

ASSESSING SOIL ORGANIC CARBON REDISTRIBUTION WITH FALLOUT ¹³⁷CESIUM

J.C. Ritchie^A, G.W. McCarty^B, E.R. Venteris^B, T.C. Kaspar^C, L.B. Owens^D, M. Nearing^E and M.H. Nichols^E

^AUSDA-ARS Hydrology and Remote Sensing Laboratory, Beltsville, MD 20705 USA.

^BUSDA-ARS Environmental Quality Laboratory, Beltsville, MD 20705 USA

^CUSDA-ARS National Soil Tilth Laboratory, Ames, IA 50011 USA.

^DUSDA-ARS North Appalachian Experimental Watershed, Coshocton, OH 43812 USA.

^EUSDA-ARS Southwest Watershed Research Center, Tucson, AZ 85719 USA.

Abstract

Patterns of soil organic carbon (SOC) vary widely across the landscape leading to large uncertainties in the SOC budget especially redistribution in agricultural areas. 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 ¹³⁷Cesium technique in tilled agricultural fields in Maryland, Ohio, and Iowa. Grazed semiarid rangeland watersheds sampled in Arizona. In an Iowa field, SOC had an order of magnitude difference in concentration (0.5 to 5%) and was significantly correlated ($r^2=0.50$) with soil ¹³⁷Cs concentration and soil erosion/deposition rates. Sites of soil erosion have significantly lower average concentrations of SOC (2.4%) than sites of soil deposition (3.4%). SOC was significantly correlated with erosion rates calculated from ¹³⁷Cs in Ohio and Maryland fields although the r^2 values were lower. Patterns of erosion and deposition were defined for the semiarid watersheds also. These studies show the importance of understanding soil redistribution patterns within a field or watershed for understanding soil loss and SOC patterns and the potential for developing or implementing better management systems to increase SOC in agricultural areas based on an improved understanding of patterns of soil movement.

Additional Keywords: soil carbon, SOC, ¹³⁷Cesium, 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 plays a significant role in understanding SOC patterns at the field and landscape levels (Ritchie and McCarty, 2003; McCarty and Ritchie, 2002). The purpose of this study was to expand earlier studies into farming systems in different physiographic region of the United States to determine the relationship between SOC, ¹³⁷Cesium (¹³⁷Cs), and soil redistribution patterns in different agricultural practices and landscapes.

Materials and Methods

Sample Sites

Single use 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 Optimizing Production Inputs for Economic and Environmental Enhancement (OPE³) 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 with different management practices on each. The watershed is approximately 25 ha and 40 m a.s.l. Mean annual rainfall is 1035 mm with a range from 547 to 1584mm for the 1871 -2000 period. Mean annual temperature is approximately 13 °C with monthly averages ranging from 4 °C in February to 27 °C 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* spp.] and hardwood [*Quercus* spp., *Acer* spp.] forest. The watersheds have 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 four small research watersheds. 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 300- 600 m. Mean annual rainfall is 944 mm. Mean annual temperature is approximately 10 °C with monthly averages ranging from -2 °C in

January to 22 °C in July. The soils are Hapludults 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; Venteris and Slater in Press). Bulk soil samples of the 0 -30 cm layer were collected in 22 of the watershed by randomly sampling soil profiles. Bulk soil samples were also collected at two small agricultural fields using a 25-m grid. Bulk soil samples were collected for the 0-30 cm layer.

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 8 °C ranging from -6 °C in January to 22 °C in July. The soils are Udolls and Udalfs. The native vegetation is prairie grass. Two fields on different operational farms were sampled. The fields were in a corn [*Zea mays* L.] and soybean [*Glycine 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 watersheds are in 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 began in 1953 on the Walnut Gulch Experimental Watershed. The elevation of the Lucky Hills watershed is 1370 m while the Kendall watershed is 1525 m. Mean annual temperature is 17 °C ranging from 1 °C in January to 35 °C in June and mean annual rainfall of approximately 356 mm (Nichols et al., 2002; Emmerich, 2003). The soils in Lucky Hills watershed are Ustochreptic Calciorthids while Ustollic Calciorthids soils are found on the Kendall watershed. The vegetation on Lucky Hills is shrub dominated (Acacia, [*Acacia constricta* Benth.]; Tarbush [*Flourensia cernua* DC]; Creosote [*Larrea divaricata* Cav.]). The vegetation at Kendall is dominantly grass (Grama grasses [*Bouteloua* spp.]; 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

Soil samples were collected to a depth of 30-cm as a bulk sample 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 insure the total depth of soil with ¹³⁷Cs was collected. At selected sites samples were collected in 5-cm depth increments to study the vertical distribution patterns of ¹³⁷Cs and carbon. Soil samples were dried, sieved to pass a 2-mm screen, placed into Marinelli beakers, and sealed for ¹³⁷Cs analyses. Analyses for ¹³⁷Cs were made by gamma-ray analyses using a Canberra¹ 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 Analytic¹ mixed radionuclide standard (10 nuclides) whose calibration can be traced to U.S. National Institute of Standards and Technology. Measurement precision for ¹³⁷Cs is ± 4 to 6 %. Soil erosion and redistribution rates and patterns were estimated based on the ¹³⁷Cs measurements and models that relate soil and ¹³⁷Cs movement (Walling and He, 1999; Ritchie and McHenry, 1990).

