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Distribution and amount of soil organic C in long-term management systems in Texas

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Abstract

Soil organic carbon (SOC) distribution is altered by residue management practices, but the effect on total C mass is not well understood, especially in warm regions. The objective of this study was to determine the effect of residue management practices on SOC distribution and amount across an 1100 km transect (northwest to southeast) of Texas. Long-term (>10 years) continuous cropping rotation and residue management plots located near Bushland, Temple, and Corpus Christi, Texas, were sampled incrementally with depth for SOC distribution and mass. The mass of SOC varied among locations depending on management, and climatic conditions. No-tillage management resulted in increased SOC concentration and mass in the surface 0.07 m in comparison to more intensive tillage management (e.g., sweep, chisel plow, moldboard plow). Fertilization had little effect on C sequestration at any site. Carbon sequestration decreased as mean annual temperature increased. Carbon may be sequestered in soil under Texas climatic conditions, but the amounts may be quite small. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Carbon sequestration; No-till; Climate

1. Introduction

Soil organic carbon (SOC) content has long been recognized as one indicator of soil quality. Tillage always results in a large decrease in SOC concentration (Whiteside and Smith, 1941; Mann, 1986; Burke et al., 1989). Less intensive tillage with residue management practiced for extended periods of time has been shown to increase SOC concentrations near the surface (Dick, 1983; Eghball et al., 1994). Soils are now being considered as a possible sink to store C to possibly mitigate the effects of increasing atmospheric CO_2 on the environment (Kern and Johnson, 1993).

Several authors have related the change in SOC to the type of tillage and the amount of biomass produced by the crop (Havlin et al., 1990; Reicosky et al., 1995; Robinson et al., 1996). Rates of C accumulation in soils under no-till or conservation till reported in the literature have varied widely, ranging from below 0 to 1300 kg ha^{-1} yr^{-1} (Reicosky et al., 1995). The greatest increases in SOC have been reported in the colder, northern regions of the United States. Only a limited amount of research on conservation tillage has been

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conducted in the warmer southwest environment. Several authors have reported that SOC concentrations were increased near the surface with no-till management (Unger, 1991; Potter and Chichester, 1993; Christensen et al., 1994). Questions remain, however, as to whether C storage has actually increased or if the distribution of C in the soil with depth has simply been changed in the southwestern region of the United States.

The objective of this study was to determine SOC distribution and total SOC in Texas soils with relatively long-term no-till management histories compared with other management systems.

2. Materials and methods

Three sites in Texas were selected that had long-term (10 years or greater) research plots, which allowed comparisons between no-till management and other management systems. Locations were near Bushland, Temple, and Corpus Christi, Texas (Fig. 1). Long-term rainfall and mean annual temperature for each location are shown in Table 1. Soils at each location had been tilled for an extended period before the long-term management studies were initiated and had developed a stable SOC level (Mann, 1986). Specific details of each study at each location are presented below.

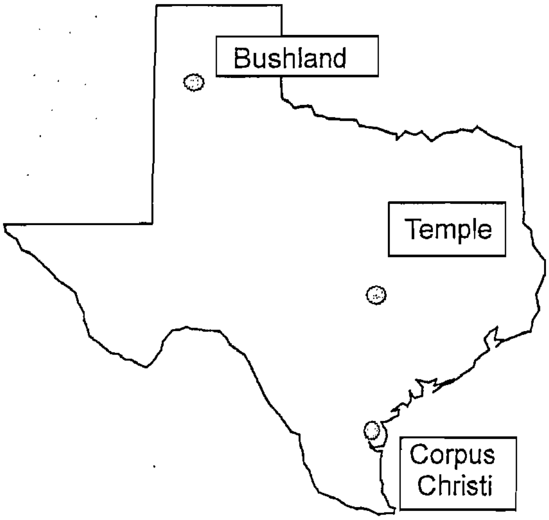

Fig. 1. Location of study sites in Texas.

Table 1
Climatic summary for the study locations

Location	Mean annual rain (mm)	Mean annual temperature (°C)
Bushland	473	14
Temple	860	19
Corpus Christi	660	22

2.1. Bushland: site and treatment information

Management trials have been conducted for 10 years near Bushland, TX on a Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll). Sand, silt, and clay contents for the surface soil averaged 21.8%, 50.0%, and 28.2%, respectively.

