

CAN THE SOIL CONDITIONING INDEX PREDICT SOIL ORGANIC CARBON SEQUESTRATION WITH CONSERVATION AGRICULTURAL SYSTEMS IN THE SOUTH?

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SUMMARY

The soil conditioning index (SCI) is a relatively simple model used by NRCS to predict changes in soil organic C. It is based on three important conditions: (1) organic material (OM), (2) field operations (FO), and (3) erosion (ER). Our objective was to develop quantitative relationships between (1) published soil organic C data derived from field experiments under various management systems and (2) SCI values predicted from those management systems. Within a field study, SCI was usually highly related to soil organic C content. The SCI appears to reasonably estimate changes in soil organic C with adoption of conservation agricultural systems in the southeastern USA.

INTRODUCTION

Rapid and reliable assessments of the potential of various agricultural management systems to sequester soil organic C are needed to promote conservation and help mitigate greenhouse gas emissions. A growing database is emerging from detailed field experiments on how conservation agricultural systems can sequester soil organic C (Franzluebbbers, 2005; 2009). Unfortunately, many results appear to be site-, soil- and cropping system-specific, resulting in uncertainty of how to predict the effect of management in different environments, soil types, and crop management systems (Sainju et al., 2007; Franzluebbbers and Stuedemann, 2008; Novak et al., 2009).

The soil conditioning index is a relatively simple model used by the USDA Natural Resources Conservation Service that could be useful to predict changes in soil organic C. It is based on three important conditions: (1) organic material (OM) grown or added to the soil, (2) field operations (FO) that alter organic material placement in the soil profile and that stimulate organic matter breakdown, and (3) erosion (ER) that removes and sorts surface soil organic matter. Our objective was to develop quantitative relationships between (1) published soil organic C data derived from field experiments under various management systems throughout the southeastern USA and (2) index values predicted from those management systems using the soil conditioning index.

MATERIALS AND METHODS

Soil organic C content data from various field studies comparing conventional and conservation agricultural management approaches were summarized in two recent publications (Franzluebbers, 2005; 2009). The soil conditioning index (SCI) was run for individual management conditions under the soil and geographical conditions of sites listed in Table 1. Soil organic C and SCI values were analyzed separately by regression from within individual field studies with multiple management conditions. Multiple field studies were then pooled within the same major land resource and/or state to test if relationships were stable.

RESULTS AND DISCUSSION

On a Cecil sandy loam in Watkinsville GA, soil organic C increased with decreasing tillage intensity and time since last tillage (Franzluebbers et al., 1999). The SCI varied similarly and resulted in a curvilinear relationship between soil organic C content at the end of 4 years of management and SCI (Fig. 1). The hockey stick shape of the curve suggests that when SCI is positive, very large increases in soil organic C could occur (as compared to relatively small changes in soil organic C with large variations when SCI was negative).

On a Pacolet sandy loam in Auburn AL, soil organic C increased in all crop rotations following 3.5 yr of conservation tillage (Siri-Prieto et al. (2002)). The average rate of soil organic C sequestration was 1402 lb/acre/yr ($1.57 \pm 0.26 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$ among the five rotations investigated). The SCI was linearly related to the soil organic C content in these cotton management systems that were previously managed for 100 yr under conventional tillage (Fig. 2). The SCI allowed only 800 lb/acre of dry matter accumulation with annual clover as cover crop. Changing the cover crop to wheat allowed 4080 lb/acre of dry matter accumulation and this increased the strength of the relationship between soil organic C and SCI from $r^2 = 0.40$ to $r^2 = 0.58$. This adjustment suggests that some modification is likely needed to adjust cover crop growth dynamics to the conditions prevalent in the

