Investigation of Soil Conditioning Index Values For Southern High Plains Agroecosystems

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ABSTRACT

The United States Department of Agriculture, Natural Resources Conservation Service has proposed the Soil Conditioning Index (SCI) to predict the consequences of management actions on the state of soil organic carbon (SOC), a soil quality indicator. 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 determined the effects of management on SCI, SOC, and other soil properties in semiarid, hot, sandy soils located in the Southern High Plains of western Texas. Agroecosystems studied included native rangeland, conservation grassland, cotton and wheat rotations, and high-residue forage sorghum. The sites included irrigated and dryland conditions under conventionally tilled and no-tillage practices. Mean SCI values varied from -1.49 for conventionally-tilled dryland cotton to 2.15 for the conservation grassland. All native rangelands and conservation grasslands and no-tillage fields (dryland and irrigated) had positive SCI values, which indicates increasing organic matter levels. In contrast, all of the conventionally-tilled cotton fields had negative SCI values, indicating decreasing organic matter levels. The SCI was most strongly correlated with the residue equivalent value (r=0.68) as estimated in the Revised Universal Soil Loss Equation, but based on measured values, and particulate organic matter carbon, POM-C (r=0.57). The SCI successfully distinguished fields with the highest levels of POM-C and when no-tillage or limited management was practiced from agroecosystems that were aggressively tilled. Additional research is needed to adjust the SCI sub-factors to better relate the index with SOC.

Keywords: Organic matter, Soil conditioning index, Soil assessment, Soil quality, Tillage

As new questions and concerns arise about our ability to sustain our limited land and water resources, the importance of adequate assessment tools for evaluating the effects of land management practices on soil, air, and water resources grows. 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. Soil organic carbon (also called soil organic matter) is a primary indicator of soil quality and an important factor in carbon (C) sequestration and global climate change.

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

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

where OM represents the organic material from animal or plant sources produced and returned to the soil, FO signifies field operations including tillage and other field procedures that stimulate organic matter breakdown and decomposition, and ER corresponds to the influences of wind and water erosion (NRCS, 2003). Note that OM and FO each account for 40% of the final SCI value (total of 80% combined) and wind and water erosion represent 20%.

The SCI is an important soil management index and is required by several USDA-NRCS 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 Program of the Farm Security and Rural Investment Act of 2002. However, only one published study testing the SCI for various conservation systems has been reported (Hubbs et al., 2002).

The SCI was developed based on research conducted from 1948 to 1959 in a humid region with high clay soils at Renner, Texas, USA. The SCI was originally developed as a soil rating system for soils of the western US (SCS, 1974). A shorter version of this rating system was prepared for use by the USDA, Soil Conservation Service (SCS), Southern National Technical Center region (SCS, 1987). Further testing of the concept was provided using data from Iowa and Montana to develop the index currently in use (NRCS, 2002, 2003). An evaluation of SCI using nine long-term C studies found that positive trends in C followed positive trends in SCI and negative SCI trends were associated with negative C trends (Hubbs et al., 2002). Correlations of C and SCI were improved when data were separated by states.

The SCI assumes field operations reduce SOC by stimulating decomposition and that maintaining organic residues will maintain and increase soil organic levels. The amount of reduction of SOC due to field operations and erosion depends on the native level of carbon 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 or clayey Southern High Plains (SHP) soils (Potter et al., 1997; Unger, 2001; Bronson et al., 2004) but no studies investigating the SCI and its relation to SOC and other soil quality indicators are available for sandy soils. Studies have related microbial enzymes and microbial community structure to a variety of semiarid agroecosystems in sandy soils of SHP of Texas (Acosta-Martinez et al., 2003a and 2003b). In addition, previous research from a sandy soil in the SHP has shown that tillage of long-term grassland will reduce SOC levels by 50% (Zobeck et al., 1995). In a companion study of the effects of SHP cropping systems on carbon pools (Bronson et al., 2004), the total soil carbon in the upper 30 cm (12 in) was 34 Mg ha^{-1} (15 T Ac^{-1}) for native rangeland and 23 Mg ha^{-1} (10 T Ac^{-1}) for cropland soils. Total soil C in conservation grassland was greater than cropland soils only in the 0- to 5 cm layer, and was 24 Mg ha^{-1} (11 T Ac^{-1}) in the upper 30 cm (12 in).

Particulate organic matter (POM) is plant material in various stages of decomposition that represents active fractions of C and N in soil (Cambardella and Elliott, 1992; Cambardella, 1998; Wander and Bidhart, 2000) and may also be related to SCI. Native prairie and conservation grasslands have significant fractions of total C as particulate organic matter carbon (Cambardella and Elliott, 1992; Huggins et al., 1997). The POM fractions of soil C have been reported to be active (labile) fractions of C (Cambardella and Elliott, 1992). Particulate organic matter carbon was greater in native grassland than in cropped soils in the upper 30 cm (12 in) profile in SHP soils (Bronson et al., 2004). Conservation grassland had similar levels of POM-C as cropped soils in the surface 0-10 cm (0-4 in) depths (Bronson et al., 2004). The relation of total C or POM-C with SCI was not investigated.

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.

METHODS AND MATERIALS

Soils and Site Management

We identified 16 field locations 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 agroecosystem combinations were sampled (Table 1) including native rangeland, conservation grassland, different cotton and wheat rotations, and a high residue sorghum (*Sorghum bicolor*, L.), with various combinations of irrigation and tillage intensity. The sites (grower fields and pastures) were selected with the assistance of USDA-Natural Resources Conservation Service personnel and were classified as Aridic Paleustalfs or Aridic Paleustolls (Soil Survey Staff, 1996).

Native rangelands consisted of native warm-season grasses, shrubs, and forbs that had never been tilled for crop production [main species: blue grama, *Bouteloua gracilis* (Kunth) Lag. Ex Griffiths; sand dropseed, *Sporobolus cryptandrus* (Torr.) A. Gray; Kleingrass, *Panicum coloratum* L., honey mesquite, *Prosopis glandulosa* Torr.; yucca, *Yucca spp*.; silverleaf nightshade, *Solanum elaeagnifolium* (Cav); goldaster, *Heterotheca canescens* (DC.) Shinners]. Conservation grassland fields were formerly in crop production but had been planted to warm-season grasses [main species: switchgrass, *Panicum virgatum* L.; sand dropseed; Canada wild rye, *Elymus Canadensis* L.; little bluestem, *Schizachyrium scoparium* (Michx.) Nash; sideoats grama, *Bouteloua curtipendula* (Michx.) Torr., blue grama, Old World bluestem, *Bothriochloa ischaemum* L., and weeping lovegrass, *Eragrostis curvula* (Schrad.) Nees] and been in place for at least 10 to 15 years.

In conventionally tilled (CT) cotton systems, cotton stalks were usually shredded and incorporated into the soil using a disc plow in December, the fields were chisel plowed in February, herbicide incorporated with a spring-tooth chisel followed by raising beds in March, and rod-weeding before planting in early May. After planting in May, a rotary hoe was used for wind erosion control and to break crusts after rain events in May and June. Field cultivation using sweep cultivators was done in June and July. Irrigation generally consisted of providing a preplant irrigation in March and April and 10 to 20 cm (4 to 8 in) per month from May through August. There was some variation in these irrigation amounts and distributions depending on crop and site conditions.

Sites under cotton and wheat rotations, including dryland and irrigated fields, had cotton planted into the previous wheat crop residue. Terminated wheat/cotton systems often had wheat planted in the fall. Cover crops such as rye (*Secale cereale* L.) were sometimes used in place of wheat. Typically, these systems were chiseled to a depth of about 10 cm (4 in) with sweeps in November, bedded with a lister or bedder, and then wheat was drilled in November or December. The cover crop was usually killed (terminated) by herbicide in April and cotton was planted in early May.