The effect of two tillage treatments on SOC was determined on continuous wheat (*Triticum aestivum* L.) (CW) and continuous grain sorghum (*Sorghum bicolor* L. Moench.) (CS) cropping systems. Tillage treatments included conventional stubble-mulch tillage (stubblemulch), and no-tillage with chemical weed control (no-till). In the stubble-mulch tillage plots, a Richardson[1] sweep plow with one 1.5 m and two 1.8 m blades was used for weed control. This implement did not invert surface residue, but mixed the surface 10 cm of soil. Two fertilizer treatments were also tested: fertilized (45 kg N ha^{-1} applied at planting) and no fertilizer. The study was designed as a randomized complete block with tillage and crop rotation as the main blocks and fertilizer rate as a split plot treatment. Treatments were replicated three times. Other management information has been presented in Jones and Popham (1997).

One soil core (5.5 cm diam.) was taken from each plot and subdivided for SOC determination. Sample increments for the SOC determinations were 0–2, 2–4, 4–7, 7–10, 10–15, 15–20, 20–35, 35–50, and 50–65 cm. A separate set of soil cores were taken and soil bulk densities were determined by the core method (Blake and Hartge, 1986). Sample increments for the bulk density samples were 0–4, 4–10, 10–20, 20–35, 35–50, and 50–65 cm.

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2.2. Temple: site and treatment information

Management trials have been conducted for 10 years near Temple, TX on a Houston Black clay (fine, montmorillonitic, thermic Udic Pellustert). Sand, silt, and clay contents for the surface 0.3 m of soil averaged 4.8%, 39.0%, and 56.2%, respectively.

A winter wheat/grain sorghum/corn (*Zea mays* L.) crop rotation was used to determine the effects of annual tillage and no-tillage management systems. Each crop was represented each year of the study, but only the wheat and corn phases were sampled because the grain sorghum no-till phase block was tilled in 1990. A wide-bed management system was used in this study. Details have been presented in Morrison et al. (1990). Briefly, the system involved the use of 1.5 m wide beds raised 0.15 m above 0.5 m wide furrows. For the annual tillage treatments, the beds were disrupted to a 20 cm depth by fall chisel plowing, disked twice and the beds reformed. For the no-till treatments, the soil was not disturbed, except for planting and minor reshaping of the beds every third year. A high and low fertilizer treatment was also applied (the rates of fertilizer application are presented in Table 2). The experiment was a split plot, randomized complete block design with the tillage treatments as the main plot and fertilizer treatments as the split plot. Treatments were replicated four times.

One soil core (4.3 cm diam.) was taken from each plot and subdivided for SOC and bulk density determinations. Sample increments were 0–2, 2–4, 4–7, 7–10, 10–15, 15–20, 20–35, 35–50, and 50–65 cm.

2.3. Corpus Christi: site and treatment information

Management trials have been conducted for 15 years near Corpus Christi, TX on an Orelia sandy clay loam (fine-loamy, mixed, hyperthermic Typic Ochraqualf). Sand, silt, and clay contents for the surface 0.3 m averaged 55.7%, 20.8%, and 23.5%, respectively.

Tillage treatments have been continuously imposed for 15 years with a crop rotation of 4 years of cotton (*Gossypium hirsutum* L.) rotated with 4 years of corn. Five tillage treatments were imposed: (1) Conventional tillage (Conv); (2) Moldboard plow 30 cm deep (Mold-plow); (3) Chisel plow 30 cm deep (Chisel); (4) Disk and shallow cultivation <7.5 cm deep (Min-till); and (5) No-tillage (No-till). The conventional treatment consisted of ridged beds 1 m apart. Tillage in this system consisted of using a bedder to first break the stale bed and then rebed in the same location as the original bed, secondary tillage to control winter weeds, planting, and cultivation. Up to 10 tillage operations per year may occur in this system. Fertilizer was applied uniformly in the corn plots the first 12 years of the study at a rate of 90 kg N ha^{-1} and 30 kg P ha^{-1}. The plots were split and a low fertilizer treatment (45 kg N ha^{-1} and 30 kg P ha^{-1}) was included in the corn portion of the experiment the last three years of the study. The cotton received a uniform rate of fertilizer (67 kg N ha^{-1} and 22 kg P ha^{-1}). The original experimental design for the corn was a randomized complete block. The experimental design was a randomized complete block for the cotton experiment. Treatments were replicated four times.

One soil core (3.8 cm diam.) was taken from each plot and subdivided for SOC determinations after the corn and cotton crops. Sample increments for the SOC determinations were 0–5, 5–12.5, and 12.5–20 cm. Bulk density was determined by the core method after the corn crop and by the clod method (Blake and Hartge, 1986) after the cotton crop for the same depth increments.

