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Effect of Good Agricultural and Environmental Conditions on erosion and soil organic carbon balance: A national case study

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ABSTRACT

Since, the Common Agricultural Policies (CAP) reform in 2003, many efforts have been made at the European level to promote a more environmentally friendly agriculture. In order to oblige farmers to manage their land sustainably, the GAEC (Good Agricultural and Environmental Conditions) were introduced as part of the Cross Compliance mechanism. Among the standards indicated, the protection of soils against erosion and the maintenance of soil organic matter and soil structure were two pillars to protect and enhance the soil quality and functions. While Member States should specifically define the most appropriate management practices and verify their application, there is a substantial lack of knowledge about the effects of this policy on erosion prevention and soil organic carbon (SOC) change. In order to fill this gap, we coupled a high resolution erosion model based on Revised Universal Soil Loss Equation (RUSLE) with the CENTURY biogeochemical model, with the aim to incorporate the lateral carbon fluxes occurring with the sediment transportation. Three scenarios were simulated on the whole extent of arable land in Italy: (i) a baseline without the GAEC implementation; (ii) a current scenario considering a set of management related to GAEC and the corresponding area of application derived from land use and agricultural management statistics and (iii) a technical potential where GAEC standards are applied to the entire surface. The results show a 10.8% decrease, from 8.33 Mg ha^{-1} year^{-1} to 7.43 Mg ha^{-1} year^{-1}, in soil loss potential due to the adoption of the GAEC conservation practices. The technical potential scenario shows a 50.1% decrease in the soil loss potential (soil loss 4.1 Mg ha^{-1} year^{-1}). The GAEC application resulted in overall SOC gains, with different rates depending on the hectares covered and the agroecosystem conditions. About 17% of the SOC change was attributable to avoided SOC transport by sediment erosion in the current scenario, while a potential gain up to 23.3 Mt of C by 2020 is predicted under the full GAEC application. These estimates provide a useful starting point to help the decision-makers in both ex-ante and ex-post policy evaluation while, scientifically, the way forward relies on linking biogeochemical and geomorphological processes occurring at landscape level and scaling those up to continental and global scales.

1. Introduction

Land degradation due to soil erosion is an old threat (Chapline, 1929; Ayres, 1936) which has turned into a major agricultural and environmental problem worldwide (Lal, 2014). The scientific community recognizes it as one of the most pressing environmental problems, because it can decrease agricultural productivity (Pimentel et al., 1995), degrade ecosystem functions (Foley et al., 2005), amplify hydrogeological risk (Poesen and Hooke, 1997) and, in severe cases, lead to displacement of human populations (Opie, 2000).

The ongoing erosion-associated loss of productivity has reduced the food supply capacities of many agricultural areas during the last few decades (Pimentel et al., 1995). Per capita shortages of arable land due to severe erosion and population growth have been observed in Africa, Asia and Europe (Lal, 1990). Despite the general increases in the agricultural production per capita (FAO,

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2015; Oldroyd, 2015), soil erosion and land degradation remain significant threats for most agricultural lands (Bai et al., 2008) and constitute a limiting factor for the per capita food production growth in several locations especially in the African countries (Nachtergaele et al., 2010; FAO, 2015).

Erosion rates accelerated by unsuitable land-use and management (Felix-Henningsen et al., 1997) affect soil fertility and productivity by reducing the water infiltration, water-holding capacity, organic matter, nutrients and organic biota (Morgan, 2009). The use of fertilization is an expensive practice that can partially mitigate the yield losses, however without stabilizing the erosion process. As a result, the soil is still moved by erosion carrying nutrients, pesticides, and other harmful farm chemicals into the receiving stream (Hodgkin and Hamilton, 1993; Novotny, 1999).

Recent studies have found that the mobilization and deposition of agricultural soils can also significantly alter nutrients and carbon cycling (Quinton et al., 2010), although the net effect of erosion and deposition in the carbon cycle is the subject of debate (Quine and Van Oost, 2007).

In eroding sites, the physical removal of SOC causes a depletion of the carbon pool, which may be partially compensated by the incoming fixed carbon (Kirkels et al., 2014). In addition considering the same depth, the exported SOC is replaced by more recalcitrant subsoil pools leading to complex feedbacks on vertical fluxes components (respiration and fixation). All these complex interactions still feed the dichotomous debate whether the erosion induces a net carbon source (Lal, 2004) or sink (Van Oost at el., 2005a).

Soils are the third largest global reservoir of carbon (Lal, 2004) and the largest terrestrial ecosystem sink or source of atmospheric CO_2 depending on land-use and management (Paustian et al., 1997; Houghton et al., 2012). In the last decades the use of process-based models has become a powerful approach to understand the main drivers of SOC dynamics, to provide new stock estimations and to make scenario analysis both at national/regional level (Van Wesemael et al., 2010; Álvaro-Fuentes et al., 2011) and at larger scale (Smith et al., 2005; Lugato et al., 2014a). However, the lateral carbon fluxes induced by the erosion, transport and deposition processes are often neglected in SOC models, since these geomorphological processes are generally known only at watershed level. While the coupling of SOC and erosion/transport models is not a technical limitation (Van Oost et al., 2005a,b), the lack of spatially-detailed information is still the major constraint to extend the simulation beyond small basins.