The limited-tillage (LT) systems were generally ridge tilled with ridges made in the winter or spring as the only significant tillage. The dryland, high residue agroecosystem consisted of a continuous forage sorghum crop that was sprayed with herbicide in April and cultivated with a cultivator/rod weeder combination and planted in May. The beds are cultivated with undercutting blades in July and the crop is harvested in October. The field was tilled into ridges using a lister in late November or December.

Soil Sampling and Analyses

Each field site was sampled at the following depths: 0-5, 5-10, 10-15, 15-30, and 30-60 cm (0-2, 2-4, 4-6, 6-12, 12-24 in) . Many of the same sites were used in a previous study to report carbon and nitrogen (N) pools of SHP cropland and grassland soils (Bronson et al., 2004). The study reported here considers the average or cumulative sums of soil properties from 0-10 cm (0-4 in) (Tables 1 and 2), corresponding to the depths modeled by the SCI. Three replications were sampled in each site. Samples were collected with a Giddings probe, sampling five cores per replication. Samples were combined by depth.

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. Wet aggregate stability was measured on 4 g (0.07 oz) of 1 to 2 mm (0.04-0.08 in) diameter aggregates by the method described by Kemper and Rosenau, (1986). Soil sub-samples were air-dried, ground overnight in a roller mill and total C and N were determined using the Vario Max Elementar CN analyzer (D-63452 Hanau, Germany). Soil texture was determined using a Beckman-Coulter LS230 (Zobeck, 2004). The pH values were determined on air-dried soil (<2 mm, <0.08 in) using a 1:1 soil:water ratio (Watson and Brown,1998). Soil nitrate nitrogen (NO_3-N) was determined by flow injection analysis (Lachat Instruments, 2000). Soil phosphorus was measured using the Olsen ($NaHCO_3$) procedure (Frank et al., 1998). Particulate organic matter carbon was determined according to the method of Gregorich and Ellert, 1993.

Data Analyses

Details of the calculation of SCI and the SCI sub-factors are described in the USDA-NRCS National Agronomy Manual, Part 508 (NRCS, 2002). In this study, the SCI values and sub-factors (Eq. 1) for organic matter, field operations, and water erosion were determined using the Revised Universal Soil Loss Equation (RUSLE2) version 1.25.8 (Dec, 2005) (http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm) for each agroecosystem and site (Tables 3 and 4). Individual field management practices were established using information on producer surveys. Wind erosion estimates are also needed to determine SCI, for fields where wind erosion is active. However, wind erosion is not determined by RUSLE2 and must be provided by another method. Wind erosion was estimated using an MS Excel spreadsheet program (Sporcic et al., 1998), written by USDA-NRCS agricultural engineers and agronomists, based on the Wind Erosion Equation, WEQ (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 procedures outlined by the USDA-NRCS National Range and Pasture Handbook (NRCS, 2006).

RUSLE2 calculates the OM sub-factor of SCI based on the RUSLE2 predicted biomass production of the test site, scaled to the biomass produced at the Renner site (D. Yoder, personal communication). This sub-factor is based on the amount of organic matter returned to the soil as residue, roots, cover crops, green manure, etc. for organic matter restoration, called the residue equivalent value, REV (NRCS, 2002). In RUSLE2, the OM factor includes a parameter to account for the effect of texture on decomposition and also estimates root biomass to a depth of 10 cm (4 inches) based on the ratio of maximum root mass to aboveground residue produced at harvest, as found in the RUSLE2 database (NRCS, 2002). The observed values of crop/plant residues were used in WEQ and RUSLE2 to adjust the yields for the determination of REV.

Statistical analyses were performed using procedures of SAS ver. 9.1 (SAS, 2002). Analyses of variance of the soil physical and chemical properties were performed using Proc Mixed with (sites*reps within sites) as a random effect. Analysis of variance of SCI factor results were not performed due to lack of sufficient sample size. However, meaningful evaluations of the results were possible by comparing means and correlations. Statistical significance tests were performed at the P=0.05 level of significance unless indicated otherwise.

RESULTS AND DISCUSSION

Physical and Chemical Soil Properties

The 16 field locations consisted of 52 fields sites that represented a total of twelve different combinations of crops/plant communities, irrigation level, and tillage intensity (called agroecosystems in this paper) (Tables 1, 2 and 3). Some of the agroecosystems in this study had very few observations but were included in this study because limited information is currently available in the literature (Table 3). Details of the data collected by agroecosystem are presented in Table 4.

The physical soil properties observed are found in Tables 1 and 4. Although the soil surface textures of individual sites varied from fine sand to clay loam (Fig. 2), the majority of the agroecosystems in this study were fine sandy loams and loamy fine sands. The only exception was the dryland wheat/cotton CT rotation which had a sandy clay loam soil surface (Table 1). Mean soil surface bulk density had little deviation, varying from 1.26 Mg m^{-3} (78.7 lbs ft^{-3}) for the conventionally tilled terminated wheat/cotton field to 1.42 Mg m^{-3} (88.6 lbs ft^{-3}) for the conservation dryland fields. Although soil bulk density can be modified by management, it is not currently considered in SCI determinations. Bulk density was used in this study to determine soil C and N mass.

Soil wet aggregate stability may also be changed by management and has been correlated with organic matter (Kemper and Koch, 1966; Chaney and Swift, 1984). Mean wet aggregate stability was much more variable and depended upon soil management, varying from 4.7% for the irrigated wheat/cotton rotation CT field to 40.0 % for the native rangeland (Fig. 3). The native rangeland wet aggregate stability was significantly greater than all other agroecosystems tested. The conservation grassland, with at least 10 years in grassland after cultivation, had the next highest wet aggregate stability (24.9%); about 62% of the native rangeland stability. The conservation grassland had a greater aggregate stability than all other systems with the exception of the dryland high residue, dryland wheat/cotton CT, and terminated wheat/cotton CT agroecosystems which had similar aggregate stability values. Conservation grassland also had a significantly greater aggregate stability than the dryland cotton NT and wheat/cotton NT rotation, but at the P=0.10 level of significance. These results suggest that even long-term no-tillage practices may not restore wet aggregate stability in SHP sandy soils to the levels found in native rangelands. The stability was partially restored in the conservation grassland but was still only 62% of the native rangeland. Part of the lack of significant differences in some of these sites is attributed to sampling variation and low observation numbers. For example, the mean terminated wheat/cotton CT aggregate stability appears much lower than that of the conservation grassland (Table 1) but large standard errors and low observation numbers did not allow statistical separation of means. Additional sites are needed to verify this result.

The chemical properties of the soils are shown in Tables 2 and 4. Some of the chemical properties of the surface soils may have been related to tillage method or intensity and fertility management. The no-tillage, dryland cotton field had the lowest pH and the no-tillage and limited-tillage sites had the highest soil surface phosphorus content (Table 2). These results were probably related to surface application of fertilizers with no or very limited incorporation. Detailed investigation of fertility management effects on SCI was beyond the scope of this study.

Total surface soil N and C showed few clear trends for the soils in this study (Fig. 3). Total soil N of native rangeland was significantly greater than dryland cotton CT and NT ($P<0.10$), and terminated wheat/cotton LT ($P<0.10$). Total soil N in conservation grassland was significantly greater than only dryland cotton CT. All other sites had statistically similar ($P>0.10$) total soil N values. Although total SOC seemed to vary among agroecosystems in a manner similar to the total soil nitrogen, the data had considerable variation and no statistical differences among sites were detected (Fig. 3).

