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Soil Carbon Changes Influenced by Soil Management and Calculation Method

Maysoon M. Mikha[1*], Joseph G. Benjamin[1], Ardell D. Halvorson[2], David C. Nielsen[1]

[1]US Department of Agricultural, Agricultural Research Service, Central Great Research Station, Akron, USA; [2]US Department of Agricultural, Agricultural Research Service, Northern Plains Soil Plant Nutrient Research, Fort Collins, USA.
Email: [*]Maysoon.Mikha@ars.usda.gov

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ABSTRACT

Throughout the years, many studies have evaluated changes in soil organic carbon (SOC) mass on a fixed-depth (FD) basis without considering changes in soil mass caused by changing bulk density (ρ_b). This study evaluates the temporal changes in SOC caused by two factors: 1) changing SOC concentration; and 2) changing equivalent soil mass (ESM) in comparison with FD. In addition, this study evaluates calculating changes in SOC stock over time using a minimum equivalent soil mass (ESM_{min}) basis from a single sampling event compared with the FD scenario. A tillage [no-tillage (NT) and chisel plow (CP)]-crop rotation (multiple crop and continuous corn), and irrigation (full and delayed)) study was initiated in 2001 on Weld silt loam soil. After seven years, SOC concentration in the 0 - 30 cm depth was 19.7% greater in 2008 compared with 2001. Standardizing the soil mass of 2001 to the ESM of 2008 for each individual treatment showed an average gain in SOC of 5.8 Mg C·ha^{-1} in 2008 compared with 2001. However, the increase in SOC using ESM was twice the SOC gained with the FD calculation, where some treatments lost SOC after seven years of management. Estimating SOC levels using the ESM_{min} and, thereby, eliminating the confounding effect of soil ρ_b indicated that SOC stock was influenced by crop species and their interaction with irrigation, but not by tillage practices. Over all, the ESM calculation appears to be more effective in evaluating SOC stock than the FD calculation.

Keywords: Soil Organic Carbon Stock; Equivalent Soil Mass; Minimum Equivalent Soil Mass; Fixed-Depth; Management Practices

1. Introduction

Numerous studies [1-8] have assessed management practice-induced changes in SOC due to anthropogenic and environmental effects. The majority of previous research [1-6] evaluated SOC mass using SOC concentration and soil bulk density (ρ_b) associated with a specific soil depth. However, management practices that influence SOC concentration may also affect soil ρ_b [5,9-12]. Consequently, researchers have argued that changes in soil ρ_b and its effect on unequal soil mass associated with the fixed depth have a confounding effect on SOC mass estimation when comparing changes in SOC associated with different management practices [13-17]. With an acknowledgment that SOC storage depends on soil mass and soil ρ_b, recent research estimated SOC and other soil nutrients based on their concentration, soil thickness, and soil ρ_b [13-18]. Researchers have suggested alternative methods to calculate SOC and other soil nutrients to account for the changes in soil volume under different management practices [13,14,16].

The equivalent soil mass (ESM) is one of the methods being used to assess SOC and other soil nutrients on a normalized soil mass per unit area basis to account for differences in soil masses caused by soil management [13-16,18]. In the ESM calculation scenario, soil masses associated with different management practices are standardized to a particular soil mass per unit area of a specified layer and the equivalent soil C mass is adjusted to the ESM [13,16,19]. The goal of using the ESM and its associated equivalent C mass calculation is to reduce the SOC error calculated in soil profiles due to changing soil ρ_b under different management practices [13,16]. Lee *et al.* [16] proposed two other scenarios for SOC estimation associated with a single sampling event when the initial SOC or initial (ρ_b) values were not available. The first method was based on using the minimum equivalent soil

[*]Corresponding author.

mass (ESM_{min}) measured and the second alternative measurement was based on using the maximum equivalent soil mass (ESM_{max}) measured. The ESM_{min} uses the lowest soil mass measured, on an FD basis, to standardize other soil masses associated with different management practices. The ESM_{max} uses the greatest soil mass measured, on an FD basis, among the different management practices as the standard [16].

The concept of soil mass and expressing SOC on an equivalent mass basis has been adopted by researchers for more than a decade, but this approach has not been readily applied to evaluate different management practices [13,16]. There has been limited research on the influence of different management practices on the standardized soil ρ_b, soil mass, and the associated SOC using field measured SOC and soil ρ_b. This type of research is vital due to the fact that, in recent years, there has been a great interest for evaluating SOC stock and improving soil C sequestration as influenced by different management practices. Preventing SOC losses due to soil management practices, especially tillage, and increasing crop residue return to the soil are important parameters in improving soil quality and sustainability. However, the confounding effect of soil ρ_b variability and the accuracy the soil ρ_b measurement are influencing the perceived temporal changes in SOC stock or SOC content in any given sampling period.

