Innovative Approaches to Analysing Carbon Sequestration as a Mitigation Strategy in Tropical Pasture Landscapes in Two Emblematic Contexts, the Amazon and the West African Sahel

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"Innovative approaches to analysing carbon sequestration as a mitigation strategy in tropical pasture landscapes in two emblematic contexts, the Amazon and the West African Sahel"

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Abstract

The relationship between ruminant production systems and climate change is complex. As a major contributor to greenhouse gas (GHG) emissions, the sector has been the subject of considerable controversy, with particularly severe criticism in the 2000s. However, ten years ago, the attitude towards grazing lands began to change. Their efficient use of non-renewable energy and their contribution to carbon (C) sequestration were considered as key factors in the new environmental challenge. The reality of this mitigation potential was recently called into question once again in the global agriculture and climate change debate, including that of sequestration in the soil where grazing lands occupy a major position (30-40% of the land surface representing 30% of the soil organic C of the world). Few scientific references are available on these questions in tropical regions, and the standard metrics and methods used may turn out to be unsuitable for the correct evaluation of grazed ecosystems in these regions. Significant work is therefore required to establish baselines and design strategies to ensure sustainable grazing in these regions where the global sequestration potential is high relative to the surface areas concerned.

To contribute to this debate, we focus on mitigation options offered by rangelands and grasslands and their management in two emblematic tropical contexts, humid and dry tropics, where field studies have been based on original and holistic approaches at different levels. In Amazonia, if curbing deforestation remains a priority, it needs to be accompanied by sustainable management of deforested areas. In the French Amazon (French Guiana), monitoring fields using chronosequences and flux towers has produced scientific knowledge on the significant mitigation capacities of grassland ecosystems. In the Brazilian Amazon, the spatial logic of the agro-ecological intensification of forage production has enabled a transition from individual extractive systems to farm management at communal levels. In the West African Sahelian region (Northern Senegal), an integrative study at landscape scale revealed the unexpected capacity of soil and shrubs for C sequestration that can offset the GHG emissions for which pastoralism in dry tropical zones is usually blamed.

Introduction

The complex relationship between livestock grazing systems and climate change raises a number of questions. As an important GHG emitter, the sector was the subject of controversy in the 2000s. Subsequently, the potential for a significant reduction in its emissions was taken into account by highlighting a low level of non-renewable energy consumption (Vigne et al., 2013) and its effective contribution to carbon (C) sequestration (Gerber and al., 2013). Recently, the reality of this mitigation potential has again been called into question (Garnett et al., 2017), in the global agriculture and climate change debate, including that of sequestration in the soil where grazing lands occupy a major position (30-40% of the land surface representing 30% of the soil organic carbon of the world). The studies conducted in two extensive grazing livestock contexts: grazing lands resulting from deforestation in Amazonia and native Sahelian rangeland ecosystems in semi-arid West Africa, that we present here contribute to this debate.

The Amazonian region is emblematic of the issues involving agricultural development and conservation, and strategic in both local and global terms. The debate has focused in particular on the expansion of livestock farming in recent decades. According to the FAO, approximately 80% of deforested areas were converted into pastures resulting in rapid carbon (C) emissions (Vigne et al., 2016). Efforts to curb deforestation should therefore continue to be a priority to preserve C stocks and forest biodiversity, but need to be accompanied by sustainable management of areas that have already been converted into pastures, including strategies for the mitigation of GHG emissions.

In the French Amazon (French Guiana), research revealed significant mitigation capacities of grassland ecosystems. This knowledge has already been implemented in decision-making tools at farm and regional level to establish carbon balances, contribute to the management of rural areas, as well as for carbon accounting (Stahl et al., 2017; Dallaporta et al., 2016).
In the Brazilian Amazon, studies on the carbon cycle at plot level in pasturelands (C. E. P. Cerri et al. 2018), highlighted the role of management practices, and the potential of high technologies to increase mitigation and contribute to nationally determined contributions (NDCs) on emissions mitigation (De Oliveira Silva et al. 2018). Landscape approaches are less common. In the Brazilian Eastern Amazon, a landscape research program has shown that livestock intensification leads to new spatial organisation and natural resource use rules (Osis, Laurent, and Poccard-Chapuis 2019). This favour forest restoration on land of limited agricultural suitability, and the construction of landscapes that are more efficient from the point of view of the carbon cycle and other ecosystem services (Pinillos et al. 2020).