Particulate organic matter carbon by agroecosystem was less than about one-third the amount of total SOC (Table 1 and Fig. 3 and 4). Due to experimental constraints, POM-C was not measured on all sites. Particulate organic matter C of the surface soil of native rangeland was significantly greater than all other agroecosystems with the exception of the conservation grassland and the dryland wheat agroecosystems. Conservation grassland had statistically greater surface soil total POM-C contents than dryland cotton CT, irrigated cotton CT ($P<0.10$), and the terminated wheat/cotton LT agroecosystems. These results are similar to the results found for wet aggregate stability. These results suggest that even long-term no-tillage practices may not restore POM-C values in SHP sandy soils to the levels found in native rangelands. The POM-C was partially restored in the conservation grassland but was only 57% of the native rangeland. Again, part of the lack of significant differences in some of these sites is attributed to sampling variation and low observation numbers. Additional sites are needed to verify this result.

Soil Conditioning Index Sub-Factors

The variable response of different soil properties to management emphasizes the importance of adopting an index (such as SCI) to indicate soil quality changes by considering several site and management characteristics simultaneously. The soil conditioning index sub-factor values, by agroecosystem, are reported in Tables 3 and 4. In general, the more positive the sub-factor value, the greater assumed potential to build organic matter.

The SCI-OM factor generally had a negative value with the exception of the conservation grassland and the wheat/cotton NT rotation. Unexpectedly, the native rangelands had a negative mean SCI-OM value. The native rangelands were representative of common native sites in the region. Most were grazed in the past but were not grazed during the year of sampling. The amount of residue observed for these rangelands was less than the maintenance level required to maintain OM in three out of the five sites tested (Table 4). Although the REV may have exceeded the maintenance amount of organic matter, residue was removed during grazing, resulting in a negative OM factor. All of the conservation grassland grew biomass with no removal, resulting in positive OM factors.

Field operations for most agroecosystems in this study were generally less aggressive than the conventional systems represented by the irrigated and dryland cotton CT systems. Both irrigated cotton CT systems had negative SCI-FO values and 7 out of 17 of the dryland cotton systems had negative SCI-FO values (Table 4). However, other agroecosystems in this study had less aggressive field operations as reflected in the positive SCI-FO values.

The SCI-ER values include consideration of the wind and water erosion sediment losses predicted by the WEQ spreadsheet and RUSLE2 (Tables 3 and 4). Both erosion models estimate erosion based on soil properties, field operations, crop growth and residue cover, and climatic conditions. Water erosion was estimated to be very low for all agroecosystems tested (soil loss tolerance T value is 11 Mg ha^{-1}, 5 T Ac^{-1}). Mean wind erosion estimates varied from a high of 40.5 Mg ha^{-1} (18.1 T Ac^{-1}) for dryland cotton CT to zero for the native rangeland and conservation grassland.

Residue returned to the soil and needed to maintain organic matter levels in the soil are important concepts embodied in the determination of the SCI. The REVs were developed to convert all crop residues to a common standard for each crop group (NRCS, 2002). The REV of any plant material is its mass expressed as the equivalent mass of the standard crop group to which it belongs, based on a relative decomposition rate found in the database for that crop group. In this study, the REVs were determined based on the clipped residue values (Residue Equivalent Values in Table 3 and REV values in Table 4). The clipped masses (or crop yield multiplied by a harvest index) were multiplied by a root adjustment and texture factor found in the RUSLE2 data base. This result was then multiplied by a crop group conversion factor to obtain the REV.

The amount of residue assumed in SCI to maintain constant levels of organic matter in a given climate and soil texture is called the maintenance residue level (MRL) (Maintenance Residue Levels in Table 3 and MRL in Table 4). Research at the Renner, Texas (Blacklands Farming Systems studies), 1948-1959 was used to determine the amount of organic residues needed to maintain constant soil organic matter levels (NRCS, 2002). Maintenance levels for other locations are determined in RUSLE2 by adjusting to account for differences in climate and annual decay rate of the crop group. The REV and MRL amounts listed in Tables 3 and 4 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). The MRL amounts calculated in these worksheets included a texture scaling factor to correct for site texture differences.

The results for REV and MRL are difficult to reconcile in this study of the SHP of Texas. The REV for the conservation grassland was generally 25% greater than the native rangeland values. The conservation grassland included improved variety of grasses that usually exceed growth of native species. None of the SHP cropping systems had REV values that exceeded the estimated MRL, including all no-tillage systems. In addition, only 40% of the grazed native rangelands and 50% of the conservation grasslands had REV values that exceeded the MRL values. Yet, the native rangeland had the highest SOC, exceeding the conservation grassland by 18 percent. This result suggests the maintenance level of organic matter may be higher than needed to maintain SOC levels at levels found in native grasslands commonly found in the Southern High Plains.

Soil Conditioning Index, Soil Management, and Soil Properties

The computed SCI values seem to be closely associated with field operations and subsequent erosion estimates. The SCI values were negative for all conventionally-tilled sites and positive for the native rangeland, conservation grassland and all no-tillage agroecosystems (Table 3 and 4, Fig. 5). In this study, all agroecosystems had SCI values in which all sites within agroecosystems were either all negative or all positive for all agroecosystems (Table 4). Only the irrigated wheat/cotton rotation CT had sites with positive and sites with negative SCI values.

The results presented in Tables 3 and 4 and Fig. 5 demonstrate the effect of soil management on SCI values among cropping agroecosystems. For example, this study included both dryland and irrigated wheat/cotton CT rotations. The *dryland* wheat/cotton CT rotations had a negative SCI values while the *irrigated* wheat/cotton CT rotations had positive SCI values. The irrigated wheat/cotton CT rotation returned more organic matter to the soil and had less erosion because the systems had two years of wheat and one year of cotton in the rotation. Conversely, the dryland wheat/cotton CT rotation returned less organic matter and had one year of wheat and two years of cotton in the rotation, resulting in more wind and water erosion (Table 3).

A more subtle effect of soil management on SCI is seen in the terminated wheat/cotton agroecosystems. These agroecosystems were all irrigated and had cotton planted into wheat or other small grain crop that had been killed with herbicides prior to planting cotton. However, these agroecosystems had positive SCI values for the LT systems and negative SCI values for the CT systems. The terminated wheat/cotton CT in this study area uses a form of minimum tillage as the conventional tillage system. The only tillage consists of the use of undercutting sweeps prior to bed formation and a disk-bedder is often used to bed the fields prior to planting. In the terminated wheat/cotton CT in this study, bedding was done in the spring, exposing the soil surface during the wind erosion season. As a result, wind erosion sediment loss was estimated to range from 8.5 to 15.7 Mg ha^{-1}, (3.8 to 7.0 T Ac^{-1}) with the SCI varying from -0.28 to -0.47, respectively. In the terminated wheat/cotton LT systems, sweeps were not used, no bedding occurred in the wind erosion season, and less than 3.6 Mg ha^{-1} (1.6 T Ac^{-1}) wind erosion sediment loss was estimated for these systems. These details in management can be considered in RUSLE2 and WEQ and used in erosion estimates.

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 changes in soil organic carbon/matter-related properties. To explore this effect, we correlated the SCI value with other variables (Table 4). The SCI was strongly correlated with aggregate stability, POM-C, total nitrogen, carbon mass, and the residue equivalent value (Table 5).

All parameters tested in Table 5 were significantly correlated with SCI. However, some parameters were more strongly related to the SCI than others. Of the five parameters listed, soil carbon and nitrogen mass in the soil surface were the least related to SCI. This seems reasonable since total carbon mass includes humified, recalcitrant organic carbon with a long residence time in soils as well as more labile forms that may be more representative of current management. Particulate organic matter C and REV represent organic matter of recent origin. Thus, POM-C and the REV were much more highly correlated with SCI (0.57 and 0.68, respectively). In addition, wet aggregate stability was also correlated with SCI (r=0.47). This is expected since the correlation of aggregate stability and POM-C was 0.79.

