What's Growing On?

Farming Carbon—a brief look at carbon and agriculture

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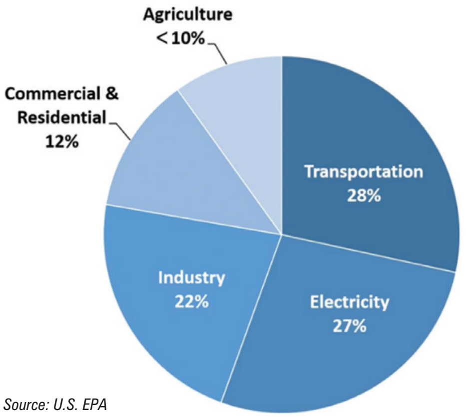
Carbon is at the forefront of discussions concerning greenhouse gases (GHG's), climate change, and agriculture's role in the future of a green economy. Recently, it is difficult to find a sentence with *carbon* that does not also include *agriculture*. For the foreseeable future, these two words will be most likely intertwined in agriculture policy decisions aimed at reducing greenhouse gases and battling climate change worldwide.

On a relative scale, U.S. agriculture is reported to account for 10 percent of the total U.S. GHG emissions. (Figure 1). Current discussions are largely focused on how agriculture can be used to offset GHG emissions and reduce its relatively small emission footprint. While some view this as a panacea for GHG reductions, others are taking a more cautious and realistic approach as to how much of an impact agriculture can have. Irrespective, this is not a bad spot for agriculture to be in.

What is agriculture's role in all this and how can agriculture contribute to the reduction in GHG's? The buzzword here is carbon sequestration—or trapping carbon in annual and perennial plants, trees, decaying residues, and largely in the soil beneath our nations row cropping systems. However, sequestration does not end there as there are much broader implications regarding soil health, conservation, and implementation of progressive farming technologies.

Figure 1

Total Greenhouse Gas Emissions in the U.S. during 2018.



Source: U.S. EPA

The carbon cycle of life

Carbon is *the* backbone of life. It is also a drifter—transient in our atmosphere and typically only stopping for brief stays. This movement of carbon through life (and death) and the interludes through air, water, and earth has implications for GHG emissions depending on how long carbon stays in one place, and how willing it is to stay for a longer time. This movement of carbon is called the carbon cycle and a discussion of sequestration begins here (Figure 2).

Carbon in its most well-known form, carbon dioxide (CO_2), is an important part of our atmosphere, but when there is too much in the air it can create problems. Although CO_2 accounts for roughly 0.04% of our atmosphere, its levels have been rising at an increasing rate and this rise is correlated with increasing global temperatures and climate instability, referred to as the "greenhouse effect".

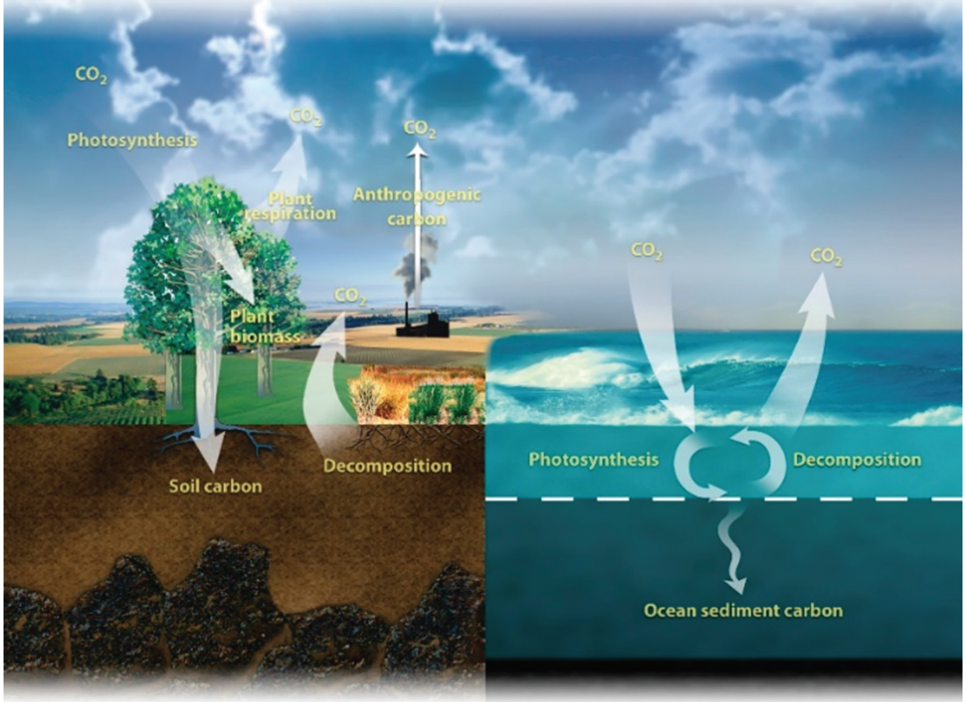
Carbon is taken in by plants as CO_2 through the pores in leaves, stems, and other plant organs. This phenomenon is known as photosynthesis where CO_2 is converted into carbohydrates. It is here that CO_2 is fixed or captured within the plant to produce a multitude of organic carbon compounds necessary for plant growth and metabolism. The compounds are used to construct cell walls and are the backbone of the structure of plants from roots to stems to leaves to grain. In fact, carbon, along with its carbohydrate components, hydrogen, and oxygen, make up over 90-95 percent of the dry weight of most plants.

