Print

Proceedings

Erosion and soil carbon sequestration

BERNOUX Martial, FELLER Christian, ROOSE Eric
Centre IRD Montpellier, UR 179 SeqBio, BP64501, F-34394 Montpellier cedex 5: bernoux@mpl.ird.fr, roose@mpl.ird.fr, feller@ird.mg

Résumé

Cette communication traite de l'érosion et de la séquestration du carbone (C). En effet, toute modification de l´usage des terres ou, même toute modification de l'itinéraire technique des sols agricoles, peut induire des variations du stockage du carbone dans les sols. Mais en outre, le C du sol est particulièrement intéressant pour lutter contre l'érosion. Les points suivants sont soulevés et répondus : (i) le C érodé (solide et soluble) fait-il partie du bilan de la « séquestration du C ». Autrement dit, qu'est-ce que la séquestration du C ? (ii) au cours de son cheminement de l'amont vers l'aval, le C érodé est-il transformé ? Et quel impact cela a-t-il sur le bilan de la séquestration ? (iii) que se passe-t-il aux différentes échelles de paysage ? Et (iv) quelles sont les pratiques agricoles et forestières permettant à la fois une lutte contre l'érosion et une séquestration accrue du C ?

Introduction

Concerns on global warming and on increasing atmospheric greenhouse gas concentrations (GHG, mainly CO_2, CH_4, and N_2O) have lead to questions on the role of the soils in terms of carbon (C) source or sink (Houghton, 2003). Soils constitute the largest surface organic C pool, approximately 1500 Gt C, which is equivalent to almost three times the quantity stored in the terrestrial biomass, and twice that in the atmosphere.

"Soil carbon sequestration" appears an important multi-disciplinary issue encompassing economics, environment, and agronomy (Bernoux et al., 2006b). This issue is important for all kind of soils, for instance, arid and semi arid lands are concerned by land degradation caused by loss of vegetation, overgrazing and ground water harvesting cover. These soils cover an estimated 40% of the world land surfaces, and are, therefore, important for soil organic carbon (SOC) stocks globally despite low SOC stocks on a per unit area basis.

Any modification of the land-use, or limited to the management practices, even for the agricultural systems at the steady state, can induce variations of the SOC stocks and fluxes (Schuman et al., 2002). Moreover increasing soil C stocks are particularly interesting concerning erosion control. SOC, a principle constituent of soil organic matter (SOM), is a major determinant of soil fertility, water holding capacity and biological activity and is highly correlated to levels of above and below ground biodiversity. SOC also influences soil compactability, friability and aggregation, which have major implications for soil permeability and erodibility. Loss of SOC is a standard feature of non-sustainable land use leading to land degradation. Likewise practices that maintain and enhance SOC are almost always synonymous with land rehabilitation and sustainability. Therefore an optimum biomass management should be a solution for different problems such as food security, soil and water quality, erosion control, and the fight against the increase of GHG concentration.

In the global C balance, flows of eroded C (in the solid or soluble form) of the soil towards the river, lake or marine sediments are not at all negligible since they represent 0,6Gt C yr^{-1} to be compared with the total emissions of C-CO_2 due to the continental ecosystems which are about 1,5 Gt C yr^{-1}. Also, in the relations between erosion, streaming and sequestration of C, some important points are raised, and exposed:

Print

Proceedings

- Is the Eroded C (solid and soluble) to be accounted in the balance of the “C sequestration?” In other words, what is the sequestration of C?
- During its transportation from the upstream towards the downstream, is the eroded C transformed? And which impact that does it have on the C sequestration?
- What does it occur at various landscape scales?
- Which husbandries and forest practices allow at the same time a fight against erosion and C sequestration?

Eroded C and C sequestration

Bernoux et al. (2006b) defined “Soil carbon sequestration, in a specific agro-ecosystem in comparison with a reference system, as the result, for a given period of time and area, of the net balance of all GHG, expressed in C-CO_2 equivalent or CO_2 equivalent, computing all emissions sources at the soil-plant-atmosphere interface”. In other words (i) soil C sequestration is not limited to the CO_2 fluxes, and (ii) C sequestration concern only fluxes in a gaseous form between soil and the atmosphere, i.e. other C fluxes, in solid or soluble states, as it is the case for erosion and deposition along a soil toposequence are excluded. During the timeframe of a soil study part of the observed variations (reduction or increase) may be due to a loss of solid or soluble C by erosion and run-off (upslope) and by an accumulation downslope. According to the above definition, this variation of C stock must not be accounted as a C sequestration or “un-sequestration”.

