Influence of land use changes on soil carbon stock and soil carbon erosion in a Mediterranean catchment

C. Boix-Fayos [(1)], M. Martínez-Mena [(1)], J. de Vente [(2)], J. Albaladejo [(1)]

[(1)] Soil and Water Conservation Department, CEBAS, CSIC (Spanish Research Council), Campus Universitario de Espinardo, PO Box 164, 30100 Murcia, Spain. cboix@cebas.csic.es

[(2)] Desertification and Geoecology Department, EEZA, CSIC (Spanish Research Council), General Segura 1, 04001 Almería , Spain.

ABSTRACT

The effect of changing land uses on the organic soil carbon (C) stock and the soil C transported by water erosion and buried in depositional wedges behind check-dams was estimated in a Mediterranean catchment in SE Spain. The 57 % decrease in agricultural areas and 1.5-fold increase of the total forest cover between 1956 and 1997 induced an accumulation rate of total organic carbon (TOC) in the soil of 10.73 g m^{-2} yr^{-1}. The mineral-associated organic carbon (MOC) represented the 70 % of the soil carbon pool, the particulate organic carbon (POC) represented a 30 % of the soil carbon pool. The average sediments/soil enrichment ratio at the subcatchment scale (8-125 ha) was 0.59 ±0.43 g kg^{-1}. Eroded soil C accounted for between 2 % to 78 % of the soil C stock in the first 5 cm of the soil in the subcatchments. The C erosion rate varied between 0.008 and 0.2 t ha^{-1} yr^{-1}. Observed changes in land use (decrease in agricultural areas) reduced soil C erosion, although sediments from non-agricultural sources are richer in organic C. At catchment scale from the 4 % of the soil C stock mobilized by water erosion, 77 % is buried in the sediment wedges behind check-dams. Soil C replacement due to increased vegetation cover between 1974 and 1997 represented a 36 % of the original soil organic C stock. All together represent an erosion-induced sink of soil organic C of 40 % compared to the original levels of 1974. We can conclude that the catchment is behaving as a soil C sink within the soil erosion subsystem as a consequence of the changes on the land use pattern that took place since the 1950's. The meaning of this erosion-induced C sink in a wider C balance which takes into account soil respiration remains uncertain.

Keywords: soil C erosion; land use change; C stock.

INTRODUCTION

Budgets of organic C at the catchment scale are scarce and the results diverse. Soil organic C erosion rates at this scale are estimated at 0.07 t C ha^{-1} yr^{-1} (Mississipi basin, direct estimations, Smith et al., 2005), 0.02-0.218 t C ha^{-1} yr^{-1} (Albergel et al., 2006, small semiarid catchments, direct estimations), 0.113 t C ha^{-1} yr^{-1} and between 0.03-0.212 t C ha^{-1} yr^{-1} (Jacinthe et al., 2004 and Izaurralde et al., 2007, respectively, direct estimations, in small watersheds with 950 mm annual average precipitation) and 0.1 t C ha^{-1} yr^{-1} (Smith et al., 2007, modeled results). Sequestration rates by erosion processes have been estimated at 0.03-0.1 t C ha^{-1} yr^{-1} (Van Oost et al., 2005). Other authors talk about C storage rates in eroded sediments within catchments of 0.11 t C ha^{-1} yr^{-1} (Haregeweyn et al., 2008). These rates are lower than the recently estimated burial rates of organic C in agricultural impoundments suggested by Downing et al. (2008), who mention figures ranging from 1.48 to 170 t C ha yr^{-1}. In recent years has been demonstrated that sediments in depositional environments and at different spatial scales may bury substantial amounts of soil C derived from soil erosion processes, and even control atmospheric C dioxide levels on geological timescales (Galy et al., 2007).

