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Carbon Concentrations and Transport in Sediment Leaving Small, Cropped Watersheds

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ABSTRACT

With the current interest in CO_2 emissions and their potential impacts on global climate change, it is important to evaluate the role of agriculture in the global carbon budget. The impacts of various tillage practices on carbon release/sequestration need to be assessed. At the USDA-ARS research station near Coshocton, Ohio, various conservation tillage practices including corn/soybean rotations with no-till, chisel-plow, paraplow, and disk preceding the corn and soybean crops of a corn/soybean/wheat-meadow rotation are being studied on small watersheds (0.55 - 0.79 ha). Each small watershed is instrumented with a 60-cm H-flume mounted on a concrete approach, and a Coshocton wheel for collecting a proportional sample of water and sediment. Over a 13-year period, samples of sediment deposited in the flume approach and in runoff were collected and stored. These stored sediment samples have been analyzed for total carbon, and comparisons of soil C have been made among management practices. Weighted averages of soil C in the sediment that passed through the flumes during the treatment periods did not differ significantly among tillage treatments, although no-till was the highest (2.8%) and chisel-plow was the lowest (1.9%). Weighted averages of soil C in the flume floor sediments were slightly lower with no-till being the highest (2.3%) and paraplow being the lowest (2.1%). For comparison, weighted soil C averages in sediment that passed through flumes from small fertilized, pastured watersheds ranged from 5.2 to 7.2%. Average annual sediment loss was 437, 656, and 753 kg ha^{-1} for no-till, chisel-plow, and disk, respectively. Annual average transport of soil C (the product of total sediment transported and the C concentration) in the sediment was 11.8, 12.0, 10.9, and 17.6 for no-till, chisel-plow, paraplow, and disk, respectively. Although tillage practices may reduce C transport in sediment by lowering concentrations, a greater factor for reducing C movement is reducing sediment movement. Thus, practices that conserve soil also conserve carbon.

INTRODUCTION

The interrelationship of green house gas emissions and global climate change is an environmental and political issue on a multi-national scale. This has brought new emphasis to carbon in the environment and the factors that influence processes such as CO_2 emissions and C sequestration. Agriculture has an important role in C cycling, especially on a global scale. Organic matter has long been recognized as a component of "good" soil, and one of the factors for maintaining or increasing soil health is to maintain or increase soil organic matter (Doran et al., 1996). Not only does increasing soil organic matter improve soil properties but it impacts the global C budget through sequestration of atmospheric C in soil (Doran et al., 1998).

Lal et al. (1994, 1995, 1997, 1998a,b) have been leaders in addressing the interactions of soil processes, C sequestration, global change, and management practices that favor C sequestration. There are many specific aspects to this overall topic. There is wide acceptance that cultivating native land, either prairie or forest, causes loss of soil organic matter. Davidson and Ackerman (1993) reported 20-40% loss of soil organic matter following the conversion of previously untilled soils to agricultural production. After 70 years of cultivation, organic C decreased by 36% in the soil profile at the midslope position in a native prairie catena (Voroney et al., 1981). Changes in agricultural practices are reversing this trend (Buyanovsky and Wagner, 1998). Römkens et al. (1999) found that conversion of arable land in the Netherlands to pasture caused regeneration of the soil C content. Conversion of land from plow tillage to long-term no-tillage management is generally accepted as having a positive influence on soil quality (Doran, 1980, 1987; McCarty et al., 1995; McCarty and Meisinger, 1997). Some changes have been observed in only a few years. McCarty et al. (1998) found stratification of organic matter in the soil profile characteristic of long-term no-till soils to progress rapidly within three years after conversion to no-till management, although "evidence was equivocal for any significant increase in organic matter content". Opposite results have also been reported. In the Rolling Pampa of Argentina, Alvarez et al. (1998) found a negative annual C budget under no-tillage and plow tillage systems. They concluded that no-tillage systems would not significantly affect soil organic matter pools compared with plowing in regions with low erosion losses.

Among the multiple pathways of carbon loss from agricultural fields is C lost with eroded sediment. Assessment of C losses have frequently been part of nutrient loss studies (e.g. Massey and Jackson, 1952; Wan and El-

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Table 1. Tillage treatments and selected landscape and soil characteristics of the seven watersheds (WS) (Shipitalo and Edwards, 1998).

