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FACT SHEET

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HOW COVER CROPS SEQUESTER CARBON

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INTRODUCTION

Carbon (C) sequestered in the soil represents carbon dioxide (CO_2) that has been removed from the atmosphere, contributing to reductions in greenhouse gas emissions. Soil organic matter is approximately 58% carbon, so another way of thinking about sequestering carbon is to think of building soil organic matter. Understanding how cover crops sequester C in the soil can help you determine how you might manage your cover crop to maximize soil organic matter formation. Building soil organic matter and soil carbon can improve soil structure, increase water infiltration and water holding capacity, and enhance nutrient cycling.

Carbon sequestration by cover crops is the result of three separate but linked processes:

1. Accumulation of organic C in both the aboveground and belowground cover crop biomass;
2. The formation of soil aggregates that protect organic matter from breaking down. Aggregates are formed by fine root hairs and soil organisms feeding on cover crop root secretions; and
3. Protecting the organic C that is already in the soil from loss, such as through erosion

Cover cropping must integrate into your farming system to provide the greatest benefit to your soil. This requires an investment of time and skill to manage the cover crop as a crop rather than an afterthought. Success can sometimes be measured as increases in yield but should also be measured in the long-term resilience of your soil.

Integrating cover crops into your cropping system may be eligible for funding to cover costs for establishment or professional advice by a Certified Crop Adviser, agronomist or agrologist under the On-Farm Climate Action Fund. For farms in Nova Scotia and Newfoundland and Labrador, you can find more information by visiting: **ofcaf.perennia.ca**

Carbon is found in soil in two forms: inorganic carbon and organic carbon. An example of inorganic carbon is the carbon that is bound up with minerals like magnesium and calcium forming compounds such as calcium carbonate. Carbon dioxide in the interpore space is another example of inorganic carbon. Organic carbon refers to carbon that is or was once part of a living thing, i.e., bacteria, fungi, living plant roots, dead plant roots, proteins, lignin, humic substances, etc.

1. HOW COVER CROPS ACCUMULATE ORGANIC C

Any plant growing in the soil will add organic carbon as the roots grow and exude organic compounds into the rhizosphere (the zone immediately around the roots), and the unharvested top growth is left in the field to break down. For most grain crops, however, the organic carbon additions from crop residue are minimal since some carbon is lost as the aboveground residue breaks down, and some carbon is lost through erosion. Most cash crops have been bred to maximize the accumulation of resources such as carbohydrates and proteins in the harvested part of the crop, leaving less to go into the soil from crop residues. An even larger factor is the short time cash crops are actively growing: Out of the twelve months of the year, a cash crop is typically only actively growing for four months or less. Even a full-season crop such as corn puts less energy into root growth once the plant has switched from vegetative to reproductive growth. Cover crops help to overcome this deficit, putting growing roots in the field for months that are otherwise barren.

There are three factors in how well cover crops will contribute to soil organic matter and soil organic carbon:

1. How much biomass the cover crop is producing – this is the engine that drives everything else
2. The physical and chemical structure of the cover crop biomass, which impacts its fate in the soil
3. Where that biomass ends up (i.e., above- or below-ground)

Conventional wisdom was that organic materials that were resistant to breakdown would stay in the soil longest, which led to puzzlement about why large volumes of corn stalks or cereal straw did not seem to be effective at increasing soil organic matter content. New theories that are gaining acceptance suggest that the release of easily degraded compounds from roots is far more important to building soil organic matter than surface residue (Sokol et al., 2019) and that the organic matter that accumulates in the soil is the leftovers from microbial growth (Lehmann & Kleber, 2015; Moukanni et al., 2022). This will influence the choice of cover crop species and the way the cover crop is managed.

Would letting the weeds grow accomplish the same as planting a cover crop?

This is an attractive notion, since weed growth is free, but it is unlikely to be effective. Aside from the risk of building the weed seed bank and creating competition for the following crop, most common weed species share the drawbacks of annual crops: short life cycles, with priority to producing as much seed as possible rather than returning carbon to the soil through extensive root growth.

Organic compounds will accumulate in the soil in two main ways.