Another crucial process able to drastically alter the soil C stock at the catchment scale is large scale land use changes. The review of Guo and Gifford (2002) pointed to a decrease of 59 % in SOC due to a change from pasture to crop land. An increase of more than 50 % in soil C storage was reported by Dawson and Smith (2007) after the conversion from arable to forest land. At regional scales, Vagen et al. (2005) report a decrease from 0 to 63% of soil organic C following deforestation in subhumid and semiarid savannas. In China reductions of 10 % to 40 % of the soil C in cultivated soils compared with the non-cultivated soils have been reported, the soils showing the highest losses being located in the semiarid and subhumid areas of that country (Wu et al., 2003).

In this work we present a summary of the changes in soil C stock induced by land use changes over a period of 41 years and estimations of the soil C mobilized and buried in sediments over a period of 27 years at the catchment and subcatchment scales. A detailed and deeper analysis of these results can be seen in Boix-Fayos et al. (in press).

STUDY AREA AND METHODS

The study was carried out in the Rogativa catchment (province of Murcia, SE Spain, 38º 08' N, 2º 13' W). The catchment has a size of 47.2 km^2 , with a subhumid Mediterranean climate, 583 mm of average annual rainfall and average annual temperature of 13.3º C. The dominant lithology consists of marls, limestones, marly limestones and sandstones of the Cretaceous, Oligocene, and Miocene (IGME, 1978). Mountains are mainly limestones, while mid and bottom valley locations are dominated by marls. The catchment experienced hydrological correction works in the mid 1970's, consisting of reforestation and construction of 58 check-dams. In addition the Rogativa catchment has undergone important land use changes since 1956, the forest cover increasing and the dry land agricultural area decreasing. The effect of land use changes and check-dams on the channel morphology and in the sediment yield exported at catchment scale were analysed and described in detail in Boix-Fayos et al. (2007) and Boix-Fayos et al. (2008).

At the catchment, the soils (50 sampling locations) at the drainage area of several subcatchments (7) were sampled as well as the sediments retained by check-dams at the outlet of the subcatchments. Buld density, total organic carbon (TOC), particulate organic carbon (POC) and mineral associated organic carbon (MOC) were determined in soils and sediments. GIS analysis was used to explore characteristics of the subcatchments. All details over the study area, sampling strategy, laboratory analysis and GIS procedures can be seen in Boix-Fayos et al. (in press).

RESULTS AND DISCUSSION

The TOC stock in the soil gradually decreases from the high density forest, to the low density forest, followed by pasture, shrubland and dry land agricultural soils. The values vary between 1419±896 g m^{-2} and 457±201 g m^{-2} for high density forest and agricultural soils, respectively. These values are within the range of values estimated for other areas in the same region (Martínez-Mena et al., 2008).

The MOC is the main pool of soil C for all land uses, the dry land agricultural soils having the highest MOC pool (80 %) and the shrubland soils the lowest (67 %). The POC pool represents between the 20 % and the 33 % of the TOC in the dry land agricultural and shrubland soils, respectively.

The TOC concentration in the sediments varies from 0.7 g kg^{-1} to 35.16 g kg^{-1} with an average of 9.61 g kg^{-1}.

Enrichment ratios (sediments/soil) for the TOC concentration vary between 0.35 and 0.89, with an average of 0.59±0.43. These enrichment ratios are lower than most of those reported in the literature referring to recently exported sediments due to water erosion at finer scales (plot scale) (Owens et al., 2002, ER= 1.5 in small watersheds <0.8 ha; Quinton et al., 2006 ER=2.6-4.5 in plots 25 x 30 m; Martínez-Mena et al., 2008, ER= 1.91-2.38 in plots 8 x 2 m). The sediments retained by the check-dams include suspended and bedload sediments. Sediments may originate from superficial soil horizons through sheet and rill erosion but also from deeper soil layers removed by gully erosion. All these factors result in a lower ER than that derived from measurements at finer spatial and temporal scales (event-based).