Watershed No.	Tillage	Area (ha)	Average slope (%)	Maximum Length (m)	Shape	Dominant soil†
WS 113	No-till	0.59	11	118	Triangular	Coshocton sil
WS 118	No-till	0.79	10	132	Triangular	Coshocton sil
WS 109	Chisel-plow	0.68	13	110	Pentagonal	Rayne sil
WS 123	Chisel-plow	0.55	7	107	Fan	Keene sil
WS 115	Paraplow/Disk	0.65	7	119	Triangular	Coshocton sil
WS 127	Paraplow/Disk	0.68	9	104	Fan	Coshocton sil
WS 111	Disk	0.45	6	143	Pentagonal	Keene sil

†Rayne = fine-loamy, mixed, mesic Typic Hapludult; Keene = fine-silty, mixed, mesic Aquic Hapludalf; Coshocton = fine-loamy, mixed, mesic Aquultic Hapludalf.

Table 2. Tillage and cropping management for the conservation tillage watersheds.

	No-till		Chisel-plow		Paraplow		
Year	WS113	WS 118	WS 109	WS 123	WS 115	WS 127	WS 111
1984	Corn	Corn	Corn	Corn	Corn	Corn	
1985	SB†	SB	SB	SB	SB	SB	
1986	Corn	Corn	Corn	Corn	Corn	Corn	
1987	SB	SB	SB	SB	SB	SB	
1988	Corn	Corn	Corn	Corn	Corn	Corn	
1989	SB	SB	SB	SB	SB	SB	
						Disk‡	
1990	Corn	SB	Corn	SB	SB	Wh/Cl†	Corn
1991	SB	Corn	SB	Corn	Wh/Cl	Corn	SB
1992	Corn	SB	Corn	SB	Corn	SB	Wh/Cl
1993	SB	Corn	SB	Corn	SB	Wh/Cl	Corn
1994	Corn	SB	Corn	SB	Wh/Cl	Corn	SB
1995	SB	Corn	SB	Corn	Corn	SB	Wh/Cl
1996	Corn	SB	Corn	SB	SB	Wh/Cl	Corn

†SB = Soybean followed with a rye winter cover crop, except in the 3y rotation; Wh/Cl = winter wheat over-seeded with clover; WS = watershed.
‡Reduced chemical input.

Swaify, 1997; Zobisch et al., 1995). Sediments being enriched with organic C compared with surface soil has been observed for a variety of soils — from silt loam soils in Wisconsin (Massey and Jackson, 1952) to clay soils in Hawaii (Wan and El-Swaify, 1997). In a review of literature about C redistribution and loss by erosion, Gregorich et al. (1998) stated two main ways that the physical processes of erosion and deposition impact soil C distribution. First, these processes "drastically alter the biological process of C mineralization in soil landscapes". The second way is the redistribution of soil C "within a toposequence or a field, or to a distant site". The focus of this paper is with the latter of the two above-mentioned impacts.

With the hypothesis that some cropping practices cause greater sediment attached carbon loss than others, the objectives of this research were to (a) measure the total C content in sediment leaving small watersheds (field edge) in a corn-soybean rotation (or corn-soybean-wheat/clover rotation) under various conservation tillage practices, and (b) determine the amounts of C transported in the sediments from these watersheds.

MATERIAL AND METHODS

This study was conducted at the North Appalachian Experimental Watershed near Coshocton, OH (U.S.A.). Six watersheds, each <0.8 ha (Table 1), were farmed in a corn-soybean rotation for 6 years. A rye winter cover crop followed the soybean. Two of the watersheds were chiseled each spring to 25-cm depth at 30-cm spacing (Table 2). Two other watersheds were paraplowed each fall to approximately 35 cm at 50-cm spacing. The remaining two watersheds received no tillage (Edwards et al., 1993). In the seventh year, the two paraplowed watersheds along with a seventh watershed were placed in a 3-yr, reduced chemical input rotation (corn-soybean-wheat/clover)(Shipitalo and Edwards, 1998). Three watersheds in this rotation made it possible to have a watershed in each stage of the rotation each year. To achieve this in the corn-soybean rotation watersheds, cropping was changed in the seventh year to have one watershed in each tillage practice in each crop every year (Table 2).

The soils are formed in residuum and colluvium derived from underlying sandstone and shale bedrock. The dominant soil types (Soil Survey Staff, 1975 classifications in parentheses) are Coshocton silt loam (fine-loamy, mixed, mesic Aquultic Hapludalf), Keene silt loam (fine-loamy, mixed, mesic Aquic Hapludalf), and Rayne silt loam (fine-loamy, mixed, mesic Typic Hapludult) (Table 1). The B horizon of the Rayne series contains less clay than the B horizons of the Coshocton or Keene series. This was a factor in the Rayne series having better internal drainage -- 11.7×10^{-4} m sec^{-1} for the Ap layer of Rayne compared with 2.1 and 4.1×10^{-4} m sec^{-1} for the Ap layers of the Coshocton and Keene series, respectively (Kelley et al., 1975). Greater details on the soils, geology, and geomorphology of these watersheds were described by Edwards et al. (1993) and Kelley et al. (1975).

