ASSESSING SOIL ORGANIC CARBON REDISTRIBUTION WITH FALLOUT ^{137}CESIUM

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Abstract
Patterns of soil organic carbon (SOC) vary widely across the landscape leading to large uncertainties in the SOC budget especially for agricultural areas where water and wind erosion redistributes soil across the landscape. This study was designed to determine SOC distribution patterns related to soil redistribution in four different physiographic regions of the United States. Soil redistribution (erosion/deposition) patterns were estimated using the fallout ^{137}Cesium technique in tilled agricultural fields in Maryland, Ohio, and Iowa and in grazed semiarid rangeland watersheds in Arizona. In an Iowa field, the range of SOC had an order of magnitude difference in concentration (0.5 to 5%) and was significantly correlated (r^2=0.68) with soil ^{137}Cs concentration and soil erosion/deposition rates. Sites of soil erosion in Iowa had significantly lower average concentrations of SOC (2.4%) than sites of soil deposition (3.4%). SOC was also significantly correlated with erosion rates calculated from ^{137}Cs in Ohio and Maryland fields although the r^2 values were lower. Patterns of erosion and deposition for the semiarid watersheds showed the grassed watershed to have less erosion than the shrub watershed. These studies show the importance of better understanding soil movement and redistribution patterns within a field or watershed for understanding soil loss and SOC patterns and the potential for developing or implementing management systems to increase SOC in agricultural areas.

Additional Keywords: soil organic carbon, SOC, ^{137}Cesium, erosion, deposition

Introduction
Maintaining soil quality is a key factor for understanding and managing sustainable agricultural systems. Two key factors for maintaining or improving soil quality are managing soil erosion and soil organic carbon (SOC) movement and loss at the field or watershed level (Lal et al., 1998). Recent studies indicate that soil erosion and redeposition play a significant role in understanding SOC patterns at the field and landscape levels (Ritchie and McCarty, 2003; McCarty and Ritchie, 2002). This study was to expand the scope earlier studies into farming systems in different physiographic regions of the United States to determine the relationship between SOC, ^{137}Cesium (^{137}Cs), and soil redistribution patterns under different agricultural practices and landscapes.

Materials and Methods
Sample Sites
Single use (i.e., tilled, no-till, grazed, or grass) agricultural watersheds and fields were sampled in Maryland, Ohio, and Iowa. Two small grazed semiarid rangeland watersheds were sampled in Arizona.

The Maryland site is located on the <u>O</u>ptimizing <u>P</u>roduction Inputs for <u>E</u>conomic and <u>E</u>nvironmental <u>E</u>nhancement (OPE^3) research watershed (Gish et al., 2003) in the Northern Coastal Plain physiographic province at the USDA Agriculture Research Service (ARS), Beltsville Agriculture Research Center near Beltsville, MD, USA. The site is divided into four small watersheds. The sampled watershed is approximately 25 ha and 40 m a.s.l. Mean annual rainfall is 1035 mm with a range from 547 to 1584 mm for the 1871-2000 period. Mean annual temperature is approximately 13EC with monthly averages ranging from 4EC in February to 27EC in July. The soils on the upland areas of the watershed are Hapludults, Paleudults, and Fragiudults. The native vegetation of the area is pine [*Pinus* ssp.] and hardwood [*Quercus* spp., *Acer* spp.] forest. The watershed has been tilled and planted in corn [*Zea mays* L.] since 1998. Bulk soil samples were collected for the 0-30 cm layer in a 30-m grid pattern across the research watershed. Soil profiles were also collected by 5-cm depth increments to 40-cm along transects in the watersheds (Gish et al., 2003; Ritchie and McCarty, 2003).

