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The dynamics of soil organic matter accumulation in Portuguese grassland soils

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SUMMARY – Carbon sequestration in LULUCF activities occurs by soil organic matter (SOM) accumulation, which varies with grassland type. We built dynamic models to estimate SOM increases in several rainfed grassland soils in Portugal. We considered Sown biodiverse permanent Grasslands (SG), Fertilized Natural Grasslands (FNG), and Natural Grasslands (NG). These results may then be used to estimate the value of sequestered carbon. We considered for all cases a saturating exponential pattern, even though statistically we cannot always reject the hypothesis of linear increases (which would imply the ecologically unsound result that there is no upper boundary for SOM accumulation). Considering that we start from the same initial SOM level, we show that SG accumulate about twice as much as FNG and seven times as much as NG.

Keywords: Soil organic matter, grasslands, fertility, soil dynamics, land use, carbon sequestration.

***RESUME –** "La dynamique d'accumulation de la matière organique dans les sols des prairies au Portugal". La séquestration du carbone dans le cadre des activités de LULUCF se produit par accumulation de la matière organique du sol (SOM), qui varie selon le type d'herbage. Nous construisons des modèles dynamiques pour estimer les augmentations de SOM dans les sols des prairies au Portugal. Nous considérons des prairies permanentes semées biodiverses (SG), des prairies naturelles fertilisées (FNG), et des prairies naturelles (GN). Ces résultats peuvent ensuite être utilisés pour estimer la valeur du carbone piégé. Nous estimons pour tous les cas une tendance exponentielle à la saturation, même si statistiquement on ne peut pas toujours rejeter l'hypothèse d'augmentation linéaire (ce qui impliquerait le résultat écologiquement malsain selon lequel il n'y a pas de limite supérieure pour l'accumulation SOM). Considérant que nous partons du même niveau initial SOM, nous montrons que SG accumule environ deux fois plus que FNG et sept fois plus que GN.*

***Mots-clés :** Matière organique des sols, prairies, fécondité, dynamique des sols, utilisation des sols, séquestration du carbone.*

Introduction

Carbon sequestration in grassland soils occurs via soil organic matter (SOM) accumulation (Sollins *et al*., 1996). At each moment in time, there is a SOM input due to mass stock change in plant roots, which grow using photosynthetic carbon. However, there is also SOM mineralization. Both of these effects are influenced by different factors, like soil type, climatic factors, land occupation and management. Some authors have tried to model SOM and carbon dynamics. The most typical pattern is a saturating negative exponential. This dynamics is characteristic and supported in most available reviews in the literature, like for example Six *et al*. (2004) and West and Six (2007), who have a systematization of carbon change in soils with several parameters.

In Portugal, there are mainly three types of rainfed grassland, depending on management type: Natural Grasslands (NG), Fertilized Natural Grasslands (FNG), and Sown biodiverse permanent Grasslands (SG) rich in legumes. This paper intends to compare soil characteristics, namely SOM content, of the three types of grasslands. Our results are based on SOM monitorization in time and in several locations in Portugal. They were obtained in two research projects: project AGRO 87, "Sown biodiverse permanent pastures rich in legumes – a sustainable option for degraded land use" (Carneiro *et al*., 2005), and project AGRO 71, "Recovery and improvement of Alentejo's degraded soils using grasslands".

Materials and methods

SOM data

We used data from eight farms in Portugal from 2001 to 2005 (Table 1). It is important to notice that these were not isolated test sites, but active pastures in private land currently used by farmers for animal production. Therefore, all values were obtained from farmers' current practices.

Table 1. Soil characterization in the sites of Projects Agro 87 (farms 1 to 6) and Agro 71 (farms 7 and 8)

Farm No.	Farm	Location	Soil original material	Texture
1	H. Cabeça Gorda	Vaiamonte	Gneiss	Loam
2	H. Mestre	São Vicente	Limestone	Loamy clay
3	H. Claros Montes	Pavia	Granite	Loamy sand
4	H. Refroias	Cercal	Schist	Loamy sand
5	H. Cinzento e Torre	Coruche	Sandstone	Sand
6	Quinta da França	Covilhã	Granite	Loamy sand
7	H. Monte da Achada	Castro Verde	Schist and Greywacke	Sandy loam
8	H. Corte Carrilho	Mértola	Schist	Loamy sand

Dynamic model

We used a statistical model to try to identify the SOM dynamics, which was then calibrated using data shown above. The simplest mass balance for SOM increase is:

$$\frac{dSOM_i(t)}{dt} = K_i - \alpha_i SOM_i(t) \tag{1}$$

where $SOM_i(t)$ is the SOM content (%) in grassland type $i = \{SG, FNG, NG\}$ at time t, K_i is the organic matter input in each parcel and period, and α_i is the organic matter mineralization rate. Therefore, we consider that SOM accumulation is the balance between uptake and mineralization. Integrating Equation (1) between $t - \Delta t$ and t, we obtain:

$$SOM_{i,t} = SOM_{i,t-1} e^{-\alpha_i \Delta t} + \frac{K_i}{\alpha_i}\left(1 - e^{-\alpha_i \Delta t}\right) \tag{2}$$