The USDA-NRCS currently uses SCI as part of the criteria for consideration of participation in certain farm programs. The results of this study suggest that SCI is not a precise tool and may include significant variation in index estimates. Although we had 52 sites for comparison in this study, SCI error values listed in Table 3 and other statistics describing the SCI variation do not generally support establishment of precise SCI cut-off limits. The standard error of our most numerous system, the dryland cotton CT, was 0.35 (Table 3). Although the standard error was rather low, varying from 0 to 0.10 for all other cropped agroecosystems, the average coefficient of variation was 32%. In addition, the average standard deviation of all cropped agroecosystems was 0.29.

SUMMARY AND 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. The conservation grasslands had the highest SCI value and the conventionally-tilled dryland cotton had the most negative SCI value. Rather subtle changes in soil management were detected by using RUSLE2 and a spreadsheet version of the WEQ to determine SCI.

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 and more labile form of soil organic carbon, POM-C. The SCI was even more strongly correlated with a measure of residue production, the REV, which serves to add organic matter to the soil and protect the soil from the forces of erosion.

Caution should be used when using SCI in a very precise manner. Due to variability in SCI estimates, it may be advisable to have a buffer of plus or minus 0.2 or 0.3 considered when assigning SCI values. The buffer is suggested to account for the variation in SCI suggested by the standard error values listed in Table 3. 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. Further field testing of SCI over a wide range of climatic and agroecosystems is recommended.

DISCLAIMER

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.

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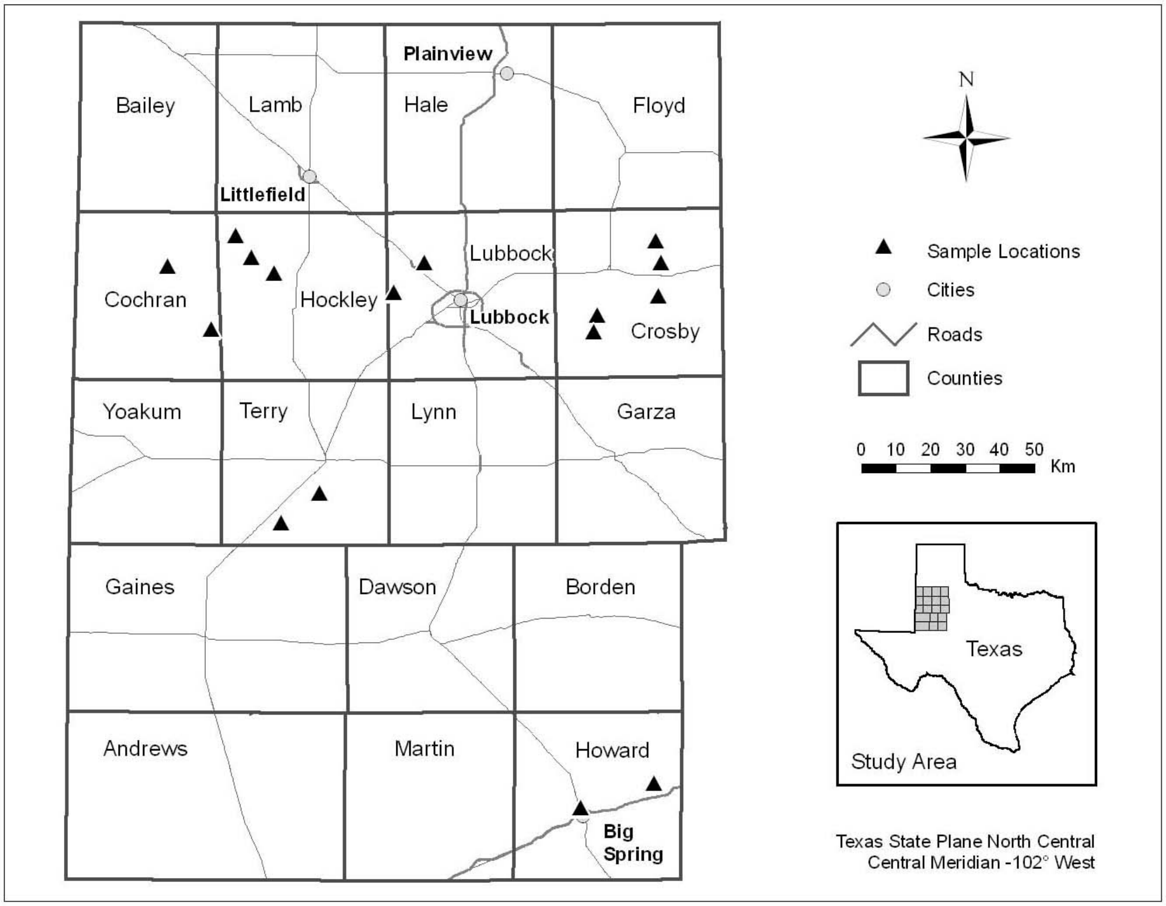

Fig. 1. Location of study areas.

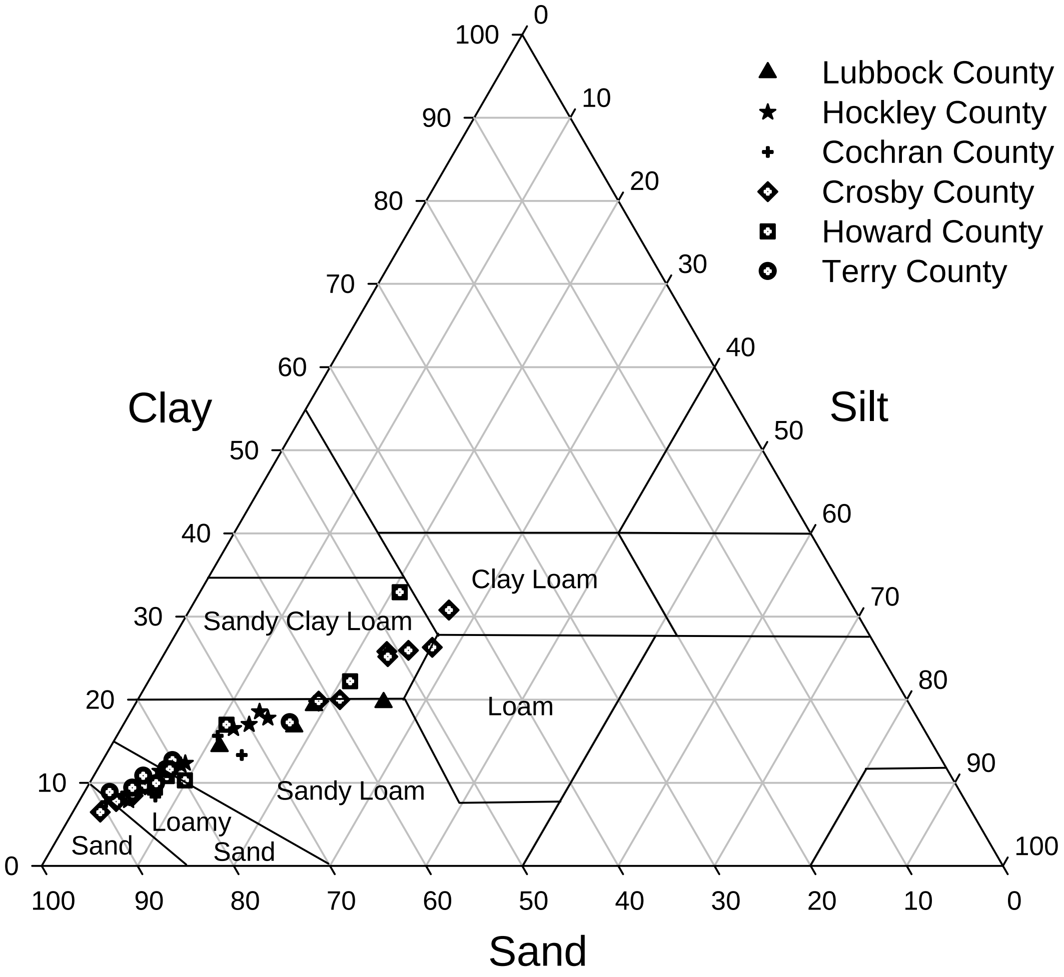

Fig. 2. USDA Texture class of the study areas by county.