On the other side of Atlantic Ocean in the Sahelian region of West Africa, extensive pastoral production systems are often accused of harming the environment and of emitting excessive amounts of GHG per kilogram of milk or meat produced (Steinfeld et al., 2006) due to large-scale enteric methane emissions. On the other hand, livestock movement plays an important role in the reorganization of nutrient and carbon (C) cycles in sylvo and agro-pastoral ecosystems, and may help maintain soil fertility (Manlay et al., 2004; Bisson et al., 2019). The use of an ecosystem approach to a pastoral territory recently identified a C balance with unexpected potential for climate change mitigation (Assouma et al., 2019).

Methods and Study Site

The objective of this work is to identify original points of view, and to adapt analytical methods to them to produce information that is complementary to current knowledge on the complex and spatially variable carbon cycle. The three studies we present here were conducted in two different agro-ecological contexts: the Amazon and the West African Sahel.

In French Amazonia (the coastal part of French Guiana), research began in 2010 to understand the long-term dynamics of C in deep soil in established tropical pastures planted with the grass (*Brachiaria humidicola)* after deforestation in 1970. Indeed, little is known about the long-term capacity of tropical pastures to sequester C after deforestation and most studies on soil organic carbon (SOC) sequestration in the world, including in grassland areas, only consider the topsoil (i.e., down to a depth of 0.3 m, Budiman and al., 2017). Stahl et al. (2017) set up a unique combination of a large chronosequence study (C stock at a depth of 1 m) and eddy covariance measurements (flux tower). The second phase of the study consisted of establishing the C/GHG balance and efficiency at farm level in 15 cattle farms. Direct and indirect GHG emissions were calculated using the ACCT method (a tool for energy and emissions analysis, Dallaporta and al. 2017).

Research in the Brazilian Amazon focused on livestock farmers' decision-making systems, changes in their land-use strategies, and the resulting landscapes. The research was based on farm surveys, mapping and remote sensing (Osis and al., 2019), and on modelling at the farm and landscape scales (Pinillos et al. 2020). The study area was the Paragominas municipality, which covers 20,000 square kilometres along the Belém-Brasília highway, in a post-frontier context.

Finally, the study conducted in a typical Sahelian rangeland landscape in northern Senegal using an ecosystem approach, described and explained the spatial heterogeneity of the C balance (Assouma et al, 2019). The landscape concerned is the area surrounding the Widou borehole (15°59'N, 15°19'W, 706 km²), a circular zone with a radius of 15 km from the borehole where six different land units were defined: the land in the vicinity of the borehole, natural ponds, grazing lands, forest plantations, settlements, and enclosed plots (Assouma et al, 2017). A spatial-explicit and monthly measurement protocol was implemented from May 2014 to October 2015 to estimate GHG emissions (enteric methane from livestock, nitrous oxide and methane from soil and water and other sources of emissions termites, fuel consumed by the borehole motor pump and bush fires) and C sequestration (aboveground and belowground biomass of trees and shrubs, soil and animal).

Results of the three studies

Soil carbon stocks after conversion of Amazonian tropical forest into grazed pasture

Results in French Amazonia showed that pastures stored at least 1.27 ± 0.37 tC ha-1 yr-1 while the nearby native forest stored 3.23 ± 0.65 tC ha-1 yr-1. These results suggest that the use of appropriate practices (no fire and no overgrazing, with a mixture of grasses and legumes and a grazing rotation plan in French Amazonia old permanent tropical pastures (≥ 24 years old) can restore part of the C storage observed in native forest. These practices allows farmers to maintain these pastures in the long-term with no loss of soil fertility as often observed in cultivated soils. Conservation of soil fertility should help limit the conversion of new fertile areas and consequently, should limit deforestation. (Stahl and al., 2017). These results were then incorporated in a GHG diagnosis tool designed for pasture systems (AgriClimateChange Tool (ACCT), Dallaporta and al. 2017). Stable systems (no more deforestation) are characterised by a yearly C sequestration of grasslands (>24 years old) which, in 2013, compensated for up to 80% of the farm's GHG emissions.

