Memo

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Grasses are vital for carbon sequestration: Here is why.

The storage capacity of grassland ecosystems is large accounting for ~34% of the terrestrial carbon stock. This is because a larger proportion of their carbon is stored belowground in their root system. In grassland ecosystems, ~60% of net primary productivity is allocated belowground.

This carbon is translocated belowground within their root tissue and deposited as root litter over time and rapidly as root exudates deposited from the root surface. Further, these carbon-containing compounds are incorporated with minerals forming mineral-associated organic matter (a stable form of soil organic matter). Additionally, sowing grasses or the conversion croplands to grasslands removes disturbance from tillage and increases root carbon to soil. Collectively, plants with greater carbon allocation to roots contribute more to soil carbon sequestration. As such the current incorporation of grass or grass-clover leys into Danish crop rotations represents a vital mitigation technique to sequester stable carbon.

For a detailed review see: Bai, Y., & Cotrufo, M. F. (2022). Grassland soil carbon sequestration: Current understanding, challenges, and solutions. Science, 377(6606), 603-608.

Impacts of improved management practices on SOC sequestration rate

Several different management practices are available to enhance the rate of soil carbon sequestration in grasses (see Figure 2). Those associated with the largest soil carbon sequestration rates include:

- Conversion from cultivation to grasslands
- Increasing plant diversity
- Sowing legumes and grasses
- Fertilization

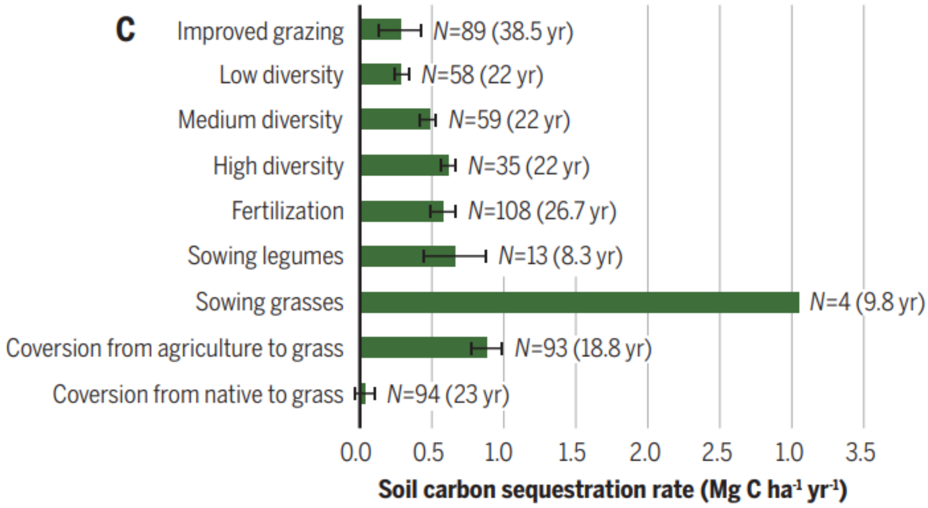
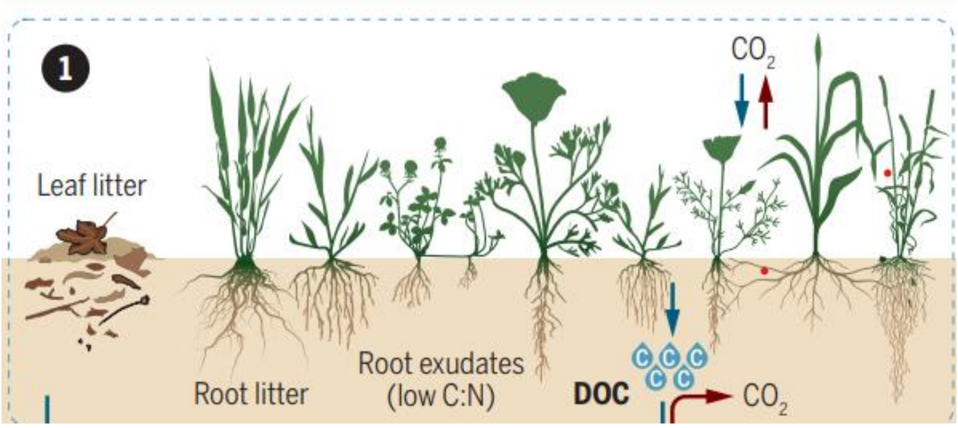


Figure 2. Impacts of improved management practices on soil organic carbon (SOC) sequestration rate. The study duration (years) for each type of management is indicated in parentheses and number of studies are reported (Bai and Cotrufo, 2022; Conant et al., 2017; Yang et al., 2019).