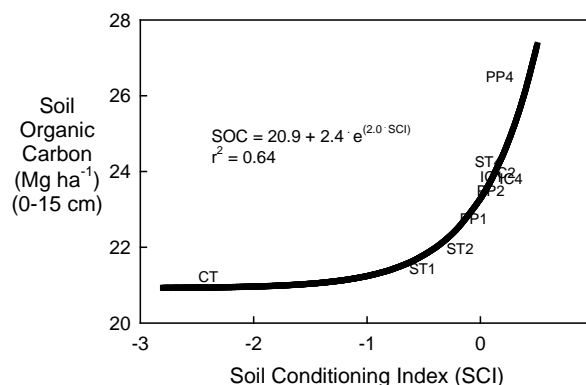


Figure 1. Relationship of soil organic C at the end of 4 yr of management to the soil conditioning index on a Cecil sandy loam in Watkinsville GA. Management was crimson clover / pearl millet rotated with crimson clover / cotton under conventional disk tillage (CT) and no-tillage planting with either paraplow (PP), in-row chisel (IC), or shallow cultivation tillage (ST) with frequencies of 1, 2, and 4 yr ago. Soil organic C data from Franzluebbers et al. (1999).

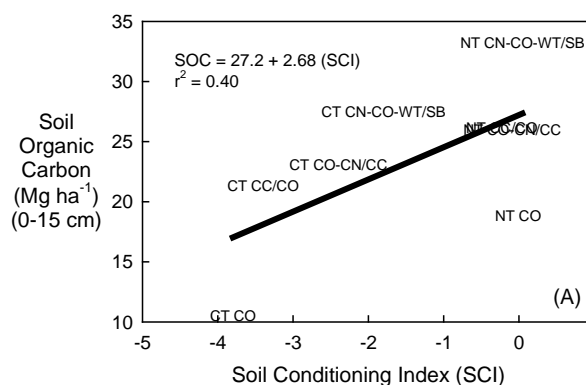


Figure 2. Relationship of soil organic C at the end of 3.5 yr of management to the soil conditioning index on a Pacolet sandy loam in Auburn AL. Management was continuous cotton (CO), crimson clover (CC) / cotton, crimson clover / cotton – crimson clover / corn (CN), and crimson clover / cotton – crimson clover / corn – wheat (WT) / soybean (SB) under conventional tillage (CT) and no tillage (NT). Soil organic C data from Siri-Prieto et al. (2002).

southeastern USA (rather than the Pacific Northwest region, in which annual clover was derived in the SCI simulation).

On a Weswood silty clay loam in College Station TX, soil organic C increased with a change from conventional tillage to no tillage and also with greater complexity of crop rotations (Fig. 3). The changes in soil organic C were highly related to the SCI values for these cropping systems. Since published studies varied in the depth of soil sampled and the number of years that cropping systems had been implemented, soil organic C were averaged over time and normalized to a common sampling depth. Soil organic C averaged 11.5 kg C m^{-3} under conventional tillage and 14.3 kg C m^{-3} under no tillage ($p < 0.01$), while SCI was -2.7 ± 0.7 under conventional tillage and -0.3 ± 0.3 under no tillage. The normalization step that was necessary in this evaluation suggests that consistency in estimating soil organic C sequestration (with regards to soil depth and time) is needed to obtain the most robust comparisons. Further work is needed to obtain peer-reviewed and verifiable relationships between soil organic C and SCI under a diversity of evaluation conditions.

Comparing across three locations in North Carolina and South Carolina, relationships of SCI to soil organic C were all linear within a location, but non-linear across locations (Fig. 4). Similar to the result in Georgia in Figure 1, a sharp increase in soil organic C was observed with a small change in SCI when positive. This curvilinear feature was also observed when SCI was compared against simulated soil organic C using the process-based model, EPIC (Abrahamson et al. 2007, 2009). Further work will be needed to explore cropping systems with positive SCI values to understand if soil organic C more typically follows a curvilinear or linear relationship with SCI. This will likely require more complex crop rotations, and especially with sod-based grasses and legumes in rotation with grain and fiber crops (Franzluebbers, 2007).

