C sequestration of a grazed permanent grasslands: uses of complementary methods for data analyses and interpretation

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Abstract

Temperate grasslands have been recognized for their great potential to sequester an important amount of carbon, contributing to slow down the current rise in "greenhouse" gases and associated effect. However, the quantification of this C sink activity has been greatly questioned, due to the uncertainty associated to those values being as important as the sink itself. So far, soil inventories are the most direct approach to investigate C sequestration via changes SOC, while an alternative to the direct measurement of C stock changes in grasslands is to measure the net balance of C fluxes exchanged at the system boundaries. This approach provides a high temporal resolution and changes in C stock can be detected within one year. Here we measured net C sequestration over 12 years using both methods (i.e. three soil inventories and eddy covariance technique) on two upland semi-natural pasture grazed by heifers at two contrasted stocking rate (high vs low). Moreover, to assess the becoming of sequestrated C, soils were analysed in details i) for their soil organic matter pools (i.e. labile, passive, inert; Zimmermann et al method) and ii) spatial distribution of soil C stock changes at field scale over time.

Keywords: soil organic matter pools, eddy covariance, soil inventory, grazing, grasslands

Introduction, scope and main objectives

In the introduction, state the objectives of the work and provide an adequate background, avoiding a detailed literature survey or a summary of the results.]

Temperate grasslands have been recognized to significantly contribute to the terrestrial C sink by sequestering C in soil organic matter. Grasslands have thus a great potential to sequester an important amount of carbon, contributing to slow down the current rise in "greenhouse" gases and associated effect. However, the quantification of this C sink activity has been greatly questioned, due to the uncertainty associated to those values being as important as the sink itself. Average values of 0.7±0.1 t C ha-1 yr-1 has been cited by different studies (Soussana et al. 2010, Ciais et al. 2010) (eddy covariance-technique, EC) while soil inventory measurements reported only 0.05±0.3 t C ha1 yr-1. Accordingly, the quantification of this “sink-strengh” has been greatly questioned, due to the uncertainty associated to those values being as important as the sink itself. More recent studies have shown that high uncertainties linked to EC-technique can be attributed to management practices, climate and grassland type (natural, sown, tall grass, etc) affecting soil carbon sequestration rates (Klumpp et al. 2011). So far, soil inventories are the most direct approach to investigate C sequestration via changes SOC. Despite the fact that this method require a large number of soil profiles, sampled at time scales longer than 5 years, it may take into account stock changes until deep soil layers (Weismeier et al. 2012). However, past studies, often report SOC changes of top and medium soil layer (0 -

30cm) leading to the conclusion that grasslands are in equilibrium (Smith et al. 2014). In spite of this, management-related change often happen in deeper (>30cm) soil layers C (Weismeier et al. 2012).

An alternative to the direct measurement of C stock changes in grasslands is to measure the net ecosystem exchange of C (NEE) at the system boundaries. Net carbon storage (NCS) can be estimated by uses of NEE and by taking to account other carbon imports (i.e. organic fertilisation) and exports (i.e. losses via C leaching, harvest, animal body mass increase) in the field. This approach provides a high temporal (i.e 10-20Hz) and spatial resolution (i.e. fetch corresponds to ~ 100 times the measure height) and changes in C stock can be detected within one year. Only few studies have compared EC measurements and soil inventories in grassland ecosystems, concluding that the caution needs to be taken with regard to C budget closure.

Here we like to assess the ability to capture net carbon sequestration of grassland ecosystems over 12 years using both methods (i.e. soil inventories and eddy covariance technique) on two upland semi-natural pasture grazed by heifers at two contrasted stocking rate (high vs low). Moreover, to assess where sequestrated C goes, soils were analysed in details i)for their soil organic matter pools with respect to soil layers (i.e. labile, passive, inert; Zimmermann et al method) and ii) spatial distribution of soil C stock changes over time at field scale.

Methodology

The study is located on an upland semi-natural permanent grassland (SOERE-ACBB Laqueuille, France 45°38'N, 2°44'E, 1040m asl.) The experimental field comprises two adjacent paddocks (2.8 and 3.4ha), continuously grazed by heifers from May to October with a high and low animal stocking rate (1.1 and 0.6 LSU/ ha.yr) and fertilization (210 and zero kg/ha.yr), respectively. Both paddocks are equipped with an eddy covariance flux measurement system (EC) and measure actively since 2003. H2O and CO2 flux (i.e. net ecosystem exchange, NEE) calculation and correction are done following European Fluxdata guidelines . Annual NCS calculation were carried out for each paddock using EC data and measured C imports (non) and C exports (i.e. CH4, animal weight gain, leaching).

Since setup of the field site, soil inventories were carried out in 2004 (t0, initial C stocks), 2008 (t1) and 2012 (t2). Inventories comprised a spatial sampling design and sampling were done down to bedrock on 60 cm depth (0-10cm, 10-20cm 20-40cm and 40-60cm) in order to account for changes in deeper layers. To asses changes in soil C stock, soil organic matter fraction were analyzed according to the soil fractionation method described by [Zimmermann et~al., 2007] for the 2008 and 2012 campaign.