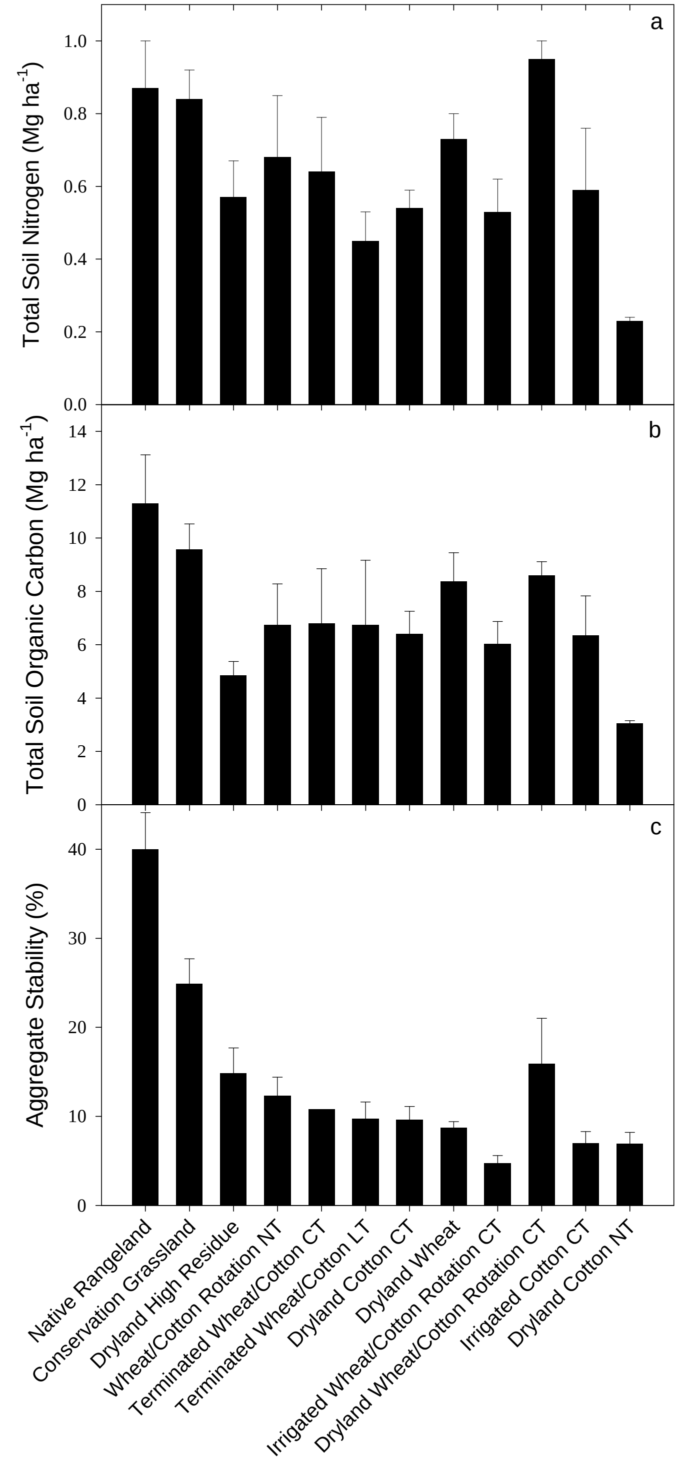

Fig. 3. Total soil nitrogen (a), organic carbon (b), and wet aggregate stability (c) by agroecosystem. CT=Conventional tillage, NT=No tillage, LT=Limited tillage. Error bars are standard errors.

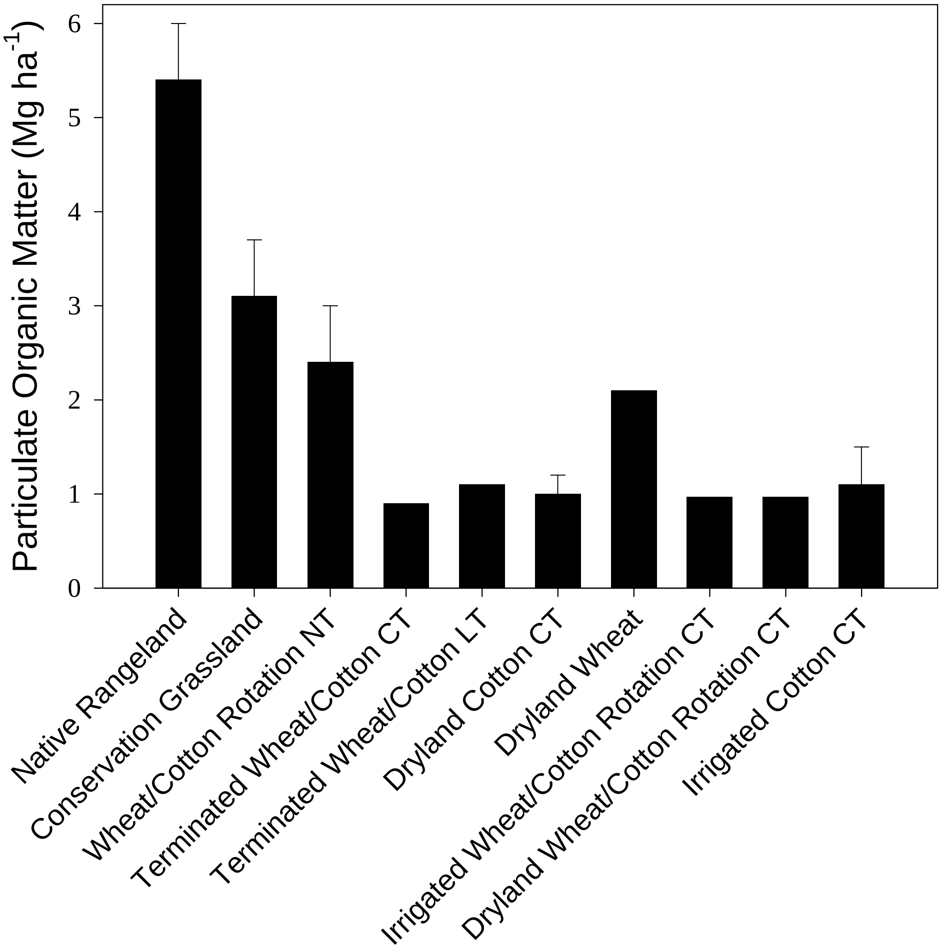

Fig. 4. Particulate organic matter carbon by agroecosystem. CT=Conventional tillage, NT=No tillage, LT=Limited tillage. Error bars are standard errors.

