂ levels will require a reduction of fossil fuel use and minimize the amount of CO₂ release from soils to the atmosphere.

Key Word: Soil carbon, atmospheric CO₂, soil management, carbon dynamics

Toprak Yönetimi Sistemlerinin Toprak Karbon Dinamiğinin Üzerine Etkileri


Anahtar Kelimeler: Toprak karbonu, atmosferik CO₂, toprak yönetimi, karbon dinamiği

Introduction

Recent studies have shown a link between increasing atmospheric CO₂ concentration and global warming (IPCC, 2001). Atmospheric concentrations of CO₂ 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 CO₂ to the atmosphere that is 10 times greater than that from fossil fuel combustion; however much of this respired CO₂ 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 CO₂ concentration. Studies have shown that increased atmospheric CO₂ 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 CO₂ 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 CO₂ levels from ice core data from Greenland (ΔCO₂), and Antarctica (•) (various symbols represent different sampling sites)) - monitoring at Mauna Loa (o) (IPCC, 2001).
Soil C Dynamics in Agricultural Ecosystems

Agricultural systems in the past have reduced soil organic C levels and contributed to atmospheric CO₂ (Houghton et al., 1983). Decreases in soil C as a result of intensive tillage are well documented (Haas et al., 1957; Greeeland 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 partly recovered in the second half as soil conservation practices improved and cropping intensified. Minimum cultivation and improved hybrids have also played a role in 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 CO₂ occurs immediately after tillage (Reicosky and Lindstrom, 1993). Tillage causes higher fluxes of CO₂ compared with no-tillage (Dao, 1998; Lupwayi et al., 1999). Reicosky et al. (1999) determined that cumulative CO₂ 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 at 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**