This study aims to evaluate different scenarios of SOC calculation where the confounding effect of soil ρ_b variability and its associated soil mass could be eliminated or reduced. We hypothesize that eliminating the differences in soil ρ_b and standardizing the soil masses into an ESM basis may be more effective in predicting the temporal changes in SOC stock or in SOC content at any given time period compared with FD scenario. Therefore, the objectives of this study were to: 1) evaluate the temporal changes in SOC concentration to eliminate the temporal variation in soil ρ_b; 2) evaluate the temporal changes in SOC stock as influenced by the FD and the ESM calculation methods; and 3) evaluate treatment effects on SOC using the ESM_{min} basis of standardization. Overall, this study identifies the temporal changes in SOC stock as influenced by different calculation scenarios after seven years of different management practices and subsequent changes in soil ρ_b and soil mass.

2. Materials and Methods[1]

2.1. Site Description

An irrigation-tillage-crop rotation study was established in 2001 with an individual plot size of 18 m × 9 m at the USDA-ARS Central Great Plains Research Station near Akron, CO [6]. The research station is located within a semiarid climate region with approximate mean annual precipitation of 418 mm. The study site is located at 40˚8'N latitude and, 103˚9'W longitude with elevation of 1384 m. The soil type is a Weld silt loam (fine, smectitic, mesic Aridic Argiustolls). Treatments were arranged in a split-plot design with three replications. The main plot was an irrigation treatment and the subplot was the tillage and crop system that were randomized within the main irrigation plots. Details of tillage practices, irrigation treatment, previous and current cropping history, and site management were reported in detail by Benjamin *et al.* [6]. Briefly, tillage treatments included NT (directly planting into the previous crop residues; no-till) and CP (fall chisel plow at 35 cm depth with a parabolic-shank deep ripper and spring pass with a mulch treader disrupting the approximately 0 - 5 cm depth). The irrigation treatment consisted of either full or delayed irrigation. The crop system treatments consisted of either continuous corn (CC) or a rotation (Rot) of a variety of crops throughout the study period, red kidney bean (*Phaseolus vulgaris* L.), spring barley (*Hordeum vulgare* L.), sunflower (*Helianthus annuus* L.), corn (*Zea mays* L.), spring pea (*Pisum sativum* L.), winter wheat (*Triticum aestivum* L.).

2.2. Soil Sampling

Soil samples were collected from non-wheel-tracked areas from the 0 - 15 and 15 - 30 cm depths in the spring of 2001 and 2008 before planting. The soil samples were collected from each plot using a 5 cm diam. probe attached to a Giddings hydraulic soil sampler (Giddings Machine Co., Windsor, CO). Soil samples were stored in sterile polypropylene bags placed coolers during field sampling and then stored at 4˚C in a walk-in cooler for about a week before processing. Soil samples were prescreened through a 2 mm sieve to remove large pieces of plant material before being air dried and ground to pass through a 2 mm screen using a flail-type soil grinder. Soil samples for determining soil bulk density (ρ_b) were also collected at the same sampling dates in 2001 and 2008. Soil ρ_b samples were collected for each plot using a 7.5 cm diam. by 60 cm long probe containing 7.5 cm diam. by 7.5 cm deep aluminum rings. The probe was attached to a Giddings hydraulic soil sampler for insertion into the soil. The rings were sectioned in the field to ensure an undisturbed soil sample with depth. Data were averaged for the 0 - 15 cm and 15 - 30 cm depths used in this study.

2.3. Soil Total C, Soil Inorganic C, and Soil Organic Carbon

Three subsamples per sampling bag were composited,

[1]Mention of commercial products and organization in this paper is solely to provide specific information. It does not constitute endorsement by USDA-ARS over other products and organization not mentioned. The US Department of Agriculture, Agricultural Research Service, is an equal opportunity/affirmative action employer and all agency services are available without discrimination.

ground to pass a 150 μ screen, and analyzed for different forms of soil carbon. Soil total C (STC) contents from the 0 - 15 and 15 - 30 cm depth were determined by dry combustion using a Carlo Erba C-N analyzer (Haake Buchler Instruments, Inc., Saddle Brook, NJ) at a commercial lab (Ward Laboratories, Kearney, NE). Soil inorganic C (SIC) content was evaluated using a modified pressure-calcimeter method reported by Sherrod *et al.* [20]. Soil organic C (SOC) content was calculated from the differences between STC and SIC. The SOC at 0 - 30 cm depth presented in this study is a sum of SOC associated with 0 - 15 and 15 - 30 cm depths. Data at 0 - 15 and 15 - 30 cm depths for SOC on a fixed depth basis were explained in details by Benjamin *et al.* [6].