Table 2
Fertilizer application rates for the Temple studies

Crop	High		Low	
	N	P	N	P
	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})
Wheat	112	27	28	12
Sorghum	140	32	28	12
Corn	168	37	28	12

2.4. Sample analysis and statistical tests

Soil samples were air dried, and large identifiable pieces of plant material removed. Soil materials were ground to a fine mesh (<200 mesh) and sample aliquot (approx. 1 g) analyzed for SOC with a Leco CR12 Carbon Determinator (LECO Corp., Augusta, GA)[2]

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using the combustion method of Chichester and Chaison (1992). Soil samples from the Temple location were also analyzed for inorganic C using a high temperature combustion (Chichester and Chaison, 1992). Analysis of variance was conducted and protected Least Significant Difference (LSD) tests were used to separate means at (P=0.1) level (SAS Institute, 1988). Regression analysis was used to determine climatic effects among locations (SAS Institute, 1988).

3. Results and discussion

3.1. Organic C distribution

Soil organic C concentration profiles are presented for the three locations in Texas; Bushland (Fig. 2), Temple (Fig. 3), and Corpus Christi (Fig. 4). At all three locations, no-till management over 10 to 15 years resulted in increased SOC concentration near the surface as compared to other management practices.

At Bushland, the greatest differences in SOC concentration between tillage treatments occurred in the surface 7 cm (Fig. 2). This corresponds roughly with the depth of tillage used in the stubble-mulch management system. Below 7 cm, SOC concentrations did not vary significantly between stubble-mulch tillage and no-till systems. Fertilization had little effect on the SOC concentration in both no-till and stubble-mulch tillage systems in the continuous wheat and continuous grain sorghum crops. SOC concentrations were not significantly different between the wheat and grain sorghum crops.

At Temple, differences in SOC concentration due to the management system were observed in the surface 20 cm (Fig. 3). After the wheat crop, SOC concentration was greatest in the surface 4 cm of soil for the no-till system. For the 7 to 20 cm depths, however, SOC concentration decreased to levels below that observed in the chisel-till management system. Below 20 cm, there was little difference in mean SOC concentration between tillage treatments. After the corn crop, differences in SOC concentration between tillage systems were greatest in the surface 4 cm. Fertilizer rate had little effect on SOC concentration in either the corn or wheat rotation phases (Fig. 3).

The variability in SOC concentration among samples at depths greater than 20 cm increased greatly with depth at Temple (Fig. 3). This was not observed at the Bushland or Corpus Christi locations where variability decreased with depth. The variability at deeper depths may be explained by the presence of an undulating genetic soil horizon associated with the presence of gilgai in the Houston Black soil. Gilgai are naturally occurring depressions rimmed by low ridges which occur in vertisols (Wilding and Tessier, 1988). An indicator of the depth of this soil is an increase in inorganic C, usually in the form of carbonates. Depth to the carbonate layer may vary from 0.3 m to >2 m. We analyzed the Houston Black clay samples for both organic and inorganic C and found a close correlation between the increase in inorganic C and the rapid decrease in SOC concentration (data not shown). Similar results have been reported previously for the Houston Black soil (Wilding and Tessier, 1988). The random selection of sample sites resulted in large variability of depths to the carbonate layer for the no-till system, thus resulting in the observed increase in variability in SOC below 30 cm. In contrast, the randomly selected sites for the conventional tillage treatment were located where the depth to the carbonate layer was greater than the depth of sampling, which resulted in less variability at greater depths.

At Corpus Christi, no-till tended to increase mean surface SOC concentration, although differences were not significant at P=0.10 (Fig. 4). Fertilizer had no significant effect on SOC concentration in the corn plots. A fertilizer variable was not applied in the cotton plots. Soil organic C concentration was reduced for all tillage treatments after 4 years of cotton, probably because cotton produces less biomass residue to return to the soil compared to corn.

3.2. Total organic C in the surface 20 cm

Total SOC is a function of SOC concentration and soil bulk density. Total SOC was calculated for the surface 20 cm, the depth increment most affected by management systems. Also, summing C contents over this depth increment avoided the confounding effect of the varying depth of carbonate at the Temple location. Most researchers agree that management effects are expressed mainly in the near surface soil horizons (Dick, 1983; Unger, 1991).