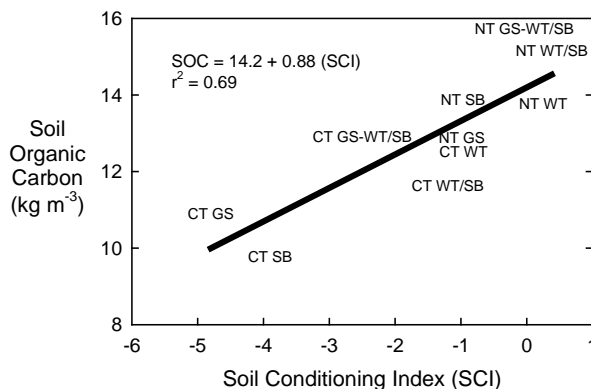


Figure 3. Relationship of soil organic C to the soil conditioning index on a Weswood silty clay loam in College Station TX. Management was continuous grain sorghum (GS), continuous soybean (SB), continuous wheat (WT), wheat / soybean, and sorghum – wheat / soybean under conventional tillage (CT) and no tillage (NT). Soil organic C data were collected at the end of 9, 10, and 20 yr of management at depths of 15, 20, and 30 cm from a number of studies, including Franzluebbers et al. (1994, 1995, 1998), Wright and Hons (2004, 2005), and Dou and Hons (2006).

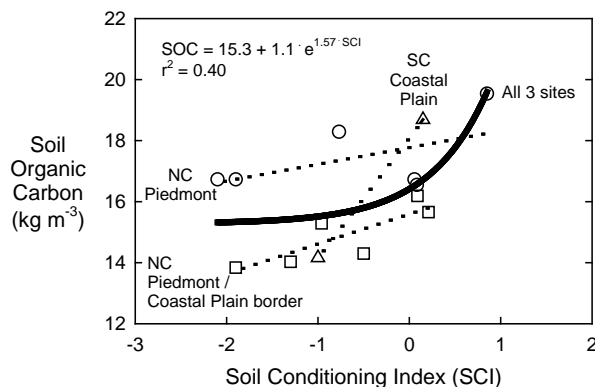


Figure 4. Relationship of soil organic C to the soil conditioning index at a Piedmont, Coastal Plain, and border location in North Carolina and South Carolina. Soil organic C data in South Carolina were from Karlen et al. (1989), Hun et al. (1996), Novak et al. (1996, 2007), Ding et al. (2002), and Bauer et al. (2006). Soil organic C data in North Carolina were from Naderman et al. (2004) and Franzluebbers and Brock (2007).

From 260 observations throughout the region, SCI was only weakly related to soil organic C (Fig. 5). However, soil organic C was greater ($p < 0.001$) under no tillage ($14.7 \pm 0.4 \text{ kg m}^{-3}$) than under conventional tillage ($12.8 \pm 0.5 \text{ kg m}^{-3}$). As well, SCI was greater under no tillage (0.2 ± 0.1) than under conventional tillage (-1.7 ± 0.2). The weak strength of all data together may be as much a function of how soil organic C inherently differs among locations and studies as much as the influence of SCI. We plan to further investigate how to better express soil organic C and SCI relationships, as there certainly may be other ways of presenting the strong differences in both SCI and soil organic C between these two contrasting tillage systems.

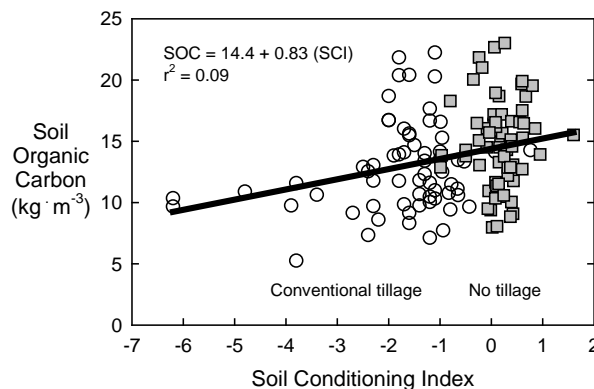


Figure 5. Relationship of soil organic C to the soil conditioning index across the 27 locations listed in Table 1.