The Ohio site is at the ARS North Appalachian Experimental Watershed (NAEW) located near Coshocton, Ohio in the Allegheny Plateau region of the Appalachian Mountains. The elevation of area is 250-400 m. Mean annual rainfall is 944 mm. Mean annual temperature is approximately 10EC with monthly averages ranging from -2EC in January to 22EC in July. The dominant soils are Hapludults and Inceptisols formed on residuum and colluvium derived from sandstone and shale bedrock. The native vegetation is mixed oak [*Quercus* spp.] and hickory [*Carya* spp.] forest (Kelly, 1975). The NAEW has 27 small single cover watersheds that are less than 4 ha in size and have been monitored since the late 1930's. Management histories, including tillage and cropping records are available for each watershed for this time period (Kelly, 1975, Owens et al., 2001, 2002). Bulk soil samples of the 0-30 cm layer were collected in 22 of the watersheds by randomly sampling soil profiles in each watershed (Venteris and Slater, In Press). Bulk soil samples were also collected at two small agricultural fields using a 25-m grid.

The Iowa sites are on the ARS Walnut Creek Study Area in the Central Iowa Till Prairie near Ames, Iowa. The elevation of the sites is approximately 300 m. Mean annual rainfall is 835 mm. Mean annual temperature is approximately 8EC ranging from –6EC in January to 22EC in July. The soils are Udolls and Udalfs. The native vegetation is short grass prairie. Two fields on different operational farms were sampled. The fields were in a corn [*Zea mays* L.] and soybean [*Glycime max* (L.) Merr.] rotation (Jaynes et al., 2003; Parkin and Kaspar, 2003). Bulk soil samples were collected for the 0-30 cm layer on a 25-m grid. Deeper soil samples were collected for the 30-50 cm layer at sites of deposition.

The Arizona sites are in the Southeastern Arizona Basin and Range province on two small watersheds (Lucky Hills and Kendall) that are subwatersheds of the ARS Walnut Gulch Experimental Watershed near Tombstone, Arizona. Active research and monitoring began in 1953 on the Walnut Gulch Experimental Watershed. The elevation of the Lucky Hills and Kendall watersheds are 1370 m and 1525 m respectively. Mean annual temperature is 17EC ranging from 1EC in January to 35EC in June and mean annual rainfall of approximately 356 mm (Nichols et al., 2002; Emmerich, 2003). The soils are Ustochreptic Calciorthids in Lucky Hills watershed and Ustollic Calciorthgids soils on the Kendall watershed. The vegetation on Lucky Hills is shrub dominated by (i.e., Acacia, [*Acacia constricta* Benth.]; Tarbush [*Flourensia cernua* DC]; Creosote [*Larrea divaricata* Cav.]). The vegetation at Kendall is dominantly grama grasses [*Bouteloua* spp.] and love grass [*Eragrostis lehmanniana* Nees]. The watersheds are open range and are subject to grazing by cattle. Bulk soil samples were collected for the 0-25 cm layer on a 25-m grid in each watershed.

Sample collection and analysis

Bulk soil samples were collected to a depth of 30-cm except at the Arizona site where samples were collected for a 0-25 cm layer. Soils in areas of apparent deposition were collected to 30-50-cm to ensure the total depth of soil with ^{137}Cs was collected. At selected sites samples were collected in 5-cm depth increments to study the vertical distribution patterns of ^{137}Cs and SOC. Soil samples were dried, sieved to pass through a 2-mm screen, placed into Marinelli beakers, and sealed for ^{137}Cs analyses. Analyses for ^{137}Cs were made by gamma-ray analyses using a Canberra[1] Genie-2000 Spectroscopy System that receives input from three Canberra high purity coaxial germanium crystals (HpC >30 % efficiency) into an 8192-channel analyser. The system is calibrated and efficiency determined using an Analytic[1] mixed radionuclide standard (10 nuclides) whose calibration can be traced to U.S. National Institute of Standards and Technology. Measurement precision for ^{137}Cs is ± 4 to 6 %. Soil erosion and redistribution rates and patterns were estimated based on the ^{137}Cs measurements and models that relate soil and ^{137}Cs movement (Walling and He, 1999; Ritchie and McHenry, 1990).

