EIP-AGRI Focus Group – Grazing for carbon

Mini-paper – *Mixtures of species*

Authors

M.-Teresa Sebastia, Abad Chabbi, Claudia M. d. S. Cordovil, Alex De Vliegher, Deirdre Hennessy, Branko Kramberger, Paul Newell Price, Rob Richmond, Corneel van Rijn

Introduction

Improved grazing management can increase or maintain soil organic carbon (and therefore soil organic matter - SOM) in grassland soils [1]. Under climate change conditions, where soil organic carbon (SOC) is expected to be highly vulnerable [2,3], it will be increasingly important to favour grassland management practices that lead to carbon storage [4] and conservation [5]. SOC conservation practices can contribute to preventing soil desertification currently affecting wide areas in the world, including Southern Europe.

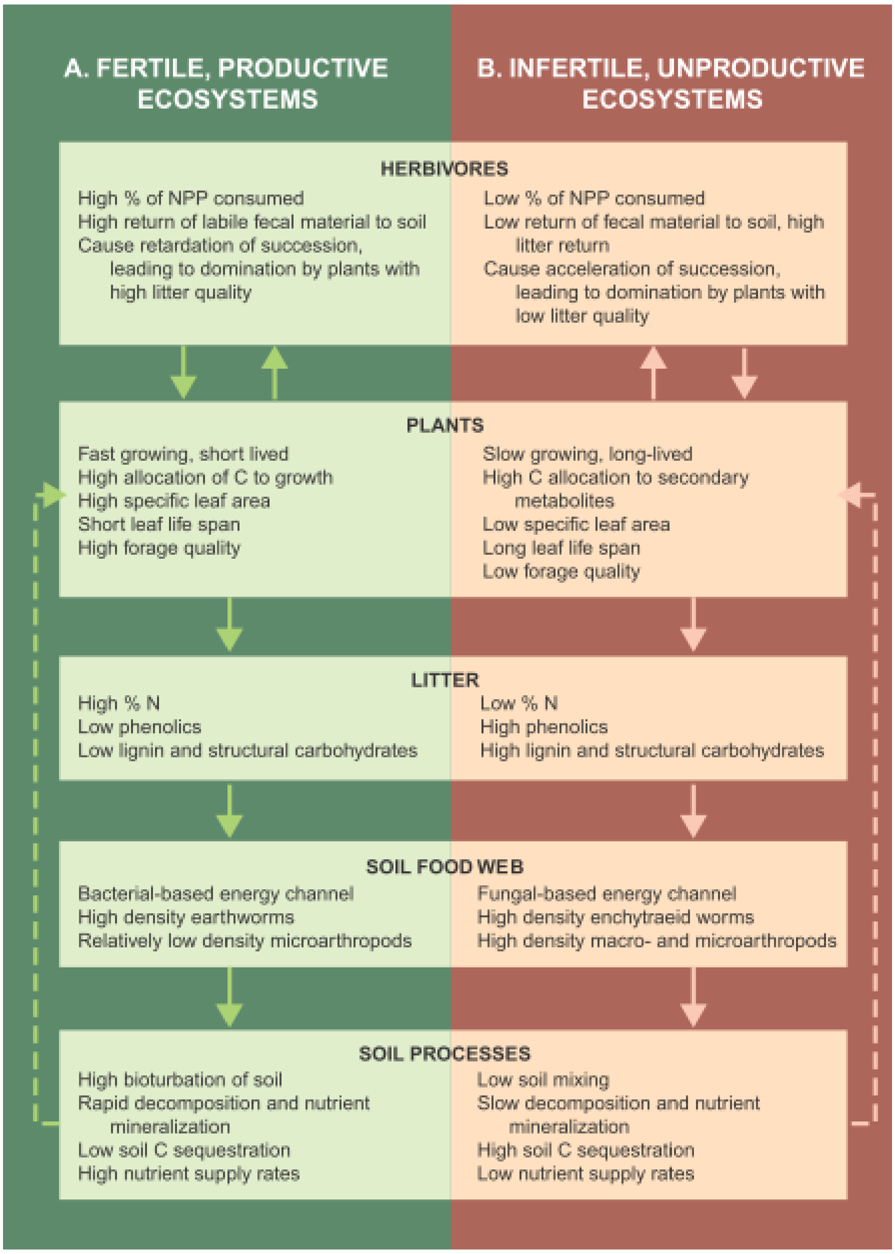
Grasslands support important and distinct biodiversity that is highly threatened [6]. Increased plant diversity has been reported to enhance ecosystem functioning both in natural [7] and sown grasslands [8]. Manipulations in experimental grasslands have shown how increased plant diversity can enhance yield [8,9] and SOC storage [10–12], and decrease greenhouse gas emissions both from the soil [13] and from livestock per unit of feed intake [14]. Organic carbon (C) is stored in soils when there is a positive balance between ecosystem C inputs and outputs [15]. Productivity increases with sown [8,16] and natural [9,17] plant diversity in low to moderate input/output systems. Furthermore, plant diversity seems to be partly driving soil microbial activity [18], and plant-microbial interactions play a role in soil carbon dynamics [19,20]. Therefore, we can expect that managing grasslands for high plant diversity will enhance SOC inputs.

