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HOW MUCH CARBON CAN YOU STORE IN THE SOIL AS ORGANIC MATTER?

Ronald W. Rickman, Clyde L. Douglas, Jr., and Stephan L. Albrecht

Introduction

There is an international interest in reducing the release of CO_2 (carbon dioxide, one of the greenhouse gasses) into the atmosphere. Greenhouse gasses are blamed by many for global warming, which may lead to more frequent undesirable, extreme weather and, if polar ice melts at accelerated rates, sea level rise (Lal et al., 1998). At the Kyoto conference on global warming in 1997, representatives of the United States government agreed to reduce greenhouse gas emission by the year 2012 to 7 percent below the emission levels of 1990. The amount of carbon (C) required to do this was estimated at 661 million tons annually (600 million metric tonnes of C). The European Union and Canada already are considering taxing atmospheric CO_2 emissions in an effort to slow CO_2 release. Industries who burn large amounts of fossil fuels, thereby emitting large amounts of CO_2 into the air, have found it will be cheaper in the short run to pay someone else to save C for them until they can upgrade or rebuild their current power generating facilities. These industries will be the source of a well funded demand for the capacity to store C.

Governmental subsidies also may be a source of funding to stimulate C storage. Among possible methods for reducing CO_2 release is to capture it in plants (using photosynthesis) and store a portion of the plant material (e.g., stubble or stalks) in the soil as organic matter (OM) (Lal, 1999). International negotiations are scheduled for the fall of 2000 to establish mutually acceptable standards for predicting and monitoring soil OM content so that it may be used as a storage medium to offset industrial burning of fossil fuels.

An important question often asked is: How much C can be stored in the soil as OM? Both field observations and modeling work conducted at the Columbia Plateau Conservation Research Center near Pendleton, Oregon provide answers to those questions. The objectives of this report are to describe the natural processes that influence soil OM formation or loss and to illustrate the influence of crop management and tillage practices on the potential for C storage in soils throughout the Pacific Northwest.

Discussion

What is C sequestration? It is the net storage, on a more or less permanent basis, of C. Sequestration of C in the soil as OM appears to be one of our more economically promising options for large scale removal of CO_2 from the atmosphere and then storage of C (Lal et al., 1998). The soil is one of the larger natural reservoirs of C. Most C in the soil occurs as OM. So, what is soil organic matter (SOM)? It is normally recognized as stable C containing compounds of animal or plant origin that remain in the soil after extensive microbial decomposition of the original residues. Soil OM is very beneficial for crop growth as it provides nutrient and water holding capacity, improved water infiltration, and the potential to resist changes in soil pH. It is distinct from actively decomposing animal or plant C-containing compounds whose origin still can be determined. Identifiable organic debris is not yet "organic matter" as just defined. It must be fully decomposed or composted and intermixed with the mineral soil before it takes on the stable qualities that make it real "organic matter."

What do crop production practices do to SOM? Tillage speeds the breakdown of crop residues and SOM. Consider the original need for tillage. The mass of grass stems and roots in an untilled prairie or in forested soil make it difficult to plant and grow most agricultural crops. Tillage helps to bury and speed the decomposition of those bothersome residues, and speeds the decomposition of the OM to release the nutrients contained in it.

Many, but not all, management practices accelerate the loss of SOM. It is not unusual to find in soils that have been cultivated for 100 years or more only half of the organic matter present in uncultivated native grassland. Annual cropping, with the return of all crop residues to the soil, infrequent tillage, and addition of supplemental organic residues such as manure, can lead to an increase in the OM content of cultivated soils.

Soil OM content has been observed regularly over a 60-year interval on long term experimental plots on the Pendleton Research Center (Rasmussen et al., 1989). In all treatments where fallow with no supplementary residues or residue removal were practiced, OM content of the soil has declined continuously. In these summer fallow systems, only where manure has been added every other year has the OM content not fallen. Other long term experiments (Rasmussen et al., 1998) illustrate that annual cropping (as compared to any rotation with a regular fallow year) slows the decline in SOM.