Carbon and nitrogen were measured by dry combustion. Samples were ground and screened through a 2 mm sieve. A sub-sample was then ground to a very fine powder with a roller grinder. A Leco CNS 2000 elemental analyzer was used to determine total %C and %N (Nelson and Sommers, 1996). When necessary (Iowa and Arizona), carbonate carbon was determined by ashing the soil samples at 400 EC for 16 hours. SOC was calculated as the difference between total carbon and carbonate carbon.

Results and Discussion

^{137}Cs was uniformly distributed in the tilled layer in the agricultural fields in Maryland (Fig. 1), Iowa, and Ohio. Tilling depths ranged between 15 and 25 cm in the agricultural fields. ^{137}Cs depth distribution is typical of

[1] Trade names are included for the benefit of the reader and do not imply an endorsement of or a preference for the product listed by the U. S. Department of Agriculture.

agricultural soils where tillage operations mix ^{137}Cs in the tilled layer of the profile (Ritchie and McCarty, 2002). In depositional areas on the fields, ^{137}Cs distribution was deeper than the tilled depth indicating the redistribution and subsequent redeposition of eroded material within the field. However, ^{137}Cs was rarely found below 30-cm in the soil profiles at any site. SOC was uniformly distributed in the tilled layer with slight decreases with depth below this tilled layer at the Maryland and Iowa site.

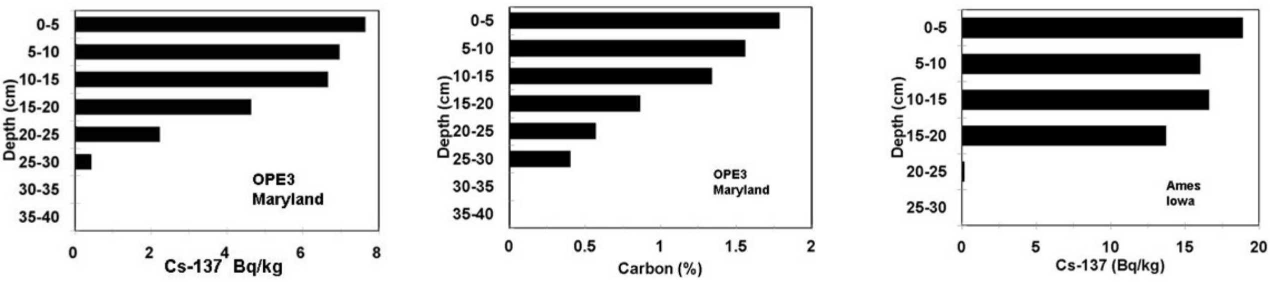

Figure 1. Vertical distribution of ^{137}Cs (left) and SOC (center) in soil profiles (Average of 6 profiles) in a tilled corn [*Zea mays* L.] field at the OPE^3 watershed in Maryland and of ^{137}Cs (left) at Ames, Iowa.

At the Maryland, Iowa, and Ohio sites (Fig. 2), a significant relationship at the 0.05 level of probability was found between ^{137}Cs concentration (Bq m^{-2}) and SOC (%) for the samples but these relationships usually accounted for less than 60% (Maryland r^2=0.23; Ohio r^2=0.30; Iowa r^2=0.68;) of the variability in SOC distribution. However these relationships do suggest that ^{137}Cs and SOC are probably moving along similar physical pathways in these systems. ^{137}Cs was used to estimate erosion rates and patterns and these erosion rates had similar significant relationships to SOC.

