SOUTHERN HIGH PLAINS CONSERVATION SYSTEMS EFFECTS ON THE SOIL CONDITIONING INDEX AND OTHER SOIL QUALITY INDEXES

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ABSTRACT

The Soil Conditioning Index (SCI) has been proposed to predict the consequences of management actions on the state of soil organic carbon (SOC). The index was developed based on research in humid, temperate, loamy soils but has not been tested for many other conditions. In this project, we determine the effects of management on SOC in semiarid, thermic, sandy soils. Study sites were located in the Southern High Plains of west Texas (SHP) where long-term native range or grasslands were adjacent to cropland. Agroecosystems studied included native rangeland, conservation grassland, cotton, wheat, wheat-cotton rotations, high residue sorghum/forages, and a sunflowers wildlife planting. The cropland included irrigated and dryland, conventionally-tilled and no-tillage systems. Three replications were sampled on each field. Soil properties measured in the upper 10 cm were soil texture, bulk density, pH, phosphorus, nitrate and total nitrogen, total organic and particulate organic matter carbon, and wet aggregate stability. The SCI was determined using RUSLE2. Soil conditioning index values varied from -1.49 for conventionally-tilled dryland cotton to 2.29 for the conservation grassland. The SCI was negative for all conventionally tilled sites and positive for the native rangeland, conservation grassland and all no tillage sites with the exception of a low production, no tillage dryland wheat site. The SCI was most strongly correlated with the average residue production ($r=0.67$) as estimated in RUSLE2 and particulate organic matter ($r=0.53$). In this study, the OM sub-factor of SCI was not correlated with SOC mass but was correlated with particulate organic matter carbon ($r=0.42$; $P<0.007$) and was most strongly correlated with the average residue production ($r=0.71$; $P<0.0001$).

INTRODUCTION

The USDA, Natural Resources Conservation Service has adopted the SCI to evaluate cropland management systems in the US. The SCI is a tool used to predict the consequences of management actions on the state of SOC, a soil quality indicator. Organic matter is a primary indicator of soil quality and an important factor in carbon sequestration and global climate change.

The index predicts qualitative changes in SOC in the top 10 cm (4 inches) of soil based on the combined effects of three determinants of organic matter using the following equation:

$$SCI = [OM \times (0.4)] + [FO \times (0.4)] + [ER \times (0.2)] \quad [1]$$

where OM represents the organic material or biomass produced and returned to the soil, FO signifies field operations including tillage and other field procedures, and ER corresponds to the influence of wind and water erosion (NRCS, 2003). Note that OM and FO each account for 40% of the final SCI value and wind and water erosion represent 20%.

The SCI is an important soil management index and is required by several criteria of practice standards, including the Conservation Crop Rotation (328) practice standard and as an additional criteria in the Residue and Tillage Management - No Till/Strip Till/Direct Seed (329) practice standard, and is specified for use in the Conservation Security Act of 2004. However, only one study testing the SCI for various conservation systems has been reported.

The SCI was developed based on research conducted from 1948 to 1959 in a humid region with high clay soils at Renner, Texas, USA. Further testing of the concept was provided using data from Iowa and Montana. An evaluation of SCI using nine long-term carbon studies found that positive trends in carbon followed positive trends in SCI and negative SCI trends were associated with negative carbon trends (Hubbs et al., 2002). Correlations of carbon and SCI were improved when data were separated by states.

The SCI assumes tillage reduces SOC and that maintaining organic residues will maintain and increase soil organic levels. The amount of reduction of SOC due to tillage and erosion depends on the native level that may be sustained for a given site and region. Research studies have evaluated the amount of SOC and other soil quality indicators for loamy SHP soils (Potter et al., 1997; Unger, 2001) but little data is available for sandy soils. Previous research from a sandy soil in the SHP of Texas has shown that tillage of long-term grassland will reduce SOC levels by 50% (Zobeck et al., 1995). In a companion study to this study (Bronson et al., 2004), the total soil carbon in the upper 30 cm was 34 Mg ha^{-1} for native rangeland and 23 Mg ha^{-1} for cropland soils. Total soil C in conservation grassland land was greater than cropland soils only in the 0- to 5-cm layer, and was 24 Mg ha^{-1} in the upper 30 cm. However, considerable uncertainty still exists in the application of the SCI concept and its relation to SOC and other soil quality parameters in warm, semiarid regions, particularly in sandy soils such as those that occupy millions of acres in the SHP. In this study, we relate SCI values with other soil quality parameters for a wide variety of SHP land management systems in sandy soils of this semi-arid, hot region.