Increasing plant diversity: The importance of belowground-resource partitioning



The positive relationship between biomass productivity (both above and belowground) and number of species within the mixture is based on a term referred to as belowground-resource partitioning (Oram et al., 2018). Here, the species within these mixtures are complementary in their ability to access available resources (nutrients and water) within the soil as compared to single mixtures.

For instance, a mixture with different rooting distributions or morphology (e.g., shallow, and deeper-rooted species) are better able to exploit the resources available at different depths. This occurs while minimizing the negative effects associated with plant competition. Overall, in these situations there is an increase in carbon to soils.

Sowing legumes

The inclusion of legumes in grass mixtures represents a cropping system with multiple benefits (Stagnari et al., (2017)):

- Produce high quality forage (enhance the crude protein content of feed).
- Improve or maintain yield.
- Nitrogen value (fixing atmospheric N_2 and contribute N to the grass sward)
- Food for pollinators

Legumes are an ideal companion plant with grasses as they represent a distinct functional plant group that can fix atmospheric nitrogen. As such, the inclusion of legumes in grass mixtures has been shown to increase both C and N input into the soil by enhancing root biomass, root exudates, and fine root turnover (Bai and Cotrufo, 2022). Legumes in general have a lower C:N ratio and a higher proportion of easily available C and N rich compounds for microbial use (Pol et al., 2022). This can simultaneously lead to the formation of stable SOM fractions (i.e., MAOM) and potential turnover of POM. Here is a situation where both pathways lead to the storage of carbon while also releasing nutrients for plant and microbial growth.

A higher microbial stability of C derived from the legume lucerne roots was documented by Peixoto et al., (2022). A likely scenario proposed was the higher relative microbial stabilization of subsoil C derived from lucerne is intimately linked to N (or the enhanced coupling of C and N) as lucerne roots are enriched with N as ascribed from the low root C:N ratio and higher amounts of N-rich amino acid compounds of the roots.
It was also noted that the quality and quantity of compounds deposited from the lucerne roots lead to an overall higher abundance of the five bacterial N cycling genes below the topsoil as a response to the exudation of more N-rich root-derived compounds in the lucerne rhizosphere. The greater input of amino acids (or other N-based compounds) created a lucerne rhizosphere enriched with C and N, i.e., a more pronounced microbial hotspot.
Overall, removing the subsoil C and N microbial limitations via the growth of deep-rooted crops leads to a balanced stoichiometric microbial demand and accelerated the microbial stabilization of rhizodeposited C of lucerne through a large living microbial biomass. This further results in a greater microbial carbon use efficiency (i.e., enhanced microbial anabolism) and subsequent turnover leading to necromass formation via in vivo microbial turnover.

Perennial-legume based mixtures in Danish dairy farming.

Most intensively managed grasslands in Denmark are sown as perennial-legume-based mixtures containing ryegrass and the leguminous white or red clover. The choice (typically white clover) from a livestock perspective is based on the high digestibility. This is also associated with high biomass production, complementary resource use, and minimal reliance on mineral fertilizer. However, even within these systems there is growing interest in increasing species diversity for further optimization (e.g., above, and belowground productivity).

Increasing species diversity within grass-clover mixtures

The importance of increasing plant diversity or functional groups with grass-clover mixtures is gaining traction (Cong et al., 2017). Here, three different deep-rooted perennial forbs: chicory (*Cichorium intybus* L.), caraway (*Carum carvi* L.), and plantain (*Plantago lanceolata* L.) were examined. This choice was based on their complementary use of resources when mixed with shallow-rooted grass-clover mixtures. Here the inclusion of 60% plantain in the grass-clover mixture increased yield by on average 14% compared to the grass-clover mixture while inclusion of 20% plantain increased yield by 10%. Further, statistically similar yields with the other mixtures with chicory or caraway as compared to the grass-clover mixture. The standing root biomass or below-ground productivity was significantly increased when including plantain or caraway in the grass-clover mixtures. Overall, this has implications for the potential to sequester additional carbon when including these forbs within established grass-clover mixtures.

Soon additional research will be published from the AU Viborg funded project: “GrassTools”. Here a field trial with increasing species diversity (up to 18 species) has been conducted to determine C and N dynamics. Specifically, the isotopic labeling of these mixtures will provide belowground information on the potential to sequester additional C in a stable form to 1-meter depth.

However, a highly provocative paper entitled: “Mitigation potential of soil carbon management overestimated by neglecting N_2O emissions” stressed that in general the capacity of N-fixing cover crops to sequester carbon would be increasingly offset by higher N_2O emission over time (Lugato et al., 2018). Additionally, under Danish conditions within arable cropping, it has been preliminary shown that the incorporation of plant residues results in N_2O emissions. Specifically, At Vejen there was high N_2O emissions during spring in 2021 in both fertilized and non-fertilized plots following the termination of grass-clover (Petersen et al., 2023).

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