Behaviour of eroded C

Theoretically eroded C must not be accounted in the sequestration balance. But this is valid only if the erosion/deposition phenomena do not induced change in the C stability. In fact, throughout the transfer process, soil aggregates will be broken-down; the soil particles will be transferred by water erosion and deposited down hill or sedimented in waters. The breakdown of soil aggregates tends to increase the potential of mineralization of soil organic C initially protected within the aggregates (Feller and Beare, 1997). In addition, the C in solid form upon deposition may be more or less stable than in the original material. These changes in the C stability both in transportation and deposition processes may affect the net CO_2 balance, and thus be accounted in the balance. Few data is available regarding these points, and the debate is still open between scientist arguing that CO_2 fluxes are enhanced during transfer and others arguing that on the contrary eroded C is stabilized upon deposition. Both processes may occur as well!

Level of Eroded C at various landscape scales

Plot and watershed levels

Roose et al. (2004ab, 2006) brought together available information on C lost at the plot level under tropical and Mediterranean situations. Compared with biomass production (1–20 t ha^{-1} yr^{-1}) losses of SOC in particulate forms by water erosion are moderate: 1 to 50 kg C ha^{-1} yr^{-1} when the soil is effectively protected by vegetative cover on residue, 50 to 500 kg C ha^{-1} yr^{-1} under clean weeded crops, burned or overgrazed grasslands, and > 1000 kg C ha^{-1} yr^{-1} on bare plots under erosion-prone conditions (very steep slopes, intensive and abundant rainstorms). Losses in soluble forms (runoff and/or drainage) are imprecisely estimated to varied in the range 1 to 600 kg C ha^{-1} yr^{-1}. Finally SOC losses by erosion and drainage are of the same order of magnitude as the C sequestration observed with improved management practices, and thus practices that lead to a fight against erosion may be also C benefit. At the watershed level, SOC stocks vary along a hill shade, according to erosion processes, declivity, the soil surface and vegetal covers (quantity and quality).

Continental scale: eroded C behaviour in rivers

In small rivers, sediment C came nearly exclusively from the SOM (Albergel et al., 2006). But in large rivers, processes are complex with several compartments, particulate (POC) and dissolved (DOC) organic carbon, and different origins (rocks alteration, atmospheric deposit, biological filters…). In main worldwide rivers exportation of organic C are limited to about 1% of the plant production, i.e. a mean flux of 500 millions tons per year. Seyler et al. (2006) reported that the Amazon basin alone is responsible for up to 10% of the total exported C by the World Rivers.

Importance of husbandries and forest practices on erosion and C sequestration

If forest can store C in biomass and soil, it has been showed that extensive pastures or inadequately managed extensive pastures degraded forage production and release soil C up to 40%. In the case of grain production the loose can reach 60%. But studies reported that in the case of reforestation with adequate species (*Pinus halepensis or Eucalyptus camaldulensis),* a large part (>90%) of the original storage can be attained in 40 years. But this solution is rarely adequate for the smallholders or farmers. On the other hand, agroforestry practices have similar impact on C dynamic (80% of original C stock reestablished), but with ancillary benefits, such as an increase of incomes and permit the use of sloped areas (Sabir and Roose, 2004).

The consequences of fire used to manage the fields are complex: it increase biomass mineralization, but the small pool of “black C” produced is more stable than the humified SOM. Fire induces temporary increase of run-off and erosion but favors plant regeneration of species that cover the surface and protect the soils.

Impact of (over)grazing onto SOC dynamics and erosion is not clear. On one hand, animals may consume 50 to 60% of the biomass but on the other their organic restitutions to soil, about 40%, are enriched in N and increased soil fertility. Overgrazing can also create a soil compaction problem and contribute to serious surface runoff. Animals have direct influence over erosion because animal trampling of wet soil can lead to the destruction of soil structure. On the opposite, low animal numbers may also contribute to desertification. Plants that are not eaten will become moribund and die and this in turn will lead to the development of bare ground. Fire is often used together with over-resting, hastening the process of desertification.

Short term fallows with legumes commonly increase SOC stocks, but can lead to enhanced N_2O emissions. Its widespread recommendation in Africa needs a change in traditional pasturing management and fire control during the dry season.

Numerous studies of direct seeding associated with the maintenance of a permanent mulch over the soil were tested in Latin America (Mexico, Argentine, Brazil, Uruguay) and Africa (Cameroon, Morocco, Mali). For instance, in the southern part of Brazil, no-tillage was developed in response to soil erosion problems and declining levels of land productivity under “conventionally” tilled systems. The underlying land management principles that led to the development of no-tillage systems were, prevention surface sealing caused by rainfall impact, achievement and maintenance of an open soil structure and reduction of the volume and velocity of surface runoff. This erosion control is generally accompanied with a SOC increase: most studies of Brazilian soils give rates of carbon storage in the top 40cm of the soil of 0.4 to 1.7 t C ha^{-1} yr^{-1} (Bernoux et al, 2006a). But there is still a lack of data for the semi-arid regions.

