EIP-AGRI Focus Group – Grazing for carbon

Mini-paper – *Effects and trade-offs*

Authors

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Introduction

Grassland ecosystems are characterized by substantial stocks of C located largely below ground in roots and soil (Jones & Donnelly 2004). This C sequestered by grasslands is the difference between C inputs, via fixation of C from the atmosphere by plants (photosynthesis), and heterotrophic respiration, biomass removal (harvest, grazing), and losses by lixiviation and run-off.

In grasslands the degree of sequestered C is primarily influenced by plant productivity and the frequency and extent of disturbance (i.e. grazing; grassland ploughing and renovation). In general, grasslands have a higher soil organic matter content and soil C has longer residence time than croplands, because there is less soil disturbance and a greater proportion of the input from root turnover is physically protected as chemically stabilised particulate organic matter (Gregorich et al., 2001; Jones & Donnelly 2004).

In addition to disturbance, the nature, frequency and intensity of biomass exports play a key role in the C cycling and balance of grasslands. In grazed grasslands, much of the primary production is ingested by animals and returned to the soil in the form of faeces (non-digestible carbon; 25 to 40% of the intake, depending on the digestibility of diet); the remainder is returned to the soil in the form of plant litter (ungrazed leaves and roots) or root exudates.

Grazing animals thus contribute to organic matter build-up in these systems. There is evidence showing that grazing pastures may sequester more C than grasslands used for silage/hay production, due to the recycling of nutrients (C and N) by the animals from faeces and plant litter (ungrazed leaves and roots) or root exudates.

Grazed grasslands are a potential sink of C, storing 0.8±0.2 Mg C ha^{-1} yr^{-1} (rates ranging from losses to gains of more than 1 Mg C ha^{-1} yr^{-1} (e.g. Soussana et al 2010; Conant et al. 2017). In spite of this, there is little information on the appropriate grazing management for specific regions (Abdalla et al., 2018). Improved grazing management, including adjustment in animal stocking rates, periodical removal of grazing livestock, and length of grazing period (e.g. rotational or short duration grazing, seasonal grazing, etc.), was reported to increase C sink by 0.28 Mg C ha^{-1} yr^{-1}.

The objective of this mini-paper is to make a quick scan of the literature on the effect of grazing/stocking systems on soil carbon and the trade-offs with grassland production in temperate EU grasslands. We take the paper from Conant et al., 2017 as a starting point. However, we do not cover grassland improvement as a whole but concentrate on grazing/stocking systems. We focus on results in Europe and record soil type, vegetation, climate, starting situation regeneration or maintenance, and N-input. Other ecosystems services

like water supply, pollination etc. or factors like labour, landscape will be taken into account but do not have the first priority in this mini-paper.

Equilibrium assumption of C sequestration under constant management

Before starting with C sequestration it is important to know the potential of C sequestration. The starting point of SOM is essential in determining the C sequestration potential because soil carbon stocks increase quite rapidly after an improved management regime is implemented, and then the rate of increase progressively declines (Johnston et al., 2009). Generally the more degraded a soil with a lower SOM, the more a soil can sequester before this saturation point is reached – soils in good condition may not be able to sequester much, if any more carbon. Secondly it is important to know the equilibrium of organic matter input and decomposition of a particular soil under a certain climatic conditions and pH (e.g. on the sandy soil in The Netherlands the equilibrium state on grassland is about 6-8% SOM (van Eekeren et al., 2010). As soils approach a new equilibrium (where carbon flow in equals carbon flow out), perhaps over 30-70 years, the net removal of CO_2 from the atmosphere dwindles to zero. This equilibrium can to a certain level be influenced by management (e.g. through adding lime to grasslands and increasing the pH the equilibrium will decrease). Moreover, the stock also needs to be maintained since any change in management, which undermines the improved regime, will decrease the SOM again. Grazing also plays an important role in maintaining the grassland sward to overcome grassland renovation and ploughing of the grassland sward. A quick scan of the literature on the effect of management duration and carbon sequestration is shown in Fig 1.

