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SUMMARY – Sown biodiverse rainfed permanent grasslands are based on diverse mixtures of about twenty different species, and rich in legumes. These grasslands were much more productive than the natural ones, thus allowing sustainable animal carrying capacity to be increased. They also highly accelerate the rate of soil organic matter (SOM) increase, which contributes to carbon sequestration. This effect led Portugal to select, within the framework of the voluntary LULUCF activities under Article 3.4 of the Kyoto Protocol, the "Grassland Management" activity. However, the implication of using sown grasslands is more widespread, influencing the carbon accounting in other Articles of the Protocol. In this paper we determined the CO_2 sequestration potential of this type of sown grasslands. We estimated a net carbon balance of 4,5-5,3 ton CO_2eq/ha/year. Considering an implementation scenario of 300,000 ha, the total sink effect would be 0.96-1.35 Mton CO_2eq/year.

Keywords: Carbon sequestration, Kyoto Protocol, animal feeding, sown grasslands, legumes, biodiversity.

RESUME – *"Séquestration du carbone dans des prairies biodiverses ensemencées". Les prairies permanentes biodiverses semées sont fondées sur divers mélanges d'une vingtaine d'espèces différentes, mais riches en légumineuses. Ces prairies sont beaucoup plus productives que les prairies naturelles, permettant ainsi une augmentation de la capacité de charge animale durable. Elles ont également fortement accéléré le taux d'augmentation de la matière organique du sol (SOM), ce qui contribue à la séquestration du carbone. Cet effet a conduit le Portugal à choisir, dans le cadre des activités volontaires LULUCF au titre de l'article 3,4 du Protocole de Kyoto, le "Grassland Management". Cependant, l'implication de l'utilisation de prairies ensemencées est plus répandue, ce qui influe sur la comptabilisation du carbone dans d'autres articles du Protocole. Dans le présent document, nous déterminons le potentiel de séquestration du* CO_2 *de ce type de prairies ensemencées. Nous estimons un bilan de carbone de 4,5-5,3 ton* $CO_2eq \cdot hectares^{-1} \cdot année^{-1}$*. Considérant la mise en œuvre de 300.000 ha dans ce scénario, l'effet de puits total serait de 0.96-1.35 Mton* $CO_2eq \cdot année^{-1}$*.*

Mots-clés : *Séquestration du carbone, Protocole de Kyoto, alimentation animale, prairies ensemencées, légumineuses, biodiversité.*

Introduction

The baseline reference is an extensive rotation system where annual crops are grown with conventional tillage systems, involving ploughing and/or harrowing. The crops are grown for one to two years, followed by a number of fallow years, dominated by natural grasslands with low carrying capacity and prone to be invaded by shrubs. We propose a system based on the conversion of such marginal and abandoned cropland and degraded natural grasslands to permanent highly productive grassland that requires direct animal grazing, based on diverse mixtures rich in legumes. These grasslands are hereafter named "sown biodiverse permanent rainfed grasslands", or SBPRG. Differences between baseline and proposed scenarios are summarized in Table 1.

Table 1. Differences between baseline and proposed scenarios

Baseline Scenario Degraded natural grasslands / former cropland areas:	Proposed Scenario Sown biodiverse permanent grasslands:
• Net carbon emissions (from animals)	• Carbon sequestration by agricultural soils and improved soil fertility
• Low stocking rate	• Increased stocking rate
• Shrub invasion and fire	• Shrub control and reduced fire risk
• Low inputs and machinery	• Increase in production factors' consumption
• Synthetic nitrogen fertilization	• Nitrogen fixation by legumes
• Erosion and low water cycle regulation	• Benefits in soil and water cycle regulation

Increased productivity in SBPRG allows a sustainable increase in animal carrying capacity. Animals graze the plants, which have an annual life cycle. The plant's root system renews every year, and plant biodiversity implies a high density of roots. Furthermore, a large part of the produced grass (biomass) returns to the soil by leaves' senescence, since without grazing control animals only consume 50% of pasture production. Therefore, SOM content increases every year by accumulation of roots, and, to lesser degree, aerial biomass residues, and faeces of grazing animals.

Materials and methods

Carbon is sequestered by grassland plants, resulting from photosynthesis. Part of atmospheric CO_2 used for plant growth is introduced in the soil, from root and stem decomposition and dead biomass (such as grass leaves), or from the decomposition of animals' faeces. Article 3.4 of the Kyoto Protocol refers directly to this effect.

However, there are three new greenhouse gases sources:

- Emissions due to the increased stocking rate, mainly CH_4 and N_2O from enteric fermentation and faeces. Two scenarios are considered for grasslands used by bovines: in the first one, all animals are newly installed, and, in the second, finishing steers are transferred from intensive to extensive feeding in improved grasslands. These emissions are always credited to the agricultural sector, regardless of optional mechanisms.

- N_2O emissions due to the accumulation of nitrogen by legumes. Soil microbiological activity increases, and so do the nitrogen cycle processes. Therefore, denitrification emissions may be promoted. The corresponding emission factor is highly uncertain, since it depends not only on the number of nitrogen-fixing plants, but also on other plants species that require higher levels of nitrogen, such as grasses or other nitrophilous plants. Climatic factors may also influence N_2O emissions.

