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Greenhouse Gases and Soil Organic Carbon in Vegetable Production and the Role of Cover Crops

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Increasingly, attention is being paid to the intersection of agricultural production and greenhouse gases. This is an opportune time to **consider how vegetable production interacts with carbon sequestration and greenhouse gas emissions, and how using cover crops may alter this picture.**

When considering the climate change impacts of agriculture, there are many aspects to consider: sequestration of atmospheric carbon in the soil as soil organic carbon (SOC), emissions of greenhouse gases such as carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) from the soil, and the emissions associated with agricultural inputs.

Attempts to combat climate change in vegetable production can target any of these areas, however they should not come at the expense of yield. In fact, the surest ways to reduce greenhouse gas emissions overall are to increase yield while keeping inputs constant, or maintaining yield while decreasing inputs.

Soil Organic Carbon Impacts

What is Soil Organic Carbon?

Soil organic carbon (SOC) refers specifically to the carbon content of soils, not including large materials (> 1/16"). SOC is a portion of soil organic matter (SOM) and is easier to measure. Often, SOC is thought to be ~58% of SOM, though this is not an exact number and can vary with soil type and other factors.[1] SOM, and by extension SOC, is very important in agricultural soils as it is critical in water infiltration, water holding capacity, moderating soil temperature, supporting soil microbes, and more. Increasing SOC is also talked about as a way to fight climate change by sequestering carbon in the soil. Because of the large area of agricultural land this can be done on, even small increases in SOC could make a big difference.

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Current Research's View of Soil Organic Carbon and Vegetable Production

A variety of studies have attempted to address these topics and have arrived at a variety of conclusions. One model-based study of ten years of organic vegetable production showed that carbon is lost from the soil at a rate of 660 lb C/ac/yr.[2] Another study which focused on high tunnel vegetable cultivation in China over 11 yrs came to a different conclusion. In this study, conventional methods increased SOC by 450 lb/ac/yr and organic methods increased SOC by 3500 lb/ac/yr in the top 8" of soil. SOC also increased below the typical plow layer (8 – 16") but not by very much.[3] A meta-analysis of scientific papers also showed a large difference between SOC in organic vs conventional systems.[4]

However, the higher sequestration rates in organic context may be because these farms are importing carbon in the form of compost and other organic fertilizers.[4] In the context of the soil health benefits of increasing SOC, the source of the imported carbon does not really matter. However, in the context of carbon sequestration and climate change, where and how the carbon is pulled out of the atmosphere matters for greenhouse gas accounting and any potential carbon payment scheme.

Net Greenhouse Gas Emissions

How Does Net Greenhouse Gas Accounting Work?

When thinking about the greenhouse gas (GHG) implications of vegetable production (or anything else), it's important to consider nitrous oxide (N_2O) and methane (CH_4) in addition to carbon dioxide (CO_2). This is especially true since N_2O is about 300 times as bad as CO_2 as a greenhouse gas, and CH_4 is about 30 times as bad. When multiple GHGs are emitted, the overall impact can be expressed as an equivalent amount of CO_2, or CO_2-eq. For example, if 1 ton of CO_2, 0.01 tons of CH_4, and 0.002 tons of N_2O were emitted, this could be expressed as 1.9 tons CO_2-eq.

Direct emissions of CH_4 during vegetable production are usually minor, so the focus here is on CO_2 and N_2O.

Sources and Estimates of Emissions for Vegetable Crops

A study modelling all the GHG emissions associated with organic vegetable production in Western Washington found that between 0.045 and 0.623 lb CO_2-eq were emitted per lb for crops such as onions, squash, dry bush beans, potatoes, and chard.[5]

Compost application offers an attractive way to increase SOC and build soil health, in part, because the carbon in compost is relatively stable and less likely to decompose and turn back into CO_2. This is because as the compost was produced, the portion of the organic matter that would easily decompose did so, releasing some CO_2 in the process.

Frequent tillage associated with intensive vegetable production exposes soil organic matter and enables the release of CO_2 through soil mineralization thus reducing SOC levels.[6] Essentially, the frequent exposure to oxygen burns off the organic matter and turns it into CO_2. (A more nuanced discussion of tillage and reduced tillage is certainly necessary but will be saved for another time.)

There is no clear and definitive answer to whether/how much vegetable crops are contributing to building SOC or even what the net GHG emissions are. This variation is driven by what crop is being grown, what methods (e.g., fertilizer type, tillage intensity, cover cropping) are used, how long those methods have been used, soil type, climate, and more.[7] Some ongoing research seeks to better understand this overall picture while other research seeks to understand the impact of specific management practices on SOC and GHGs.