2.4. Expression of Soil Organic Carbon (SOC)

The SOC associated with an ESM was calculated using the approach outlined by Ellert and Bettany [13] and Lee *et al.* [16]. The calculations presented in this study represent three scenarios for SOC evaluation. The first scenario estimates the temporal changes only in SOC concentration (g·C·kg^{-1} soil) from 2001 to 2008 (**Table 1**). The second scenario estimates the temporal changes in SOC stock from 2001 to 2008 adjusted to the ESM of 2008 for every treatment combination in the 0 - 30 cm depth. The third scenario evaluates treatment effects on SOC after 7 yrs of differing management practices adjusted to the ESM_{min} as if there was a single sampling in 2008. In addition, changes in SOC in the 0 - 30 cm depth using the second calculation scenario (ESM) will be compared to SOC calculated by the FD method reported by Benjamin *et al.* [6].

2.5. Equivalent Soil Mass (ESM) Scenario

To evaluate the temporal changes in SOC stock between 2001 and 2008 in the 0 - 30 cm depth, soil mass of 2001 was adjusted to the soil mass of 2008 (ESM) as influenced by management practices. In 2001, soil at this study site exhibited a high bulk density, ranging between 1.46 to 1.51 Mg·m^{-3} at the 0 - 30 cm depth. In 2008, soil bulk density at the 0 - 30 cm depth ranged between 1.21 to 1.37 Mg·m^{-3} (**Table 2**). The soil mass in 2008 associated with each treatment was considered the baseline for the ESM calculation.

Table 1. The 2001 and 2008 soil organic C (SOC) concentration (g·kg^{-1}) and the changes in SOC from 2001 to 2008 at 0 - 30 cm depth as influenced by irrigation, cropping, and tillage practices.

Irrigation	Tillage	Cropping	SOC 2001	SOC 2008	Δ SOC[a] 2008-2001
			0 - 30 cm		
			g·kg^{-1}		
Full	NT[b]	CC[c]	8.47	10.03	1.56
Full	CP	CC	8.29	9.61	1.32
Delayed	NT	CC	7.05	9.42	2.37
Delayed	CP	CC	7.01	8.97	1.96
Full	NT	Rot	7.91	9.00	1.09
Full	CP	Rot	7.75	8.67	0.92
Delayed	NT	Rot	7.60	8.60	1.00
Delayed	CP	Rot	7.50	9.43	1.93
			PR > F		
Irrigation (I)			0.08	0.27	0.22
Cropping (Cr)			0.95	0.004	0.074
Tillage (T)			0.67	0.56	0.94
I × Cr			0.07	0.028	0.64
I ×T			0.86	0.13	0.53
Cr × T			0.98	0.049	0.24
I × Cr × T			0.94	0.07	0.28

[a]Δ SOC = Changes in SOC concentration from 2001 to 2008; [b]NT = No-tillage; CP = Chisel plow; [c]CC = Continuous corn; Rot = Mixed grass and broadleaf crops.

Table 2. The 2001 and 2008 soil organic C (SOC) mass (Mg·ha^{-1}), soil bulk density (ρ_b) in Mg·m^{-3}, soil mass (Mg·ha^{-1}), and changes in SOC from 2001 to 2008 at 0 - 30 cm depth evaluated on a fixed depth (FD) basis and on an equivalent soil mass of the 2008 (ESM_{2008}) as influenced by irrigation, cropping, and tillage practices.

