Memo

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Winter-killed vs. green cover crop residues on carbon sequestration

Several abiotic and biotic factors will influence the degree of decomposability of winter-killed cover crops (CC) and residues. Specifically, if we are to consider a winter-killed cover crop to behave as a mulch or protective layer covering the soil surface. This can result in a unique micro-environment that can differ from the growing CC. However, I suggest the major difference between winter-killed and green CC residues is in the formation of different SOM fractions. This is based on variations in both the quality (C:N ratio) of the C input as well as the dominant pathway of C allocation (above vs. belowground C inputs).

Winter-killed CC residues: Contribution predominately to POM

Winter-killed CC residues could predominately lead to the formation of particulate organic matter (POM) that is formed during the decomposition of leaf litter. This could also include fungal structural components as fungi prefer the degradation of more complex compounds. An additional input could also be from dissolved organic carbon (DOC), but this is likely a relatively small C source. Here DOC could directly sorb onto the mineral surface contributing to mineral-associated organic matter (MAOM) (Cotrufo and Lavallee, 2022). Further, the degree of belowground input from the roots will depend on the establishment period or plant age and whether an annual or perennial CC (Figure 1; Pausch and Kuzyakov, 2018).

Green CC residues: Contribution predominately to MAOM

With green cover crops, there is a predominance in the formation of MAOM as compared to winter-killed CC residues. With living CCs, photosynthetically fixed carbon compounds belowground is an active process. This continual allocation of carbon belowground is of particular importance as the carbon derived from living roots (or rhizodeposition) is a key belowground pathway for C sequestration (Rasmussen et al., 2019). Rhizodeposited carbon in the form of root exudates is of high quality (low C:N ratio) that is effectively transformed and interacts with minerals or becomes occluded within aggregates to form mineral-associated organic matter (MAOM) (e.g., Cotrufo and Lavallee, 2022). However, as previously mentioned, the amount of carbon deposited from the living green CCs roots is contingent on age (including annual vs. perennial) and functional type (grass vs. legume) (Figure 1). Specifically, perennial grass CCs allocate a larger proportion of their carbon belowground for a longer period as compared to annual crops. On the contrary, annuals exhibit an enhanced carbon allocation from the root to shoot during the growing season (Pausch and Kuzyakov, 2018).

Impact of plant age on belowground carbon allocation

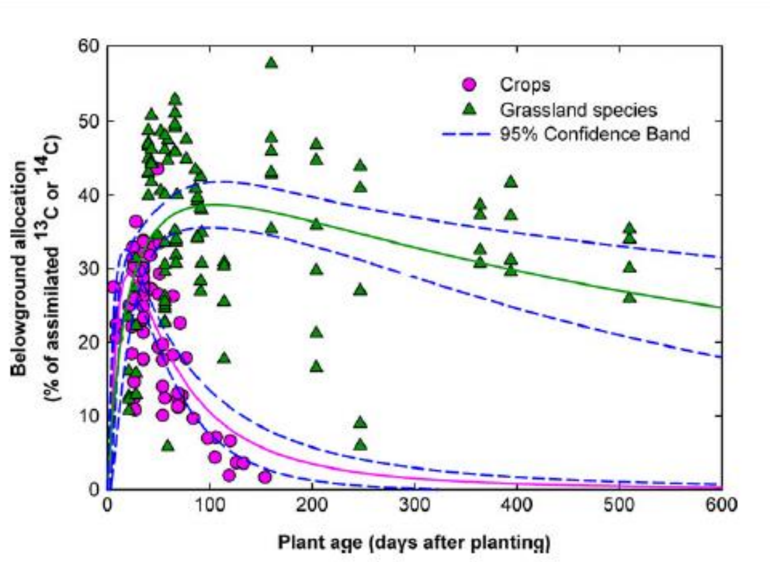

Figure 1. Total ^{13}C or ^{14}C allocation of recent assimilates to all belowground pools for crops and grassland species depending on plant age.

Different factors influence belowground allocation of carbon and of particular interest when comparing winter-killed vs. green CCs would be plant age as related to days after planting. Here young crops allocate proportionally more C to roots as compared to older plants with higher allocation to the shoots. The consequence is a reduction in root exudation in older plants. The pattern of carbon allocation differs substantially between crops and grass species.