MATERIALS AND METHODS

We identified 54 field sites in six counties (Crosby, Cochran, Hockley, Howard, Lubbock, and Terry) across the SHP that represented major cropping systems, and conservation planted and native grasslands (Fig. 1). Twelve agroecosystems were sampled (Table 1). Most conservation grassland sites had been in grassland for at least 10 years and are adjacent to conventionally

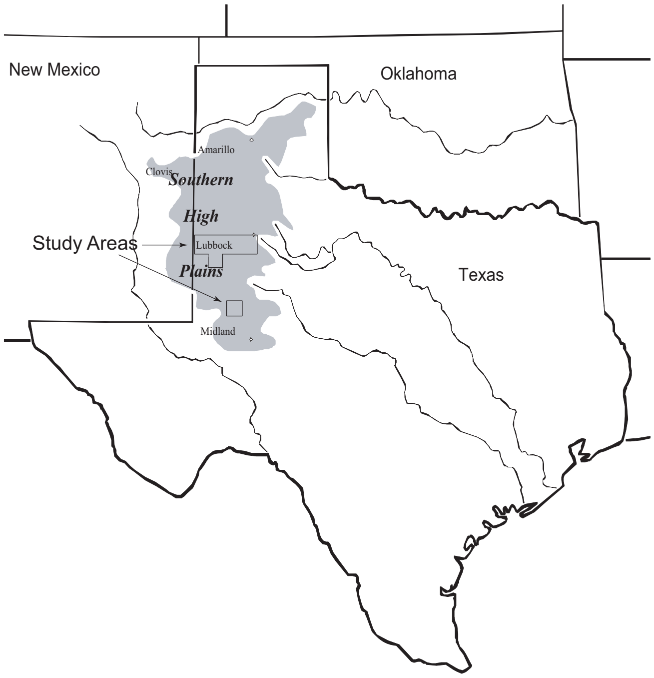

Figure 1. Location of study sites.

managed fields with the same soils. We also located conservation systems (such as no tillage systems) nearby in the same soil when available.

Each field site was sampled at the following depths: 0-5, 5-10, 10-15, 15-30, and 30-60 cm. This study reports the average or cumulative sums of soil properties from 0-10 cm, corresponding to the depths modeled by the SCI (Tables 1 and 2). Three replications were sampled in each site. Samples were collected with a Giddings probe, sampling five cores per replication. Bulk density was determined using the soil cores (Blake and Hartge, 1986). Bulk samples were collected using a shovel for determination of the wet aggregate stability. Soil subsamples were air-dried, ground overnight in a roller mill and total C and N were determined using the Vario Max Elementar[1] CN analyzer (D-63452 Hanau, Germany). Soil texture was determined using a Beckman-Coulter LS230 (Zobeck, 2004). Wet aggregate stability was measured on 2-g of 1 to 2-mm diameter aggregates by the method described by Kemper and Rosenau, (1986). The pH values were determined on air-dried soil (<2.mm) using a 1:1 soil:water ratio (Watson and Brown,1998). Nitrate nitrogen was determined by flow injection analysis (Lachat Instruments., 2000). Phosphorus was measured using the Olsen ($NaHCO_3$) procedure (Frank et al., 1998). Particulate organic matter carbon (POMC) was determined according to the method of Gregorich and Ellert, 1993.