Fig 1. C sequestration rate as a function of number of years since management practices were implemented and SOM content. (Data source quick scan literature; Klumpp et al. in preparation)

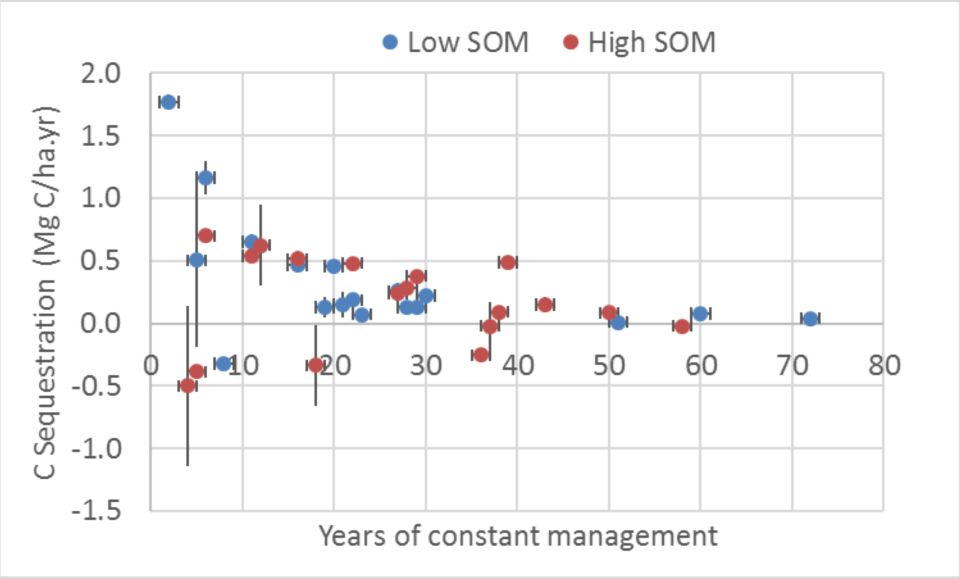
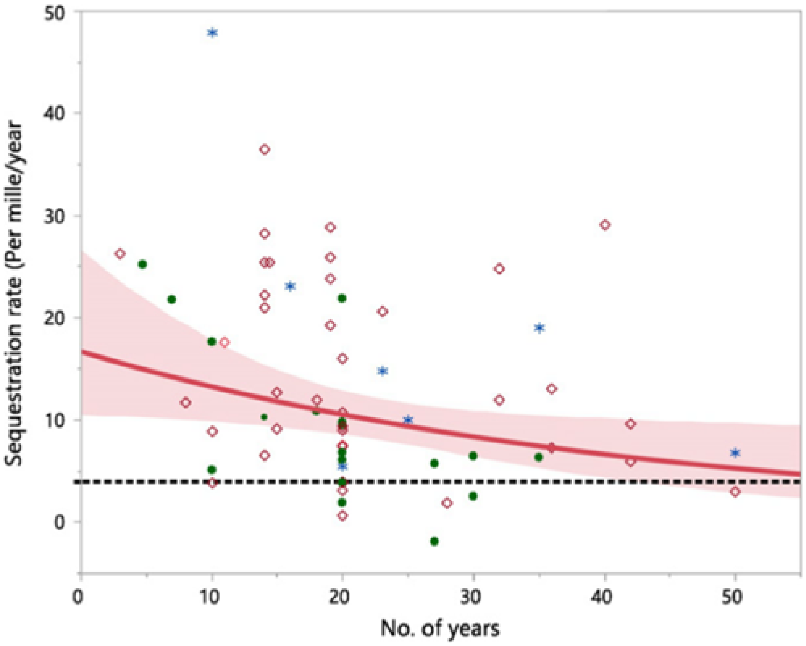