Table 1. TOC mobilized by water erosion, total erosion and organic carbon stock of the original soils at the subcatchment scale

Subcatchments	TOC stock (upper 5 cm of soil) (t)[a]	TOC mobilized by water erosion[b] (t)	TOC erosion rate (t ha^{-1} yr^{-1})[c]	Ratio TOC erosion/ total soil erosion	% Eroded TOC of the original soil[d]
Check-dam 3	1494.23	26.39	0.008	0.0121	1.76
Check-dam 14	132.67	11.30	0.032	0.0095	8.52
Check-dam 21	95.14	12.28	0.041	0.0106	12.91
Check-dam 29	52.95	41.04	0.199	0.0120	77.51
Check-dam 49	621.50	13.44	0.004	0.0046	2.16
Check-dam 53	120.51	20.60	0.085	0.0118	17.10
Check-dam 58	1665.00	185.57	0.051	0.0071	11.14

[a] Total Organic Carbon estimated with reference samples taken within the subcatchments at sites with no land use change between 1956-1997
[b] Total Organic Carbon by estimation of the weight of sediments retained behind each check-dam
[c] Total Organic Carbon in sediments retained by check-dams
[d] Percentage of eroded TOC in relation to the soil carbon stock at each subcatchment area in 1981

The average soil C erosion rate for the studied subcatchments is 0.06 t ha^{-1} yr^{-1} while the highest TOC erosion rates are found in the smallest subcatchments (check-dam 29, check-dam 53) (Table 1). The highest percentage of eroded TOC with respect to the TOC stock in the catchment area are also observed for the smallest subcatchments as were the highest the ratios of TOC erosion/total erosion. The catchment of check-dam 3 with the highest percentage of forest cover also shows a high TOC erosion/total erosion ratio. The ratios of TOC erosion to total erosion oscillate from 0.005 to 0.012, which are lower than the ratios reported by Smith (2005) for several subcatchments of the Mississipi basin (from 0.0093 to 0.0233) mainly dedicated to agricultural use. However, these ratios are very significant when related to the soil C stock of the catchment. The percentage of TOC erosion with respect to the C stock of the original soil varied from 1.76 % to 77.51 %, suggesting that in catchments with a low soil C stock, erosion processes may represent an important output of soil C.

CONCLUSION

The hydrological control works (afforestation and check-dam construction) in the mid 1970's, together with the progressive abandonment of agricultural activities, has led to the Rogativa catchment behaving as a soil erosion-induced carbon sink from the 1950's onwards. It is estimated that the sink accounted for approximately 40% taking as reference the soil C stock of the first 5 cm of soil in the catchment in 1974. From this 40%, a 4% is soil C mobilized by water erosion and buried in the sediment wedges behind check-dams.

ACKNOWLEDGEMENTS

This work was financially supported by the projects CICYT CGL2004-03179/BTE (Ministry of Science and Technology of Spain), SENECA 03027/PI/05 (Region of Murcia Government) and ERCO (CGL2007-62590/BTE) from the Ministry of Science and Innovation of Spain. Thanks to Adolfo Carrasco Sánchez and Raquel Ros Alcaraz who contributed to the laboratory analysis and the interpretation of some data.