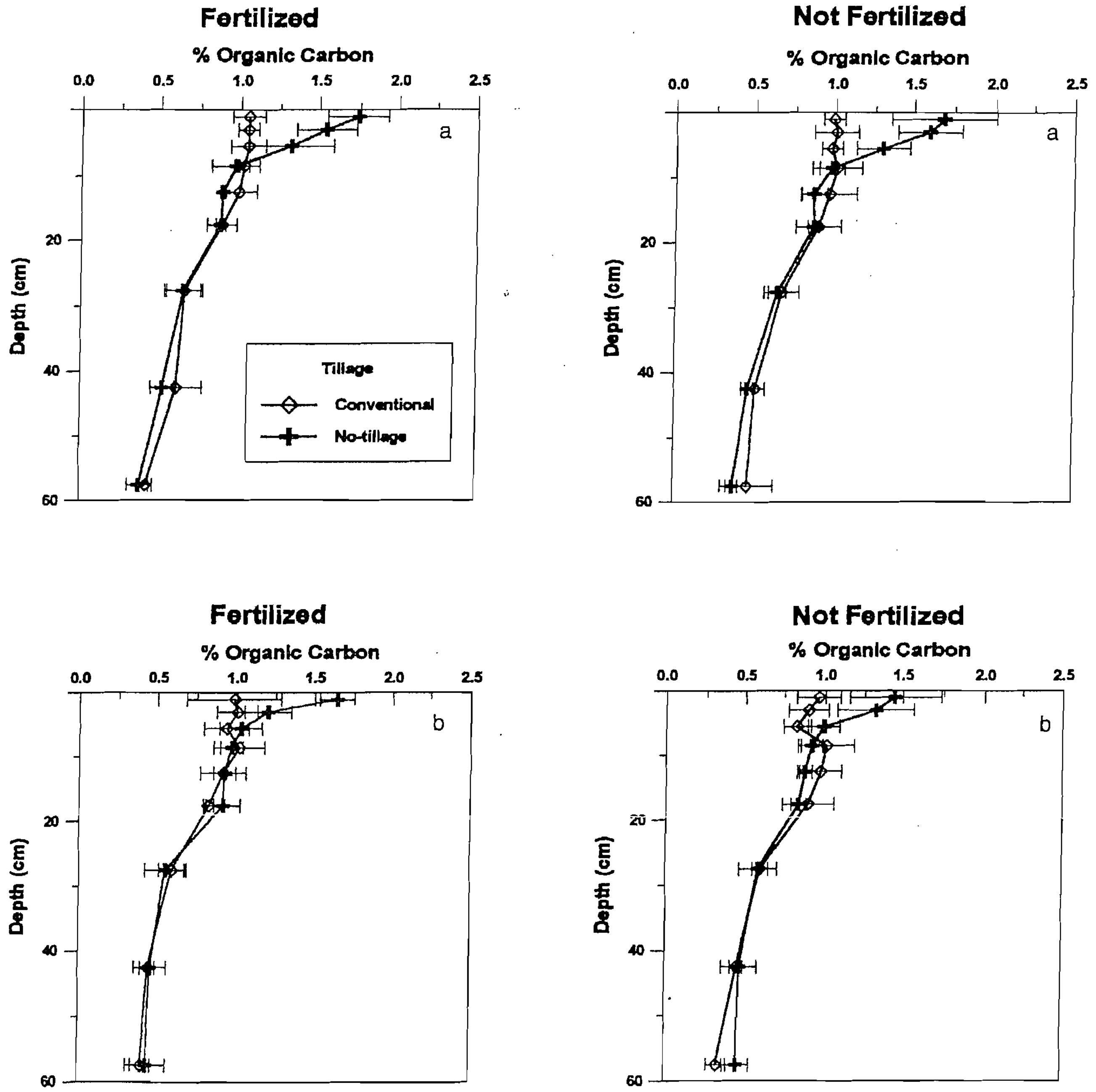
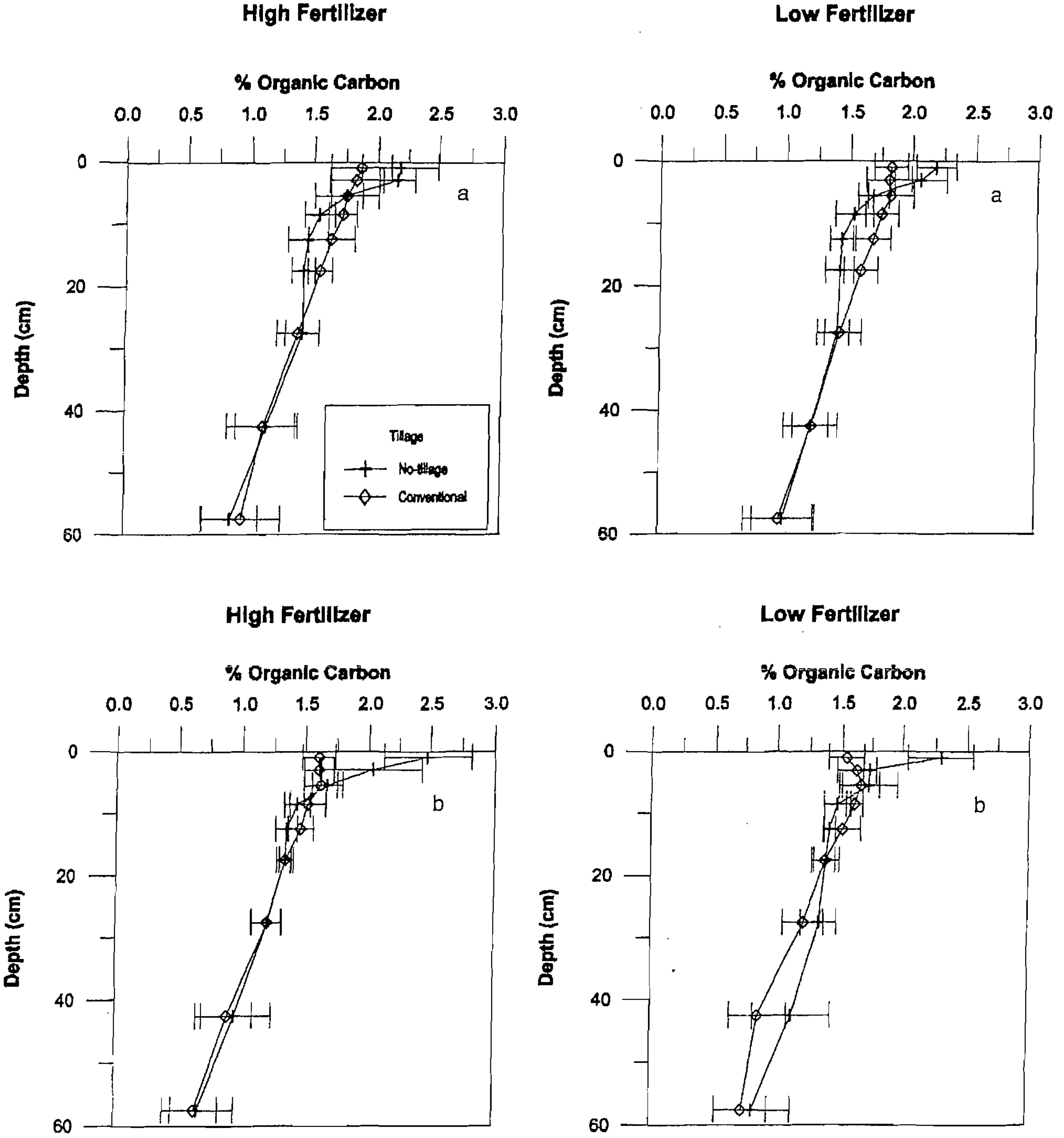