			Fixed depth							ESM_{2008}	
			SOC		ρ_b		Soil mass		Δ SOC[a]	SOC	Δ SOC[b]
Irrigation	Tillage	Cropping	2001	2008	2001	2008	2001	2008	2008-2001	2001	2008-2001
			0 - 30 cm								
			Mg·ha^{-1}		Mg·m^{-3}		Mg·ha^{-1}				
Full	NT[c]	CC[d]	38.3 a[e]	41.4 a	1.505 a	1.370 a	4515 a	4110 a	3.2 a	34.88 a	6.5 a
Full	CP	CC	37.0 a	36.5 a	1.481 ab	1.270 a	4443 ab	3810 a	−0.5 a	31.58 a	4.9 a
Delayed	NT	CC	31.1 a	37.3 a	1.464 b	1.313 a	4392 b	3939 a	6.2 a	27.78 a	9.5 a
Delayed	CP	CC	31.0 a	32.3 a	1.477 ab	1.208 a	4431 ab	3624 a	1.3 a	25.41 a	6.9 a
Full	NT	Rot	35.2 a	34.6 a	1.485 ab	1.295 a	4455 ab	3885 a	−0.6 a	30.72 a	3.9 a
Full	CP	Rot	34.5 a	31.5 a	1.483 b	1.213 a	4449 ab	3639 a	−2.9 a	28.18 a	3.3 a
Delayed	NT	Rot	33.9 a	32.1 a	1.500 a	1.242 a	4500 a	3727 a	−1.8 a	28.32 a	3.8 a
Delayed	CP	Rot	32.7 a	34.6 a	1.463 b	1.226 a	4389 ab	3678 a	1.9 a	27.72 a	7.0 a
			PR > F								
Irrigation (I)			0.08	0.10	0.45	0.17	0.47	0.17	0.61	0.08	0.26
Cropping (Cr)			0.94	0.0007	0.88	0.004	0.87	0.006	0.02	0.34	0.07
Tillage (T)			0.51	0.02	0.17	0.003	0.19	0.004	0.16	0.14	0.85
I × Cr			0.06	0.01	0.16	0.13	0.17	0.15	0.87	0.06	0.70
I × T			0.83	0.07	0.87	0.33	0.96	0.28	0.67	0.60	0.53
Cr × T			0.89	0.01	0.29	0.06	0.30	0.06	0.18	0.63	0.20
I × Cr × T			0.68	0.06	0.02	0.20	0.02	0.19	0.36	0.86	0.29

[a]Δ SOC = Changes in SOC from 2001 to 2008 calculated on a fixed depth basis (FD) as reported by [6]; [b]Δ SOC = Changes in SOC from 2001 calculated on ESM_{2008} basis to 2008 calculated on a fixed depth basis; [c]NT = No-tillage; CP = Chisel plow; [d]CC = Continuous corn; Rot = mixed grass and broadleaf crops; [e]Different letter represents significant ($P < 0.05$) differences among the treatments within the same measurement and year.

Soil masses for each treatment in 2001 and 2008 were calculated on an FD basis using soil depth at 0 - 30 cm and field measured bulk density (**Table 2**) as

$$M_{soil} = d \times \rho_b \times 10^{-4} \quad (1)$$

where M_{soil} represents soil mass measured in (Mg·ha^{-1}), d represents soil depth measured in (m), ρ_b represents soil bulk density measured in (Mg·m^{-3}) at the FD, and 10^4 is the conversion factor (m^2·ha^{-1}). The SOC mass for the FD of 0 - 30 cm was calculated from field measured SOC concentration as

$$M_C = M_{soil} \times C_{cons} \times 10^{-3} \quad (2)$$

where M_C represents soil C mass (Mg·C·ha^{-1}) at the fixed-depth, C_{cons} represents SOC concentration (kg·Mg^{-1}), and 10^{-3} is the conversion factor (Mg·kg^{-1}).

To account for the difference in soil masses and bulk densities between 2001 and 2008, the soil mass and associated SOC in 2001 were adjusted to the ESM determine in 2008 using a calculation procedure similar to Ellert and Bettany [13] and Lee *et al.* [16]. The equivalent soil mass for each treatment (i) [$ESM_{(i)}$] in 2008 was considered to be the baseline soil mass in 2001 for the same treatment. For each treatment (i) in 2001, the SOC content on an $ESM_{(i)}$ basis was calculated as shown in **Figure 1**. The example calculation in **Figure 1** represents the data from the first treatment in **Table 2** in the 0 - 30 cm depth, Full irrigation with NT and continuous corn (CC) cropping system. In this example, the soil mass in 2001 at 0 - 30 cm depth on a FD basis was reduced by 405 Mg·ha^{-1} due to different management practices compared with the baseline of the same treatment (4110 Mg·ha^{-1}) in 2008 (**Table 2**), calculated as