Pausch, J., & Kuzyakov, Y. (2018). Carbon input by roots into the soil: quantification of rhizodeposition from root to ecosystem scale. Global change biology, 24(1), 1-12.

Supplemental Information:

Mitigation potential for N_2O emission from crop residues and effects on carbon dynamics

Table 1
Overview of mitigation measures for N_2O emissions from crop residues.

Categorization	Mitigation measure	Mitigation potential	Time frame	Negative side-effects	Positive side-effects
Removal	Crop residue removal versus residue in the field	High	Short and long term	- Lower SOC, yield, and soil physical and biological quality - Higher N leaching and soil erosion	- Feedstock for biofuel and biorefinery - Lower NH_3
Crop residue type	Avoid incorporation of residues from immature crops	High	Short and long term	- Lower SOC - Higher costs, N fertiliser requirement	- Animal feed - Higher yield
Soil management	Residues left at the field surface (e.g., mulching) instead of residue incorporation	Low	Short term	- Higher NH_3 - Lower yield	- Lower N leaching, soil evaporation, and soil erosion
	Shallow instead of deep incorporation	Medium	Short and long term	- Lower yield - Higher use of pesticides, NH_3	- Higher SOC, soil fauna, water infiltration and moisture conservation - Lower costs, soil erosion
Timing of residue incorporation	Autumn instead of spring incorporation	Low	Short term	- Higher N leaching, soil erosion, P losses	- Higher yield
	Crop residue incorporation when the soil is dry instead of when the soil is wet	Medium	Short term		- Better soil structure
Interactions with fertilisation	Synthetic instead of organic fertiliser	Medium	Short term	- Lower SOC - Higher off-farm GHG emissions	- Higher yield
Residue removal, transformation, and return under other forms	Biochar	High	Short and long term	- Higher costs - Lower nutrient supply	- Higher yield, SOC, soil physical and biological quality - Lower N leaching
	Anaerobic digestion	Low to Medium	Short term	- Lower SOC	- Heat and power generation
Additives for application with crop residues	Nitrification inhibitors	Medium	Short term	- Higher costs	- Lower N leaching - Higher yield
	N-immobilizing materials with high C:N ratio	Medium	Short and long term	- Lower yield	- Lower N leaching - Higher SOC, CH_4 uptake
Crop mixtures	Crop mixtures instead of single crops	Medium	Short and long term	- Increased management complexity and costs	- Higher SOC, yield, biodiversity - Lower N leaching, soil erosion
Interactions with edaphoclimatic conditions	Crop residue incorporation in clay soils instead of incorporation in sandy soils	Medium	Long term	- Lower yield	- Lower N leaching, NH_3 - Higher SOC
	Crop residue incorporation when aridity index is <1	Medium	Long term	- Lower SOC, soil health	- Lower N leaching

Abalos, D., Recous, S., Butterbach-Bahl, K., De Notaris, C., Rittl, T. F., Topp, C. F., ... & Olesen, J. E. (2022). A review and meta-analysis of mitigation measures for nitrous oxide emissions from crop residues. Science of the Total Environment, 828, 154388.

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Cotrufo, M. F., & Lavallee, J. M. (2022). Soil organic matter formation, persistence, and functioning: A synthesis of current understanding to inform its conservation and regeneration. Advances in agronomy, 172, 1-66.

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Rasmussen, J., Gylfadóttir, T., Dhalama, N. R., De Notaris, C., & Kätterer, T. (2019). Temporal fate of ^{15}N and ^{14}C leaf-fed to red and white clover in pure stand or mixture with grass–Implications for estimation of legume derived N in soil and companion species. Soil Biology and Biochemistry, 133, 60-71.

Interesting reviews on cover crops:

Fernando, M., & Shrestha, A. (2023). The Potential of Cover Crops for Weed Management: A Sole Tool or Component of an Integrated Weed Management Sytem?. Plants, 12(4), 752.

Moukanni, N., Brewer, K. M., Gaudin, A., & O'Geen, A. T. (2022). Optimizing Carbon Sequestration Through Cover Cropping in Mediterranean Agroecosystems: Synthesis of Mechanisms and Implications for Management. Frontiers in Agronomy, 4, 844166.

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Liang, C., Schimel, J. P., & Jastrow, J. D. (2017). The importance of anabolism in microbial control over soil carbon storage. Nature microbiology, 2(8), 1-6.

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