Grazing has the capacity to change vegetation by modifying plant ecophysiology[21,22], species richness [23], community composition [24–26] and structure [27,28] and functional traits [29,30]. Those in turn can affect not only grassland productivity, but also SOM decomposition. Therefore, there are benefits in investigating the optimal plant forage species for the best mixtures maximizing productivity and soil carbon storage under grazing conditions across the different European pedoclimatic environments. It is relevant to investigate how grassland management (e.g. grazing, mowing, fertilisation, sowing, liming, etc.) will affect those mixtures and the interactions between management and pedoclimate. Most of the literature on diversity-function in grasslands report results from ungrazed systems. Ideally, a common framework at European level should be developed, combining locally-adapted species with a standard set of desirable traits (morphological: digestibility, sugars, roots; and physiological: regrowth, nitrogen and water use) for long-term grassland productivity and soil organic carbon storage across pedoclimatic and managements in Europe.

Plant interactions and diversity regulate carbon sequestration in grasslands

Numerous studies have shown how yield in low to moderate output grassland systems is stimulated by increased diversity [8,9], yet many questions remain around the effect of grassland diversity on C sequestration

in soils [31,32], particularly under grazing conditions and different management regimes. It is accepted that species choice can affect organic matter input and rhizosphere activity, thereby resulting in contrasting SOM storage [31]. The question therefore is to clarify the interactive effects between grazing and plant diversity on soil carbon storage, and more precisely to determine if these effects are additive and/or species-dependent. We need to investigate further if there are identifiable patterns of SOC storage involving biological interactions at species, functional type or trait level, and how these are modified by grazing regime or grassland management.



Positive interactive effects among species can be explained by species packing (assemblages); well-structured space distribution and efficient and different resource use among species, which is a clear

advantage over monocultures. Hence, the presence of mixtures of specific plant functional types and traits, contributes to positive interactions and the advantages of plant diversity on ecosystem function. Nonetheless, there is a need to investigate if the putative effects of local vegetation patterns and management regimes, and their presumed interactions, are modified by pedoclimate.

Land use change and grazing intensity are the most commonly investigated management topics in relation to grassland SOC[1,33], but there are many other grazing management aspects known to control grassland vegetation[34,35], and whose role on SOC storage still need to be clarified. These include type of grazing (rotational, continuous, seasonal…), and livestock type and diversity. Accordingly, the question remains whether all plant species are equally suitable for mixing [36,37], what are the desirable plant attributes to be combined in mixtures to achieve optimal benefits, and the long term effects of grazing management and pedoclimatic conditions on selected species mixtures.

Moreover, as shown by long-term studies there are residual plant diversity effects on ecosystem function that are unaccounted for by the obvious drivers [17,38]. Although the effects of combining plant functional types have shown multiple benefits [13,39], a thorough analysis of the importance of mixing plant functional traits on soil C storage is still needed, along with a better understanding of the possible effects of grazing and grazing systems on forage mixture-soil carbon interactions. Furthermore, in addition to ecological and agronomical questions, there are some practical issues to be addressed, including seed availability and cost for potential mixtures[40], particularly when using native species[41], and cost-benefit analysis of mixtures[42].