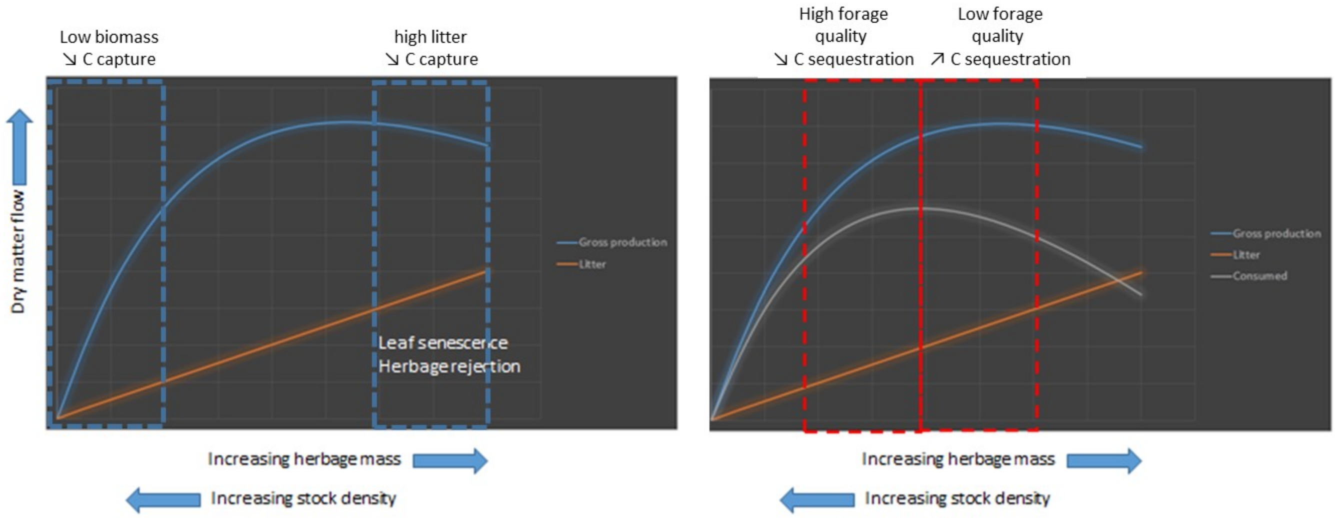
Fig. 2. Sequestration rate as a function of number of years since management practices have been implemented (expressed as C sequestration rate; sequestered per SOC stock, per mille). The red curve is a regression model fitted to the data with 95%confidence interval presented as shaded areas. Red diamonds refer to cropping land, green dots are grassland, and blue stars are forestry/plantation (Minasny et al. 2017).



Mechanisms/carbon balance above- and belowground

Grazing has a large direct impact on grassland productivity, plant community structure and biogeochemical cycling. Effects of grazing are driven by plant tissue removal (defoliation), excretion (urine and dung deposits) and trampling, which exerts mechanical pressure and causes physical damage to the vegetation where animals pass repeatedly. In the short term, grazing results in a reduction in aboveground standing biomass and litter production, as well as changes in plant nutrient status. If there is much dead plant material in the sward, shading the live leaves, grazing can allow light to penetrate into the plant canopy and encourage new tillers. Conversely, if grazing is too intense or the period between successive grazings is too short, the amount of live leaf can be reduced in the way that light interception falls and growth/carbon capture is reduced. Between these two extremes, there is relatively little change in growth with changes in grazing pressure. However, the quality of the herbage and the production of litter do still respond to changes in grazing pressure within this range; higher grazing pressure increases herbage quality (given there is sufficient N available) and reduces litter production, and vice versa. There is therefore a tradeoff between quality (promoting animal production) and litter production (promoting carbon sequestration). What constitutes low/medium/high grazing pressure varies between locations and over time; the lower the pasture growth, the lower the grazing pressure or the longer the period between grazing events, and vice versa.

Fig 3. Relation between above-ground herbage mass, stocking density, forage quality and plant litter (Hutchings)



Under medium to high grazing pressure, fast-growing, palatable species typical of nutrient-rich, managed grasslands have higher quality (lower C:N), promoting a rapid degradation by bacteria and thus short residence time of C in soil. Grasslands adapted to low grazing levels are generally characterized by slow-growing plant species and lower above-ground net primary productivity, a microbial community dominated by fungi, as well as greater N retention and C storage. In these latter pastures, grazing may have long-term effects on litter quality and quantity, driven by changes in plant community composition; prolonged defoliation tends to promote fast-growing, defoliation-tolerant species or unpalatable species. Grazing animals promote spatial heterogeneity in CNP pools and fluxes via uneven patterns of defoliation and animal returns. Consequently, grazed grasslands can be considered as a mosaic of patches of variable vegetation height and feed quality, depending on the presence or absence of urine and dung.