The SCI values and sub-factors were determined using RUSLE2 version 1.25.8 (Dec, 2005) (http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm). Individual field management practices were established using producer surveys. Values for specific SCI sub-factors (Eq. 1) for organic matter (OM), field operations (FO), erosion (ER), a soil tillage factor (STIR), and water erosion were determined by RUSLE2 (Table 3). Wind erosion estimates are also needed to determine SCI, for fields where wind erosion is active, but wind erosion is not determined by RUSLE2 and must be provided by another method. Wind erosion was estimated using an MS Excel spreadsheet program, written by USDA-NRCS agricultural engineers and agronomists, based on the Wind Erosion Equation (Woodruff and Siddoway, 1965). The program calculates erosion using the management period method. The observed values for the crop/plant residues for each management system were determined by clipping rangeland and grassland plots and using producer survey crop yield results for cropped fields (Table 3). Plot clipping followed the

[1]Mention of trade names or commercial products is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the USDA-ARS, USDA-NRCS, or Texas A&M University.

Table 1. Selected average soil physical properties by agroecosystem (0 to 10-cm depth).

Agroecosystem	Obs.	Sand	Clay	Texture	Bulk Density	Aggregate Stability
		----- % -----			lbs ft^{-3}	%
Native Rangeland	22	61.6 (2.6)†	19.7 (1.4)	FSL	82.4 (1.2)H	39.4 (2.8)
Conservation Grassland	27	74.7 (2.7)	14.5 (1.2)	FSL	88.6 (1.2)	23.3 (2.9)
Dryland Cotton CT‡	41	74.5 (2.1)	15.2 (1.1)	FSL	82.4 (0.6)	9.6 (0.9)
Dryland Cotton NT	3	79.9 (1.5)	12.7 (0.8)	FSL	82.4 (1.9)	6.3 (0.1)
Irrigated Cotton CT	6	82.4 (2.9)	11.4 (1.3)	LFS	84.3 (1.2)	7.0 (1.3)
Dryland High Residue	3	82.4 (0.6)	10.7 (0.2)	LFS	83.7 (0.6)	14.8 (2.9)
Terminated Wheat/Cotton CT	2	73.3 (6.7)	15.7 (2.7)	FSL	78.7 (3.1)	10.8 (-)
Terminated Wheat/Cotton LT	8	82.3 (2.7)	11.4 (1.4)	LFS	84.3 (0.6)	9.7 (1.9)
Dryland Wheat NT	3	73.6 (1.6)	15.5 (1.1)	FSL	80.5 (2.5)	8.7 (0.7)
Wheat/Cotton Rotation CT	10	74.4 (4.4)	16.7 (2.7)	FSL	85.5 (1.9)	8.1 (2.2)
Wheat/Cotton Rotation NT	9	70.8 (5.8)	14.6 (2.1)	FSL	84.9 (1.2)	12.3 (2.1)
Sunflowers for Wildlife	3	51.3 (2.0)	24.0 (1.5)	SCL	83.0 (1.9)	32.6 (3.5)

† - Sandard errors in parentheses; FSL fine sandy loam; LSF loamy fine sand; SCL sandy clay loam

‡ - CT Conventional tillage; NT No tillage; LT Limited tillage.

procedures outlined by the USDA-NRCS National Range and Pasture Handbook, Chapter 4 (http://www.glti.nrcs.usda.gov/technical/publications/nrph.html).

RUSLE2 calculates the average annual residue production based on the observed residue values (Ave-Res in Table 3) and the amount of residue assumed in SCI to maintain constant levels of organic matter in a given climate and soil texture (Main-Res in Table 3), but the results are not shown. These annual residue production and maintenance values were determined using previous versions of an MS Excel-based SCI calculation program called the Soil Conditioning Index Worksheet, Version 24 (March 2003) or Version 25 (April 2003). Statistical analyses were performed using procedures of SAS ver. 9.1 (SAS, 2002).

RESULTS AND DISCUSSION

The agroecosystems in this study were dominated by fine sandy loams and loamy fine sands (Table 1). Only one agroecosystem, the plot that had a wildlife sunflower planting in a conservation grassland field (sun flowers for wildlife), had a sandy clay loam texture.

The no tillage and limited tillage sites had the highest phosphorus content, probably related to surface application of fertilizers (Table 2).