$$M_{sub(i)} = M_{soil(2001)(i)} - ESM_{(i)} \quad (3)$$

where $M_{sub(i)}$ represents the soil mass subtracted from

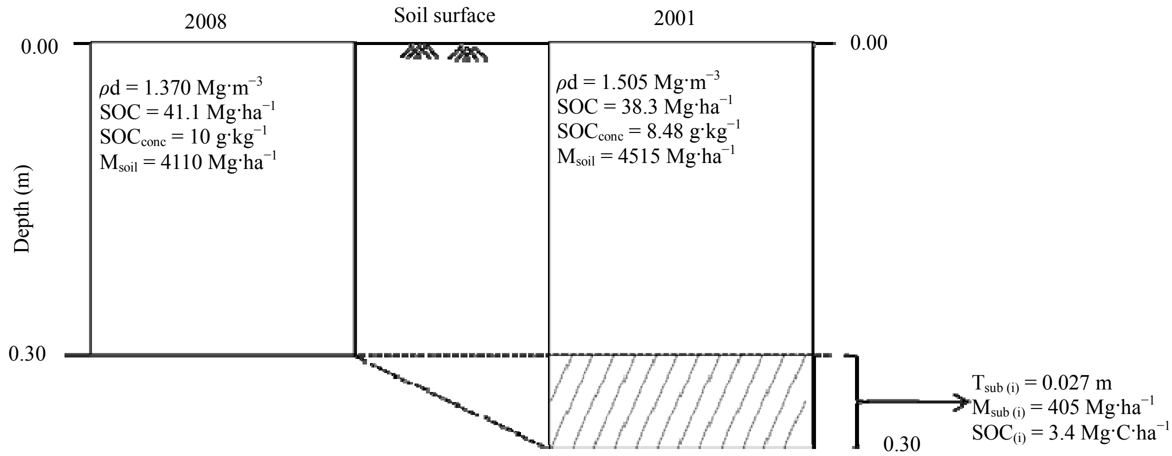

Figure 1. Example calculation for 2001 soil organic C (SOC) on an equivalent soil mass (ESM) basis of the 2008 soil mass at 0 - 30 cm depth. M_{soil} represents soil mass in $Mg \cdot ha^{-1}$ on a fixed-depth basis (FD) for 2001 and 2008, ρ_b represents soil bulk density in $Mg \cdot m^{-3}$, and SOC value represents soil C concentration (SOC_{conc}) in $g \cdot kg^{-1}$ and SOC mass in $Mg \cdot ha^{-1}$. The shaded area associated in 2001 represents the soil thickness ($T_{sub(i)}$) measured in m, soil mass ($M_{sub(i)}$) measured in $Mg \cdot ha^{-1}$, and its corresponding $SOC_{(i)}$ measured in $Mg \cdot ha^{-1}$ that needs to be subtracted from the 2001 value associated with the treatment (i) to standardized to the 2008 soil masses.

2001 ($Mg \cdot ha^{-1}$) for specific treatment (i), $M_{soil\ (2001)\ (i)}$ represents soil mass on an FD basis ($Mg \cdot ha^{-1}$) in 2001 associated with a specific treatment (i), $ESM_{(i)}$ represents an equivalent soil mass on an FD basis ($Mg \cdot ha^{-1}$) in 2008 associated with the same specific treatment (i). The SOC associated with the subtracted layer of 2001 was equivalent to 3.4 $Mg \cdot ha^{-1}$ and was calculated using SOC concentration following Equation (2). Therefore, the SOC in 2001 was reduced to ~34.9 $Mg \cdot ha^{-1}$ to adjust to the $ESM_{(i)}$ for the same treatment (**Table 2**). In addition, as the soil mass of treatment (i) in 2001 was reduced, the soil thickness in 2001 for the same treatment was also reduced. The specific soil thickness (0.02691 m) associated with $M_{sub(i)}$ was also subtracted from 30 cm depth in 2001 (**Figure 1)** calculated as follows:

$$T_{sub(i)} = \frac{M_{sub(i)}}{\rho_{b(2001)(i)}} \times 10^{-4} \quad (4)$$

where $T_{sub(i)}$ represents the soil thickness (m) that needs to be subtracted from 2001 for a specific treatment (i), $M_{sub(i)}$ represents the soil mass subtracted from 2001 ($Mg \cdot ha^{-1}$) to adjust to the soil mass of 2008 for a specific treatment (i), $\rho_{b\ (2001)\ (i)}$ represents the 2001 bulk density ($Mg \cdot m^{-3}$) of treatment (i), and 10^{-4} represents the conversion factors ($ha \cdot m^{-2}$).

2.6. Minimum Equivalent Soil Mass Basis (ESM_{min}) Scenario

To estimate changes in SOC in 2008 among different management practices in the 0 - 30 cm depth, SOC was evaluated on the ESM_{min} as proposed by Lee *et al.* [16]. This type of SOC evaluation can be used when the initial conditions (SOC or bulk density) are not available. In this method, all soil masses associated with different treatments will be adjusted to the minimum observed soil mass and its associated ρ_b measured in 2008 in the 0 - 30 cm depth. The ESM_{min} chosen from the 2008 was 3624 $Mg \cdot ha^{-1}$ that represents the minimum ρ_b (**Table 2**). In this approach, since the minimum soil mass was chosen, a specific amount of soil mass, with its associated SOC, was subtracted from each treatment in 2008 to equal the ESM_{min} (**Table 3**). For each treatment in 2008, the SOC on an ESM_{min} basis was calculated as in Equation (1) and Equation (2), except that $M_{sub(i)}$ was calculated as

