Cornell University

Soil Carbon Management & Greenhouse Gas Mitigation Opportunities

Information Sheet #6

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Information Sheet #6 – OVERVIEW

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Fast Facts

- **Impacts**: Soil carbon management can store (sequester) carbon in soil organic matter, which can reduce carbon dioxide in the atmosphere and improve soil health.
- **An imperative to act:** Improved soil carbon management increases soil health, increases grower profits and reduces carbon dioxide emissions to the atmosphere, reducing climate change.
- **An opportunity for proactive change**: Reducing tillage and adding crop residues to soil both increase soil carbon storage (**sequestration**), increase soil health, improve profitability, and reduce greenhouse gas emissions.
- **A concern for implementation:** Reduced tillage and especially no-till can increase soil carbon, but subsequent tillage can release this carbon back to the atmosphere.

Introduction

Soil carbon (closely related to soil organic matter) is beneficial for soil health for many reasons, including improved water infiltration, improved water retention, reduced erosion, improved tilth, and improved biological activity. Increasing the amount of carbon stored in soils has multiple agricultural and environmental benefits, including improved yields, increased resistance to drought and flooding, improved water quality, and reduced carbon dioxide (CO_2) in the atmosphere. This Information Sheet focuses on how farms can reduce CO_2 emissions using soil health best management practices (BMPs). However, it should be noted that it takes decades to build up (sequester) soil carbon but only months or a few years to lose the sequestered carbon due to tillage and other soil disturbing practices.

Environmental Concerns

Reducing GHG emissions is important to reduce the extent and impacts of climate change. Improving soil carbon management can provide cost-effective GHG mitigation opportunities.

Adequate soil organic carbon is important for soil health (the capacity of a soil to function), and has a direct impact on crop production and an indirect impact on water quality. Unhealthy soils with less soil carbon are more likely to erode and have a higher potential for runoff during storm events. Soil erosion can carry sediments, nutrients and pesticides to surface water bodies degrading water quality. Healthy soils are able to absorb and supply water, retain nutrients, suppress pests and weeds, and produce high crop yields.

Summary of Regulation of GHG Emissions and GHG Markets

Emissions of GHGs from soil are not regulated. However, there may be opportunities for soil carbon management activities to qualify for GHG mitigation credits (also called carbon credits or carbon offsets) from various carbon markets. For example, the Climate Action Reserve, the American Carbon Registry, and the Voluntary Carbon Standard have defined quantifiable management practices that are qualify for carbon (or GHG) markets (Tonitto et al. 2016). Carbon markets in the USA include the former Chicago Carbon Exchange, the Climate Action Reserve, and the Regional Greenhouse Gas Initiative (Tonitto et al. 2016, Fahey et al. 2010). While such programs may provide opportunities for payments for soil carbon sequestration, the requirements may be very stringent and the costs of compliance high (Fahey et al. 2010, Tonitto et al. 2016).

Goal

This Information Sheet is intended to help technicians and educators work with landowners to help them better understand and navigate methods for reducing GHG emissions from soil through soil carbon management.

Summary of Potential GHG Mitigation Practices

Description of Strategy	Opportunities	Considerations
Reduce tillage.	Increases soil carbon and soil health when practiced over many years.	Soil carbon can be lost quickly if tillage is later increased making it difficult to qualify as 'permanent' mitigation of GHG.
Add crop residues.	Increases soil carbon, especially combined with reduced tillage. Improves soil health, including tilth.	Excess residues on the soil surface can keep soil too cool and wet in spring, and can interfere with planting or early crop growth.
Add manure, compost, or biochar.	Increases soil carbon, especially combined with reduced tillage. Improves soil health, including tilth.	Transporting these materials from off the farm can be difficult and costly. Biochar is expensive to produce and there is little to no commercial experience with it in New York State.
Add cover crops or double crops.	Having crops cover the soil and build additional root systems for more of the year increases soil health and soil carbon.	Cover crops require time and money to manage. Double crops increases total yield, but may reduce yields of the primary crop.
Convert land from annual to perennial crops.	Perennial crops, pasture, and tree root systems sequester soil carbon, use nutrients more efficiently, reduce erosion, and reduce GHG emissions.	It may be difficult to find appropriate markets for some perennial crops.