Corn was planted in 76-cm rows and soybean was drilled in 18-cm rows, approximately on the contour for both crops. Recommended residual corn and soybean herbicides were used each year for weed control in the corn-soybean rotation. Rye, used as a winter cover crop following each soybean year, was killed the following spring with a contact herbicide. A half-rate of herbicide was used on the reduced-input watersheds when planted to corn and herbicide was applied only to a band over the row when soybean was planted. The corn and soybean crops in the reduced-input watersheds were cultivated for additional weed control twice during the growing season. Wheat was drilled into the reduced-input watersheds following soybean harvest in October. Red clover was broadcast seeded into the standing wheat in March or April. Further details on operations and fertility management are presented by Edwards et al. (1993) and Shipitalo and Edwards (1998).

Surface runoff from the watersheds was automatically measured with 0.90-m H-flumes and sampled with Coshocton wheels (Brakensiek et al., 1979) modified to continuously deliver a proportional sample of runoff water and suspended sediment to a refrigerated container during each runoff event. Separate samples were usually collected for each runoff event unless storms occurred less than a few hours apart. Soil losses were determined by filtering the runoff samples to ascertain sediment concentrations and multiplying by the runoff volumes calculated from the hydrographs. Sediment was occasionally deposited in the flume and flume approach. This sediment was collected and weighed also.

Total carbon on sediment was analyzed by the dry-combustion method using a model PE2400 Series II CHN

Table 3. Annual weighted average carbon content (%) on sediments passing through the H-flume and collected with the Coshocton wheel.

	No-till		Chisel-plow		Paraplow		
	WS 113	**WS 118**	**WS 109**	**WS 123**	**WS 127**	**WS 115**	**WS 111**
	% C						
May 84 - Apr 85	2.8†	2.4	1.6	1.7	1.8	1.8	
1985-86	2.7	2.3	1.8†	1.8	1.4	1.8	
1986-87	2.8	2.4	1.6	1.8	2.0	1.9	
1987-88	2.6	2.6	2.4	1.9	2.7	2.1	
1988-89	2.8	2.7	-----	1.9	2.8	2.0†	
1989-90	2.8	2.3	1.5	2.4	2.5	2.1	
						Disk	
1990-91‡	3.4	2.9	1.5	2.1	2.8	1.6	3.2
1991-92	3.3	3.3	-----	2.4	2.8	1.6†	3.5
1992-93	3.3	3.2	2.0†	2.4	2.8	2.0†	3.5
1993-94	3.2	2.6	2.6	2.5	2.7	2.3	3.3
1994-95	3.8	2.4	2.8†	2.5	2.7	2.9†	3.4
1995-96	2.9	2.5	2.6	2.9	2.5	2.4	3.6
1996-97	2.9	2.4	2.8	2.9	2.9	2.6	3.6
	Average for tillage practice§						
					Paraplow		Disk
Corn	2.9 ± 0.4		2.1 ± 0.5		2.1 ± 0.3		2.9 ± 0.5
Soybean	2.7 ± 0.3		2.2 ± 0.4		2.1 ± 0.4		2.6 ± 0.5
Wheat/Clover							2.9 ± 0.6
Over-all	2.8 ± 0.4		2.2 ± 0.5		2.1 ± 0.4		2.8 ± 0.6
	Average for last 4 years						
Corn	3.0 ± 0.5		2.7 ± 0.2				
Soybean	2.8 ± 0.3		2.6 ± 0.2				
Over-all	2.9 ± 0.5		2.7 ± 0.2				

†Annual sediment <10 kg ha^{-1}

‡There were some changes in practices beginning in May 1990. See Table 2.

§These are averages for all of the watersheds in the same tillage practice ± one standard deviation

Table 4. Average annual flume floor and wheel sediment and carbon transport by crop and tillage practice.

