Soil Carbon Under Dryland Agriculture in the Columbia Basin of the Pacific Northwest as Assessed by C-Farm

C. O. Stöckle[1], A. R. Kemanian[2], D. R. Huggins[3], S S. Higgins[4]

[1]Department of Biological Systems Engineering, Washington State University, Pullman WA 99164-6120, stockle@wsu.edu
[2]Blackland Research and Extension Center, Texas Agricultural Experiment Station, Temple, TX, 76502
[3]USDA Agricultural Research Service, Pullman WA 99164
[4]Department of Biological Systems Engineering, Washington State University, Pullman WA 99164-6120

Introduction

Growers are increasingly interested in participating in the emerging carbon trading market and managing their cropping systems to increase the potential for carbon sequestration in the soil. Cropping systems using direct seeding technology provide environmental services by protecting the soil surface from water and wind erosion, reducing the energy requirement for mechanized operations, and sustaining soil quality. The current expectation is that direct seed technology will also enhance soil carbon sequestration.

Conditions leading to soil organic carbon (SOC) storage require evaluation, which cannot be easily accomplished via experimentation or direct observation. The use of computer simulation models has emerged as a valid approach to address carbon sequestration in agriculture, with increasing acceptance as a reasonable degree of confidence in model capabilities and accuracy is becoming well established.

The C-Farm Model

The principles for modeling soil carbon and nitrogen cycling (CNC) were formulated during the last decades and compiled in simulation models. A good review of models is given by Shaffer et al (2001). Models vary in the number of soil carbon compartments considered, in the detail with which residue decomposition is represented, and in the treatment of management operations affecting CNC. Although multi-pool models provide a more detailed representation of the system, it is arguable that they necessarily provide better predictability than single-pool models. The more complex models have the shortcomings of requiring proper initialization of the fraction of soil carbon to be apportioned to each pool and the need to calibrate decomposition and transfer rates among multiple pools. Single-pool models are much simpler to calibrate and do not require initializing multiple pools. For this reason, we have developed C-Farm as a simplified version of CropSyst (Stöckle *et al*, 2003), and we are starting to use the model with growers and extension personnel in the US Pacific Northwest (PNW). The use of C-Farm can be mastered with minimum training. The single-pool differential equation in C-

Farm for each soil layer is $dC_s/dt = h_x[1 - (C_s/C_{sx})^n]C_i - f_e f_t k_x(C_s/C_{sx})^m C_s$, where C_s is soil carbon (Mg ha^{-1}), t is time (year), C_i is carbon inputs (Mg ha^{-1}), h_x is the organic carbon inputs humification (yr^{-1}), which is a function of soil clay concentration and residue type (aboveground, belowground biomass, or manure), C_{sx} is the saturation carbon concentration for that layer (Mg ha^{-1}), n and m are empirical constants, k_x is the apparent maximum soil carbon respiration rate (yr^{-1}), and f_e and f_t are factors accounting for environmental and tillage effects on soil apparent respiration rate. In C-Farm, h_x is a function of soil texture and is different for root and aboveground biomass. Local effects of climate and soil type are accounted for through factors affecting the apparent soil decomposition rate k ($k_x = 0.055$ yr^{-1}). The factor f_e combines both soil temperature and moisture effects on k. Tillage accelerates soil turnover rates and mixes soil layers along with all the state variables (moisture, organic matter, and residues).

Simulations for Dryland Systems in Eastern Washington

An accurate assessment of current SOC is critical to establish the potential for carbon sequestration. This is demonstrated by simulation runs using C-Farm, based on cropping systems information provided by direct seeding growers in the PNW. Two options are given in Table 27.1 for initial soil organic matter (SOM) for each site and crop rotation, being the low and high ends of the SOM range of typical soils in each location (USDA NRCS, nd).

Table 27.1. Soil organic carbon (SOC) gain or loss (0 – 30 cm) over a 50-year simulation as a function of cropping systems and high/low initial soil organic matter (SOM) at selected locations of the US Pacific Northwest. All cases are for dryland farming using direct seeding.