Fig. 2. Organic C concentration profiles for the Pullman clay loam at Bushland, Texas, for continuous wheat (a) and continuous grain sorghum (b) with two tillage systems and two fertilizer rates. Error bars represent ± one standard deviation.

At Bushland, in the Pullman clay loam, soil bulk density values were slightly lower in the surface 10 cm with stubble-mulch tillage compared to no-till for all treatments except the fertilized sorghum plots (Table 3).

Total SOC was increased at Bushland in the surface 20 cm with no-till management as compared to stubble-mulch tillage for both wheat and grain sorghum (Table 4). Wheat produced higher total SOC than grain sorghum, even though grain sorghum produced more than three times as much grain and 150% to 200% as much above-ground biomass remaining after harvest as did the wheat during the 10 years of the


High Fertilizer

Low Fertilizer

High Fertilizer

Low Fertilizer

Fig. 3. Organic C concentration profiles for the Houston Black clay at Temple, Texas, for a wheat (a) grain sorghum-corn (b) crop rotation with two tillage systems and two fertilizer rates. Error bars represent ± one standard deviation.

study (Jones and Popham, 1997). Differences between tillage systems were also larger for wheat than for grain sorghum.

At Temple, mean soil bulk density values for conventional and no-till were similar near the surface (0 to 4 cm) for the Houston Black clay (Table 5). At depths