Results

According to soil inventories and EC technique, both paddocks are a net sink of C with a mean C sequestration rate of 2 t C/ ha.yr. Concerning management, both methods showed a slightly higher C sequestration under high animal stocking rate and fertilization than under low stocking rate. However, no significant differences could be highlighted between managements. Soil inventories provided evidence that C was mostly stored in deeper soil layers (10-60 cm) whereas top soil C stocks decreased over time in both fields. Soil fractionation results revealed changes in the size of soil C pools over time and between soil layers. For Example, between 2008 and 2012, the humidified C pool in the 10-20cm layer seems to move to the inert (stable) soil C pool of the 20-40cm soil layer. Spatial analyses of soil C stocks, revealed the grazing intensities have a significant effect on the spatial distribution of carbon stocks (fig 1).

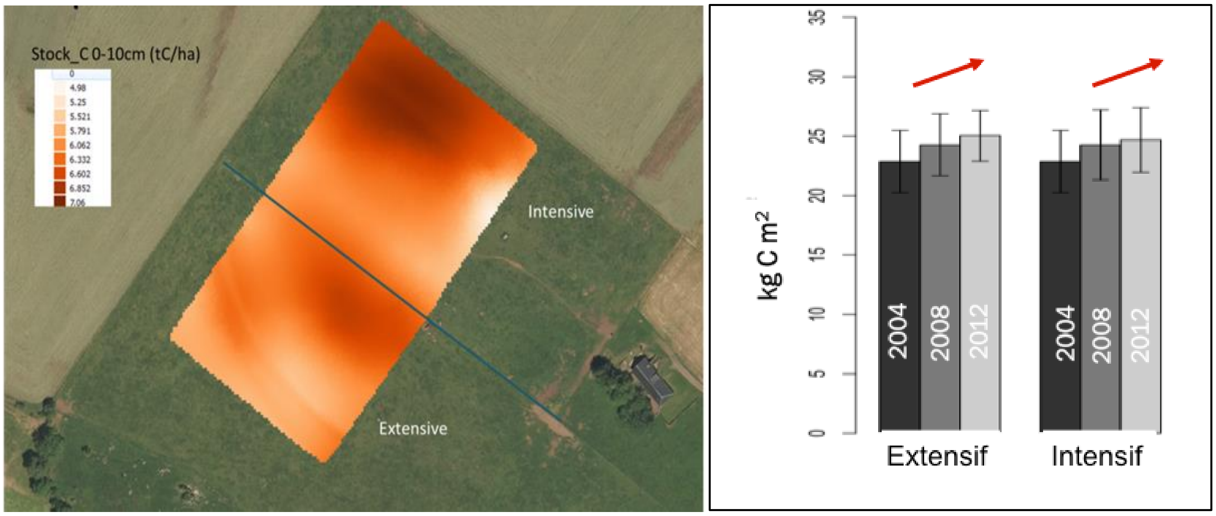

Fig. 1: Soil C stocks distribution in the 0-10cm layer (map) and stock changes over time (0-60cm) under high (intensive) and low (extensive) stocking density grazed paddock.

Discussion

Both methods confirm (NCS and soil inventories) that Laqueuille permanent grasslands acts as a "sinks" of C from the atmosphere, and the comparison of methods, the volumetric approach was in good agreement with the NCS estimation. Nonetheless, the ability of the two methods to detect significant changes in soil C stocks were limited by their total uncertainty resulting from spatial and temporal variation of C stock changes (i.e. soil) and C sequestration (EC-Technique). Accordingly, long term experiments are needed to compare methods over longer time periods. Detailed analyses of stock changes per soil layer and soil organic fraction allowed to follow C sequestration overtime and space; C is stored and transferred to deeper layers.

Conclusions

Both methods measured comparable net C sequestration, while each methods and analyses exhibits complementary results which may help to i) understand the impact of environmental (climate), management (stocking rate) on C sequestration when using EC -technique, ii) soil stock change over a soil profile when using soil inventories, iii) mechanisms and processes and using soil fractionation methods and iv)spatial variabilities when using a spatial sampling design for soil inventory measurements.

References

Ciais P, Soussana JF, Vuichard N et al. (2010) The greenhouse gas balance of European grasslands. Biogeosciences. 7: 5997–6050

Klumpp K, Tallec T, Guix N, Soussana JF (2011) Long-term impacts of agricultural practices and climatic variability on carbon storage in a permanent pasture. Global Change Biology. 17: 3534–3545

Smith P (2014) Do grasslands act as a perpetual sink for carbon? Global Change Biology. 20: 2708-2711

Soussana JF, Tallec T, Blanfort V (2010) Mitigating the greenhouse gas balance of ruminant production systems through carbon sequestration in grasslands. Animal. 4: 334–350

Wiesmeier M, Spörlein P, Geuß U, Hangen E, Haug S, Reischl A, Schilling B, von Lützow M, Kögel-Knabner I (2012) Soil organic carbon stocks in southeast Germany (Bavaria) as affected by land use, soil type and sampling depth. Global Change Biology. 18:2233-2245