Soil 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 °C for 16 hours. SOC was calculated as the difference between total carbon and carbonate carbon.

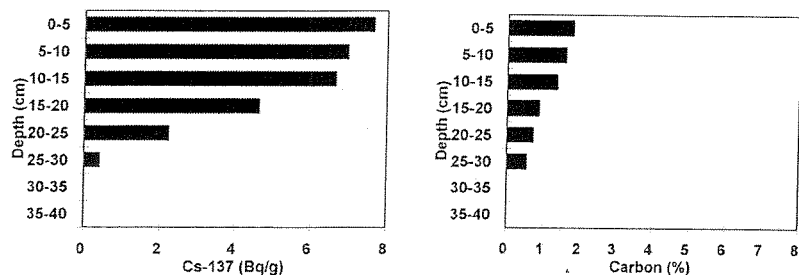
Results and Discussion

¹³⁷Cs 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. ¹³⁷Cs depth distribution is typical of agricultural soils where tillage operations mix ¹³⁷Cs in the tilled layer of the profile (Ritchie and McCarty, 2002). In depositional areas on the fields, ¹³⁷Cs distribution was deeper than the tilled depth indicating the redistribution and subsequent redeposition of eroded material within the field. However, ¹³⁷Cs was rarely found below 30-cm in the

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.
Paper No. 613

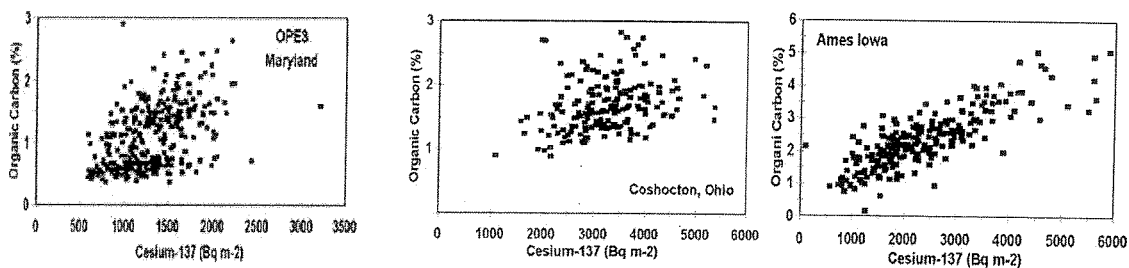
soil profiles at any site. Carbon was uniformly distributed in the tilled layer with slight decreases with depth below this tilled layer at the Maryland site.

Figure 1. Vertical distribution of ¹³⁷Cs (left) and carbon (right) in soil profiles (Average of 6 profiles) in a tilled corn [*Zea mays* L.] field at the OPE³ watersheds in Maryland.



At the Maryland, Iowa, and Ohio sites (Fig. 2), a significant relationship ($P < 0.05$) was found between ¹³⁷Cs concentration and SOC (%) for the samples but these relationships usually accounted for less than 50% (Iowa $r^2=0.68$; Maryland $r^2=0.23$; Ohio $r^2=0.30$) of the variability in SOC distribution. However these relationships do suggest that ¹³⁷Cs and SOC are probably moving along similar physical pathways in these systems. ¹³⁷Cs was used to estimate erosion rates and patterns and these erosion rates similar relationships to SOC.

Figure 2. Relationship between soil organic carbon and ¹³⁷Cs measured on area base in Maryland (left), Ohio (center) and Iowa (right).



Comparing erosion rates and patterns estimated using the ¹³⁷Cs 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 ¹³⁷Cs and SOC in the soil profile are strongly correlated suggest that ¹³⁷Cs and SOC are moving in similar physical pathways and probably by the similar physical mechanism since eroding areas have less ¹³⁷Cs and SOC than depositing areas.