Location	Precip (mm)	Rotation[†]	Initial SOM (%)	Final SOM (%)	SOC Gain/Loss (Mg CO_2e ac^{-1} yr^{-1})
Colfax, WA	500	**WW-SW-SB-CF**	3.4	3.0	-0.12
Colfax, WA			1.6	1.9	0.30
Colfax, WA		Crn-WW-Crn-Crn	3.4	3.0	-0.13
Colfax, WA			1.6	1.9	0.29
Colfax, WA		**WW-SW-WW-CP**	3.4	3.0	-0.09
Colfax, WA			1.6	2.0	0.34
Cottonwood, ID	550	**WW-SW-F**	2.8	2.4	-0.15
Cottonwood, ID			1.5	1.7	0.17
Cottonwood, ID		**WW-SW-SC**	2.8	2.5	-0.12
Cottonwood, ID			1.5	1.7	0.18
Cottonwood, ID		WC-WW-SC-WW-F	2.8	2.6	-0.02
Cottonwood, ID			1.5	1.9	0.31
Davenport, WA	380	**SB-SW-SW-WW**	3.5	3.1	-0.14
Davenport, WA			1.8	2.0	0.22
Heppner, OR	350	**WW-F**	1.9	1.7	-0.03
Heppner, OR			0.8	1.0	0.14
Heppner, OR		SB-SC-SW-CF-WW	1.9	1.8	-0.02
Heppner, OR			0.8	1.0	0.15

[†]WW = winter wheat, SW = spring wheat, SB = spring barley, Crn = maize, CP = chickpea, F = fallow, SC = spring canola, WC = winter canola, CF = chemical fallow

The projected average 50-year gain or loss of SOC in the top 30 cm of soil varies greatly and includes negative and positive SOC change depending on conditions. The annual change in SOC in these simulations (Fig. 27.1) further illustrates that an accurate knowledge of initial SOC is fundamental to properly evaluate the potential carbon sequestration of agricultural systems.

Figure 27.1. C-Farm simulation of SOC gain or loss as a function of initial SOM for selected sites and direct-seed cropping systems in the US Pacific Northwest.
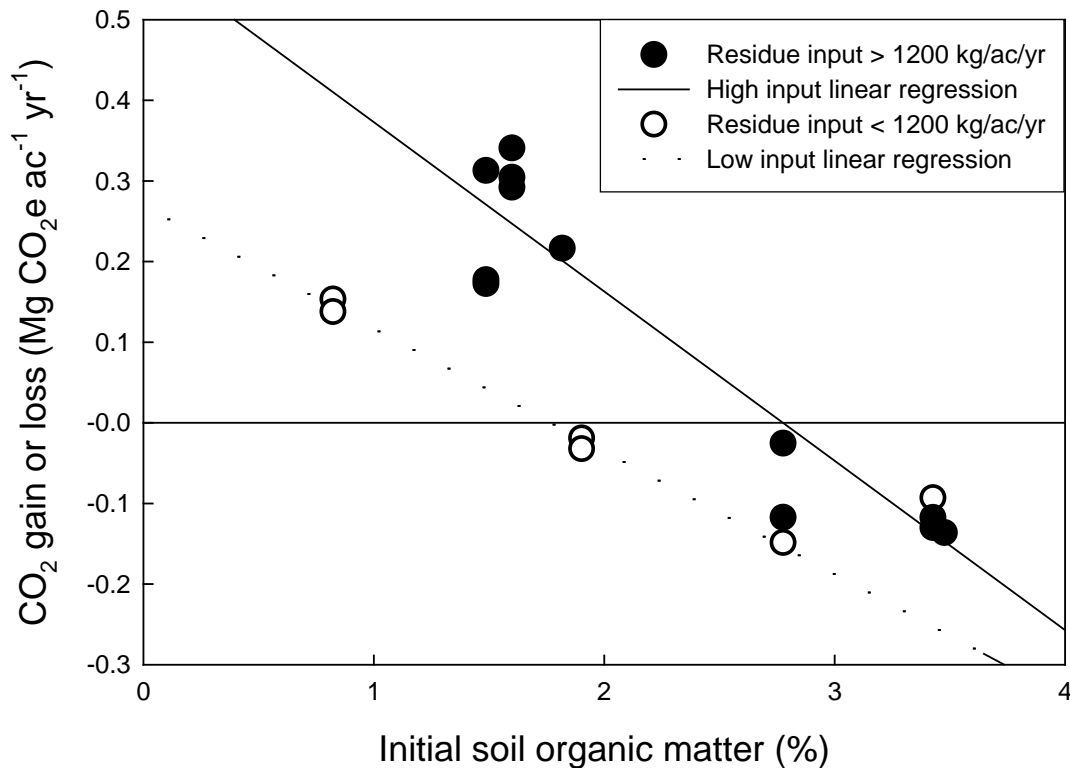
Our simulation results thus far indicate that the main factors defining the SOC sequestration potential of dryland agricultural systems in the US PNW are initial SOC (low better than high) > residue input to the soil (high better than low) > tillage intensity (low better than high), with the bulk of the potential defined by the first two factors.