A residue decomposition model ('D3R') created at the CPCRC (Douglas and Rickman, 1992) was calibrated locally and has been tested successfully throughout the continental U.S. and internationally. The model 'D3R' accurately has predicted residue decomposition for a variety of crops (wheat, barley, corn, soybeans, peas, canola, red clover) utilizing a number of data sets from Alaska (Cochran, 1991), Washington (Stott et al., 1990), Oregon (Douglas et al., 1980), Idaho (Smith and Peckenpaugh, 1986), Missouri (Broder and Wagner, 1988), Indiana (Stott et al., 1990), North Carolina (Buchanan and King, 1993), Georgia (Thomaston, 1984), Texas (Stott et al., 1990), Colorado (Liang Ma et al., 1999), Canada (Moulon and Beckie, 1993, 1994; Curtin et al., 1998), and Uppsula, Sweden (Berg et al., 1987). The decomposition model uses multiple pools of exponentially decaying compounds. Temperature drives the decay process, which is modified further by water and nutrient content of the residue. Cropping rotations determine the amount and type of residues returned to the soil, and tillage practices determine residue burial.

The decomposition model was expanded to include routines to determine SOM loss and formation and given the name "CQESTR." In addition, it was designed to utilize existing data already contained in files created for the Revised Universal Soil Loss Equation (RUSLE, Renard et al., 1997). CQESTR was calibrated (Rickman et al., 2000) using the management history and SOM observations from a crop residue experiment at the Pendleton Experiment Station (Rasmussen & Smiley, 1994).

To use CQESTR to determine the expected trend in SOM for a specific field, one needs to provide specific management information for that field. That information includes the crop rotation practiced in the field with expected crop yields, amount and timing of all tillage practices, local average daily temperature, past or current OM content of the soil, and the nitrogen content of residues added to the soil. Most of the crop rotation and tillage information are very conveniently available from c-factor files created by the RUSLE erosion prediction equation (Renard et al., 1997). For this reason, CQESTR is designed to use those existing c-factor files. Residue nitrogen content and initial SOM information can be obtained from available historic crop residue analyses and county soil surveys.

To illustrate the possible range of C storage as SOM, Pullman, Washington, Pendleton, Oregon, and Moro, Oregon (located with stars in Figure 1) were selected to represent three of the major agronomic zones in the Pacific Northwest (Douglas et al., 1985). The same rotations of wheat/fallow and annual cropping with moldboard plow, sweep till, and no-till are used in each zone. The actual tillages used in the rotations are listed in Table 2. It is the amount of residue burial by the actual tillage operations that drives the model, not the type of tillage operation used. For example, a sweep could bury far less residue than a heavy no-till drill that causes significant soil disruption. Table 1 provides the predicted rates of loss or gain of C for all of the rotations for all three of the agronomic zones. Note that it is the actual burial of residue by tillage implements (Table 2) that controls the accumulation of OM, not just the name (e.g., no-till) of the management system.

Storage of C in cultivated soils of the Pacific Northwest appears to be possible. However, the CQESTR model predicts that the use of fallow in a rotation will make it very difficult to store C, and this is consistent with observed results in the region. Both annual cropping and reduced burial of crop residues by tillage increase the chances for long term building of SOM. Addition of supplemental organic residues or other organic material can provide a boost to SOM content.

This analysis is only for the impact of farming practices and biological processes on SOM content. Other factors that may influence trends in OM content in a field must be considered independently. For example, soil erosion by water or wind moves surface soil from one place to another. The migrating soil almost always is from the surface, which is richest in OM. Loss of this soil is a blow to any attempt at building the average OM content in that field. However, if soil eroded from one field can be captured in another, the captured soil may well be carrying a bonus of OM with it.

As questions about SOM content and soil C storage become important to individual farms, the computations available from the model CQESTR will provide guidance as to the effect of rotations and practices on changing SOM.

Figure 1. Agronomic zones in the Pacific Northwest.