Table 1. Averaged ¹³⁷Cs and SOC concentrations on single use watersheds at Coshocton, Ohio

Watershed Management	¹³⁷ Cs (Bq m ⁻²)	Erosion (Mg ha ⁻¹)	SOC (%)
Tilled	3235	0.85	1.48
No-till (With Manure)	3332	2.36	2.14
Grass (Grazed)	3096	-1.01	1.53
Grass (Harvested not Grazed)	3331	2.02	1.57

Table 1 shows the average ¹³⁷Cs, SOC, and erosion rates for four of the single use watersheds at Coshocton, Ohio. These tilled and grassed watershed have been under the same management since 1938. The no -till watershed has been continuous no-till corn since 1964. The tilled watershed has been in corn since 1955. Slopes of the tilled and no-till watershed are 6-12% while the grassed watershed are 12-25%. The high SOC on the on the no-till watershed is due to the addition of animal manure added to watershed several months prior to sampling. There was no significant difference in SOC in the other watersheds. The grazed grass watershed had the greatest erosion, but erosion rates and ¹³⁷Cs content were not significantly different between the watersheds.

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

Conclusions

¹³⁷Cs and soil carbon concentrations of upland soils are significantly correlated with in the study area. Eroding soils in the upland areas as determined using ¹³⁷Cs measurements have significantly less soil carbon than deposition areas in the upland area. These data suggest that ¹³⁷Cs patterns may be used to help understand soil carbon dynamics on the landscape. Different productivity and oxidation rates of carbon of eroded versus deposited soil would also contribute different patterns of carbon on the landscape. However, the strong relationship between ¹³⁷Cs and soil carbon concentrations in the upland soil suggest that they are moving along similar physical pathways.

Acknowledgements

Any acknowledgements we should add.

References

- Emmerich, W. (2003) Carbon dioxide on Walnut Gulch Experimental Watershed. In: *First Interagency Conference on Research in the Watersheds*, K.C. Renard, S.A. McElroy, W.J. Gburek, H.E. Canfield, and R.L. Scott (eds.), p554-559, U.S. Department of Agriculture, Agricultural Research Service Special Publication, Washington DC.
- Gish, T.J., C.L. Walthall, C.S.T. Daughtry, G.W. McCarty, and W.P. Dulaney. (2003) Watershed scale sensing of subsurface flow pathways at the OPE3 site, In: *First Interagency Conference on Research in the Watersheds*, K.C. Renard, S.A. McElroy, W.J. Gburek, H.E. Canfield, and R.L. Scott (eds.), p192-197, U.S. Department of Agriculture, Agricultural Research Service Special Publication, Washington DC.
- Jaynes, D.B., Kaspar, T.C., Colvin, T.S., and James, D.E. (2003) Cluster analysis of spatiotemporal corn yield patterns in an Iowa field. *Agronomy Journal* **95**, 574-586.
- Kelley, G.E. (1975) *Soils of the North Appalachian Experimental Watershed*. USDA ARS Miscellaneous Publication No. 1296, 145 pp. Washington, DC.
- Lal, R., Kimble, J.M., Follett, R.F., and Cole, C.V. (1998) The potential of US cropland to sequester carbon and mitigate the greenhouse effect. Ann Arbor Press, Chelsea, MI, USA.
- Nelson, D.W. and Sommers, L.E. (1996) Total carbon, organic carbon, and organic matter, In: *Methods of Soil Analysis Part 3- Chemical Methods*, J.M. Bartels and J.M. Bigham (eds.), p. 961-1010, Soil Science Society of America, Madison WI., USA
- Nichols, M.H., Renard, K.G. and Osborn, H.B. (2002) Precipitation Changes From 1956 to 1996 on the Walnut Gulch Experimental Watershed. *Journal of the American Water Resources Association* **38**, 161-172.
- Owens, L.B., Malone, R.W. and Lal, R. (2001) Carbon concentration and transport in sediment leaving small cropped watersheds, In: *Sustaining the Global Farm, Selected papers from the 10th International Soil Conservation Organization Meeting*, D.E. Stott, R.H. Mohtar, and G.C. Steinhardt (eds.), p. 503-508, International Soil Conservation Organization, West Lafayette, Indiana USA.
- Parkin, T.B. and Kaspar, T.C. (2003). Temperature controls on diurnal carbon dioxide flux: Implications for estimating soil carbon loss. *Soil Science Society of America Journal* **67**, 1763-1772.
- Ritchie, J.C. and McCarty, G.W. (2003) Using ¹³⁷Cesium to understand soil carbon redistribution on agricultural watersheds. *Soil and Tillage Research* **69**, 45-51.
- Ritchie, J.C. and McHenry, J.R. (1990) Application of radioactive fallout cesium-137 for measuring soil erosion and sediment accumulation rates and patterns: a review. *Journal of Environmental Quality* **19**, 215-233.
- Venteris, E.R. and Slater, B.K. (in press). A comparison between contour elevation data sources for DEM creation and soil carbon prediction, Coshocton, Ohio. *Transactions in GIS*.
- Walling, D.E. and He, Q. (1999) Improved models for estimating soil erosion rates from cesium-137 measurements. *Journal of Environmental Quality* **28**, 611-622.