The SCI was negative for all conventionally-tilled sites and positive for the native rangeland, conservation grassland and all no-tillage sites with the exception of the dryland wheat no-tillage site (Fig.2). The no-tillage dryland wheat field had a hay yield of 0.75 tons/acre, resulting in a low negative SCI value (-0.045). The SCI did not exceed 0 until the hay yield was changed to 1.4 tons/acre.

Since the SCI is a tool used to predict the consequences of management actions on the state of SOC, it is expected that the SCI values would be correlated with organic carbon/matter-related properties. The SCI was most strongly correlated with the average residue production as estimated in RUSLE2 and particulate organic matter (Table 4).

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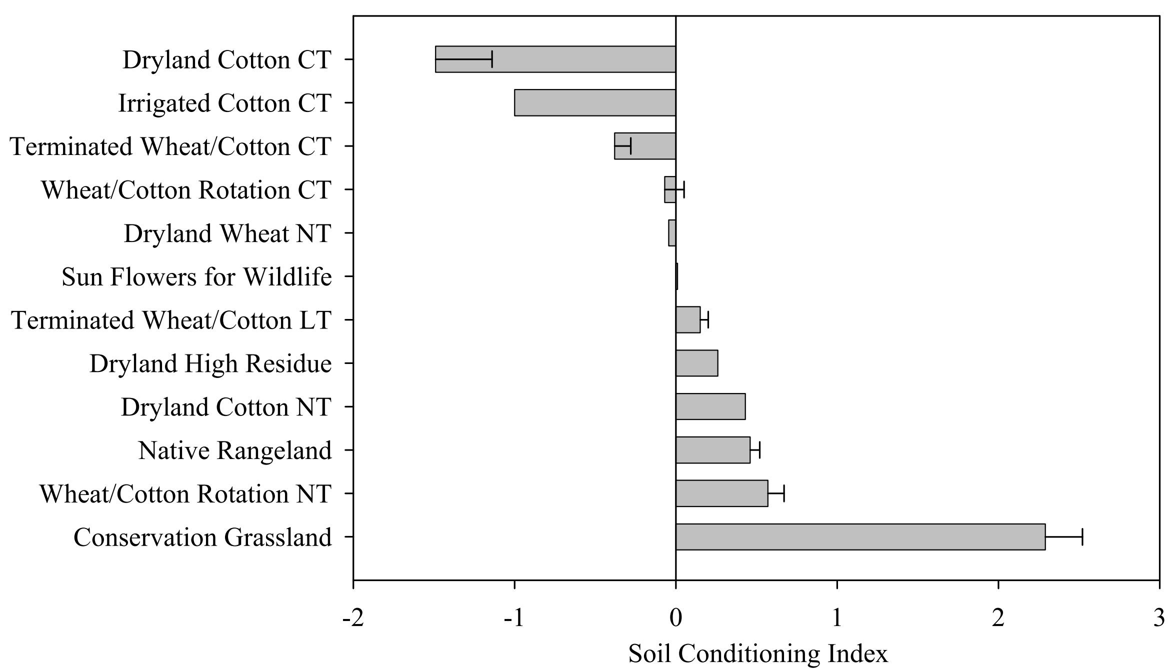

Figure 2. Soil conditioning index by agroecosystem. Error bars are standard errors.

Table 2. Selected average soil chemical properties by agroecosystem (0 - 10-cm depth).