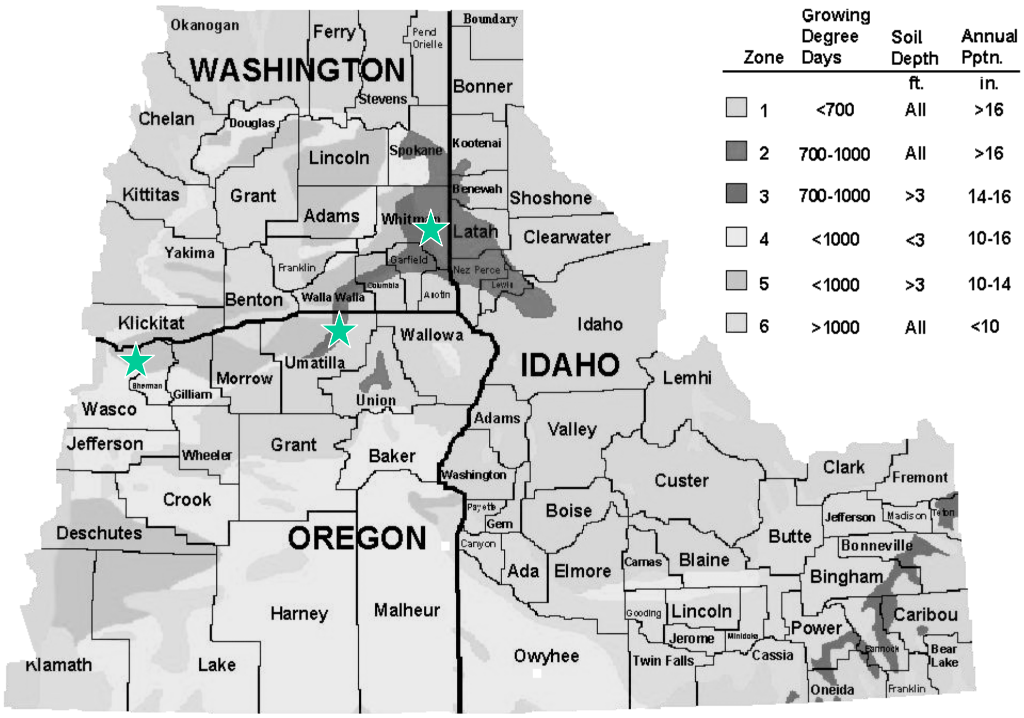

Table 1. Predicted rate of carbon storage (or loss) for several rotation options at three locations in the Pacific Northwest.

Tillage System	Moro-AZ* 5		Pendleton-AZ 3		Pullman-AZ 2	
	W/F** 50 bu/a	Annual 30 bu/a	W/F 80 bu/a	Annual 50 bu/a	W/F 110 bu/a	Annual 70 bu/a
	----------Pounds/acre/year in 2 feet of soil----------					
Plow	(-75)	85	(-185)	40	(-220)	255
Sweep	60	380	15	500	105	985
No-till	185	295	190	360	400	775

* AZ = Agronomic zone (see Fig. 1 and Douglas et al., 1992).
** W/F = Wheat-fallow crop rotation.

Table 2. Tillage operations used in each rotation.

Primary Tillage			-------Moldboard plow--------		------------Sweep------------		----------No-till----------	
Mo	Day	Yr.	Operation	Residue remaining	Operation	Residue remaining	Operation	Residue remaining
				(%)	**Wheat Fallow**	(%)		(%)
10	15	1	disk drill	90	disk drill	90	Heavy nt drill	65
3	15	2	spray weeds	100	spray weeds	100	spray weeds	100
7	15	2	harvest	100	harvest	100	harvest	100
4	10	3	moldboard plow	5	sweep	85	spray weeds	100
4	15	3	light disk	55	-----	--	-----	--
4	20	3	field cultivator	75	-----	--	-----	--
5	15	3	rodweeder	90	field cultivator	75	stubble bust	100
6	10	3	rodweeder	90	rodweeder	90	-----	--
7	10	3	rodweeder	90	rodweeder	90	spray weeds	100
9	15	3	rodweeder	90	rodweeder	90	spray weeds	100
					Annual Wheat			
10	15	1	disk drill	90	disk drill	90	Heavy nt drill	65
3	15	2	spray weeds	100	spray weeds	100	spray weeds	100
7	15	2	harvest	100	harvest	100	harvest	100
9	1	2	moldboard plow	5	stubble bust	100	stubble bust	100
9	15	2	field cultivator	75	sweep	85	spray weeds	100

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