However, all plant tissues die, and most of the carbon that was fixed or captured within tissues is quickly "cycled" back to CO_2. This happens as the dead plant matter is consumed by microorganisms, and invertebrates, on and below the soil surface. These organisms also expire, and in turn the initial plant carbon is "turned over" once again and consumed by other organisms. As the process continues, more CO_2 is released as the carbon compounds are oxidized by microorganisms. This phenomenon, called soil respiration, is the combined respiration of millions of organisms that are consuming the decaying organic carbon that for the most part originated from plants. This carbon is called active carbon, and it is considered unstable because once the carbon inputs cease, the amount of active carbon in the soil declines as the microorganisms eventually cannibalize the remaining active carbon pool. Irrespective, active carbon cycling is the first step in meaningful carbon sequestration in agriculture ecosystems.

A small fraction of active carbon that enters the soil becomes "trapped" in stable, relatively large, recalcitrant carbon compounds that are resistant to further soil microbial decomposition.

These compounds are collectively called humus and represent the largest carbon storage capacity of soil. Humus carbon can last much longer in soil than active carbon and can be sequestered in agriculture ecosystems for longer periods. Much of the focus of recent interest is that this carbon can be sequestered into a dynamic, stable cycle whereby more carbon can be maintained in the soil ecosystem.

Figure 2
Global Carbon Cycle.



Source: U.S. Carbon Cycle Science Program.

Soil Organic Matter—the basis for agricultural carbon sequestration

The amount soil carbon (soil C) is directly correlated with the amount of soil organic matter (SOM). That is why organic matter levels are of great interest and the measure by which soil carbon gains or losses is evaluated. In undisturbed soils such as those found under long-established forests, grasslands, and prairies the level of SOM is “maxed out” and mostly in equilibrium with the environment. The amount of carbon sequestered will not increase or decrease much unless environmental conditions change. Factors such as rainfall, temperature, soil type, human disturbance, and others determine both the amount of carbon inputs and the amount of biological activity which in turn determine the level of SOM.