1. Particulate organic matter (POM) is small bits made up mostly of cell walls from bacteria and fungi, along with a few random plant pieces. If this is floating freely in the soil, it will rapidly become food for the next round of microbes, but POM that gets integrated into the middle of a soil aggregate is physically protected from degradation – think of the interior of the aggregate as being shielded from being attacked and consumed by microbes (Figure 1).

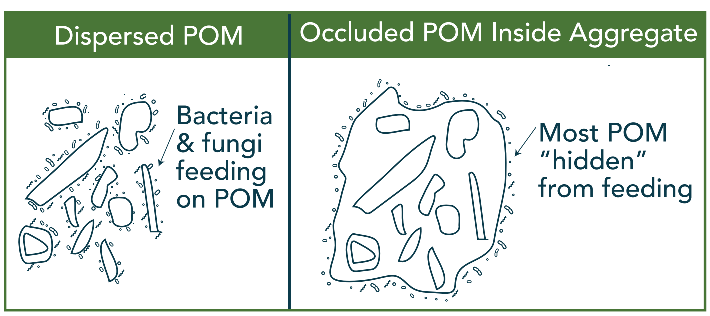

Figure 1. Particulate organic matter (POM) inside of soil aggregates is protected from degradation.

2. The second group of compounds are ones that bind tightly to soil minerals. This "mineral-associated organic matter" is protected because the bonds to the minerals block the places where enzymes normally attach during the breakdown process. Neither of these protections are permanent since mineral and organic compounds in the soil are always in a state of flux, but adding cover crops and perennial crops into the mix can help to shift the balance towards more organic carbon being held in the soil.

The root of it all!

For POM and mineral-associated organic matter, rapid root growth and high rates of root exudation (release of sugars and amino acids from the root surfaces) are important (Poirier et al., 2018). However, there are still questions about how root architecture affects soil carbon stabilization. Deep-rooted crops, compared to fibrous roots, will contribute to soil organic carbon differently.

- Deep-rooted crops will likely contribute more to mineral-associated organic matter because they can release root exudates in the subsoil below the depth of most microbial activity
- Fibrous roots, particularly of crops associated with mycorrhizal fungi, encourage the formation of aggregates in soil, contributing to the production and protection of POM

Root growth and root exudates (soluble organic substances secreted by the root, such as sugars, amino acids, organic acids, and enzymes) have a far greater impact on carbon accumulation than aboveground biomass. Typically, vigorous aboveground biomass will support extensive root systems. Blanco-Canqui (2022) found that aboveground biomass of less than 2 T/ha resulted in negligible soil organic carbon accumulation.

Mixtures of grasses and broadleaf plants (legume and non-legume) will often generate more total biomass than pure stands, and have roots at different depths, so will contribute to both POM and mineral-associated organic matter.

Other factors that contribute to organic matter accumulation besides root structure include:

Termination timing: for greater soil organic carbon accumulation, the cover crop should be tilled or killed by herbicides while plants are still vegetative – before they begin reallocating carbon from roots to flowers and seeds.

Underlying organic matter content: areas with low organic matter will be dominated by mineral-associated organic matter because of inherently low microbial activity. Degraded soils with low organic matter content will often respond quicker to OM additions than soils with a higher organic matter content for this reason.

2. AGGREGATE FORMATION TO PROTECT ORGANIC CARBON

A key part of sequestering organic carbon in the soil is protecting organic compounds, particularly POM, inside aggregates where they are not available for degradation by soil organisms (Figure 1). Cover crops enhance this process, and the impact is larger than the amount of organic carbon they add to the soil. Aggregates form through chemical, physical, and biological processes. The physical action of roots growing through the soil, and the differential drying of the soil around those roots, moulds and forms the soil into clods. The fine roots that die off, along with fungal hyphae, form a latticework that helps to hold these newly forming aggregates together. Earthworms and soil arthropods are supported by the food supplied by the growing cover crops – the microclimate under the growing cover is more comfortable for them as well – and this also contributes to aggregate formation. As the earthworms and soil arthropods such as mites, springtails and beetles consume the organic matter produced by the cover crop, they help break it down into particulate organic matter that is then formed into aggregates. The secretions as the organic matter passes through their digestive tract also helps this process. This, added with root exudates and other microbial excretions, form an effective "glue" to bind the aggregates together. Aggregates can be easily destroyed by tillage, so reducing recreational tillage, or switching to no-till or minimum-till, can also help with aggregate formation.