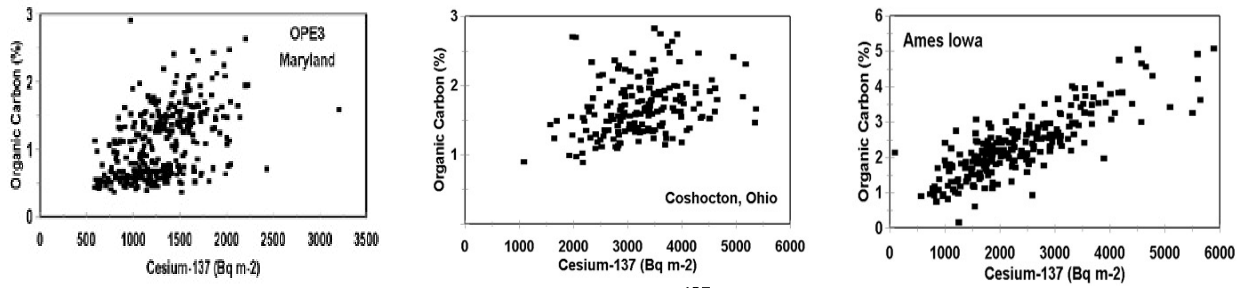

Figure 2. Relationship between soil organic carbon and ^{137}Cs in Maryland (left), Ohio (center) and Iowa (right).

Comparing erosion rates and patterns estimated using the ^{137}Cs data (Walling and He, 1999) with the SOC data found that eroding sites on the upland soils at the Maryland site averaged 1.1% SOC in the tilled layer while deposition sites of the upland soils averaged 1.4% SOC in the tilled layer. In Iowa, a similar pattern was found with eroding sites averaging 2.4% SOC and depositing sites averaging 3.4% SOC. At both sites these means are significantly different at the 0.05 level of probability. Combining this with the fact that ^{137}Cs and SOC in the soil profile are strongly correlated suggest that ^{137}Cs and SOC are moving in similar physical pathways and probably by the similar physical mechanism since eroding areas have less ^{137}Cs and SOC than depositing areas.

Table 1. Average ^{137}Cs and SOC concentrations and soil movement on single use watersheds at Coshocton, Ohio

Watershed Management	^{137}Cs (Bq m^{-2})	SOC (%)	Soil movement (mt ha^{-1})
Tilled	3235	1.48	0.85
No-till (With Manure Added)	3332	2.14	2.36
Grass (Grazed)	3096	1.53	-1.01
Grass (Not Grazed)	3331	1.57	2.02

Table 1 shows the average ^{137}Cs, SOC, and erosion rates for four of the single use watersheds at Coshocton, Ohio. The grass watersheds have been under the same management treatment since 1938. The no-till watershed has been in continuous no-till corn since 1964. The tilled watershed has been in corn since 1955. Slopes of the tilled and no-till watershed are between 6 and 12% whereas the slopes of the grassed watershed are between 12 and 25%. The high SOC on the no-till watershed is probably due to the addition of animal manure to the watershed over the last ten years. There was no significant difference in SOC in the other watersheds. The grazed grass watershed had the greatest erosion, but erosion rates and ^{137}Cs content on the other watersheds showed no net loss. However, there were no significant differences between any of the watersheds at the 0.05 level of probability.

The two Arizona watersheds were significantly different. The grassy watershed (Kendall) had significantly higher ^{137}Cs at the 0.01 level of probability and significantly lower erosion rates than the shrub watershed (Lucky Hills). The percent rock fragments in the soil profile (0-25 cm) was also significantly higher in the Lucky Hills watershed (37%) than at Kendall (30%). Emmerich (2003) reported SOC levels of 0.8% at Lucky Hills and 1.1% at Kendall. His data follow the trend that is suggested by our ^{137}Cs, erosion, and rock fragment data. We are currently analysing our samples for SOC to determine if the patterns SOC in these semiarid watersheds will be similar to those found in the more humid watershed in the eastern United States.

Conclusions

^{137}Cs and SOC concentrations of upland soils are significantly correlated in our study areas. In the upland areas eroding soils, determined using ^{137}Cs measurements, have significantly less SOC than soils in deposition areas. These data suggest that ^{137}Cs patterns may be used to help understand SOC dynamics on the landscape. Different productivity and oxidation rates of SOC of eroded versus deposited soil would also contribute different patterns of SOC on the landscape. However, the strong significant relationships between ^{137}Cs and SOC concentrations in the upland soil suggest that they are moving along similar physical pathways in these systems.

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