$$M_{sub(i)} = M_{soil(i)} - ESM_{min} \quad (5)$$

where $M_{sub(i)}$ represents the soil mass subtracted ($Mg\ ha^{-1}$) from each treatment (i) in 2008, $M_{soil(2008)(i)}$ represents soil mass on an FD basis ($Mg \cdot ha^{-1}$) in 2008 associated with a specific treatment (i), and ESM_{min} represents the chosen minimum equivalent soil mass ($Mg \cdot ha^{-1}$) in 2008. The specific soil thickness associated with $M_{sub(i)}$ was also subtracted from 30 cm depth in 2008 calculated as follows:

$$T_{sub(i)} = \frac{M_{sub(i)}}{\rho_{b(i)}} \times 10^{-4} \quad (6)$$

where $T_{sub(i)}$ represents the soil thickness (m) that needs to be subtracted from a specific treatment (i) in 2008, $M_{sub(i)}$ represents the soil mass subtracted from 2008 ($Mg \cdot ha^{-1}$) to adjust to the ESM_{min}, $\rho_{b(i)}$ represents the 2008 bulk density ($Mg \cdot m^{-3}$) of treatment (i), and 10^{-4} represents the conversion factors ($ha \cdot m^{-2}$).

2.7. Statistical Analyses

Analyses of variance were calculated using SAS Version 9.2 [21] to determine statistically significant effects of irrigation, tillage, and crop system on SOC content. The data were analyzed as a split plot design, with irrigation being the main effect and the factorial tillage and crop rotation treatments being sub plots within the main plots. The F-test was used to evaluate the treatment factors main effects and interactions. An F-protected t-test was used on a pair-wise comparison to follow up any significant findings. All results were considered significantly different at $p < 0.05$ unless noted otherwise.

3. Results and Discussions

3.1. Soil Organic Carbon on the Concentration Basis

The first scenario, where SOC and changes in SOC are presented on a concentration basis ($g \cdot C \cdot kg^{-1}$ soil) is used to eliminate the temporal variation and the error associated with soil ρ_b measurements [22,23]. This scenario could be used as an option if the temporal changes in soil ρ_b are high or if the soil ρ_b was not measured.

Average SOC in the 0 - 30 cm depth, expressed on a concentration basis, was 19.7% greater in 2008 compared with 2001 (**Table 1**). These data also show that SOC concentration was higher in 2008 than 2001 for every treatment combination, indicating that all management practices improved SOC at this study site. There were no treatment differences in SOC concentrations in 2001, because 2001 represents the initial condition for this study. However, SOC in 2008 was influenced by cropping system ($p = 0.004$), where SOC associated with CC system was 6.5% greater than the Rot system. All treatments gained SOC between 2001 and 2008, and the increase ranged between 0.13 to 0.34 $g \cdot kg^{-1} \cdot yr^{-1}$ (**Table 1**). The increase of SOC with CC plots was, on average 23%, where the increase of the Rot plots was 16%.

3.2. Soil Organic Carbon Stocks on the Equivalent Soil Mass of 2008 Basis (ESM)

Soil ρ_b in the 0 - 30 cm depth significantly decreased with time ($p < 0.0001$) by an average of 14.6% in 2008 compared with 2001 (**Table 2**). Averaged across all the treatment combinations, there was insignificant change in SOC, as evaluated by the FD basis, between 2008 and 2001. The SOC in the CC cropping system increased an average 7.4%, compared with an average of 2.3% with Rot system. Benjamin *et al.* [6] also concluded that SOC, measured on an FD basis, in NT plots gained an average of 2.1 $Mg \cdot ha^{-1}$, whereas the CP plots lost an average of 0.1 $Mg \cdot ha^{-1}$ at the 0- to 30-cm soil depth during the seven-year study period. Many researchers argue the fact that changes in soil ρ_b, and its effect on unequal soil mass associated with the FD, has a confounding effect on the SOC mass estimation [12-14,16,17]. The changes in ρ_b between 2001 and 2008 (**Table 2**) influenced soil mass, SOC, and the temporal change in SOC in the 0 - 30 cm layer, calculated on a fixed-depth basis. The principle behind the ESM calculation scenario is to evaluate the temporal changes in SOC mass by eliminating the changes in soil ρ_b caused by time and different management practices. In this scenario, the soil masses of 2001 were standardized to the soil masses of 2008 for each treatment. The decision to normalize soil mass of 2001 to the mass of 2008 was influenced by two facts: 1) the soil ρ_b and, consequently, the soil masses associated with 2001 were higher than 2008; and 2) no soil samples were measured below 30 cm depth, which provided no additional information about soil ρ_b and SOC below 30 cm for the 2008 sampling period. This is important because to adjust the low soil mass of 2008 to the high soil mass of 2001, a specific soil mass and SOC need to be added to soil mass of 2008 from the layer below 30 cm.