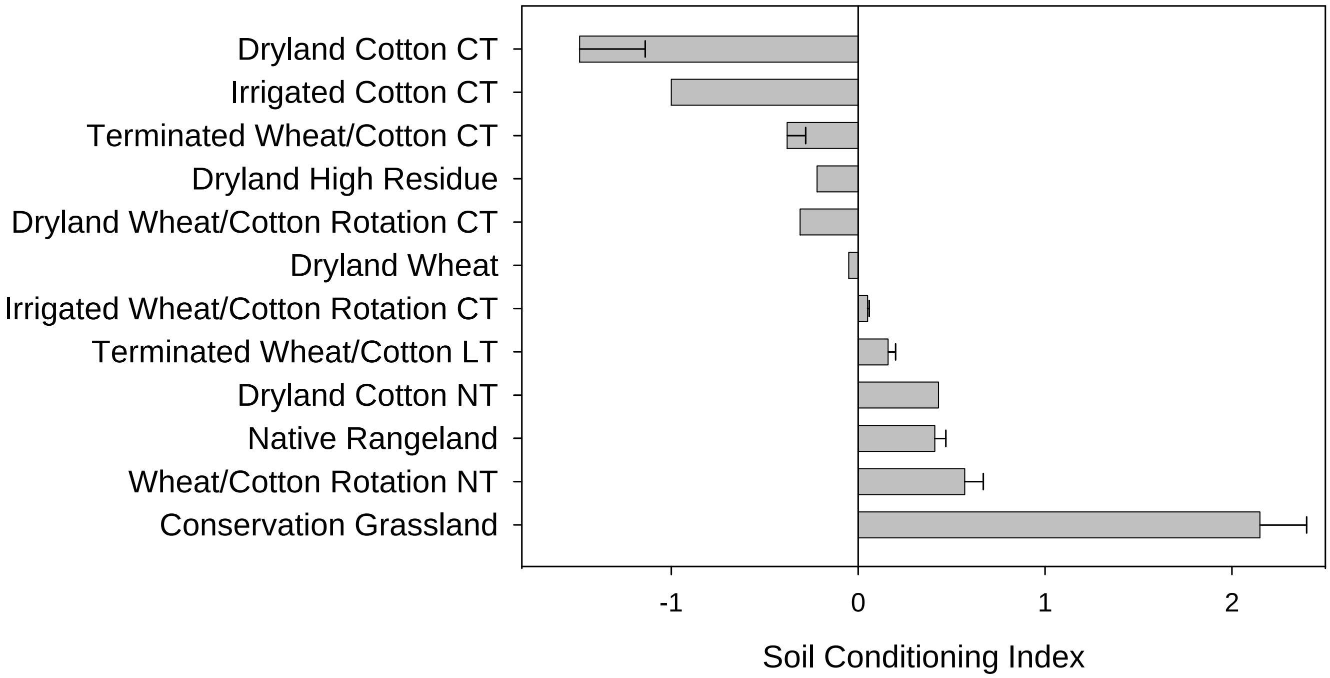

Fig. 5. Soil conditioning index by agroecosystem. CT=Conventional tillage, NT=No tillage, LT=Limited tillage. Error bars are standard errors.

Table 1. Selected average soil physical properties by agroecosystem.

Agroecosystem	Total Obs.	Sand	Clay	USDA Texture	Bulk Density	Aggregate Stability
		----- % -----			Mg m^{-3}	%
Native Rangeland	13	67.6 (2.8)[H]	16.1 (1.4)	Fine Sandy Loam	1.41 (0.02)	40.0 (4.1)
Conservation Grassland	30	72.4 (3.1)	15.2 (1.5)	Fine Sandy Loam	1.35 (0.02)	24.9 (2.8)
Dryland Cotton CT[I]	41	73.0 (2.6)	15.5 (1.3)	Fine Sandy Loam	1.32 (0.01)	9.6 (0.9)
Dryland Cotton NT	3	80.0 (1.5)	12.7 (0.7)	Fine Sandy Loam	1.32 (.03)	6.9 (1.3)
Irrigated Cotton CT	6	84.2 (2.6)	9.8 (1.3)	Loamy Fine Sand	1.35 (0.02)	7.0 (1.3)
Dryland High Residue	3	83.5 (1.4)	9.4 (0.8)	Loamy Fine Sand	1.34 (0.01)	14.8 (2.9)
Terminated Wheat/Cotton CT	2	76.0 (8.4)	14.1 (3.7)	Fine Sandy Loam	1.26 (0.05)	10.8 (-)
Terminated Wheat/Cotton LT	8	83.5 (2.5)	10.3 (1.3)	Loamy Fine Sand	1.35 (0.01)	9.7 (1.9)
Dryland Wheat	3	73.9 (1.9)	15.6 (1.1)	Fine Sandy Loam	1.29 (0.04)	8.7 (0.7)
Irrigated Wheat/Cotton Rotation CT	7	84.0 (2.1)	10.2 (1.1)	Loamy Fine Sand	1.37 (0.04)	4.7 (0.9))
Dryland Wheat/Cotton Rotation CT	3	48.9 (2.4)	25.9 (1.4)	Sandy Clay Loam	1.35 (0.01)	15.9 (5.1)
Wheat/Cotton Rotation NT	9	70.8 (5.3)	15.6 (2.1)	Fine Sandy Loam	1.36 (0.02)	12.3 (2.1)

H- Sandard errors in parentheses; - no data available

I - CT=Conventional tillage, NT=No tillage, LT Limited tillage.

Table 2. Selected average soil chemical properties by agroecosystem.

				Total Nitrogen		Total Organic Carbon		Particulate Organic Matter
Agroecosystem	pH	NO_3-N	Phosphorus	Mean 0-10cm	Sum 0-10cm	Mean 0-10cm	Sum 0-10cm	Sum 0-10cm
		------- ppm -------		%	Mg ha^{-1}	%	------ Mg ha^{-1} ------	
Native Rangeland	7.3 (0.2)[H]	5.0 (2.1)	5.0 (0.4)	0.07 (0.01)	0.87 (0.13)	0.86 (0.14)	11.31 (1.81)	5.4 (0.6)
Conservation Grassland	7.4 (0.1)	1.6 (0.3)	7.5 (0.9)	0.06 (0.01)	0.84 (0.08)	0.68 (0.07)	9.57 (0.96)	3.1 (0.6)
Dryland Cotton CT[I]	7.4 (0.1)	9.3 (1.4)	12.3 (0.8)	0.04 (0.004)	0.54 (0.05)	0.48 (0.06)	6.41 (0.84)	1.0 (0.2)
Dryland Cotton NT	6.3 (0.1)	10.2 (1.0)	52.0 (2.0)	0.02 (0.001)	0.23 (0.01)	0.23 (0.01)	3.05 (0.10)	1.2 (-)
Irrigated Cotton CT	7.7 (0.1)	5.9 (1.2)	6.8 (0.7)	0.04 (0.01)	0.59 (0.17)	0.46 (0.10)	6.36 (1.47)	1.1 (0.4)
Dryland High Residue	7.9 (0.1)	4.5 (0.4)	13.7 (1.6)	0.04 (0.01)	0.57 (0.10)	0.35 (0.04)	4.86 (0.51)	-
Terminated Wheat/Cotton CT	7.8 (0.2)	18.5 (10.4)	8.5 (1.0)	0.05 (0.01)	0.64 (0.15)	0.54 (0.18)	6.80 (2.05)	0.9 (-)
Terminated Wheat/Cotton LT	7.8 (0.1)	4.4 (1.2)	25.4 (3.5)	0.03 (0.01)	0.45 (0.08)	0.50 (0.18)	6.76 (2.41)	1.1 (0.0)
Dryland Wheat	7.4 (0.3)	9.3 (1.8)	9.3 (1.1)	0.06 (0.01)	0.73 (0.07)	0.64 (0.09)	8.37 (1.08)	2.1 (-)
Irrigated Wheat/Cotton Rotation CT	7.6 (0.1)	5.9 (1.4)	20.6 (2.3)	0.04 (0.01)	0.53 (0.09)	0.43 (0.05)	6.04 (0.83)	0.97 (-)
Dryland Wheat/Cotton Rotation CT	8.2 (0.1)	7.9 (2.3)	11.5 (1.3)	0.07 (0.004)	0.95 (0.05)	0.63 (0.04)	8.60 (0.51)	0.97 (-)
Wheat/Cotton Rotation NT	7.2 (0.1)	15.3 (3.4)	38.5 (4.6)	0.05 (0.01)	0.68 (0.17)	0.50 (0.12)	6.74 (1.54)	2.4 (0.6)

[H] - Sandard errors in parentheses; - no data available

[I] - CT=Conventional tillage, NT=No tillage, LT Limited tillage.