					Total Nitrogen		Total Organic Carbon		Particulate Organic Matte
Agroecosystem	Obs.	pH	NO^3-N	Olsen-P	------ Sum 0-10cm -----		Mean 0-10cı	Sum 0-10cm	Sum 0-10cm
			------- ppm -------		%	lbs ac^{-1}	%	------- lbs ac^{-1} -------	
Native Rangeland	22	7.2 (0.1)†	4.7 (1.4)	5.0 (0.4)	0.08 (0.01)	902 (80)	1.0 (0.1)	11279 (1081)	4019 (625)
Conservation Grassland	27	7.4 (0.1)	1.6 (0.3)	7.6 (1.0)	0.06 (0.01)	705 (80)	0.6 (0.04)	8082 (911)	2858 (625)
Dryland Cotton CT‡	41	7.4 (0.1)	9.3 (1.4)	12.3 (0.8)	0.04 (0.0)	482 (45)	0.5 (0.06)	5724 (750)	893 (179)
Dryland Cotton NT	3	6.3 (0.1)	10.2 (1.0)	52.0 (2.0)	0.02 (0.0)	205 (9)	0.2 (0.01)	2724 (89)	-
Irrigated Cotton CT	6	7.7 (0.1)	5.9 (1.3)	6.8 (0.7)	0.04 (0.01)	527 (152)	0.5 (0.10)	5679 (1313)	893 (357)
Dryland High Residue	3	7.9 (0.1)	4.5 (0.4)	13.7 (1.6)	0.04 (0.01)	509 (89)	0.4 (0.04)	4340 (455)	-
Terminated Wheat/Cotton CT	2	7.8 (0.2)	18.5 (10.4)	8.5 (1.0)	0.05 (0.01)	572 (134)	0.5 (0.2)	6072 (1831)	804 (-)
Terminated Wheat/Cotton LT	8	7.8 (0.1)	4.4 (1.2)	25.4 (3.5)	0.03 (0.01)	402 (71)	0.5 (0.2)	6037 (2152)	982 (0.0)
Dryland Wheat NT	3	7.4 (0.3)	9.3 (1.8)	9.3 (1.1)	0.06 (0.01)	652 (63)	0.6 (0.1)	7474 (964)	1875 (-)
Wheat/Cotton Rotation CT	10	7.8 (0.1)	6.5 (1.2)	17.9 (2.1)	0.05 (0.01)	589 (80)	0.5 (0.05)	6081 (625)	893 (0.0)
Wheat/Cotton Rotation NT	9	7.2 (0.1)	15.3 (3.4)	38.5 (4.6)	0.05 (0.01)	607 (152)	0.5 (0.12)	6019 (1375)	2143 (536)
Sunflowers for Wildlife	3	6.8 (0.04)	12.1 (2.0)	3.7 (0.9)	0.08 (0.00)	920 (27)	1.0 (0.2)	11618 (1920)	-

† - Standard errors in parentheses

‡ - CT Conventional tillage; NT No tillage; LT Limited tillage.

Table 3. Soil conditioning index (SCI) subfactors by agroecosystem.