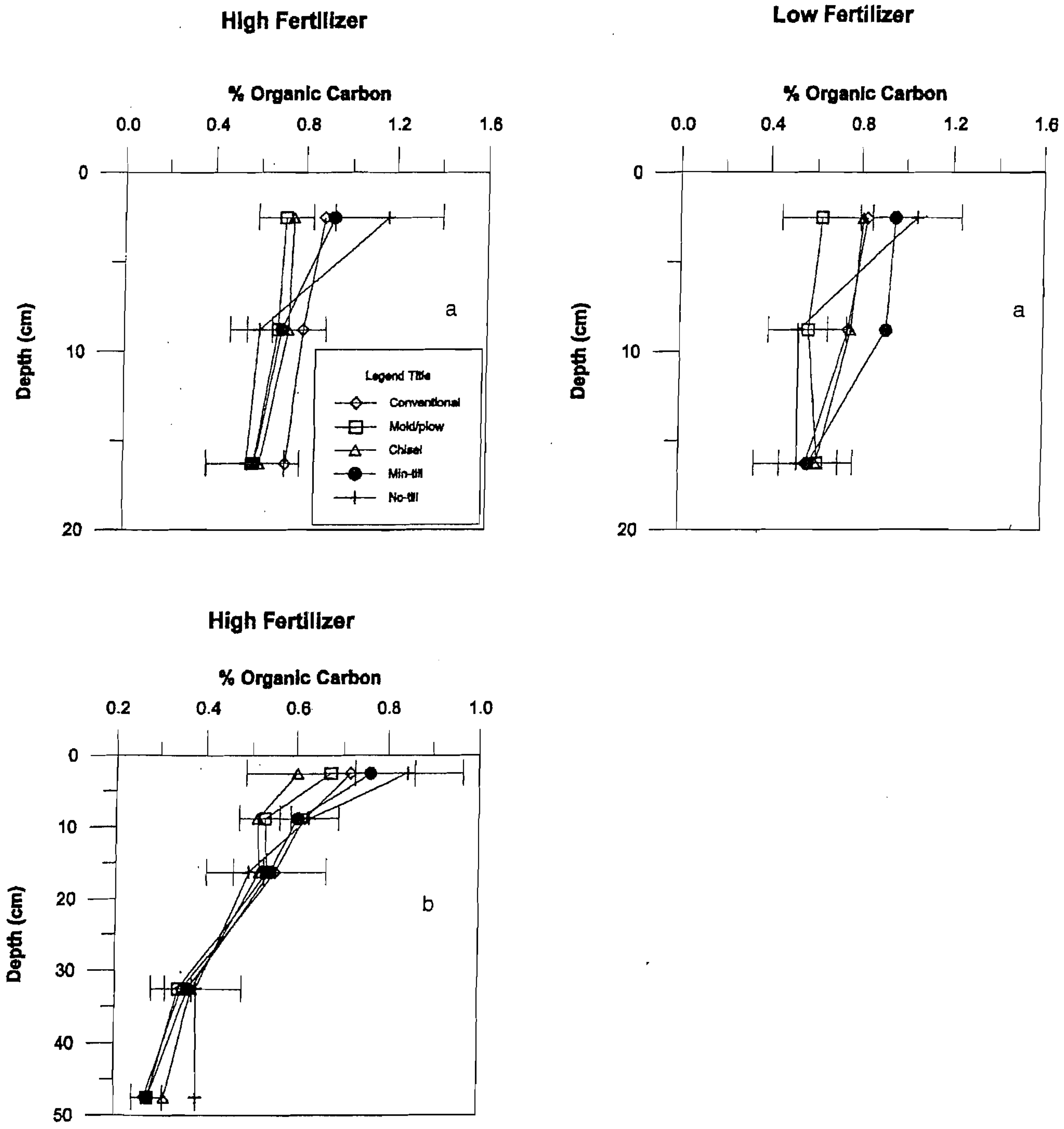


Fig. 4. Organic C concentration profiles for the Orelia sandy clay loam at Corpus Christi, Texas, for a corn (a) cotton (b) crop rotation with five tillage systems and two fertilizer rates. Error bars presented for the moldboard plow and no-till treatments represent ± one standard deviation.

of 4 to 15 cm, the no-till soil had greater bulk density values than with chisel tillage. Below 15 cm, soil bulk density values were similar.

Total SOC was similar (Table 6) for management systems after the wheat crop at Temple, despite differences in SOC concentration distribution in the soil

Table 3
Soil bulk density values for the Pullman clay loam at Bushland, Texas

Depth (cm)	Stubblemulch		No-till	
	Fertilizer ($Mg\ m^{-3}$)	No-fertilizer ($Mg\ m^{-3}$)	Fertilizer ($Mg\ m^{-3}$)	No-fertilizer ($Mg\ m^{-3}$)
Sorghum				
0–4	1.47±0.22 [a]	1.39±0.19	1.48±0.24	1.51±0.21
4–10	1.49±0.06	1.44±0.17	1.49±0.11	1.51±0.08
10–20	1.49±0.03	1.61±0.13	1.51±0.12	1.53±0.04
20–35	1.68±0.10	1.63±0.04	1.65±0.05	1.65±0.02
35–50	1.70±0.04	1.69±0.03	1.67±0.04	1.65±0.02
50–65	1.81±0.08	1.74±0.07	1.70±0.06	1.74±0.02
Wheat				
0–4	1.42±0.10	1.34±0.32	1.53±0.19	1.49±0.07
4–10	1.37±0.13	1.24±0.05	1.54±0.19	1.57±0.13
10–20	1.40±0.03	1.49±0.16	1.42±0.07	1.35±0.10
20–35	1.54±0.11	1.64±0.12	1.55±0.07	1.48±0.13
35–50	1.63±0.07	1.65±0.04	1.66±0.05	1.61±0.08
50–65	1.70±0.04	1.72±0.01	1.67±0.02	1.68±0.04

[a] Mean (n=3) and standard deviation.