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

Agroecosystem	Fields Evaluated	OM[H]	FO	ER	Wind Erosion Estimate	Water Erosion Estimate	Residue Equivalent Values	Maintenance Residue Level	SCI
					------ Mg ha^{-1} -----		------ Mg ha^{-1} ------		
Native Rangeland	7	-0.43 (0.15)[I]	1.00 (0.00)	0.94 (0.02)	0.0 (0.0)	0.3 (0.1)	5.44 (1.41)	7.64 (0.42)	0.41 (0.06)
Conservation Grassland	11	3.88 (0.63)	1.00 (0.00)	1.00 (0.00)	0.0 (0.0)	0.0 (0.0)	8.24 (1.20)	7.78 (0.15)	2.15 (0.25)
Dryland Cotton CT[HH]	17	-0.41 (0.13)	0.08 (0.06)	-6.79 (1.67)	40.5 (9.6)	3.8 (0.4)	1.67 (0.18)	7.85 (0.21)	-1.49 (0.35)
Dryland Cotton NT	1	-0.17	0.97	0.58	2.24	0.2	3.20	8.77	0.43
Irrigated Cotton CT	2	-0.52 (0.03)	-0.28 (0.01)	-3.55 (0.05)	23.1 (0.0)	2.9 (0.4)	1.94 (1.67)	8.57 (0.0)	-1.00 (0.00)
Dryland High Residue	1	-0.48	0.73	-1.6	13.7	1.2	1.19	7.90	-0.22
Terminated Wheat/Cotton CT	2	-0.62 (0.07)	0.63 (0.03)	-1.85 (0.25)	12.1 (3.6)	4.2 (2.0)	5.33 (1.16)	8.04 (0.53)	-0.38 (0.10)
Terminated Wheat/Cotton LT	4	-0.29 (0.12)	0.48 (0.05)	0.39 (0.21)	1.7 (1.0)	1.7 (0.2)	4.44 (0.84)	9.29 (0.37)	0.16 (0.04)
Dryland Wheat	1	-0.88	0.93	-0.33	4.7	2.9	0.46	7.51	-0.05
Irrigated Wheat/Cotton Rotation CT	2	-0.12 (0.07)	0.52 (0.00)	-0.56 (0.08)	7.8 (0.2)	1.0 (0.2)	1.72 (0.53)	8.57 (0.0)	0.05 (0.01)
Dryland Wheat/Cotton Rotation CT	1	-0.72	0.72	-1.5	10.5	3.8	1.59	7.51	-0.31
Wheat/Cotton Rotation NT	3	0.05 (0.24)	0.93 (0.04)	0.89 (0.08)	0.1 (0.07)	0.6 (0.4)	4.61 (0.72)	9.28 (0.88)	0.57 (0.10)

[H] - OM=SCI organic matter factor; FO=SCI field operations factor; ER=SCI erosion factor.

[I] - Standard errors in parentheses.

[HH] - CT=Conventional tillage, NT=No tillage, LT=Limited tillage.

Table 4. Mean physical and chemical properties of study sites by agroecosystem.

						Aggregate	Carbon	Nitrogen		SCI Sub-Factors				Wind	Water		
Agroecosystem	Sand	Clay	NO_3-N	P^H	pH	Stability	Mass	Mass	POM-C	OM	FO	ER	SCI	Erosion	Erosion	REV	MRL
	---- % ----		---- ppm ----			%	------------ Mg ha^{-1}------------							------------------ Mg ha^{-1} ------------------			
Native Rangeland	79.9	10.3	1.1	3.8	7.8	43.2	6.99	0.58	-	-0.06	1.00	0.99	0.57	0.0	0.1	8.30	7.90
Native Rangeland	72.5	13.3	7.6	6.3	6.7	46.8	19.56	1.32	6.49	-0.91	1.00	0.85	0.20	0.0	0.9	1.25	7.51
Native Rangeland	65.6	17.3	10.4	5.0	6.8	20.9	5.17	0.31	4.50	-0.54	1.00	0.96	0.37	0.0	0.2	3.47	8.95
Native Rangeland	54.6	19.7	3.1	6.5	7.6	55.2	17.86	1.61	5.19	-0.46	1.00	0.97	0.41	0.0	0.2	8.65	7.51
Native Rangeland	56.8	22.2	1.6	4.2	8.0	44.0	11.36	1.04	-	-0.17	1.00	0.95	0.52	0.0	0.3	5.54	6.34
Conservation Grassland	87.0	7.9	3.8	4.0	7.5	15.6	13.87	1.38	2.96	4.80	1.00	1.00	2.50	0.0	0.0	8.63	7.51
Conservation Grassland	86.3	8.4	0.4	3.8	7.1	32.4	5.30	0.64	-	3.30	1.00	1.00	1.90	0.0	0.0	6.36	8.77
Conservation Grassland	86.2	8.7	0.8	16.0	7.3	7.2	5.13	0.48	1.31	4.70	1.00	1.00	2.50	0.0	0.0	9.24	7.51
Conservation Grassland	83.1	9.9	1.2	13.0	7.0	7.1	3.90	0.20	2.30	2.40	1.00	1.00	1.60	0.0	0.0	4.42	7.66
Conservation Grassland	81.6	10.8	1.0	5.8	7.8	41.3	5.17	0.54	-	3.70	1.00	1.00	2.10	0.0	0.0	6.09	7.90
Conservation Grassland	84.0	10.8	0.8	8.8	7.0	5.6	3.60	0.25	0.85	0.60	1.00	0.99	0.84	0.0	0.1	1.58	8.95
Conservation Grassland	65.4	16.7	4.3	12.0	7.5	21.1	10.90	1.42	2.94	5.80	1.00	1.00	2.90	0.0	0.0	18.00	7.51
Conservation Grassland	69.9	17.0	0.7	4.5	7.4	26.8	19.71	0.80	2.28	3.70	1.00	1.00	2.10	0.0	0.0	5.99	7.51
Conservation Grassland	62.0	19.3	0.5	5.0	7.8	30.0	13.65	1.10	3.27	3.50	1.00	1.00	2.00	0.0	0.0	11.98	7.51
Conservation Grassland	62.0	20.5	4.3	7.8	8.0	31.9	14.68	1.15	7.54	7.60	1.00	1.00	3.60	0.0	0.0	11.00	7.51
Conservation Grassland	46.2	26.3	0.6	1.8	7.1	42.2	15.09	1.33	4.91	6.30	1.00	1.00	3.10	0.0	0.0	7.50	7.51
Conservation Grassland	42.2	30.8	1.0	7.0	7.5	39.4	14.18	1.28	2.51	0.12	1.00	0.97	0.64	0.0	0.2	8.09	7.51
Dryland Cotton CT^{l}	90.7	6.4	6.1	18.5	7.1	4.8	2.91	0.23	-	-0.72	0.22	-7.10	-1.60	43.7	2.1	2.01	8.77
Dryland Cotton CT	89.5	7.7	7.3	9.7	7.8	7.2	5.08	0.40	0.78	-0.79	-0.29	-7.10	-1.80	43.7	2.2	1.21	7.51
Dryland Cotton CT	84.0	8.3	15.8	8.5	6.1	6.9	4.19	0.46	1.23	-0.62	-0.15	-5.00	-1.30	30.0	4.0	1.01	7.51
Dryland Cotton CT	88.3	8.4	5.0	6.5	7.6	3.1	21.70	0.61	0.67	0.22	-0.03	-3.80	-0.68	23.1	1.8	1.51	7.51
Dryland Cotton CT	86.7	8.4	6.5	15.8	6.9	9.8	3.36	0.28	-	-0.72	0.22	-26.00	-5.40	151.9	2.1	2.01	8.77
Dryland Cotton CT	88.5	8.9	2.3	13.3	6.0	3.9	2.19	0.17	0.36	-0.29	0.41	-5.90	-1.10	37.9	1.2	3.72	8.95
Dryland Cotton CT	85.9	9.4	24.9	11.8	6.4	3.5	1.40	0.12	0.30	-0.54	-0.10	-4.90	-1.20	30.7	2.9	2.65	10.16
Dryland Cotton CT	82.7	10.7	10.3	19.3	6.6	8.1	5.12	0.56	0.75	-0.75	-0.29	-7.00	-1.80	42.3	3.4	1.21	7.51
Dryland Cotton CT	79.5	12.1	9.8	5.5	7.7	16.3	30.20	0.77	0.57	-0.69	0.43	-1.80	-0.47	13.0	3.1	1.61	7.51
Dryland Cotton CT	74.3	14.4	12.7	6.5	8.0	2.2	4.48	0.49	0.73	-0.70	0.04	-23.00	-4.90	132.2	5.2	0.60	7.51
Dryland Cotton CT	71.8	16.5	13.9	7.0	8.0	5.9	7.17	0.69	-	-0.80	-0.17	-2.80	-0.95	15.7	6.0	2.39	7.51
Dryland Cotton CT	72.3	17.0	2.6	6.8	8.2	15.0	3.70	0.50	-	0.78	0.50	-5.10	-0.51	31.6	3.4	1.49	7.90
Dryland Cotton CT	61.3	19.8	4.1	10.8	8.3	14.7	5.40	0.59	-	-0.64	-0.19	-3.70	-1.10	21.7	5.2	1.51	7.51
Dryland Cotton CT	59.0	20.0	14.7	12.8	7.2	18.1	9.87	0.96	2.55	-0.36	0.13	-2.80	-0.66	15.2	6.5	1.48	7.51
Dryland Cotton CT	51.4	25.2	19.7	10.0	7.7	16.2	9.71	0.95	1.67	-0.36	0.13	-2.80	-0.66	15.2	6.5	1.48	7.51
Dryland Cotton CT	51.2	25.8	7.4	17.5	8.2	13.1	9.27	0.84	1.00	-0.77	0.03	-2.60	-0.81	14.3	5.8	1.01	7.51
Dryland Cotton CT	46.3	32.9	2.6	9.8	8.2	5.4	6.96	0.82	-	0.78	0.50	-4.10	-0.31	26.2	2.7	1.49	6.34
Dryland Cotton NT	80.0	12.7	10.2	52.0	6.3	6.8	3.05	0.23	1.17	-0.17	0.97	0.58	0.43	2.2	0.2	3.20	8.77
Irrigated Cotton CT	89.5	7.3	7.9	5.8	7.5	4.5	4.00	0.35	0.76	-0.55	-0.29	-3.50	-1.00	23.1	2.5	0.27	8.57
Irrigated Cotton CT	78.9	12.3	3.9	7.8	7.9	9.5	8.72	0.84	1.47	-0.49	-0.27	-3.60	-1.00	23.1	3.4	3.61	8.57
Dryland High Residue	83.5	9.4	4.5	13.7	7.9	14.8	4.86	0.57	-	-0.48	0.73	-1.60	-0.22	13.7	1.2	1.19	7.90
Terminated Wheat/Cotton CT	84.4	10.4	8.1	9.5	7.6	10.8	4.75	0.49	0.90	-0.69	0.60	-2.10	-0.47	15.7	2.2	6.49	7.51