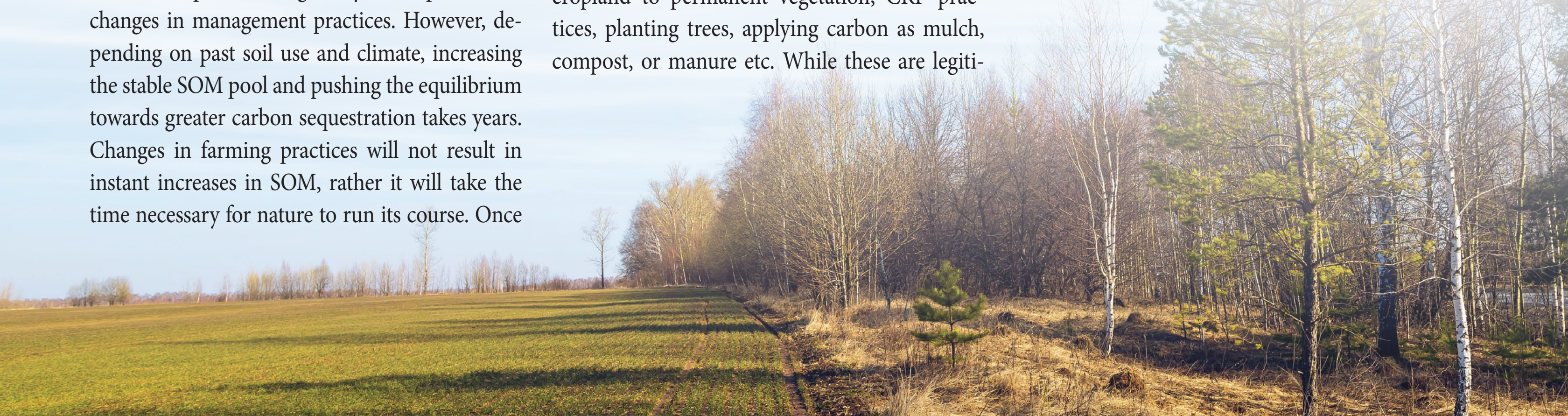
As agriculturists altered the landscape for cropping, SOM levels dropped due to erosion, vegetation change, constant cultivation, along with other factors that altered the dynamics of carbon inputs and the soil atmosphere. These events were viewed as necessary for the development of society, irrespective of how we view them today. While some dwell on the negative aspect of agriculture’s past impacts, the upshot is that we now have several hundred million acres of agricultural lands that can store more carbon than they currently do.

Today, most topsoil under cultivation ranges between one and six percent SOM. The SOM of many of these soils, particularly those in the less than three percent range may be improved via changes in management practices. However, depending on past soil use and climate, increasing the stable SOM pool and pushing the equilibrium towards greater carbon sequestration takes years. Changes in farming practices will not result in instant increases in SOM, rather it will take the time necessary for nature to run its course. Once the equilibrium balance has shifted, and SOM has increased, the farming practices that got it there, must be maintained or the equilibrium will regress back towards its starting point.

Management for Carbon Sequestration

Agricultural producers have multiple management options for improving carbon sequestration in their acres. However, on actively cropped ground that has the capacity to improve SOM levels, cover cropping and reducing tillage are garnering the most attention. Keep in mind this article only focuses on actively cropped acres, and not considering things like converting cropland to permanent vegetation, CRP practices, planting trees, applying carbon as mulch, compost, or manure etc. While these are legitimate practices and considerations that have large carbon implications, they are not implemented on croplands in much of the country.

Cover crops as the name implies are integrated into cropping systems to keep the soil covered with vegetation. They have a two-fold impact on carbon sequestration. The first impact is to reduce or eliminate possible SOM loss by reducing topsoil erosion. Secondly, cover crops are source of carbon inputs into the active carbon cycle. The fixed carbon results from growth of what is seen aboveground that covers the soil, but more importantly from what is not seen—the roots. It is the roots that are the greatest driver of soil health outcomes simply because root carbon is already



where it needs to be—in the soil. Irrespective, cover crops fix carbon in temporary, short-cycle, storage while slowly adding carbon to the stable, longer-term SOM pool. A thorough summary of cover crop research indicates that cover crops impact on soil carbon is site specific. Results depend on the amount of cover crop biomass (above and below ground), how long the land has been cover cropped, the soil carbon levels before implementing cover crops, soil type, cover crop species, tillage, and climate.

The impact of soil tillage on carbon sequestration is currently a point of controversy among some researchers. Nonetheless, well-understood principles of tillage suggest that less tillage, when possible, is better than more tillage for maintaining a stable SOM pool. Tillage, like cover crops, has both erosion and carbon input facets that complicate analysis of its effect on SOM.

First, tillage disturbs topsoil and makes it prone to erosion from wind and precipitation. While this may remove SOM from the site, the outcome of that carbon is not fully understood. The primary impact of minimizing tillage is a reduction in the loss of carbon rich topsoil directly by limiting soil disturbance. Overwhelming evidence indicates that no-till systems generally have higher SOM levels in the top few inches of the soil.

The effect of no-till deeper in the soil profile is not as certain. Conventional tillage does serve to incorporate aboveground plant biomass into the soil—one thing that no-till does not. This action gets the carbon from aboveground into the soil where it needs to be to become incorporated into SOM pools. However, tillage is known to breakdown soil aggregates that contain carbon and aerates soil, which in turn, may accelerate decomposition of SOM and increase soil carbon loss.