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Information Sheet #6 – IN DEPTH

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Target Audience

Target Audience: Educators and technicians helping landowners manage farms
Target Greenhouse Gases (GHG): Carbon Dioxide (CO_2)

Background Questions by Educator to Help In Landowner Planning

- What crops do you grow?
- What kind of livestock do you have?
  - How do you manage manure?
- What kind of tillage do you use?
- What kind of crop residues do you produce?
  - How do you manage your crop residues?
- What are your goals for managing your croplands, especially soil?
- Do you think your soil health could be improved?
- Would you consider converting any land from annual crops to perennial crops?
  - Or from perennial crops to annual crops?

Background on GHG Emissions from Soil Management

As plants grow, they remove CO_2 from the atmosphere and store it as carbon in the shoots, roots, and soil. As dead plant material is eaten by soil organisms, most of the carbon is released back to the atmosphere as CO_2. Soil carbon can be increased by (1) increasing carbon inputs to soil, (2) reducing the rate of soil carbon emission to the atmosphere. Figure 1 below illustrates the way in which carbon moves from the air into the plants by photosynthesis and is then distributed to the soil, water, and air depending on the pathway.

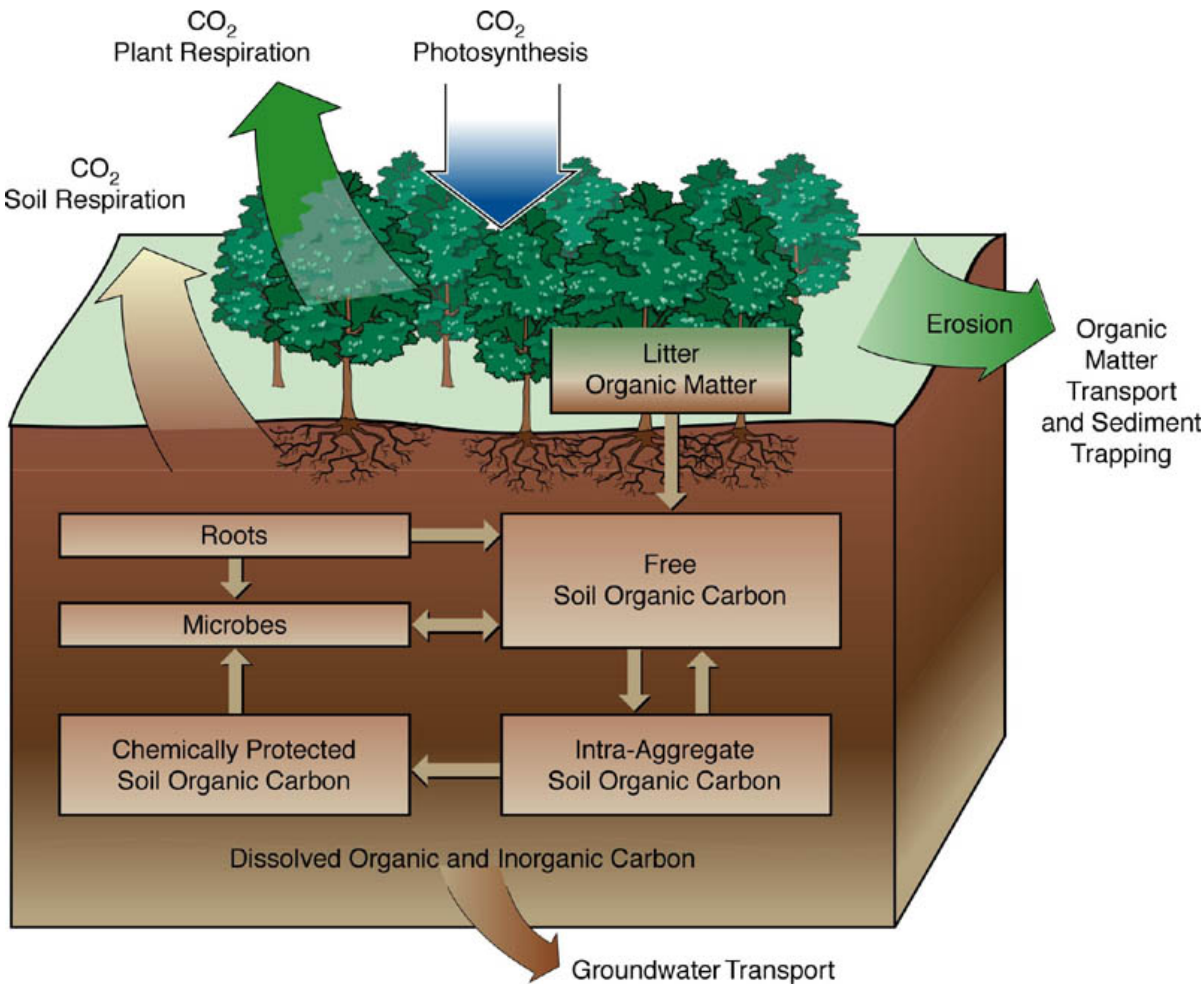

Figure 1: Carbon cycle with a focus on soils.
From Department of Energy "Carbon Sequestration Research and Development" 1999.
http://www.osti.gov/scitech/biblio/810722

Soil carbon (closely related to soil organic matter) is beneficial for soil health for many reasons, including improved water infiltration, improved water retention, reduced erosion, improved tilth, and improved biological activity. Increasing the amount of carbon stored in soils has multiple benefits, including improved crop health and yield, improved resistance to drought and flooding, improved water quality, and reducing carbon dioxide in the atmosphere.