Table 4 (Continued). Mean physical and chemical properties of study sites by agroecosystem.

						Aggregate	Carbon	Nitrogen		SCI Sub-Factors				Wind	Water		
Agroecosystem	Sand	Clay	NO_3-N	P	pH	Stability	Mass	Mass	POM-C	OM	FO	ER	SCI	Erosion	Erosion	REV	MRL
	---- % ----		---- ppm ----			%	------------ Mg ha^{-1}------------							------------------ Mg ha^{-1} ------------------			
Terminated Wheat/Cotton CT	67.6	17.8	28.9	7.5	7.9	-	8.85	0.79	-	-0.55	0.65	-1.60	-0.28	8.5	6.3	4.17	8.57
Terminated Wheat/Cotton LT	88.4	7.7	3.9	21.3	7.6	11.6	3.24	0.35	1.01	-0.34	0.51	0.79	0.23	0.0	1.2	5.89	10.02
Terminated Wheat/Cotton LT	84.3	9.8	2.9	31.0	8.0	5.2	3.70	0.35	1.11	-0.58	0.34	0.72	0.05	0.0	1.6	5.89	10.02
Terminated Wheat/Cotton LT	82.0	11.4	3.6	8.0	7.7	17.7	22.24	0.49	1.04	-0.02	0.53	0.09	0.22	3.4	1.8	3.27	8.57
Terminated Wheat/Cotton LT	68.1	18.5	11.7	38.0	7.7	-	11.04	0.95	1.17	-0.22	0.53	-0.03	0.12	3.6	2.2	2.72	8.57
Dryland Wheat	73.9	15.6	9.3	9.3	7.4	8.6	8.37	0.73	2.09	-0.88	0.93	-0.33	-0.05	4.7	2.9	0.46	7.51
Irrigated Wheat/Cotton Rot CT	87.4	8.3	4.6	20.4	7.7	5.6	4.63	0.36	0.97	-0.19	0.52	-0.48	0.04	7.6	0.8	2.25	8.57
Irrigated Wheat/Cotton Rot CT	79.5	12.6	7.7	21.0	7.5	3.6	7.91	0.76	-	-0.05	0.52	-0.64	0.06	8.1	1.3	1.19	8.57
Dryland Wheat/Cotton Rot CT	48.9	25.9	7.9	11.5	8.2	15.9	8.60	0.95	0.97	-0.72	0.72	-1.50	-0.31	10.5	3.8	1.59	7.51
Wheat/Cotton NT	80.9	11.6	25.1	33.7	7.1	9.0	4.39	0.51	3.41	-0.37	0.98	0.95	0.43	0.0	0.3	5.49	10.16
Wheat/Cotton NT	81.3	11.6	4.2	54.0	7.5	15.3	3.02	0.21	1.20	0.45	0.96	0.99	0.76	0.0	0.1	5.16	10.16
Wheat/Cotton NT	50.3	23.7	16.4	27.8	7.1	12.6	12.82	1.32	2.51	0.07	0.86	0.74	0.52	0.2	1.3	3.19	7.51

HP=Phosphorus; POM-C=particulate organic matter carbon; OM=organic matter; FO=field operations; ER=erosion; SCI=soil conditioning index; REV=residue equivalent value; MR=maintenance residue.

I CT=conventional tillage; NT=no tillage; LT=limited tillage.

Table 5. Pearson correlations of the soil conditioning index with selected study variables.

Source	Aggregate Stability	Particulate Organic Matter	Nitrogen Mass	Carbon Mass	Residue Equivalent Value
SCI Pearson Correlation, r	0.47	0.57	0.41	0.29	0.68
SCI Prob > r	0.0006	0.0002	0.002	0.037	<0.0001
Number of Observations	49	38	51	51	51