Like above-ground effects of cutting or grazing/stocking systems there could also be below-ground effects of cutting or grazing/stocking systems on root production but also on decomposition processes in the soil through soil temperature, soil humidity and root exudates (Table 1). Especially on below ground biomass production (roots) and effects on decomposition processes there are still a lot of question marks.

Table 1: Summary of effects of cutting and grazing/stocking systems on input of carbon and decomposition processes.

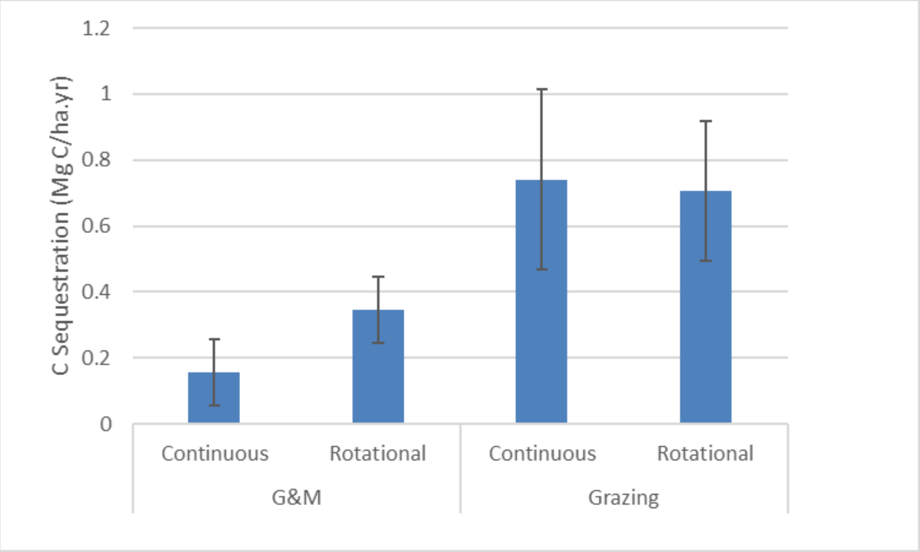
	Cutting	Continuous	Rotational	Trade -offs
Input/supply				
Herbage production	++	-	+	- Litter/residues
Litter/residues	0	+ (SR?)	++ (SR?)	
Root production	?	?	?	
Dung pat	0	+ (SR?)	+ (SR?)	+NH3
Decomposition				
Quality litter and roots	?	?	?	- Feeding value, CH4, N2O
Soil biota activity				
Temp., humidity	?	?	?	
Exudates	?	+?	?	

Effects of grazing

- ### Cutting versus grazing

From a quick literature scan it can be seen that there is a net C sequestration with grassland in general, but in a mixed grazing and cutting system there is less C-sequestration than under a pure grazing system (Fig 4.). This can be possibly explained by more faecal returns and plant litter with grazing only compared to mixed grazing and cutting systems. In this sense grazing only is more positive for C sequestration than systems which include cutting.

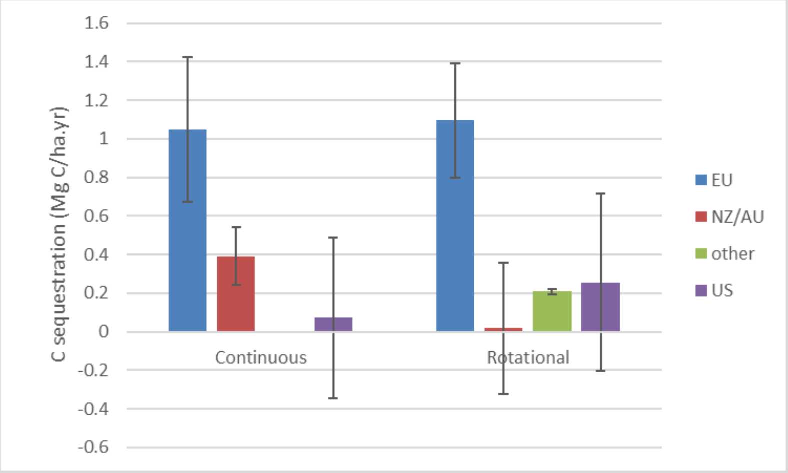
Fig 4. Mean C sequestration rate for mixed grazing and cutting systems (G&M) or grazing only systems (Grazing) (Data source quick scan literature; Klumpp et al. in preparation).