There is significant opportunity to store carbon in soil for many years or decades especially with perennial vegetation such as forests and permanent hay or pastureland. However, soil carbon can be lost quickly with tillage—GHG mitigation benefits are quickly lost if a long-term sod is plowed or disturbed. It takes decades to build up (sequester) soil carbon but only up to a few years to lose it due to tillage (Woodbury et al. 2007).

The highest potential for carbon sequestration on agricultural land comes from planting trees on non-forest lands (afforestation), because carbon accumulates both in the soil and in the trees (see Information Sheet #7, Fahey et al. 2010). However, substantial increases in soil carbon also occurs when annual cropland is converted to perennial crops or permanent pasture. Below we discuss this and other practical approaches including adding crop resides, manure, or compost, and reducing tillage.

Key concepts and mitigation opportunities

1. **Reducing tillage increases soil carbon.**
2. **Adding crop residues to soil increases soil carbon.**
3. **Adding organic matter to soil increases soil carbon.**
4. **Adding cover crops or double crops increases soil carbon.**
5. **Replacing annual crops with perennial crops can greatly increase soil carbon.**

MITIGATION OPPORTUNITY 1: Reducing tillage increases soil carbon

Reducing tillage, particularly zero tillage methods, increases soil carbon by developing soil aggregate structure and slowing decomposition of soil organic matter. Reduced tillage can also improve soil health, including reducing erosion, improving tilth, and improving water holding capacity. All of these changes can improve crop performance, including resiliency during adverse weather conditions. Improved water holding capacity can improve crop growth during droughts, and improved aggregate structure can improve soil drainage, reducing waterlogging and erosion during extreme rainfall events.