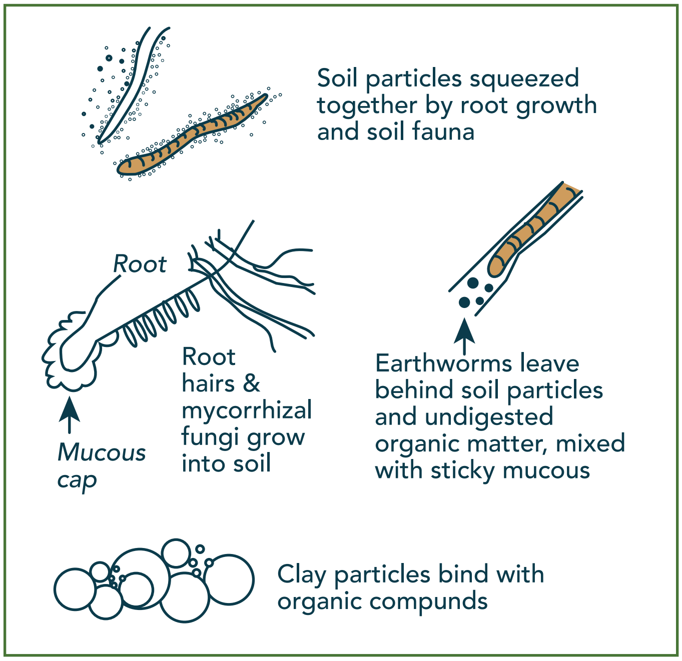

Figure 2. Physical and biological processes help to create stable aggregates in the soil.

3. PREVENTING LOSS OF ORGANIC CARBON

When soil erosion occurs, the sediment that is transported off the field by wind or water is up to five times higher in nutrients and organic matter than the soil that is left behind. Cover crops protect the soil in the period between cash crops by covering the surface of the soil with a mulch to absorb the impact of raindrops and shelter the soil from scouring wind. The mulching effect of the top growth of the cover crops protects the soil from wet-dry and freeze-thaw cycles that leave the soil more vulnerable to erosion. This effect is enhanced in our climate by the trapping of snow in the fields over winter. This is immediately obvious to anyone who has seen the amount of "snirt" (a mix of snow and dirt) that fills the ditches next to a tilled field compared to a field with a cover crop.

Figure 3. Windblown dirt on snow, aka "snirt"
Photo Courtesy of University of Minnesota Extension (**https://extension.umn.edu/yard-and-garden-news/keep-snirt-out-your-garden-winter**)

INTEGRATING COVER CROPS FOR CARBON SEQUESTRATION INTO YOUR CROPPING SYSTEM

The challenge for most farmers in Atlantic Canada is finding a time period long enough to allow vigorous cover crop growth under favourable weather conditions. Keeping green cover anytime the ground would otherwise be bare is a good thing and will help to preserve the organic carbon that is already there and can help soak up nutrients. Keep in mind, however, that a cover crop that accumulates less than 2 T/ha of dry matter is unlikely to add to the stores of soil carbon. Here are some things to consider when choosing a cover crop:

A. Planting window: choose a planting window with the greatest chance of success. For example, cover crops planted in the drier summer months after an early-harvested crop will establish more quickly with earlier growth if they are planted no-till rather than following cultivation because there is more soil moisture retention.

B. Rapid growth: choose a cover crop that will produce high amounts of biomass within the window of time that you have.

C. Maximize growing windows: fall-planted cover crops that green-up in the spring will continue to accumulate carbon. **Don't be too quick to terminate, especially if you have a later planting date for your cash crop.**

D. Different rooting depths and types: having diverse rooting structures helps accumulate carbon in different ways and at different soil depths.

E. Residual nitrogen in the soil: A non-legume broadleaf plant, such as oilseed radish or forage turnip, will grow well in a high nitrogen environment and poorly if soil N is depleted. Consider what nitrogen credits might be left in the soil, either from a legume, leftover from the cash crop, or from a manure application.

F. Termination method and timing: A cover crop should work in synchrony with your cash crop. When choosing a cover crop, always keep in mind how and when you plan to terminate it in order to not hinder the following cash crop establishment.