In all cases management of biomass with adequate complementary fertilization may lead satisfactory solution and respond to the major challenge of the XXI century: feed a population that doubles each 20 year and preserve the environment.

Print

Proceedings

Conclusions and perspectives

Further studies are still needed to better understand and precisely quantify the influence of erosion and practices to prevent erosion over carbon sequestration at different scales.

At the plot scale, some data are available about selectivity for C of erosion processes, allowing qualification and quantification of C displaced over the landscape. But it is still difficult to evaluate the rate of C in dissolved form in run-off or drainage water. In humid tropical zones DOC amounts are not dispraisable (1 to 600 kg C ha^{-1} yr^{-1}) and the composition of runoff waters is similar to that of the rivers. There is an urgent need for a quantification of aggregates disposed downhill, in the river and in the ocean, but moreover for their ability to protect or not SOC.

At the water basin, phenomena are complex. But, well known methodologies (^{137}Cs, ^{13}C…) are very useful to show the spatial variation in fluxes. Nevertheless refinements are needed to confirm that the initial deposition is really homogenous on the entire landscape even when the rainfalls are wind driven with changing direction.

Bibliography

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. P. 289-299. In. Soil Erosion and Carbon Dynamics (Roose E.J., Lal R., Feller C., Barthès B., Stewart B.A. Eds), Advances in Soil Science, CRC press, Taylor and Francis, Boca Ratton, 352 pp.

Bernoux M., Cerri C.C., Cerri C.E.P. Siqueira Neto M., Metay A., Perrin A.S., Scopel E., Razafimbelo T., Blavet D., Piccolo M.C., Pavei M., Milne E. 2006a. Cropping systems, carbon sequestration and erosion in Brazil, a review. Agronomy for Sustainable Development, 26, doi: 10.1051/agro:2005055

Bernoux M., Feller C., Eschenbrenner V. Cerri C.C., Cerri C.E.P. 2006b. Soil carbon sequestration. p13-22. In. Soil Erosion and Carbon Dynamics (Roose E.J., Lal R., Feller C., Barthès B., Stewart B.A. Eds), Advances in Soil Science, CRC press, Taylor and Francis, Boca Ratton, 352 pp.

Feller C., Beare, M.H. 1997. Physical control of soil organic matter dynamics in the tropics. Geoderma 79, 69-116.

Houghton R.A. 2003. Why are estimates of the terrestrial carbon balance so different? Global Change Biology 9, 500-509.

Roose E., De Noni G., Prat C., Ganry F., Bourgeon G. (Eds). 2004a. Bulletin du Réseau Erosion numéro 22, Gestion de la Biomasse, Erosion et Séquestration du Carbone, Actes 1, Erosion du Carbone, IRD-CIRAD, 493 p.

Roose E., De Noni G., Prat C., Ganry F., Bourgeon G. (Eds). 2004b. Bulletin Réseau Erosion numéro 23, Gestion de la Biomasse, Erosion et Séquestration du Carbone, Actes 2, Séquestration du Carbone et Erosion des sols, IRD-CIRAD, 636 p.

Roose E.J., Lal R., Feller C., Barthès B., Stewart B.A. (Eds). 2006. Soil Erosion and Carbon Dynamics, Advances in Soil Science, CRC press, Taylor and Francis, Boca Ratton, 352 pp.

Sabir M., Roose E., 2004. Influences du couvert végétal et des sols sur le stock de carbone, les risques de ruissellement et d'érosion dans les montagnes du Rif occidental, Maroc. pp. 144-154. In. Séquestration du Carbone et Erosion des sols (Roose E., De Noni G., Prat C., Ganry F., Bourgeon G. Eds). Bulletin Réseau Erosion N° 23, IRD-CIRAD, 636 p.

Seyler P., Coynel A., Moreira-Turcq P., Etcheber H, Colas C., Orange D., Bricquet J.P., Laraque A., Guyot JL. 2006. Organic carbon transported by the equatorial rivers : example of Congo-Zaire and Amazon Basins. p. 255-274. In. Soil Erosion and Carbon Dynamics (Roose E.J., Lal R., Feller C., Barthès B., Stewart B.A. Eds), Advances in Soil Science, CRC press, Taylor and Francis, Boca Ratton, 352 pp.

Print

Proceedings

Schuman G.E., Janzen H.H., Herrick J.E. 2002. Soil carbon dynamics and potential carbon sequestration by rangelands Environmental Pollution 116, 391-396.