CONCLUSIONS

The soil conditioning index was highly sensitive to the extent of tillage. This was especially true within each location investigated. When all data were compiled into a common analysis, only a weak relationship was found between soil organic C and SCI. However, there was clear separation between conventional and no tillage systems in both soil organic C content and SCI value.

Modifications to SCI management input variables may be necessary, since some conditions were not developed specifically for cropping systems in the southeastern USA. In addition, variations in soil organic C measurement protocol require some method of standardization to be able to pool data across studies, locations, and soil types.

Further work is needed to better define the relationships between soil conditioning index and soil organic C at higher index values, since variation in response was greatest and fewer observations were available at this end of the spectrum.

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Table 1. Locations and conditions for comparing soil organic C and soil conditioning index in the southeastern USA.

Location	Soil	Management variables	Source
AL Escambia Co.	Benndale fSL	Tillage	Motta et al. (2002)
AL DeKalb Co.	Hartsells fSL	Tillage, rotation	Edwards et al. (1992), Fesha et al. (2002)
AL Henry Co.	Norfolk LS	Tillage	Siri-Prieto et al. (2007)
AL, Lee Co.	Blanton LS, Pacolet SL	Tillage, rotation, cover crop	Siri-Prieto et al. (2002), Torbert et al. (2004)
AL Limestone Co.	Decatur SiL	Tillage, rotation, manure	Feng et al. (2002), Truman et al. (2003), Sainju et al. (2008)
AL Macon Co.	Compass LS	Tillage, rotation, manure	Reicosky et al. (1999), Terra et al. (2005), Reeves and Delaney (2002)
GA Bartow Co.	Dothan SL	Tillage	Sainju et al. (2007)
GA Clarke Co.	Wehadkee L	Tillage	Groffman (1984), Beare et al. (1994), Hu et al. (1995, 1997), Hendrix et al. (1998)
GA Oconee Co.	Cecil SL	Tillage, rotation, cover crop	Franzluebbers et al. (1999, 2007), Franzluebbers and Stuedemann (2008)
GA Peach Co.	Norfolk LfS	Tillage, rotation, cover crop	Sainju et al. (2002, 2006)
GA Spalding Co.	Cecil SL	Tillage	Hu et al. (1997), Hendrix et al. (1998)
GA Tift Co.	Tifton LS	Tillage	Sainju et al. (2007)
MD Howard Co.	Delanco SiL	Tillage, fertilizer	McCarty and Meisinger (1997)
MD Prince Georges Co.	Woodstown SL	Tillage	Weil et al. (1993)
MD Queen Annes Co.	Matapeake SiL	Tillage, fertilizer	McCarty and Meisinger (1997)
MD Wicomico Co.	Mattapex SiL	Tillage	Weil et al. (1998)
MS Tate Co.	Grenada SiL	Tillage, rotation	Rhoton (2002), Rhoton et al. (2002)
NC Iredell Co.	Iredell L	Tillage, rotation	Franzluebbers and Brock (2007)
NC Wayne Co.	Altavista fSL	Tillage, rotation	Naderman et al. (2004)
SC Florence Co.	Norfolk LS	Tillage	Karlen et al. (1989), Hunt et al. (1996), Novak et al. (1996, 2007), Ding et al. (2002), Bauer et al. (2006)
TX Bell Co.	Houston Black C	Tillage, rotation	Potter and Chichester (1993), Reicosky et al. (1997), Potter et al. (1998)
TX Brazos Co.	Weswood SiCL	Tillage, rotation	Franzluebbers et al. (1994, 1995, 1998), Wright and Hons (2004, 2005), Dou and Hons (2006)
TX Hidalgo Co.	Hidalgo SCL	Tillage	Zibilske et al. (2002)
TX Nueces Co.	Orelia L	Tillage	Salinas-Garcia et al. (1997), Potter et al. (1998)
VA Richmond Co.	Altavista fSL, Pamunkey L, Emporia L	Tillage, manure	Spargo et al. (2008)

C is clay, fSL is fine sandy loam, L is loam, LfS is loamy fine sand, LS is loamy sand, SCL is sandy clay loam, SiL is silt loam, and SL is sandy loam.