The reduction in soil masses from 2001 to 2008 ranged between 405 $Mg \cdot ha^{-1}$ to 810 $Mg \cdot ha^{-1}$. Likewise, the reduction in SOC from 2001 to 2008 ranged between 3.3 $Mg \cdot ha^{-1}$ to 6.3 $Mg \cdot ha^{-1}$ (**Table 2**). Using ESM as the calculation scenario showed that management practices throughout the seven year period significantly ($p < 0.0001$) increased SOC by an average of 19.7% in 2008 compared with 2001. The NT plots gained an average of 5.9 $Mg \cdot ha^{-1}$ of SOC, whereas the CP plots gained an average of 5.6 $Mg \cdot ha^{-1}$ of SOC between 2008 and 2001. Similarly, the CC treatment gained an average of 21% SOC, and the Rot plots gained an average of 16% SOC between 2008 and 2001. In fact, SOC stock and percent SOC increased over time calculated with this scenario are similar to what we observed previously when SOC was evaluated on a concentration basis.

Using the ESM scenario produced SOC increases in all of the treatments between 2001 and 2008. The SOC gained with this scenario was parallel to what we previously observed with SOC measured on a concentration basis. However, the SOC change between 2001 and 2008 with the ESM calculation scenario averaged 0.47 to 1.36 $Mg\ C\ ha^{-1} \cdot yr^{-1}$, compared with that of Benjamin *et al.* [6], which averaged −0.41 to 0.89 $Mg \cdot C \cdot ha^{-1} \cdot yr^{-1}$, (**Table 2**). Apparently, the soil ρ_b in both time periods had a confounding effect on the changes in how SOC was evaluated. These data agree with our hypothesis that normalizing the soil mass of 2001 to the ESM of 2008 for each treatment reduced the confounding effect of a changing soil ρ_b. Also these data revealed that different soil management practices affected SOC status at this study site.

3.3. Soil Organic Carbon Stocks on the Minimum Equivalent Soil Mass Basis (ESM_{min})

The minimum equivalent soil mass (ESM_{min}) is an approach for estimating SOC levels when the initial data were not previously measured [16]. The ESM_{min} approach is useful when soil ρ_b has decreased with time. In this method, all soil masses from different management practices are standardized to the lowest soil mass and lowest ρ_b across the treatments of interest. The lowest soil mass sampled in 2008, averaged across replications, was 3624 Mg·ha^{-1} (**Table 3**), and, therefore, was considered the ESM_{min}. The ESM_{min} was observed with delayed irrigation with CP tillage and CC rotation. Since the ESM_{min} was the lowest soil mass compared with any other treatment, the soil mass and associated SOC were subtracted from the 0 - 30 cm from all other treatments to adjust for ESM_{min}.

In this scenario, the soil masses were reduced by an average of 0.0 Mg·ha^{-1} to 486 Mg·ha^{-1} compared to soil masses calculated on an FD basis (**Table 3**). The reduction in soil mass, after the ESM_{min} adjustment, was greater with NT practice (300 Mg·ha^{-1}) and CC system (246 Mg·ha^{-1}) compared with CP practice (73 Mg·ha^{-1}) and Rot system (127 Mg·ha^{-1}). The greater amount of soil mass that was subtracted from NT practice was a consequence of higher soil ρ_b compared with CP practice (**Table 2**). After 7 yr of NT, soil ρ_b was 6.5% greater ($p = 0.003$) in those plots than in the CP plots, which may be due to yearly soil disturbance associated with CP treatment. Adjusting the soil masses to the ESM_{min} reduced

Table 3. Soil mass (Mg·ha^{-1}) subtracted from the original soil mass of 2008 to adjust to the minimum equivalent soil mass (ESM_{min}) of 2008, soil organic C (SOC) mass (Mg·ha^{-1}), and changes in SOC between 2008 calculated at ESM_{min} and SOC and on a fixed depth (FD) basis at 0 - 30 cm depth as influenced by irrigation, cropping system, and tillage practices.