A carbon trading market has emerged based on carbon savings that result from converting from conventional tillage (CT) to some form of conservation tillage such as direct seed (DS). But, uncertainty exists regarding the degree of benefit to be realized by converting from CT to DS. The results above were obtained by simulating DS practices, so they are of no use in determining the potential carbon benefits realized by converting from CT to a conservation tillage such as DS.

To assess the benefits of converting to DS, and to address the uncertainty in potential carbon credits, we established a new set of scenarios using only those locations and rotations highlighted in bold print in Table 27.1. For each of these locations and rotations the high and low initial SOM was retained. But in addition to a DS scenario, a CT scenario was added to allow assessment of the benefit of conversion to DS. To account for uncertainty in the benefit of conversion, two

possible SOM oxidation rates in response to tillage were programmed. Then, within a location/rotation/initial SOM/SOM oxidation rate, the annual SOC change for CT was subtracted from that for DS to obtain the C benefit to the conversion. The low SOM oxidation rate corresponds to an increase in SOM decomposition rate of 50%, while the high oxidation rate corresponds to a doubling of the decomposition rates. Thus, they provide boundaries for a large range of possible effects of tillage practices on carbon sequestration.

The results pertaining to conversion are presented in Figure 27.2. At a low SOM oxidation rate the benefit of converting to DS was about 0.1 Mg CO_2e ac^{-1} yr^{-1} except in Heppner where initial SOM was very low (Fig. 27.2.). Also at low SOM oxidation rate there was relatively little effect of initial SOM although there was a trend toward a greater benefit of conversion at the lower initial SOM. At a low oxidation rate, there was a greater benefit of conversion with a fallow season in both Colfax and Cottonwood (Fig. 27.2). Conventional tillage during the fallow season may be doing more damage to SOC where moisture is high enough to maintain microbial activity into the summer.