There is no single "best" cover crop since individual circumstances vary so much, so the following are suggestions for specific situations to start your thought process:

Condition	Possible Cover Crop Species	Comments
Summer harvested crop (winter wheat, spring cereals, early veg, after June-bearing strawberries) followed by early spring planted crop (grain corn)	Pearl millet Sorghum-Sudangrass hybrid Triticale-pea mixture Oats, or oat-pea mixture Brown mustard	These cover crops will winterkill, so should not require any additional tillage or herbicide.
Manure applied to cereal stubble, or early vegetables with high residual N, followed by grain corn	Oat-oilseed Radish Oat-oilseed radish-pea Brown mustard	These cover crops will winterkill.
Summer harvested crop followed by soybeans or late planted vegetables	Cereal rye (aka winter rye, fall rye) Cereal rye-hairy vetch Cereal rye-oilseed radish (if soil N is high)	The rye and vetch will need to be terminated in the spring, either mechanically (i.e. tillage), or with herbicides pre-flag leaf.
Soybeans or silage corn followed by late planted vegetables	Cereal rye, broadcast into soybeans before leaf drop or drilled into silage corn stubble immediately after harvest.	Spring growth will generate most of the biomass. Will need mechanical or chemical termination.
Soybeans, grain corn, or late potatoes, followed by spring cereals	Very low probability of adequate cover crop growth in the time available.	

SUMMARY

Cover crops that generate vigorous growth, both above and below ground, will add to the stores of organic carbon in the soil. This has benefits for the environment by taking this carbon out of the atmosphere, but it will also benefit your soil, your farm, and your cash crops by improving soil structure, nutrient cycling, water infiltration and available water in the soil. This may not increase crop yields every year, but it will make a big difference in those years when the weather refuses to cooperate.

Plan to include cover crops in your cropping system, but take the time to plan where and when they will fit for the greatest benefit.

REFERENCES

Blanco-Canqui, H. (2022). Cover crops and carbon sequestration: Lessons from U.S. studies. Soil Science Society of America Journal, 86(3), 501-519. **https://doi.org/https://doi.org/10.1002/saj2.20378**

Lehmann, J., & Kleber, M. (2015). The contentious nature of soil organic matter. Nature, 528(7580), 60-68. **https://doi.org/10.1038/nature16069**

Moukanni, N., Brewer, K. M., Gaudin, A. C. M., & O'Geen, A. T. (2022). Optimizing Carbon Sequestration Through Cover Cropping in Mediterranean Agroecosystems: Synthesis of Mechanisms and Implications for Management [Review]. Frontiers in Agronomy, 4. **https://doi.org/10.3389/fagro.2022.844166**

Poirier, V., Roumet, C., & Munson, A. D. (2018). The root of the matter: Linking root traits and soil organic matter stabilization processes. Soil Biology and Biochemistry, 120, 246-259. **https://doi.org/10.1016/j.soilbio.2018.02.016**

Sokol, N. W., Kuebbing, S. E., Karlsen-Ayala, E., & Bradford, M. A. (2019). Evidence for the primacy of living root inputs, not root or shoot litter, in forming soil organic carbon. New Phytologist, 221(1), 233-246. **https://doi.org/10.1111/nph.15361**

Stott, D. E., Stroo, H. F., Elliott, L. F., Papendick, R. I., & Unger, P. W. (1990). Wheat Residue Loss from Fields under No-till Management. Soil Science Society of America Journal, 54(1), 92-98. **https://doi.org/https://doi.org/10.2136/sssaj1990.03615995005400010014x**

Wei, Y., Zhang, Y., Wilson, G. W., Guo, Y., Bi, Y., Xiong, X., & Liu, N. (2021). Transformation of litter carbon to stable soil organic matter is facilitated by ungulate trampling. Geoderma, 385, 114828.

Williams, A., Scott Wells, M., Dickey, D. A., Hu, S., Maul, J., Raskin, D. T., Chris Reberg-Horton, S., & Mirsky, S. B. (2018). Establishing the relationship of soil nitrogen immobilization to cereal rye residues in a mulched system. Plant and Soil, 426(1-2), 95-107. **https://doi.org/10.1007/s11104-018-3566-0**