			---------- ESM_{min} ----------		ΔSOC_{2008}[b]
Irrigation	Tillage	Cropping	Soil mass subtracted[a]	SOC	ESM_{min}-FD
			----------≤30 cm----------		
			----------Mg·ha^{-1}----------		
Full	NT[c]	CC[d]	486	36.3	−5.1
Full	CP	CC	186	34.8	−1.7
Delayed	NT	CC	315	34.1	−3.2
Delayed	CP	CC	0	32.3	0.0
Full	NT	Rot	261	32.6	−2.0
Full	CP	Rot	15	31.4	−0.1
Delayed	NT	Rot	102	31.2	−1.0
Delayed	CP	Rot	54	34.2	-0.4
			---------- ESM (Mg·ha^{-1}) ----------		
Equivalent soil mass			3624[e]		
			---------- PR > F ----------		
Irrigation (I)			0.12	0.29	0.13
Cropping (Cr)			0.009	0.007	0.004
Tillage (T)			0.003	0.59	0.004
I × Cr			0.09	0.039	0.09
I × T			0.42	0.16	0.19
Cr × T			0.048	0.64	0.039
I × Cr × T			0.30	0.09	0.33

[a]Soil mass subtracted from the original soil mass of 2008 at 0 - 30 cm to adjust to the minimum equivalent soil mass (ESM_{min}) basis (**Table 1**); [b]ΔSOC_{2008} = changes in SOC between ESM_{min} (presented in this table) and SOC on a fixed depth basis (**Table 1**) at 0 - 30 cm depth; [c]NT = No-tillage; CP = Chisel plow; [d]CC = continuous corn; Rot = mixed grass and broadleaf crops; [e]Minimum equivalent soil mass (ESM_{min}) represents the lowest soil mass in 2008 (**Table 1**) used to adjust the mass of the other treatments at 0 - 30 cm depth.

SOC an average of 0.0 $Mg·ha^{-1}$ to 5.1 $Mg·ha^{-1}$ (**Table 3**). The reduction in SOC was influenced by tillage ($p = 0.004$), cropping system ($p = 0.004$), and the two way interaction of tillage x cropping system ($p = 0.039$). Eliminating the variability of soil ρ_b by adjusting the soil masses associated with different treatment combinations to an ESM_{min} reduced the influence of tillage practices (**Tables 2** and **3**) on changes in SOC. The differences in SOC between tillage practices disappeared because a significant amount of SOC was subtracted from the NT practices to adjust all treatments to the ESM_{min} standard. SOC evaluated on an ESM_{min} basis was 4.8% lower ($p = 0.005$) than SOC evaluated on an FD basis. However, the effect of cropping system and the two way interaction, irrigation x cropping system, had the same influence on SOC (**Tables 2** and **3**) calculated with ESM_{min} and FD scenarios. Apparently, standardizing soil masses to an ESM_{min} eliminated the influence of tillage practices on SOC evaluation. These data agree with our previous hypothesis that evaluating SOC from a single sampling event on an ESM_{min} was more effective compared with FD scenario basis due to the elimination of the soil ρ_b variation associated with different management practices.

It is important to recognize that there is another scenario of SOC calculation based on a maximum equivalent soil mass (ESM_{max}) proposed by Lee *et al.* [16] for SOC changes from a single sampling event. Briefly, the ESM_{max} is based on using the greatest soil mass, on the fixed-depth basis, among the different management practices to which the other soil masses were normalized [16]. A specific soil mass, soil thickness, and its associated SOC are then added to the treatment that exhibits smaller soil mass than ESM_{max} chosen. The ESM_{max} calculation scenario may give us a different perspective of SOC influenced by different management practices, but this type of calculation was not performed for this data set due to the sampling depth limitations In this study, the lack of available SOC information associated with soil below 30 cm depth made it difficult to adjust soil masses to the ESM_{max}.

4. Conclusion

Evaluation of the temporal changes in SOC stock was influenced by calculation scenarios as a consequence of changes in soil ρ_b. The SOC estimation depends on how one calculates changes in soil mass associated with different sampling periods or management practices. Changes in SOC evaluated on the FD basis could be influenced by soil ρ_b variability. The temporal changes in the percent SOC gained when using the ESM calculation scenario were similar to what we observed when SOC change was calculated on a concentration basis. These data indicate that the ESM was more effective in evaluating SOC stock due to the similarity to the temporal changes in SOC concentration compared with the FD scenario. The ESM_{min} method appears to be an effective scenario for SOC evaluation from a single sampling event. We were unable to compare the ESM_{min} method with other evaluation scenarios due to the sampling depth limitations. Therefore, it is advisable to sample several centimeters below the chosen depth of interest to allow for SOC evaluation with different scenarios. Over all, the ESM scenario, where the temporal changes in soil ρ_b and soil mass were adjusted for each individual treatment, appears to be an effective scenario for evaluating SOC changes under these study conditions. We recommend, however, that the FD scenario also be included in future SOC evaluations so that comparisons with historical studies on changes in SOC with management and time can be made.

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