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Induced effects of hedgerow networks on soil organic carbon storage within an agricultural landscape

Stéphane Follain [a,*], Christian Walter [a], Arnaud Legout [b], Blandine Lemercier [a], Gilles Dutin [a]

[a] UMR Sol Agronomie Spatialisation, INRA/Agrocampus-Rennes, 65 route de St Brieuc, 35042 Rennes Cedex, France
[b] Unité Biogéochimie des Ecosystèmes Forestiers, INRA, Centre de Nancy, 54280 Champenoux, France

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Abstract

Hedgerow network landscapes or "*bocages*" are present throughout a large part of Western Europe [Baudry, J., Bunce, R.G.H. et al., 2000. Hedgerows: an international perspective on their origin, function and management. Journal of Environmental Management 60 (1), 7–22.]. These manmade landscapes are typically comprised of fields separated by boundaries, often marked by perennial vegetation (hedges or shelterbelts), yet little is known about the effect of these field margins on soil organic carbon (SOC) stocks and their dynamics, which offer large carbon sequestration potential [Walter, C., Mérot, P., Layer, B., Dutin, G., 2003. The effect of hedgerows on soil organic carbon storage in hillslopes. Soil Use and Management 19, 201–207.; Falloon, P., Powlson, D., Smith, P., 2004. Managing field margins for biodiversity and carbon sequestration: a Great Britain case study. Soil Use and Management 20, 240–247.]. In hedged landscapes, hedges induce a modification to the soil A-horizon geometry at the slope scale, as attributed to an anti-erosive effect, along with a local modification of the associated SOC stocks. Most studies undertaken within this context have been performed in two dimensions and under favourable conditions for soil accumulation with the hedges lying perpendicular to the steepest slope direction. Consequently, an extrapolation of these findings to the entire landscape can lead to overestimating SOC stocks at the landscape scale. The aims of this paper were to: quantify SOC stocks, describe their spatial variability in three dimensions, and identify the main determinants behind this variability within an agricultural hedgerow network landscape. To achieve these aims, we conducted a detailed field survey that took into account all three dimensions of the soil cover and anthropogenic structures. We then analysed the spatial distribution of SOC contents and stocks with respect to pedological and landscape parameters.

Results show that SOC stocks may be locally significant in the vicinity of hedges with a median stock value of 16.6 kg C m^{-2}, in comparison with stock at the landscape scale (13.3 kg C m^{-2}). This study has highlighted the need to incorporate the three dimensions of soil cover at the landscape scale in order to characterise SOC storage. This step will prevent the generalisation of local stocks at a landscape scale given the high variability of SOC stocks (1st quartile = 10.5 kg C m^{-2}; 3rd quartile = 18.5 kg C m^{-2}) induced by hedge structures.

Keywords: Soil Organic Carbon (SOC); Hedgerow network; Spatial distribution; Landscape-scale

1. Introduction

Soils constitute the main terrestrial component of the global carbon cycle, with an amount of 1500 Pg C (Post et al., 1982; Eswaran et al., 1993; Batjes, 1996); only the oceans provide larger reservoirs on a global scale (39,000 Pg C) (IPCC, 1990). Soils represent a key component since they act as both a source and a sink of atmospheric CO_2 (Lugo and Brown, 1993). Soils would thus appear as a crucial compartment towards meeting the Kyoto Protocol guidelines (United Nations, 1998). Further developments are still required however to provide accurate estimates of SOC stocks and better understand soil carbon dynamics.

Accurate estimations of SOC stocks prove crucial, given that carbon potential mitigation is calculated as a percentage change to these stocks. Accordingly, less is known about the mitigation potential of field margins e.g. hedgerows and tree strips, as characterised by Falloon et al. (2004), in their role as landscape features for preserving long-term carbon sequestration due to their significant mitigation potential.

* Corresponding author. UMR LISAH, 2place Pierre Viala, 34060 Montpellier Cedex 1, France.
E-mail address: follain@supagro.inra.fr (S. Follain).

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Understanding the soil organic carbon (SOC) dynamics constitutes another key challenge since this dynamics varies under the influence of an array of natural and anthropogenic factors including climate, hydrology, geology, soil fertility, biological activity and even land use. In general, it is impossible to take all of these factors into account. Among them, soil use and management play an important role as regards the intensity of diffused and concentrated erosion. The redistributions induced by these processes exert a considerable impact on carbon stock by locally modifying its distribution. Robert and Saugier (2003) estimated that these processes support transfer towards hydrosystems at a rate of 0.8 Gt C on a worldwide level and accelerate transfer towards the atmosphere in CO_2 form (Lal, 1995). Human activity can thus be considered as one of the main factors in soil degradation. Along these lines, Oldeman et al. (1990) estimated that 13% to 15% of the terrestrial sphere surface is submitted to anthropogenic erosion processes.