Identifying beneficial forage species, functional types and functional traits for grazing and carbon sequestration

There is still uncertainty about the relative role of particular forage species, plant functional types, or traits on grassland productivity and SOC storage. Furthermore, there is much uncertainty about species compatibility in forage mixtures[43], and about which functional types or traits must be combined to optimize benefits. Within the different plant functional types, usually found in European grazed systems, a number of mixtures exist:

Trees and legumes deserve particular attention, because they have disproportionate agroecological impacts on grassland ecosystems compared to their relative abundance:

Trees have a critical ecological and agronomical role, even in open grassland, because they provide shade and fibre for livestock. Agroforestry systems should thus be reconsidered in the EU grassland definition, as trees:

- are critical for the maintenance of the herbaceous layer and the sustainability and profitability of the entire grassland ecosystem,
- regulate water availability and
- provide an additional nutritional source in times of scarcity.

These systems are common in the Mediterranean area, include mixtures of different annual and perennial species (e g legumes and cereals), and are often associated with extensive grazing by different livestock types. The close inter-relation within agroforestry systems improves SOM/SOC due to the contribution of trees and of grazing animals through canopy leaf fall and rooting, and manuring respectively [44,45].

As for long term pastures composed of legumes and cereals, montado/dehesa mixed grazing systems promote efficient production of high quality forage, high energy and high digestible protein content, high

nitrogen (N) fixation and C sequestration, and reduced erosion through perennial vegetation cover, improved soil structure and associated increases in SOC/SOM.

Legumes have symbiotic relations with N-fixing bacteria in root nodules, and thus the inclusion of legumes in mixtures can increase grassland productivity (in low to moderate output systems) and soil carbon storage [46,47], although positive effects of plant diversity are detected even in the absence of legumes [48]. However, legume management is a critical issue, because often legumes do not persist in the sward, particularly under grazing conditions.

Mixing of N-fixing/non-fixing plant species in sown grazed grasslands may benefit from the use and knowledge of native pasture species. Better management of native species promotes optimal pasture maintenance due to their adaptation to local conditions. The advantages of adding even a small amount of seeds from native grasslands in sown grazed swards have been reported by experts from distinct regions in Europe including Portugal and the UK. Thus a climate region-specific orientation of the research on the ideal mixtures for grazing is needed, but there is room for the development of a common working framework. For instance, the Agrodiversity experiment [49], on ungrazed grasslands, revealed the benefits on productivity of mixing forage species from different functional types across a wide range of pedoclimatic and management conditions, including very intensively managed swards [8,50,51].
Recent European-wide experiments have demonstrated the benefits of combining local knowledge on well-adapted forage species under specific environmental conditions, grown in mixtures selected according to a common functional trait complementarity scheme (N-fixing/non-fixing combined with fast-establishing/persistent). However, a similar Europe-wide framework for grazed systems is not yet available. Experimental set-ups encompassing European pedoclimatic and grazing management diversity, and including grazing-resistant traits leading to profitable livestock products, increased SOC storage and sustainable grasslands, still need to be established and tested.
Besides, a number of studies show how the combination of grassland management and plant functional traits were most influential on ecosystem properties including fodder production and soil organic matter content (C storage) [52].. Soil C storage can be limited by nitrogen availability [47,53]. Therefore, the introduction in grasslands of species that stimulate N fixation, including legumes, should provide benefits in terms of soil C stock.

Deep rooting species. Grasses have more extensive rooting systems than other plant functional types, therefore favouring organic matter input in soils. However, some forb species have deep roots thus introducing organic matter at soil depths where decomposition rates are reduced [54,55]. Different rooting depths also promote better resource (water and nutrients) capture and soil drainage with associated advantages in terms of soil structure and grassland productivity. In a long-term grassland experiment, the proportion of deep-root biomass explained variation in productivity even after accounting for legume presence/abundance and greater nitrogen availability in diverse plots [32].
C3 /C4 plants: Another trait of interest in grazing for carbon is photosynthetic pathway. An interaction between photosynthetic pathway and grazing intensity has been reported, with mixtures dominated or including C4 grasses fixing C, and C3 grasslands decreasing SOC storage, at high stocking intensities [56], [63]. An increase in C4 species should be expected in European grasslands with climatic warming[57].

Plant functional traits also have the capacity to affect the balance between input and offtake. Grazing animals respire CO_2 but also return C as dung, and the degradability and dynamics of C in this dung should be affected by those plant traits. Estimates of C return from dung into soils is of around 30% or less [58–60]. Thus, there is a direct effect of plant functional traits on SOC storage and dynamics through litter fall, and indirect effects through the degradation pattern of plants through the grazing animal, but there is also uncertainty in this area.