Agroecosystem	Obs.	OM†	FO	ER	STIR	Wind Eros	Water Eros	SCI	-------- Ave-Res --------		------- Main-Res -------	
						------ tons ac^{-1}	-----		lbs ac^{-1}	Mg ha^{-1}	lbs ac^{-1}	Mg ha^{-1}
Native Rangeland	8	-0.31 (0.15)‡	1.00 (0.00)	0.95 (0.02)	0.49 (0.00)	0.0 (0.0)	0.14 (0.04)	0.46 (0.06)	5195 (1042)	5.82 (1.17)	6616 (284)	6.90 (0.32)
Conservation Grassland	11	4.22 (0.58)	1.00 (0.00)	1.00 (0.00)	0.15 (0.00)	0.0 (0.0)	0.0 (0.0)	2.29 (0.23)	7369 (1176)	8.25 (1.32)	6970 (144)	7.81 (0.16)
Dryland Cotton CT††	17	-0.41 (0.13)	0.08 (0.06)	-6.79 (1.67)	92.3 (6.4)	18.1 (4.3)	1.7 (0.2)	-1.49 (0.35)	1492 (158)	1.67 (0.18)	7014 (186)	7.85 (0.21)
Dryland Cotton NT	1	-0.17	0.97	0.58	3	1	0.07	0.43	2856	3.2	7834	8.77
Irrigated Cotton CT	2	-0.52 (0.03)	-0.28 (0.01)	-3.55 (0.05)	129.0 (1.0)	10.3 (0.0)	1.3 (0.2)	-1.00 (0.00)	1735 (1492)	1.94 (1.67)	7656 (0.0)	8.57 (0.0)
Dryland High Residue	1	-0.48	0.75	0.78	25.5	0	0.57	0.26	1060	1.19	8240	9.23
Terminated Wheat/Cotton CT	2	-0.62 (0.07)	0.63 (0.03)	-1.85 (0.25)	37.8 (2.7)	5.4 (1.6)	1.9 (0.9)	-0.38 (0.10)	4757 (1034)	5.33 (1.16)	7182 (474)	8.04 (0.53)
Terminated Wheat/Cotton LT	4	-0.20 (0.07)	0.52 (0.01)	0.07 (0.28)	48.2 (0.6)	0.8 (0.5)	0.6 (0.2)	0.15 (0.05)	3969 (754)	4.45 (0.84)	8299 (371)	9.29 (0.42)
Dryland Wheat NT	1	-0.88	0.93	-0.33	6.8	2.1	1.3	-0.05	409	0.46	6708	7.51
Wheat/Cotton Rotation CT	3	-0.32 (0.20)	0.59 (0.07)	-0.87 (0.32)	42.1 (6.6)	3.9 (0.4)	0.9 (0.4)	-0.07 (0.12)	1499 (277)	1.68 (0.31)	7340 (316)	8.22 (0.35)
Wheat/Cotton Rotation NT	3	0.05 (0.24)	0.93 (0.04)	0.89 (0.08)	6.9 (3.8)	0.03 (0.03)	0.25 (0.18)	0.57 (0.10)	4121 (641)	4.61 (0.72)	8285 (789)	9.28 (0.88)
Sunflowers for Wildlife	1	-0.65	0.65	0.05	34.9	0.3	2.1	0.01	1279	1.43	6708	7.51

† - OM=SCI organic matter factor; FO=SCI field operations factor; ER=SCI erosion factor; STIR=SCI tillage factor; Ave-Res=average observed residue mass; Main-res=maintenance residue amount required for SCI.

‡ - Standard errors in parentheses.

†† - CT Conventional tillage; NT No tillage; LT Limited tillage.

Table 4. Pearson correlations of the soil conditioning index with selected study variables.

Source	Aggregate Stability	Particulate Organic Matter	Nitrogen Mass	Carbon Mass	Ave-Res	Wind Erosion	Water Erosion
SCI Pearson Correlation r	0.46	0.53	0.40	0.29	0.67	-0.83	-0.59
SCI Prob > r	0.0006	0.0005	0.003	0.036	<0.0001	<0.0001	<0.0001

Particulate organic matter carbon represents a fraction of the total SOC in soils. Particulate organic matter carbon by agroecosystem was less than about one-third the amount of total SOC (Table 1 and Fig. 3). The native rangeland, conservation grassland and wildlife planting had the highest SOC and POMC values (Fig 3), although there was much overlap among agroecosystems. (Due to experimental constraints, POMC was not measured on all sites.) The mean POMC of the upper 10 cm was significantly correlated with SOC mass ($r=0.40$; $P<0.0.02$) but was more highly correlated with wet aggregate stability ($r=0.71$; $P<0.001$) and nitrogen mass content ($r=0.66$; $P<0.0001$). The average residue production had about the same correlation with POMC ($r=0.37$; $P<0.02$) as SOC.

The SCI has an organic matter sub-factor (SCI-OM) that represents 40% of the final SCI value (Eq. 1). In this study, the SCI-OM was not correlated with SOC mass but was correlated with POMC ($r=0.42$; $P<0.007$) and was most strongly correlated with the average residue production ($r=0.71$; $P<0.0001$).