- **Grazing/stocking systems (Continuous vs rotational)**

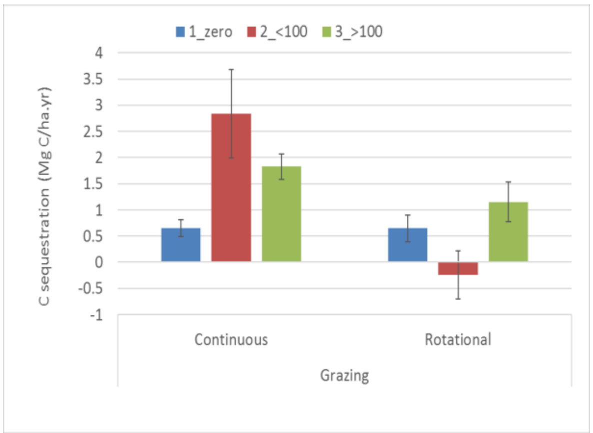
In Fig. 4 it is shown that there is little difference between continuous and rotational grazing in C-sequestration for grazing only. The information in Fig. 4 is based on research in the EU, NZ/AU, US and others together. If we consider the difference between grazing/stocking systems from the different continents, the C-sequestration from grazing only is higher in the EU than from the other continents (Fig. 5). In the EU there is little difference between continuous and rotational grazing. Differences between continents could be explained by differences in the size of the datasets, the starting point of the SOM, soil texture and vegetation type and the potential C-sequestration linked to climate. For example, higher soil temperature at sites representing ‘other continents’, compared to the more temperate climate in the EU, could make it more difficult to sequester C.

Fig 5. Mean C sequestration rate per continent for mixed grazing and cutting systems or grazing only systems together (Data source quick scan literature; Klumpp et al. in preparation).



With fertilization the C-sequestration with continuous grazing is increased dramatically while under rotational grazing/stocking it remains more stable (Fig. 6). However, more information on the data is needed to explain these differences. But as was the case for continental differences, climate, the starting point of the SOM, soil texture and vegetation type might be different for fields used for continuous (often upland area) and rotational (often high productive flat areas) grazing.

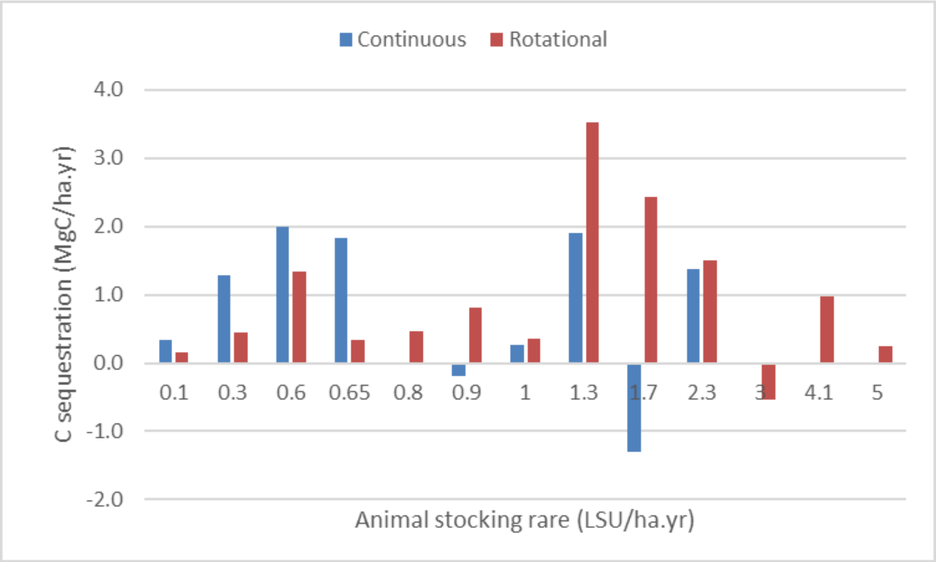
Fig 6. Mean C sequestration rate for different fertilizer levels (0, <100 kg N per ha and >300 kg N ha-1) for continuous and rotational grazing/stocking (Data source quick scan literature; Klumpp et al. in preparation).