A Look at the Numbers

There are a wide range of estimates being reported as to how much carbon can be stored in actively farmed croplands depending on the practice being implemented. For instance, some estimates for cover crops are as high as 1.1 to 1.8 metric tons of carbon per acre per year. The Sustainable Agriculture Research and Education (SARE) estimates cover crops have the potential to sequester an average as high as 0.81 metric tons of carbon per year. The standard developed from a global meta-analysis of cover cropping suggests a global average of 0.086 metric tons of carbon annually per acre. Another heavily cited research review[1] suggests soil carbon gains of 0.04-0.40 metric tons per acre per year is a more plausible range.

TABLE 1

COMET-Planner Output for Two NRCS Conservation Practices at Select Locations Across the United States.

Growth Stage	NRCS Conservation Pratice	
	Intensive Till to No Till or Strip Till (CPS 329) Non-Irrigated	Adding Non-Legume Cover Crops (CPS 340) Non-Irrigated
	Meteric Tons of Carbon Sequestered Per Acre Per Year	
Boone County, IA	0.1701*	0.0567
Cheyenne County, CO	0.0648	0.0270
Johnson County, MO	0.1566	0.1431
Lubbock County, TX	0.0864	0.0351
Onslow County, NC	0.1107	0.0945
Sharkey County, MS	0.1269	0.2403

Tillage numbers are even more difficult to pinpoint, largely because soil sampling is labor intensive—particularly at depths below two or three feet. Most research has primarily focused on SOM levels in the upper inches or foot and researchers are just beginning to understand soil C at deeper depths. Much of this disparity results from a lack of consistent research methodology for determining the amount of carbon in the soil.

In 2006, the Intergovernmental Panel on Climate Change created the Guidelines for National Greenhouse Gas Inventories. Subsequently, using these guidelines, the USDA developed methods for quantifying greenhouse gas fluxes in the United States—including soil measurements. The USDA—Natural Resources Conservation Service (NRCS) took the lead on the agricultural side by integrating data from multiple disciplines with NRCS Conservation Practices to provide estimates of emission reductions or increases with the implementation of different practices. Their platform COMET-Farm and COMET-Planner are user friendly tools that generate estimates that different practices have on carbon emissions.

The estimates are listed in CO_2 equivalents to directly compare the impact of practices on GHG emissions—but can be converted to sequestration estimates. COMET-Farm uses producer management information with spatially explicit data on climate and soils from USDA databases to model management impacts and compare changes in management scenarios to forecast future carbon sequestration. COMET-Planner on the other hand is a more generic version that provides generalized estimates for, as the name implies, planning purposes.

Output from the COMET-Planner tool on the effects of tillage and cover crops on carbon sequestration is provided below. The output of the simulations is listed as CO_2 equivalents, but since CO_2 is 27 percent carbon, converting the CO_2 equivalents to carbon sequestration is a simple task. For brevity and demonstration purposes, results for a couple of practices in multiple locations are provided for comparison (Table 1).

The values generated illustrate the sensitivity of the values depending upon the region in which the practice is implemented and reflects differences in climate, growing season length, etc. These estimates indicate a range of 0.06 to 0.17 MT of carbon sequestered annually for converting from conventional tillage to no till, and a range of 0.03 to 0.24 MT of carbon sequestered annually for implementing cover crops. The estimates for cover crops are more closely aligned with the lower end of estimates mentioned previously. These values appear to provide a realistic picture for comparison purposes.

It is evident that there is much to be examined regarding agriculture's role in sequestering carbon, GHG reductions, and climate change. This article does not discuss the great strides that animal agriculture is taking to limit C loss to the atmosphere. In addition, there are many more important factors relating to carbon—particularly soil health and its impact on cropping resiliency in the face of an uncertain climate. Moving forward, future discussions and analysis will no doubt link these factors together into more coherent policy objectives.

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[1] Blanco-Canqui, H., T.M. Shaver, J.L. Lindquist, C.A. Shapiro, R.W. Elmore, C.A. Francis, G.W. Hergert. 2015. Cover crops and ecosystem services: Insights from studies in temperate soils. Agron. J. 107:2449-2474.