Figure 27.2. Simulated carbon benefit obtained by converting from conventional tillage to direct seed for a series of locations and rotations in the Pacific Northwest. Simulations were run at low and high initial soil organic matter (see Table 27.1) and at low and high soil organic carbon oxidation rates as affected by tillage. Rotation designations are as in Table 27.1. Location abbreviations are Cx = Colfax, WA; Cd = Cottonwood, ID; Dt = Davenport, WA and Hr = Heppner, OR.
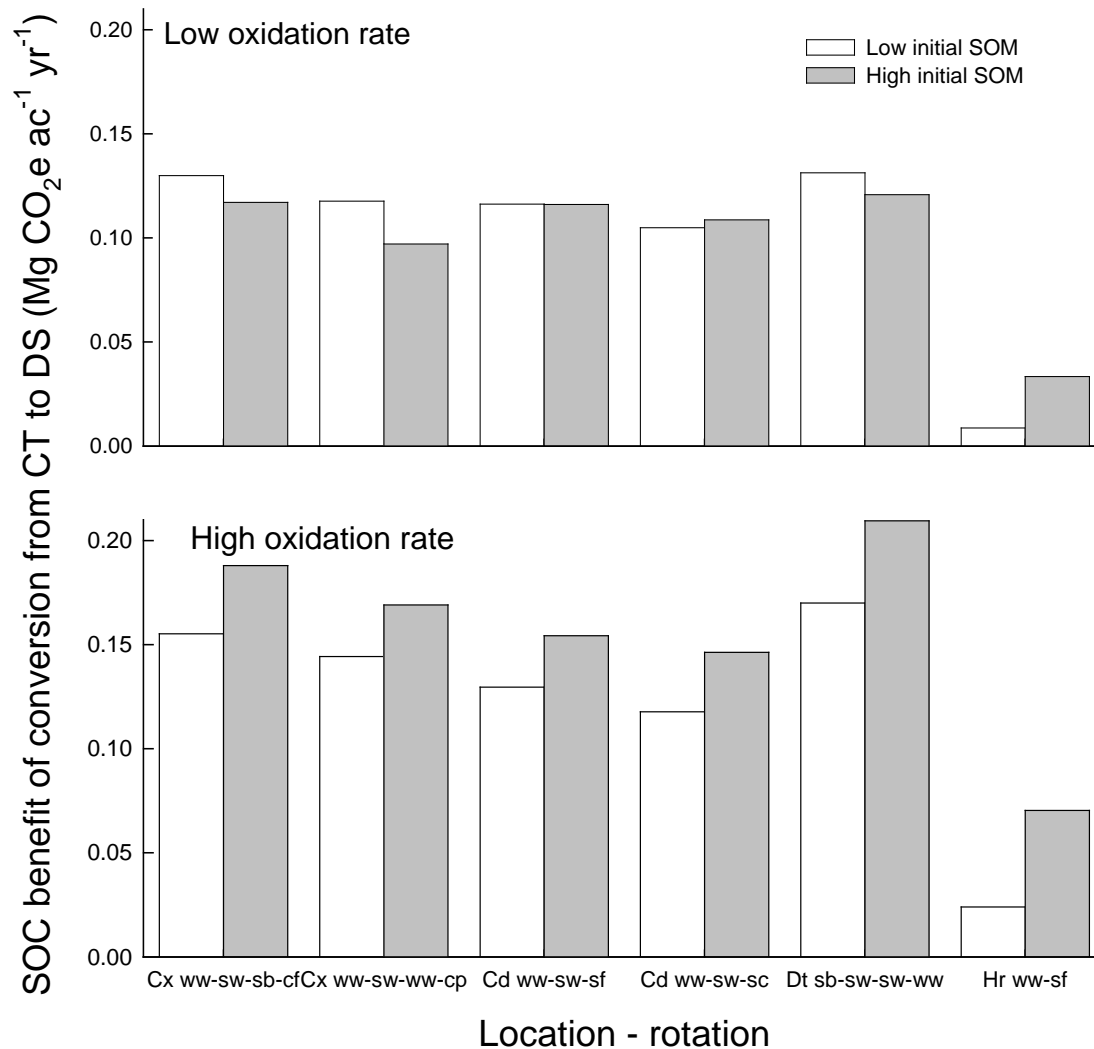
When tillage led to a higher oxidation rate the difference between DS and CT was larger (Fig. 27.2). And at the higher oxidation rate the benefit of converting to conservation tillage was consistently greater at high initial SOM than at low initial SOM (Fig. 27.2). When there was more SOC to oxidize, and the oxidation rate under CT was higher, the difference between DS and CT was magnified.

Figure 27.2 indicates a wide range in the potential benefits of converting from CT to DS. In Heppner the benefit of converting ranges from nearly zero to about 0.07 Mg CO_2e ac^{-1} yr^{-1}. In Davenport, however, the benefit ranges from a low of 0.12 to a high

of 0.21 Mg CO_2e ac^{-1} yr^{-1}. Clearly, the carbon benefit depends on numerous factors, including location, rotation, microbial activity and initial SOM.

Acknowledgements

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