Soil erosion processes by water in European agricultural areas have been widely studied on a small scale (plots and hillslopes) and river basin scale (Kosmas et al., 1997; Hill and Schütt, 2000; De Vente and Poesen, 2005; Boardmann and Poesen, 2006; Verheijen et al., 2009; Cerdan et al., 2010), however, only few studies have been carried out at national and Pan-European scale. Van der Knijff et al. (2000) and Grimm et al. (2001) employed the Universal Soil Loss Equation (USLE; Wischmeier and Smith, 1978) to perform the first spatial distributed assessment of erosion by water in Italy and Europe. Despite the knowledge gained from these pioneering studies, the methods employed to compute the USLE parameters involved a large number of approximations and inconsistencies which affected the quality of the outcomes. Later, the Pan-European Soil Erosion Risk Assessment (PESERA; Kirkby et al., 2003), although employing a more advanced modelling scheme, used poor quality input data and a coarse spatial resolution (1×1 km) making this tool unsuitable for local land management planning.

Today, the mainstreaming of geospatial technologies like Geographic Information Systems (GIS), satellite imagery and robust spatial interpolation methods can facilitate the development of new highly accurate and spatially explicit approaches to assess soil erosion and land management practices (Van Rompaey et al., 2007; Salvati and Zitti, 2009; Borrelli et al., 2014; Panagos et al., 2014a, 2015a). The improvements in the recent years yielded encouraging results for the RUSLE implementation at basin and regional scale (Märker et al., 2008; Prasuhn et al., 2013; Borrelli and Schütt, 2014). The challenge of the immediate future for this area of research in soil erosion modelling is to adapt the broad improvements arising from local applications of RUSLE to large-scales in order to achieve more reliable soil loss predictions (Van Oost, 2005b) to be implemented in the scenarios analysis (Blanco-Canqui and Lal, 2008; Pelacani et al., 2008; Wauters et al., 2010).

The insights gained have helped to better quantify the essential role of soil conservation practices in order to develop strategies to reduce soil erosion (Pimentel, 1993), and the associated environmental costs. In the USA, the estimated cost of water erosion ranges from 12 to 42 billion US$ (Uri, 2000). Thanks to a series of conservation plans carried out under the technical assistance of the United States Department of Agriculture erosion rates have been considerably reduced. According to the National Resource Inventory of 2007 (USDA, 2014a), water-driven soil erosion on U.S. cropland decreased by 43% between 1982 and 2007 due to the measures of the Conservation Reserve Program (CRP) (USDA, 2014b).

In the EU, one of the main mechanisms to promote a more environmentally friendly agriculture was introduced by the CAP reform in 2003, through the so-called Cross Compliance mechanism. According to this new approach, the farmer support payments were conditioned with respect to environmental, animal welfare and food safety standards. This led to the definition of Good Agricultural and Environmental Conditions (GAEC), firstly established by Council Regulation No. 1782/2003 and subsequently Council Regulation (EC) No 73/2009. The prevention of soil erosion and maintenance of soil organic matter were two of GAEC requirements, which each Member State was obliged to address through national/regional standards such as: (i) minimal soil cover maintenance (GAEC 4); (ii) minimum land management reflecting site specific conditions to limit soil loss (GAEC 5) and (iii) maintenance of soil organic matter level through appropriate practices including ban on burning arable stubbles (GAEC 6) (MARS, 2014).

Although Member States are required to verify whether the farmers are compliant with the regulations (cross-compliance), the environmental effect of GAEC applications on erosion and carbon budgets are still unknown. Due to the large agricultural area, the different pedo-climatic conditions and the variety of farming systems across the EU, the effectiveness of GAEC can be only verified by assessing their actual effect on the environmental components. To reach this target more data, monitoring networks, remote sensing application and modelling tools are necessary.

For the first time, the present study deals with the assessment of the physical effect of GAEC standards application at the national-scale level, coupling a high resolution erosion model with an agro-ecosystem model of SOC dynamics. All arable land in Italy was selected as a study area because it is highly sensitive to erosion (Bagarello and Ferro, 2006), as it is repeatedly subject to prolonged dry periods followed by heavy bursts of intensive and erosive rainfalls falling on steep slopes with fragile soils (Torri et al., 2002; Diodato and Bellocchi, 2010; Borrelli et al., 2013). With respect to the identified research gap, this study aims to (i) produce a thorough RUSLE-based soil loss prediction with high spatial resolution; (ii) estimate the soil carbon stock variation including both lateral (by erosion) and vertical carbon fluxes; (iii) quantify the potential soil erosion and SOC response to the application of GAEC practices.