- CO_2 emissions due to liming for soil acidity correction. IPCC (2003) indicates an emission factor of 12% of all limestone applied.

Results and discussion

Carbon sequestration

Carbon sequestration occurs via SOM increase. Therefore, the first step to determine the carbon sequestration potential of SBPRG was to study grassland SOM dynamics. To such purpose, we used results from Teixeira *et al.* (2007). They studied SOM dynamics in eight sites, and obtained curves for SOM accumulation in natural grasslands, fertilized natural grasslands, and SBPRG. The curves depict an upper bound for SOM increases as the most likely scenario. They obtain average values of 0.16 to 0.21% SOM increase per year in the first 10 cm of topsoil.

In order to determine the CO_2 equivalent to these increases, we calculated for different types of soil the carbon correspondent to each percent point increase in SOM. Since 1.25 $g \cdot cm^{-3}$ is the representative mineral bulk density (MBD) value for Portuguese soils, we considered it in all calculations. Assuming increases in the first 10 cm of a soil, an increase in 1% SOM is equivalent to the sequestration of about 25.5 ton $CO_2 \cdot ha^{-1}$. Based on these values, we estimated a yearly carbon sequestration of 4.1 to 5.4 ton $CO_2 \cdot ha^{-1} \cdot year^{-1}$.

Emissions from animals

We said earlier that SPBRG allow an increase in sustainable animal stocking rate. In this section we only considered beef cattle, and we studied three scenarios: (i) there is no change in stocking rate, since current pastures are overused; (ii) animals are new to the pasture, and have international provenience; (iii) steers are finished in grasslands, instead of common intensive systems.

In the first scenario, since natural pastures are not productive enough for the animals grazing, a change to SBPRG would not imply an increase in stocking rate, and extra emissions would be zero.

As for the second scenario, we start from a degraded grassland with a stocking rate of 0.5 CU, and then introduce 0.5 CU of breeding cows after the grassland is sown. Corresponding emissions would rise by 1.1 ton $CO_2 \cdot ha^{-1} \cdot year^{-1}$, according to the variation in emission factors between intensive and extensive production.

In the third scenario, we assume the transition from a stocking rate of 0.5 $CU \cdot ha^{-1}$, composed only by breeding cows, to a stocking rate of 1.0 $CU \cdot ha^{-1}$ where for each cow, a steer is being fed and finished during a year (from 6 to 18 months). This translates the fact that sown grasslands are more productive. The global balance would be 176 kg $CO_2 \cdot ha^{-1} \cdot year^{-1}$.

Legumes' N_2O emissions

Sown grasslands have higher dry matter (DM) productivity. According to Carneiro *et al*. (2005), productivity varies from 2,000 kg $DM \cdot ha^{-1}$ (Coruche, Portugal) to 9,000 kg DM $\cdot ha^{-1}$ (Quinta da França, Portugal). On average, about 60% of such production is due to legumes (Carneiro *et al*., 2005). Therefore, and considering an emission factor of 0.001 kg $N_2O\text{-}N \cdot kg^{-1}$ DM (IPCC, 1997), emissions would range from 1.2 to 5.4 kg $N_2O\text{-}N \cdot ha^{-1}$, or 0.3 to 1.5 ton $CO_2eq \cdot ha^{-1}$.

Emissions due to limestone application

In this paper we did not consider extraction impacts. On the field, there are emissions from limestone itself. IPCC (2003) considers a generic emission factor of 12% of all limestone applied (equal to the stoichiometric quantity of CO_2 in $CaCO_3$ or $CaMg(CO_3)_2$, depending on the type of limestone).Therefore, assuming that during the first ten years 2 ton of limestone is applied every two years (note that this only happens when $pH(H_2O)$ is inferior to 5.3), then 0.44 ton $CO_2 \cdot ha^{-1} \cdot year^{-1}$ are emitted. Note that liming is required in only 20-30% of the soils.

Global balance

We considered that the maximum plausible implementation scenario for SBPRG is 300,000 ha. The global balance is shown inTable 2.

Conclusions

In this paper, we studied the contribution of SBPRG to meet the Portuguese Kyoto target. Adding all the contributions, we obtain an estimate for the global carbon balance of 3.2-4.5 ton $CO_2 \cdot ha^{-1}$ $year^{-1}$ that are sequestered or avoided. If we consider an implementation scenario of 300,000 ha, then the global effect would be 0.96-1.35 Mton CO_2eq·year^{-1}. The predicted Portuguese deficit for the Kyoto goal is 3.73 MtonCO_2·year^{-1}. Therefore, the system we propose would be responsible for the mitigation of more than a third of the deficit.

Table 2. Carbon balance for SBPPRL, considering an implementation scenario of 300,000 ha

	Carbon storage/emission factor ton CO_2·ha^{-1}·year^{-1}	Carbon stored/emitted ton CO_2·year^{-1}
SBPPRL	4.1 - 5.4	1,620,000 - 1,230,000
Emissions from animals	-0.2	-60,000
Nitrogen emissions	-0.3	-90,000
Liming	-0.4	-120,000
Total	3.2 - 4.5	1,350,000 - 960,000

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