Several mechanisms have been proposed to explain the evolution of carbon stocks within erosive contexts: (i) a mineralisation of soil organic matter (SOM) resulting from soil aggregate breakdown under rain splash, which by means of selective mobilisation of the finest particles of soil would release the most unstable fraction of protected carbon (Tiessen and Stewart, 1983); (ii) a transformation of SOM into a more stable pool due to SOM mineralisation followed by transport under topographic control and storage on a slope either within depressions (Gregorich et al., 1998) or in foot-slope positions (Bergstrom et al., 2001) — this mechanism would support the short or long-term storage of carbon according to Gregorich et al. (1998); (iii) a burial of SOM by the successive arrival of sediments, which would support its sequestration (Yoo et al., 2006); and (iv) and losses due to exportation of particulate and dissolved SOM beyond the limits of the studied system.

The total effect of these mechanisms would tend to reduce SOC contents at the slope scale (Gregorich et al., 1998; Lal, 2003), with strong local variations (Yoo et al., 2006).

Hedgerow network landscapes or “bocages” are present throughout a large part of Western Europe (Baudry et al., 2000) and knowledge on the dynamics of SOC in such landscapes is lacking. The first effect of a hedge planting on the SOC dynamics is similar to the one observed in wooded environments: an increase in the carbonaceous restitutions on the soil, and an increase in the residence time of carbon due to absence of tillage. Walter et al. (2003) pointed out that a better estimation of SOC storage within the hedged landscape as well as an understanding of related processes must take into account the organisation of soil horizons. The presence of hedge structures actually induces two types of soil modification.

First, the hedges induce a local modification in soil properties depending on the particular pedo-climatic context. Under tropical conditions, authors have generally noted: higher SOM content in association with higher chemical concentrations (Lal, 1989a; Kang et al., 1998; Hien, 2001), greater soil structural stability (Lal, 1989b) and increased water infiltration. In temperate climates and more intensive agricultural contexts, authors have observed higher soil acidity (De Jong and Kowalchuk, 1995) as well as fewer major elements under the hedge (Carnet, 1978; Caubel, 2001). This modification of chemical properties seems to be correlated with the modification of soil physical properties in the vicinity of hedges (Baffet, 1984; De Jong and Kowalchuk, 1995).

The second type is a modification in soil horizon geometry at the slope scale. The most systematic effect is a thickening of the “A” organo-mineral horizons uphill from the hedges; this modification corresponds to an anti-erosive effect observed in various contexts (Pappendick and Miller, 1977; Carnet, 1978; Baffet, 1984; Walter et al., 2003; Salvador-Blanes et al., 2006).

Within a 5 m band on each side of the hedges, the potential increase in SOC content was estimated at 5 kg C m^{-2} ± 2 kg C m^{-2} (Arrouays et al., 2002). A few studies have quantified this storage in relation to the hedgerows network. Walter et al. (2003) estimated that SOC storage in embankments could represent between 15% and 40% of the carbon stored in soils at the landscape scale; moreover, a high spatial variability can be associated with this stock. This study however was undertaken in two dimensions and under favourable conditions for soil accumulation, with hedges lying perpendicular to the steepest slope direction. An extrapolation of these conditions to the entire landscape, on the basis of the hedge density criterion, could lead to overestimating the level of SOC stocks.

The objectives of this study were to identify and quantify the effect of the hedgerow network landscape on SOC sequestration and spatial variability at the landscape scale. We have conducted a detailed field survey based on a double sampling strategy to incorporate the three dimensions of the soil cover and anthropogenic structures. We then analysed the spatial distribution with respect to pedological and landscape parameters. Lastly, specific SOC stocks were calculated at the landscape scale using geostatistical methods. Spatial correlations between these SOC stocks, hedgerow network parameters and topography were also examined in order to identify the main factors in SOC stock variability.

2. Materials and methods

2.1. The study area

The field experiment was carried out in Montours (Brittany, France, 48°26′N, 1°19′W), in an agro-ecosystem within a hedgerow network landscape. This landscape is composed of fields separated by boundaries, e.g. hedges or shelterbelts; these boundaries are built with soil and are marked by perennial vegetation of chestnuts (*Castanea sativa*) and common oaks (*Quercus robur*).

The studied landscape unit of 8.4 ha is located on a hillside and its boundaries are defined by a natural river, a wetland and a road. The geological bedrock is a granodiorite dated at 580 Ma (pre-Cambrian). Only deep weathering alteration structures have been observed on the study site, overlain by reworked Weichselian Aeolian loam (Le Calvez, 1979; Lautridou, 1985).

This site allowed us the possibility to analyse soil organisation and SOC spatial distribution for a variety of topographical and landscape settings. On the study site, previous