- ## Grazing pressure (stocking rate)

C sequestration increases with animal stocking rate and depends on site fertilisation and grazing/stocking system. Both continuous and rotational grazing/stocking systems have thresholds where C sequestration in any given climate increases and declines. For a rotational grazing/stocking system, high C sequestration rates are sustained at a higher stocking rate than in a continuous grazing/stocking system. Here again more information on the data is necessary to clarify what mechanisms are operating within these systems and the relationships between management and C sequestration in different climates (Abdalla et al., 2018), but this could suggest that rotational grazing/stocking system could combine a high C-sequestration with a higher animal stocking rate.

Fig 7. Mean C sequestration rate for different stocking rates (Data source quick scan literature; Klumpp et al. in preparation).



Trade-offs

There are a number of trade-offs in grazed systems which need to be considered when improving soil C sequestration. There is a trade-off between:

i) leaf removal (by grazing or cutting) and leaving sufficient plant material to photosynthesize and replace tissues throughout the year;
ii) maximising forage quality to increase digestibility and minimising root and shoot litter decomposability and thus increasing mean residence time of soil organic C;
iii) maximising animal stocking density and minimising emissions of enteric CH_4 and N_2O from urine;
iv) increasing net primary productivity and associated C sequestration through use of manufactured N fertilisers and increasing nitrous oxide emissions from application of the fertilisers

Moreover, it is important to consider the alternative land-use when there is no grazing. In the absence of grazing, ecological succession will lead to shrub and woodland. If the priority is carbon sequestration (rather than rural employment and maintaining biodiversity/ cultural landscapes), then in temperate areas, woodland could be an alternative. However, in semi-arid and arid environments this could be very different, as fire is a much greater issue there.

Proposal for potential operational groups

- Work on the relationships between soil carbon and nutrient cycling, water storage and regulation, soil structure, soil biodiversity and carbon sequestration. What are the benefits and risks associated with increasing soil organic carbon content and what are the best methods to prioritise to achieve this?
- Work on best grazing and other grassland management practices for maintenance of the grass sward to overcome grassland renovation and losses of carbon with ploughing etc.
- Create awareness on the soil carbon balance of grassland in general and specifically the relationship between grazing management practices and soil carbon content.
- Specifically start an operational group with herdsman on improving soil quality and productivity through preserving and sequestering soil carbon. Herdsman are the key people in Eastern-Central Europe for sustainable grazing (even with or without traditional knowledge).
- Combine discussion on soil carbon for soil quality with discussion of soil C sequestration in the context of greenhouse gas emissions and climate change mitigation.

Proposals for (research) needs from practice

- Implement a meta-analysis on the effect of the grazing/stocking system (continuous vs rotational vs adaptive grazing management) on soil organic carbon content. Taking into account:
    - Abiotic factors: climate, soil properties, exposure/slope
    - Animal type: dairy, beef, sheep, goats….
    - Stocking rates (extensive vs intensive)
    - Recovery time/timing of grazing
    - Grassland use adapted to production
    - Farm properties
- Implement grazing experiments with continuous and adaptive grazing/stocking systems in Europe.
- Establish more data on the carbon balance, especially the input/supply of litter/residues above and below ground and the effect of grazing on decomposition processes. Taking into account:
    - Recovery time/timing of grazing

    - Critical/optimal herbage mass for C sequestration
- Try to find the optimum point of stocking rate for a certain grazing system that optimises grass intake for the animals and carbon sequestration in the soil.
- Establish data on the equilibrium state of soil carbon in different soil types in combination with climate zone and other abiotic factors.

Conclusions

- Be aware of the equilibrium state (i.e. grassland age and years since start of grassland management, respectively) for certain soil type and agro-climatic zone combinations.
- Focus first on the difference in C sequestration between grazing and cutting management before starting discussion on grazing/stocking systems.
- C sequestration in different grazing/stocking systems depends on a lot of factors including abiotic factors (e.g. climate, soil properties, exposure/slope) and management factors (e.g. fertilization, irrigation) that influence primary production and are themselves closely related to the grazing/stocking systems, such that the optimal grazing/stocking system for C-sequestration will differ in each situation.
- The key aim for sustainable grazing livestock systems is to find the optimum stocking rate where the optimum grass intake coincides with a certain amount of C sequestration in the soil.

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