Table 4
Total soil organic C in the surface 20 cm of the Pullman clay loam with continuous cropping (Bushland)

	After Wheat		After Sorghum	
	Fertilized ($kg\ C\ m^{-2}$)	Not fertilized ($kg\ C\ m^{-2}$)	Fertilized ($kg\ C\ m^{-2}$)	Not fertilized ($kg\ C\ m^{-2}$)
Stubblemulch	2.76a [a]	2.65a	2.75a	2.82a
No-till	3.31b	3.22b	3.13b	3.00b

[a] Values within a column followed by different letters are significantly different as determined by Tukey's Least Significant Difference test.

(Fig. 3). The greater SOC concentration near the surface in combination with the increased bulk density from 7 to 15 cm in the no-till soils resulted in similar amounts of SOC compared to the chisel tilled soils. Fertilizer application rate had no significant effect on total SOC in the wheat plots.

After the corn phase of the rotation, significantly greater amounts of total SOC were measured in the no-till soils than in the tilled soils (Table 6), but fertilizer rate had no effect on total SOC. While tillage treatment effects were significant after corn in the crop rotation, total SOC amounts were slightly reduced in no-till after corn compared to the levels determined after wheat. The chisel-tilled soils had much lower total SOC after corn compared to the SOC in chisel-tilled soils measured after wheat. It appears that wheat contributed relatively large amounts of organic C to the soil, and that no-till is more successful in retaining this C level than the chisel-till system.

At Corpus Christi, surface bulk density varied with tillage system and crop in the Orelia sandy clay loam (Table 7). After corn, bulk density was lowest with the moldboard plow and chisel plow treatments. No-till and the conventionally tilled soils had the greatest bulk density values of the five tillage treatments studied.

Bulk density after the cotton crop was determined by the clod method, which resulted in greater bulk density values because interaggregate pores are excluded. Bulk density values were higher after the cotton crop than after the corn crop. In contrast to the results found after corn, the no-till and conventional tillage treatments had the lowest mean bulk density values after cotton. Moldboard-plow, chisel plow, and minimum-till had the greatest bulk density values.

Table 5
Mean bulk density for a Houston Black clay soil at Temple, Texas

Depth (cm)	Conventional		No-till	
	High fertilizer (Mg m^{-3})	Low fertilizer (Mg m^{-3})	High fertilizer (Mg m^{-3})	Low fertilizer (Mg m^{-3})
Wheat				
0–2	0.92±0.23 [a]	1.05±0.11	0.91±0.15	0.85±0.14
2–4	0.98±0.09	1.01±0.14	1.05±0.16	1.01±0.10
4–7	1.29±0.11	1.25±0.26	1.49±0.16	1.45±0.20
7–10	1.44±0.22	1.38±0.11	1.66±0.09	1.58±0.18
10–15	1.51±0.06	1.50±0.11	1.63±0.06	1.62±0.09
15–20	1.60±0.07	1.63±0.07	1.64±0.09	1.69±0.08
20–35	1.66±0.04	1.65±0.05	1.64±0.10	1.66±0.04
35–50	1.72±0.07	1.70±0.07	1.74±0.06	1.69±0.06
50–65	1.75±0.10	1.72±0.08	1.77±0.07	1.75±0.08
Corn				
0–2	0.96±0.18	0.96±0.13	0.80±0.09	0.91±0.08
2–4	0.97±0.08	0.96±0.12	0.93±0.04	0.98±0.10
4–7	1.28±0.28	1.27±0.25	1.51±0.25	1.38±0.21
7–10	1.46±0.25	1.46±0.09	1.64±0.06	1.66±0.10
10–15	1.57±0.04	1.56±0.09	1.68±0.05	1.67±0.06
15–20	1.74±0.08	1.70±0.09	1.73±0.07	1.71±0.05
20–35	1.74±0.05	1.73±0.10	1.71±0.03	1.70±0.04
35–50	1.80±0.06	1.77±0.07	1.78±0.06	1.77±0.07
50–65	1.87±0.06	1.83±0.10	1.85±0.07	1.84±0.06

[a] Mean (n=8) and standard deviation.