However, these benefits require some time to build up, and may not occur for several years after the cessation or reduction in tillage. In fact, waterlogged soils can temporarily increase N_2O emissions following eliminating tillage (Six et al. 2004). Additionally, soil carbon can be lost very quickly if tillage is later increased, so it cannot be viewed as a 'permanent' mitigation of GHG emissions. Remaining knowledge gaps about effects of tillage on soil carbon include (1) whether the observed increases in soil carbon in the topsoil differ from those deeper in the profile and (2) whether erosion has been adequately accounted for in many field studies (Tonitto et al. 2016).

MITIGATION OPPORTUNITY 2: ADDING ORGANIC MATTER TO SOIL INCREASES SOIL CARBON

Adding crop residues or other organic matter to soils increases soil carbon and soil health. Such benefits will be even greater when combined with reduced tillage, which as discussed above will decrease the rate at which residues decompose. However, excess residues on the soil surface can keep soil too cool and wet in spring, and can interfere with early crop growth. Additionally, there may be other competing uses for residues, such as animal fodder, bedding, etc. Therefore, on many farms, especially those with livestock, there may be limited opportunities to return residues to soil. However, on livestock farms there is the opportunity to return manure and soiled bedding to soil, as discussed below (see Mitigation Opportunity 4).

MITIGATION OPPORTUNITY 3: Adding cover crops increases soil carbon

Having living plant root systems in the soil throughout more of the year increases soil health and soil carbon. Similar to adding crop residues, these benefits will be even greater when combined with reduced tillage. Intact root systems reduce erosion by holding the soil structure and preventing loss of carbon. However, cover crops require time, money, and careful management to avoid interfering with planting time in spring for the primary crop. Double cropping has the benefit of producing two marketable products, and many farmers in New York State include crops such as winter wheat in their crop rotations. Double crops increase total yield, but may reduce yields of the primary crop, which may limit their benefits. With ongoing climate warming that is occurring, there will be increased opportunities for double cropping throughout New York State.

MITIGATION OPPORTUNITY 4: Adding manure, compost, or biochar to soil increases soil carbon

Adding organic matter (such as manure, compost produced from plant material or manure, residues from food processing, or biochar) to soil increases soil carbon, especially combined with reduced tillage. As discussed above for other sources of organic matter, these sources can also improve soil health, including reducing erosion, improving tilth, and improving water holding capacity, which helps reduce the impacts of both drought and extreme rainfall events. When organic matter is available on the farm, it may already be returned to the soil, or it may be practical to do so, rather than disposal by other methods, such as burning. However, bringing organic matter from outside the farm can be time consuming and expensive unless a disposal (tipping) fee is paid to the farmer. Furthermore, some materials require processing, such as making compost, which adds to the time and cost required for management. In particular, biochar is expensive to produce and there is currently little or no commercial experience nor conversion facilities available to produce it within New York State. However, biochar remains in the soil longer than other forms of soil carbon, so there is research investigating whether it is possible to develop commercially viable systems for producing biochar and adding it to soils.

MITIGATION OPPORTUNITY 5: Replacing annual crops with perennial crops can greatly increase soil carbon

The highest potential for carbon sequestration on agricultural land comes from afforestation (see Information Sheet #7). Similarly, substantial increases in soil carbon also occur when annual cropland is converted to perennial crops or permanent pasture. Perennial crops, pasture, and tree root systems sequester soil carbon, use nutrients more efficiently, and reduce erosion from extreme rainfall events. Compared to annual cropping with conventional tillage, up to 25% more soil may be stored in the topsoil under perennial vegetation, whether it is pasture, hay, forest etc. (Wightman & Woodbury 2015, Woodbury et al. 2007). Because the carbon in plants comes from the air, this increased soil carbon sequestration mitigates greenhouse gas accumulation in the atmosphere.