Landscape and intensification of grazing systems in the Brazilian Amazon

The results of the studies conducted in the Amazon show that the intensification livestock production not only avoids deforestation but actually promotes forest restoration; forest dynamics not only pasture dynamics need to be included in livestock carbon balances. The results f these studies also underline the importance of land suitability in the carbon cycle: this is the basis of decisions concerning suitable locations for pasture intensification and in turn, locations where forest can regrow. The results also showed that moderate intensification is preferable to high tech solutions, because more farms can be involved and can make significant progress even when the production factors and conditions for innovation are not ideal. These results are crucial to build local policies, planning landscape efficiency through land-use regulations and incentives (Poccard-Chapuis et al. 2019; Brandão et al. 2020).

Pastoral landscapes in the Sahel: a carbon balance with unexpected potential for climate change mitigation

At the landscape level over one full year, the total C balance was -0.09 tCO_2-eq ha^{-1} $year^{-1}$. This negative C balance shows that the GHG emissions are mitigated by C sequestration in trees, soil, and animals. The C balances varied between the different land units and ranged from -3.41 tCO_2-eq ha^{-1} $year^{-1}$ in the enclosed plots to +127.1 tCO_2-eq ha^{-1} $year^{-1}$ in the vicinity of the borehole. The C balance was negative in the land units that received little or no manure (grazing lands, enclosures and forest plantations) whereas the balance was positive in units with high rates of manure deposition but that contributed little to fodder intake (in the vicinity of the borehole, ponds and settlements). Livestock movements can explain the spatial heterogeneity of the C balance. The search for mitigation options is an active research front on livestock systems, especially for rangeland ecosystems. The fact that this study focused on the spatial heterogeneity of GHG emissions and C sequestration helped us to outline a number of common-sense mitigation options, depending on the land unit (i) better managed vicinity of boreholes and ponds (ii) better managed grazing lands and surplus forage (iii) better use of manure available around the settlements and the borehole.

Discussion

The global sequestration potential of tropical grazing areas is high, relative to the extent of the areas concerned. Strategies to support sustainable grazing activities are therefore a major stake for boosting their significant and multiple mitigation potentials while also strengthening their real ability to adapt to climate change. At the same time, the need and obvious contribution to food security of large populations and the response to future demand for animal products requires considering animals as contributors when designing climate-smart farming systems (Duteurtre and al., 2019) and landscapes (Vayssières et al., 2017). Understanding interactions between grazing and climate change is therefore crucial to contribute to the new challenges that face livestock production in a context of both climate change and the need for food security. But references available in the literature on tropical areas may fail to accurately assess of the grazed ecosystems and landscapes in these regions (Dalla-Nora et al. 2014)

Our objective was thus to track down references to studies that account for the specificities of the tropics to contribute to the evaluation of the C balance of extensive livestock systems in these regions. The studies briefly described in this article aim to tackle these issues while integrating local and regional development issues in the Amazon and in semi-arid west Africa. They propose approaches and methodologies to establish baselines and to enhance our knowledge of C potential sequestration processes. Considering the strong interactions between livestock systems and their ecosystems, a more dynamic and holistic approach, in particular, is needed to design climate smart extensive livestock systems. But simply having a grassland or rangeland does not automatically result is a carbon sink, and it is unrealistic to imagine that all grasslands will act as a permanent carbon sink. (Smith 2014 in Garnett et al., 2017. On the contrary, it is necessary to continue the approaches we propose here to reduce uncertainties on C and N fluxes. Modelling carbon dynamics is also a fundamental tool for estimating actual and potential changes in soil carbon stocks. Modelling is less expensive than field measurements of carbon stock and fluxes, although field measurements and observations are obviously essential to build the models. Integrated simulation models representing C and nutrient flows in grazing ecosystems from farm to landscape levels are particularly useful tools to assess the consequences of livestock systems and practices for C sequestration and the C balance of livestock production systems (Vayssières et al., 2016).

The challenge is to move on from a partial view limited to improving the production and productivity of systems, to a more integrated and sustainable approach that incorporates climate change mitigation and adaptation (Vigne et al., 2016). These knowledge processes will need to be designed with the objective of feeding assessment and simulation tools at different decision levels, from farmers to policy makers.

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