We assumed that K_i is composed of a fixed yearly organic matter entry, named $K^{'}$, which only respects to management type and not local variation, and a variable part, which is a linear function of the initial SOM content:

$$K_i = K_i^{'} + a_i SOM_{i,0} \tag{3}$$

There are two options of model specification. We either assume that all parameters ($K_i^{'}$, α_i and a_i) vary with grassland type, or we assume that only $K_i^{'}$ varies, which agronomically makes more sense. In the first case, we obtain Model A,

$$SOM_{i,t} = \frac{K_i^{'}}{\alpha_i}\left(1 - e^{-\alpha_i}\right) + e^{-\alpha_i} SOM_{i,t-1} + \frac{a_i}{\alpha_i}\left(1 - e^{-\alpha_i}\right) SOM_{i,0} \tag{4}$$

which we estimate using one different regression for each grassland type,

$$SOM_{i,t} = C_1 + C_2 \cdot SOM_{i,t-1} + C_3 \cdot SOM_{i,0} \tag{5}$$

In the second case, we obtain Model B, which we estimate using just one regression with dummy variables for grassland type,

$$SOM_{i,t} = \sum_{i=1}^{3} \theta_i d_i + C_2 \cdot SOM_{i,t-1} + C_3 \cdot SOM_{i,0} \tag{6}$$

Results and discussion

We estimated the coefficients in both models with the available data. Then, we determined the SOM dynamics according to each model.

Model A

SOM dynamics according to Model A is shown in Fig. 1. Regression data indicate an average SOM increase for SG of 0.21 percentage points per year during the first 10 years. For NG, the yearly increase is about 0.03 percentage points and for FNG 0.12 percentage points. However, the increase is much higher in the first than in the last years.

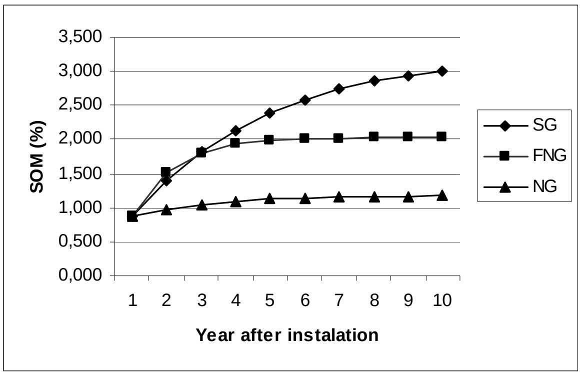

Fig. 1. SOM in each year, as estimated by Model A, starting from 0.87%. In 10 years, SOM is about 2.0% for FNG and 3,0% for SG.

Model B

SOM dynamics according to Model B is shown in Fig. 2. The first particularity about results is that coefficients of natural grasslands' dummies are not statistically significant. This means that it makes a difference whether grasslands are sown or not, but there is no distinction between natural grasslands. Regression data indicate an average SOM increase for SG of 0.16 percentage points per year during the first 10 years. For NG, the yearly increase is about 0.13 percentage points, and for FNG 0.07 percentage points. However, the increase is much higher in the first than in the last years.

Conclusions

In this paper, we assumed that SOM increases in a saturating exponential pattern. We found statistical evidence that it is the most suited hypothesis for SOM dynamics. Therefore, SOM increases become lower as SOM content approaches a given upper bound. This upper bound depends on grassland type and soil conditions, which we simulate by considering the initial SOM level.

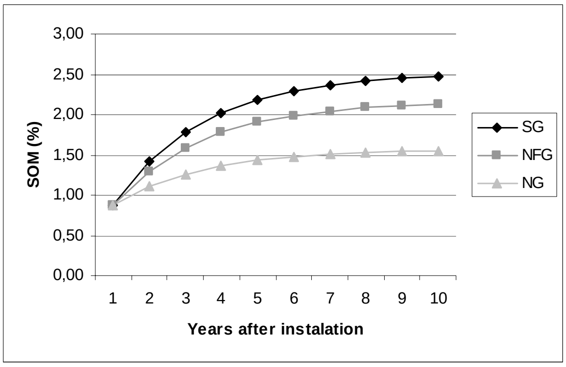

Fig. 2. SOM in each year, as estimated by Model B, starting from 0.87%. In 10 years, SOM is about 2.2% for FNG and 2,5% for SG.

Starting from 0.87% SOM, we found that in 10 years there is an average increase of 0.16 to 0.21 percentage points per year in SG, depending on the statistical model we use. It is unclear which of the model formulations is more correct. Still, increases are always higher than those obtained for NG and FNG. This shows that SG are the type of grassland that maximizes SOM. This, in turn, translates into carbon sequestration.

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