	Flume Floor		Wheel Sediment	
	Sediment	Carbon	Sediment	Carbon
	------------- kg ha^{-1} ------------		------------- kg ha^{-1} ------------	
No-till (13 yrs)				
Corn	31.1	0.7	216.4	6.1
Soybean	97.4	2.2	657.0	17.6
Over-all	64.2	1.5	436.7	11.8
Chisel-plow (13 yrs)				
Corn	305.0	4.9	923.7	16.5
Soybean	49.6	0.9	388.6	7.6
Over-all	177.3	2.9	656.2	12.0
Paraplow (6yrs)				
Corn	43.6	0.8	273.2	5.5
Soybean	109.6	2.8	738.0	16.3
Over-all	76.6	1.8	505.6	10.9
Disk (7 yrs)				
Corn	7.6	0.2	466.9	14.7
Soybean	539.2	10.8	1646.3	33.7
Wheat/Clover	20.8	0.5	146.1	4.4
Over-all	190.2	3.8	753.1	17.6

analyzer (Perkin-Elmer Corp., Norwalk, CT). After sample digestion in a block digester, total N in sediment was determined by an automated phenate method (Schuman et al. 1973) modified to include NO_3-N and NO_2-N. Carbon concentrations were multiplied by the sediment amounts to calculate the amounts of C transported. Even though sediment amounts were determined for all runoff events, not all events produced sufficient sediment for analysis. For these events, C transport was estimated by using an estimated C concentration from a recently occurring event.

RESULTS AND DISCUSSION

Carbon Concentrations on Sediments

Average C concentrations in sediments passing through the H-flume (wheel sediment) did not show great differences between crops in the rotations (Table 3). This was true for each tillage practice. For the entire 13 year period of study, weighted averages of C content in sediment were similar for no-till and disk, and more than a standard deviation greater than the C content in sediments from either chisel-plow or paraplow. As the study period progressed, the sediment C content was reasonably stable with the No-till practice, but it gradually increased with the chisel-plow practice. Although the average sediment carbon content for the entire study period was greater for the no-till than the chisel, averages for the last four years were very similar for both practices. For comparison, weighted soil C averages in sediment that passed through H-flumes from small fertilized, pastured watersheds ranged from 5.2 to 7.2%. These soil C values were from 27 samples collected over several years from multiple pasture treatments.

Approximately 18% of the sediment leaving the watersheds was deposited in the flume floor and flume approach. The weighted average C content in these sediments ranged from 2.0 to 2.3% for no-till and 1.6 to 1.9% for chisel-plow. These slightly lower values in the flume floor sediments showed a small C enrichment in the wheel sediments. A greater nitrogen enrichment was observed in the wheel sediment compared with the flume floor sediment. For the no-till practice, weighted average sediment N content was 2.1 and 3.1 mg g^{-1} for flume floor sediment and wheel sediment, respectively. For the chisel-plow practice, weighted average sediment N content was 1.5 and 2.1 mg g^{-1} for flume floor and wheel sediment, respectively. The different rates of enrichment were reflected in the C:N ratios, which ranged from 10.3 to 11.4 for the flume floor sediments and from 7.6 to 9.8 for the wheel sediments.

Carbon Transported in Sediments

Although differences and trends in sediment transport can be noted based on tillage practice or crop year (Table 4), the year to year variation was so great that there were no significant differences among the values reported. This was also true for the transport of C in the sediments. With this in mind, it can be noted that the lowest annual sediment transport tended to occur with no-till and the highest with disk. With the exception of the chisel-plow practice, average annual sediment losses tended to be greater with soybean than with corn. Sediment C transport had similar trends.

The 1990-91 year was a record high for precipitation, and major runoff events occurred during June and July. Large amounts of sediment were transported in those events. Over 38% of the sediment lost (both flume floor and wheel sediment) during the 13y study period occurred the 1990-91 year. The average amount of sediment transported from each of the watersheds that year was 3572 kg ha^{-1}. During the other 12 years, average annual soil loss ranged from 59 to 1882 kg ha^{-1}. Wide variations in annual C transport also occurred. In the 1990-91 year, an average of 65 kg ha^{-1} of C was transported from each watershed, and the average annual loss for the other years ranged from 1.1 to 42 kg ha^{-1}.

The results of these sediment analyses showed only small variations in C concentrations on sediment with different tillage practices. Tillage practices and weather affected soil loss from field scale watersheds to a greater degree than it affected C sediment content. This suggested that there is little reason to select a conservation tillage practice to reduce C losses based on sediment C concentrations. A greater factor for reducing C movement is to select a cultural practice that reduces sediment loss. Gregorich et al. (1998) and Zobisch et al. (1995) had similar conclusions. So the best way to reduce C transport in sediment leaving cropped fields is to use a practice that reduces sediment transport.

FUTURE DIRECTIONS

Soil samples have been saved from the watersheds in these conservation tillage practices. These will be analyzed for total C, and changes in C content (if any) over the life of the study can be observed. Carbon enrichment ratios of the sediment compared to the surface soil will be determined. This will give a more comprehensive view of the capabilities of difference tillage practices for sequestering C.

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