The Impact of Cover Crops...

On Soil Organic Carbon

There is a little more clarity when considering the impact of a specific management practice—in this case cover cropping—on soil organic carbon and greenhouse gas emissions. One study of cover cropping over 8 years of intensive organic vegetable production showed that increasing cover cropping frequency from 1 in 4 years to every year increased the SOC in the top 12 inches.[8] However, a portion of the increase in SOC was in a form that could easily turn back into CO_2. This study showed that planting a legume-rye, mustard, or rye cover crop can increase SOC levels. All three cover crop choices boosted SOC by similar amounts. In addition, this study demonstrated that, regardless of how often cover crops are grown, compost application increased SOC levels.

A 9-year study of cover crop introduction to vegetable production in southern Ontario, Canada showed that cover cropping increased SOC in the top 6” of soil.[9] In fact, at one site, oilseed radish used as cover crop increased SOC from 28 to 36 tons C/ac.

It’s also important to consider the full soil profile when thinking about carbon sequestration. In one study, SOC was measured over a 20-year period in a corn-tomato rotation system with and without cover crops.[10] Addition of cover crops increased SOC in the top foot of soil, however SOC decreased in the top 6 feet. In this case, the cover crops may have been successful if the goal was to improve soil health. However, if the goal was to sequester carbon, then the cover crops were unsuccessful.

On Nitrous Oxide Emissions

One often discussed benefit of cover crops is the potential to scavenge soil nitrogen and—specifically for legume cover crops—to fix atmospheric nitrogen. However, recall that N_2O is a very potent greenhouse gas. So, how do cover crops influence the emission of N_2O?

A well-established benefit of cover crops is their ability to reduce nitrate in run-off leaving the farm. Because this nitrate could result in N_2O emissions later on, reducing nitrate loads in run-off may also reduce GHG emissions.

Several studies which measured N_2O emissions over a full year saw little to no net impact from the presence of non-legume cover crops.[11] In general, not incorporating cover crop residues (i.e., leaving them as mulch) and using non-legume species minimizes N_2O emissions.[12]

How does nitrogen cycle through the soil?

Nitrogen cycling is an intricate, microbially-mediated process that involves many forms of nitrogen-based compounds, including N_2O. Each step of the cycle relies on different kinds of microbes that all produce a different form of nitrogen. Each type of microbe thrives in certain soil conditions. The microbes that are active in wet soils tend to produce nitrous oxide. When a lot of fresh, high-N content food is available and the soil is wet, the N_2O producing microbes can experience a population boom.

A lab research study measured soil emissions of N_2O for 47 days after the incorporation of various cover crops.[12] Incorporating cover crop residue increased N_2O emissions with the increase concentrated immediately after the incorporation. However, when legume cover crop residue was used, the increase in N_2O emissions was far worse than the non-legume cover crop. The water content of the soil also played a significant role. Wet soil led to far more N_2O emissions, even when there was no residue added (see Table 1). The emissions from the soil were reduced by adding non-legume cover crop residue or increased by adding legume cover crop residue. While this was a lab study, the relative ranking can be expected to be preserved in field conditions.

Table 1. Nitrous oxide (N_2O) emissions over 47 days (relative units)*

Cover Crop Treatment	Dry Soil	Wet Soil
No residue	0	6,000
Legume (pigeon pea)	100	10,000
Non-legume (black oat)	5	2,000

* Adapted from "Soil N_2O Emissions Following Cover-Crop Residues Application under Two Soil Moisture Conditions"

A field trial confirms the idea that wet soils with legume cover crops incorporated led to increased N_2O emissions. Over 4 months, plots where hairy vetch residue had been tilled in showed high N_2O emissions of up to 7 lb N_2O/ac/day compared to virtually no emissions from 50 lb-N/ac synthetic N fertilizer or no fertilizer.[13]

Taken together these studies indicate that N_2O emissions can be limited by maintaining drier soils, particularly when incorporating legume cover crops. However, more research is needed.

On Other Greenhouse Gas Emissions

Cover crops can provide a range of benefits which impact net greenhouse gas (GHG) emissions in ways that were not explored here. For example, cover crops can suppress weeds when used as a mulch. Subsequent reduction in weed management activities can reduce on- and off-farm emissions. In a study of tomato production in Maryland, cover crops (hairy vetch or crimson clover) were terminated by flail mowing and the residue was left in place as a mulch replacing black plastic.[14] Marketable yield of tomatoes increased where the cover crop residue was used relative the black plastic mulch while allowing nitrogen fertilizer application to be halved. This is a great example of reducing GHG emissions by maintaining or, in this case, increasing yield while reducing inputs.