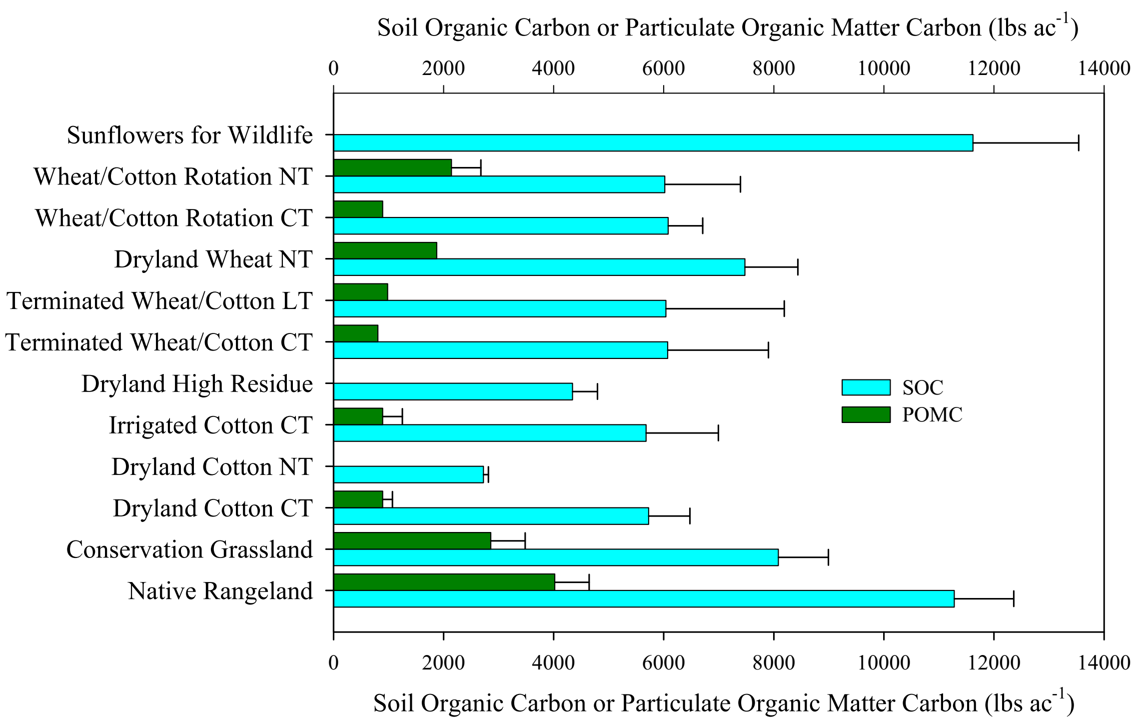

Figure 3. Soil organic carbon (SOC) and particulate organic matter carbon (POMC) by agroecosystem.

CONCLUSIONS

The SCI program implemented in RUSLE2 successfully associated the conservation grasslands, native rangelands, and no-tillage, limited (minimum) tillage and high residue croplands with positive SCI values and the conventionally-tilled fields with negative SCI values. In addition, the general trends seemed reasonable, for most situations. The conservation grasslands had the highest SCI value and the conventionally-tilled dryland cotton had the most negative SCI value.

One exception was the no-tillage dryland wheat field that had a slightly negative SCI value. This was attributed to the low residue produced in this dryland field, resulting in the lowest SCI OM sub-factor of all agroecosystems tested. The SCI value was very close to 0 (-0.05), but was still negative. To accept borderline conditions that clearly provide residue for soil cover, it may be advisable to have a buffer of plus or minus 0.1 considered as equal to 0 when assigning SCI values. This buffer may be particularly necessary in western states where the OM sub-factor in SCI may often be less than 0, even in situations with adequate cover. For example, in this study only the conservation grassland and no-tillage wheat/cotton rotations had positive SCI OM sub-factors.

Although the SCI did identify conservation systems, the stated reason for the association is not clear. Although the stated purpose of the SCI is to predict the consequences of management actions on the state of soil organic carbon, the SCI values were not strongly correlated with total SOC. The SCI values were more strongly associated with a specific form of soil organic carbon, POMC, a relatively more labile form of soil organic carbon. The SCI was even more strongly correlated with the residue production, which serves to add organic matter to the soil and protect the soil from the forces of erosion. Finally, the SCI was most strongly correlated (negatively) with wind erosion, even though the erosion sub-factor was weighted half the amount of the other SCI sub-factors. Further more detailed analysis of this data set is planned. In addition, further field testing of SCI over a wide range of climatic and agroecosystems is recommended.

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