Stability and persistence of mixing effects on grazing for carbon across environments and management regimes in Europe

The effects of biodiversity and management on grassland yield and soil C storage are expected to interact with climate and other pedoclimatic factors [52]. Models combining plant trait composition with climate and management have been proposed to predict net primary productivity [61]. The Agrodiversity experiment shows that it is possible to provide common standard guidelines for managing biodiversity adapted to local species, ecosystems, and agricultural practices. More research is needed to confirm that those guidelines can be applied also for grazed ecosystems across the wide pedoclimatic variability in Europe.

Conclusions

A final consideration is related to long-term dynamics of grazed systems managed for biodiversity, productivity and soil carbon, and stability and persistence of benefits associated to sown or natural plant diversity. According to the experimental data available, in addition to other advantages, increased plant diversity in forage systems provides stability to beneficial functions [16], even in long term grazing experiments [30]. Studies suggest an important role of both biodiversity and plant functional types or traits in promoting stability in ecosystem benefits [38,16]. The benefits of mixtures seem to last even after the initially sown species have disappeared [16,62]. However, more long-term experiments are needed, particularly for grazed systems.

Literature

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Proposal for potential operational groups

- Adaptability of native species in pasture mixtures
- Co-benefits for tree health and quality as promoted by specific plant species and mixtures in grasslands
- SOM evolution and soil drainage in different pasture mixture scenarios
- Establishment and grazing strategies for persistent, productive and economically viable mixed species grassland swards
- Comparison of the productivity and persistence of a range of plant functional types and combinations in grazed swards
- Responses of natural plant diversity and sown mixtures, and of SOC storage, to grassland management and the interactions between management and pedoclimate
- Seed availability, cost and cost-benefit analysis of mixtures

Proposals for (research) needs from practice

- How different species in a pasture mixture interact with each other in terms of vigour, persistence and propagation
- What are the rules for combining species in mixtures to maximize productivity and SOC storage
- How different species influence each other's rooting systems
- Which is the contribution of each pasture species to the maintenance or enhancement of SOM/SOC
- How to improve persistence of legumes and forbs in productive grassland swards
- Direct comparison of N and C dynamics in grazed grass, grass/clover and mixed species swards under contrasting nitrogen input (zero, low and moderate) regimes
- How does the yield, persistency and feed quality of mixtures evaluated under cutting compare with evaluation under grazing?
- How does grazing intensity (e.g. frequency, stocking rate, post-grazing sward height) influence sward and animal productivity and species persistence?
- How do we manage grazing to ensure high plant diversity and SOC storage in grasslands?
- Identifying the best plant forage species for grazing mixtures.
- Establishing a common sowing scheme combining standard plant functional types/traits in mixtures including locally adapted species and managed under grazing across pedoclimatic conditions in Europe.

Recommendations for further development

- Create a H2020 call with two projects: one to study the specificities of the different species and their interactions in a pasture; and the other project to study the effects on soils.
- Site specific calls (e.g. Mediterranean areas, particularly sensitive to desertification) to promote research in the development of sustainable and economically viable grassland management systems in Europe
- Include grasslands in circular economy research lines
- Examine the benefits of mixtures in grazed swards in terms of yield and persistence, and effects on soil C content, in different regions and under different grazing intensities and regimes
- Develop management guidelines for biodiversity conservation, grazing and soil carbon storage in semi-natural and sown grasslands

Conclusions

- Plant diversity, either sown or natural, can have benefits for grazing for carbon in terms of higher yield, livestock product profitability, SOC storage, sward persistence and stability of the benefits
- Approaches based on functional diversity (plant functional types - PFTs - and traits) would allow the development of common sward establishment schemes including locally adapted species and varieties, across pedoclimates and grazing management systems in Europe
- Trees, legumes and C4 species deserve particular attention because of idiosyncratic characteristics providing specific benefits to livestock systems, currently and under climate change conditions
- Specialized and highly selected forage species, including a proportion of native grassland species in mixtures could provide benefits that should be further explored
- Functional diversity approaches that promote long-term persistence need to be developed for grazed systems
- In addition to functional diversity, there seem to be unexplored diversity effects of grazing on grassland function