Final Message

The overall impact of vegetable production on soil carbon, nitrogen, and greenhouse gases, in general, is very complex and dependent on a wide range of specific factors. The role of cover crops was explored here. Fertilizer rate and source and tillage intensity also significantly impact both soil organic carbon (SOC) and GHG emissions but were not discussed in depth here.

- Over years, cover cropping can help build SOC, at least at the surface.
- Non-legume cover crops, and all cover crops in dry soil, have minimal N_2O emissions.
- Cover cropping can improve yield and reduce input requirements thus reducing emissions per unit of production.

Additional information on the benefits of cover crops and guides to help select cover crop species for NY growers can be found at https://covercrop.org/

References

1 Douglas W. Pribyl, “A Critical Review of the Conventional SOC to SOM Conversion Factor,” *Geoderma* 156, no. 3 (May 15, 2010): 75–83, https://doi.org/10.1016/j.geoderma.2010.02.003.

2 Cornelius Adewale et al., “Identifying Hotspots in the Carbon Footprint of a Small Scale Organic Vegetable Farm,” *Agricultural Systems* 149 (November 1, 2016): 112–21, https://doi.org/10.1016/j.agsy.2016.09.004.

3 Yi Zhao et al., “Intensive Organic Vegetable Production Increases Soil Organic Carbon but with a Lower Carbon Conversion Efficiency than Integrated Management,” *Journal of Plant Nutrition and Soil Science* 183, no. 2 (2020): 155–68, https://doi.org/10.1002/jpln.201900308.

4 Andreas Gattinger et al., “Enhanced Top Soil Carbon Stocks under Organic Farming,” *Proceedings of the National Academy of Sciences* 109, no. 44 (October 30, 2012): 18226–31, https://doi.org/10.1073/pnas.1209429109.

5 Adewale et al., “Identifying Hotspots in the Carbon Footprint of a Small Scale Organic Vegetable Farm.”

6 Kathryn E. White et al., “Winter Cover Crops Increase Readily Decomposable Soil Carbon, but Compost Drives Total Soil Carbon during Eight Years of Intensive, Organic Vegetable Production in California,” PLOS ONE 15, no. 2 (February 6, 2020): e0228677, https://doi.org/10.1371/journal.pone.0228677.

7 Pablo García-Palacios et al., “Crop Traits Drive Soil Carbon Sequestration under Organic Farming,” *Journal of Applied Ecology* 55, no. 5 (2018): 2496–2505, https://doi.org/10.1111/1365-2664.13113.

8 White et al., “Winter Cover Crops Increase Readily Decomposable Soil Carbon, but Compost Drives Total Soil Carbon during Eight Years of Intensive, Organic Vegetable Production in California.”

9 Inderjot Chahal et al., “Cumulative Impact of Cover Crops on Soil Carbon Sequestration and Profitability in a Temperate Humid Climate,” *Scientific Reports* 10, no. 1 (August 7, 2020): 13381, https://doi.org/10.1038/s41598-020-70224-6.

10 Nicole E. Tautges et al., “Deep Soil Inventories Reveal That Impacts of Cover Crops and Compost on Soil Carbon Sequestration Differ in Surface and Subsurface Soils,” *Global Change Biology* 25, no. 11 (2019): 3753–66, https://doi.org/10.1111/gcb.14762.

11 A. D. Basche et al., “Do Cover Crops Increase or Decrease Nitrous Oxide Emissions? A Meta-Analysis,” *Journal of Soil and Water Conservation* 69, no. 6 (November 1, 2014): 471–82, https://doi.org/10.2489/jswc.69.6.471.

12 Laisa Gouveia Pimentel et al., “Soil N_2O Emissions Following Cover-Crop Residues Application under Two Soil Moisture Conditions,” *Journal of Plant Nutrition and Soil Science* 178, no. 4 (2015): 631–40, https://doi.org/10.1002/jpln.201400392.

13 Tanka P. Kandel et al., “Nitrous Oxide Emissions as Influenced by Legume Cover Crops and Nitrogen Fertilization,” *Nutrient Cycling in Agroecosystems* 112, no. 1 (September 2018): 119–31, https://doi.org/10.1007/s10705-018-9936-4.

14 Aref A. Abdul-Baki et al., “Fresh-Market Tomato Production in a Low-Input Alternative System Using Cover-Crop Mulch,” *HortScience* 31, no. 1 (February 1, 1996): 65–69, https://doi.org/10.21273/HORTSCI.31.1.65.

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December 2022