Annual crops may be more vulnerable to extreme weather events than perennials. In place of some annual crops, livestock farmers may wish to explore opportunities for using perennial crops including improved pasture, hay, and forage systems, and different methods of processing and storing harvested materials, including haylage and other silage, and technologies such as ammonia fiber expansion. However, annual crops provide many important benefits as livestock feed and as marketable products, and on many farms, there may be limited opportunities to replace them with perennial crops without a change in the cropping system or farming system.

COMPLICATIONS: C:N relationships in soil

Because N_2O is 298 times more potent than CO_2, managing soil N is important. No till and cover cropping systems, especially those that fix nitrogen, increase soil N, and can in some cases increase N_2O, especially between crops (after cover crops/crops have been killed) but before crops are actively growing. In such situations, these systems may not mitigate GHG emissions, but may still be beneficial to farm productivity and soil carbon. Simply put, the nitrogen emissions from soil can sometimes negate the benefits of carbon sequestration for total GHG emissions. However, the other carbon benefits that increase yield and reduce erosion are valuable and important factors for farm sustainability. Please see Information Sheet #5 for recommendations on managing soil nitrogen to reduce GHG emissions.

Resources and Tools

The following documents provide additional information about the topics discussed in this Information Sheet.

- A scientific review article by Paustian et al. (2016) provides a brief global overview of many important ways that improved soil management can mitigate greenhouse gas emissions.
- A scientific review article by Eagle & Olander (2011) outlines the GHG mitigation potential of 42 agricultural management strategies and found that sufficient data exist to promote 20 strategies for their GHG reduction potential.
- The book chapter by Ogle et al. (2014) provides an overview of many important ways that improved soil management can mitigate greenhouse gas emissions.

To learn more about opportunities to reduce GHG emissions, see other information sheets in this series:

Tier II Worksheets	Identifying Farm & Forest GHG Opportunities

Information Sheet	**Topic**
IS#1	Intro to Farm & Forest GHG
IS#2	Dairy Manure Storage
IS#3	Planning for Quantitative Methane Capture and Destruction from Liquid Dairy Manure Storage
IS#4	Energy Efficiency
IS#5	Nitrogen Fertilizer Management
IS#6	Soil Carbon Management
IS#7	Forest Management

AEM Technical Tools	Water Quality BMPs http://www.nys-soilandwater.org/aem/techtools.html

Vocabulary

Afforestation: Planting trees on land that hasn't been forested for at least 50 years (does not include tree growth after tree harvest of forest land**).** Afforestation is a subset of reforestation.

Ammonia Fiber Expansion (AFEX™): Uses anhydrous ammonia in a controlled temperature and pressure reaction to break down plant cell walls, and then enzymes are added to break apart the sugars.

Biochar: A solid dark-colored charcoal-like material produced by means of pyrolysis (a thermochemical process) in a low oxygen environment.

Carbon Sequestration: The storage of carbon in a biological or geological sink (also called a reservoir or pool). Biological sinks include soil, trees, wetlands, and the ocean. There are many ways to sequester carbon. For carbon sequestration to have a meaningful impact on the atmosphere it is necessary to ensure that the carbon remains sequestered and is not released back into the atmosphere.

Greenhouse Gas (GHG): Any gas that causes atmospheric warming by absorbing infrared radiation in the atmosphere (common greenhouse gases include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), halogenated fluorocarbons (HCFCs), ozone (O_3), perfluorinated carbons (PFCs) and hydrofluorocarbons (HFCs).

Haylage: Silage made from grass that has been partially dried.

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Credits & Acknowledgments

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Date: Last updated 2017

Funders: This work was supported in part by the USDA National Institute of Food & Agriculture Project 2011-67003-30205, Hatch Project 1004302, McIntire Stennis Project 1000999, and by the NYS Soil & Water Conservation Committee's Climate Resilient Farming program.

Collaborators: Cornell Institute for Climate Change & Agriculture (D. Grantham) and NYS Department of Agriculture & Markets (G. Spitzer, G. Albrecht, B. Steinmuller).

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