REFERENCES

- Albergel, J., Mansouri, T., Zante, P., Ben Mamou, A., Abdeljaoued, S., 2006. Organic carbon in the sediments of hill dams in a semiarid Mediterranean area. In: E.J. Roose, Lal, R., Feller, C., Barthes, B., Stewart, B.A. (Editor), Soil erosion and carbon dynamics. Advances in Soil Science. Taylor & Francis, Boca Raton, FL.
- Boix-Fayos, C., Barberá G. G., López-Bermúdez F., Castillo V. M., 2007. Effects of check-dams, reforestation and land-use changes on river channel morphology: Case study of the Rogativa catchment (Murcia, Spain). Geomorphology 91, 103-123.
- Boix-Fayos, C., de Vente, J., Martínez-Mena, M., Barberá G. G., Castillo V. M. (2008). The impact of land use change and check-dams on catchment sediment yield. Hydrological Processes 22, 4922-4935.
- Boix-Fayos, C., de Vente, J., Albaladejo, J., Martínez-Mena, M. (in press). Soil carbon erosion and stock at the catchment scale as affected by land use changes in Mediterranean ecosystems. Agriculture, Ecosystems & Environment.
- Dawson, J.J.C. and Smith, P., 2007. Carbon losses from soil and its consequences for land-use management. Science of the Total Environment 382, 165-190.
- Downing, J.A., Cole, J.J., Middelburg, J.J., Striegl. R.G., Duarte, C.M., Kortelainen, P., Praire, Y.T., Laube, K.A., 2008. Sediment organic carbon burial in agriculturally eutrophic impoundments over last century. Global Biogeochemical Cycles 22, doi:10.1029/2006GB002854.
- Galy V., France-Lanord C., Beyssac O., Faure P., Kudrass H., and Palhol F., 2007. Efficient organic carbon burial in the Bengal fan sustained by the Himalayan erosional system. Nature 450, 407-410.
- Guo, L.B. and Gifford, R.M., 2002. Soil carbon stocks and land use change: a meta analysis. Global Change Biology 8, 345-360.
- Haregeweyn, N., Poesen, J., Deckers, J., Nyssen J., Hayle, M., Govers, G., Verstraeten, G. and Moeyersons, J., 2008. Sediment-bound nutrient export from micro-dam catchments in Northern Ethiopia. Land Degradation & Development 19, 136-152.
- Instituto Geológico y Minero de España (IGME) (1978) Mapa geológico de España 1:50000, Nerpio 909: 23-26
- Izaurralde, R.C. et al., 2007. Long-term modeling of soil C erosion and sequestration at the small watershed scale. Climatic Change 80, 73-90.
- Jacinthe, P.A., Lal, R., Owens, L.B. and Hothem, D.L., 2004. Transport of labile carbon in runoff as affected by land use and rainfall characteristics. Soil & Tillage Research 77, 111-123.
- Martinez-Mena, M., Lopez, J., Almagro, M., Boix-Fayos, C. and Albaladejo, J., 2008. Effect of water erosion and cultivation on the soil carbon stock in a semiarid area of South-East Spain. Soil and Tillage Research 99, 119-129.
- Owens, L.B., Malone, R.W., Hothem, D.L., Starr, G.C. and Lal, R., 2002. Sediment carbon concentration and transport from small watersheds under various conservation tillage practices. Soil & Tillage Research 67, 65-73.
- Quinton, J.N., Catt, J.A., Wood, G.A. and Steer, J., 2006. Soil carbon losses by water erosion: Experimentation and modeling at field and national scales in the UK. Agriculture Ecosystems & Environment 112, 87-102.
- Smith, S.V., Bullock, S.H., Hinojosa-Corona, A., Franco-Vizcaíno, E., Escoto-Rodríguez, M., Kretzschmar, T.G., FArfán, L.M. Salazar-Ceseña, J.M., 2007. Soil erosion and significance for carbon fluxes in a mountainous Mediterranean-climate watershed. Ecological Applications 17, 1379-1387.
- Smith, S.V., Sleezer, R.O., Renwick, W.H. and Buddemeier, R., 2005. Fates of eroded soil organic carbon: Mississippi basin case study. Ecological Applications 15, 1929-1940.
- Vagen, T.G., Lal, R. and Singh, B.R., 2005. Soil carbon sequestration in sub-Saharan Africa: A review. Land Degradation & Development 16, 53-71.
- Van Oost, K. et al., 2005. Landscape-scale modeling of carbon cycling under the impact of soil redistribution: The role of tillage erosion. Global Biogeochemical Cycles 19, 1-13.
- Wu, H.B., Guo, Z.T. and Peng, C.H., 2003. Land use induced changes of organic carbon storage in soils of China. Global Change Biology 9, 305-315.