Table 6
Total soil organic C in the surface 20 cm of the Houston Black clay (Temple)

	After Wheat		After Corn	
	High fertilizer (kg C m^{-2})	Low fertilizer (kg C m^{-2})	High fertilizer (kg C m^{-2})	Low fertilizer (kg C m^{-2})
Tilled	4.70 a [a]	4.60 a	4.27 a	4.23 a
No-till	4.59 a	4.74 a	4.56 b	4.53 b

[a] Values within a column followed by different letters are significantly different as determined by Tukey's Least Significant Difference test.

Table 7
Bulk density [a] values for the Orelia sandy clay loam at Corpus Christi, Texas

Depth (cm)	Conv (Mg m^{-3})	Mold-plow (Mg m^{-3})	Chisel (Mg m^{-3})	Min-till (Mg m^{-3})	No-till (Mg m^{-3})
Corn					
0-5	1.26±0.15 [b]	1.08±0.03	1.12±0.05	1.24±0.08	1.36±0.18
5-12.5	1.48±0.07	1.15±0.08	1.29±0.07	1.28±0.17	1.55±0.05
12.5-20	1.64±0.04	1.31±0.03	1.41±0.08	1.49±0.06	1.51±0.06
Cotton					
0-5	1.50±0.01	1.71±0.01	1.71 [c]	1.81±0.06	1.56±0.20
5-12.5	1.56±0.07	1.72±0.12	1.56±0.09	1.80±0.08	1.43±0.18
12.5-20	1.66±0.12	1.78±0.09	1.82±0.08	1.91±0.24	1.45±0.19

[a] Bulk density determined by the core method for corn plots, and by the clod method for the cotton plots.

[b] Mean (n=4) and standard deviation.

[c] Only one sample available.

Table 8
Total soil organic C in the surface 20 cm of the Orelia sandy clay loam (Corpus Christi)

	After Corn		After Cotton
	High fertilizer ($kg\ C\ m^{-2}$)	Low fertilizer ($kg\ C\ m^{-2}$)	High fertilizer ($kg\ C\ m^{-2}$)
Conventional	2.31 a [a]	2.03 a	1.95 b
Moldboard plow	1.53 c	1.42 b	1.98 b
Chisel plow	1.75 bc	1.83 ab	1.59 c
Minimum till	1.89 abc	2.11 a	2.09 ab
No-Till	2.09 a	1.90 a	2.32 a

[a] Values within a column followed by different letters are significantly different as determined by Tukey's Least Significant Difference test.

Total SOC was much lower in the Orelia sandy clay loam than in soils at Bushland or Temple (Table 8). No-till management resulted in increased SOC compared to the moldboard plow and chisel plow systems. Surprisingly, conventional tillage resulted in the largest amount of SOC after 4 years of corn. This was unexpected because conventional tillage practices in this region of Texas include up to 10 rather intensive tillage operations each year. Conventional practices, breaking existing beds and bedding, result in a concentration of crop residues in the bed, which was the area sampled for this study. Soil organic C concentrations in conventionally tilled soil was distributed uniformly in the surface 20 cm because of the mixing due to tillage (Fig. 4). Bulk density values from 5 to 20 cm were relatively high (Table 7). The conventional tillage practices also resulted in higher yields and contributed more biomass to the soil (Table 9). Fertilizer rate had little effect on total SOC.

Estimates of total SOC mass were not reduced after the cotton crop (Table 8), despite the lower SOC concentration in the cotton cropping system (Fig. 4). While this is probably due to the difference in determining soil bulk density, it is felt that relative differences among tillage systems should be reliable. No-till retained the largest amount of SOC of the five tillage methods studied.

3.3. Rate of C sequestration

The rate of SOC sequestration in no-till management areas, as compared with other management systems, was estimated by taking the difference between the mean no-till value and the mean value reported for tilled plots, assuming that the rate of change in tilled plots is negligible, and dividing by the number of years of continuous management. Similar assumptions have been used to estimate the effect of no-till for a diverse range of locations (Reicosky et al., 1995). No-till resulted in positive accumulation rates in 16 of the 20 comparisons possible in

Table 9
Mean annualized aboveground biomass[a] remaining after harvest

Tillage treatment	Location	Above ground biomass ($Mg\ ha^{-1}\ yr^{-1}$)			
	Bushland	Wheat/Fertilized	Wheat/Not fertilized	Sorghum/Fertilized	Sorghum/Not
Stubble-mulch		2.2	2.8	2.6	4.2
No-till		2.8	2.8	2.6	4.2
	Temple	Wheat/High fertilizer [b]	Wheat/Low fertilizer [b]	Corn/High fertilizer [b]	Corn/Low fertilizer [b]
Chisel-till		3.2	4.4	4.0	4.4
No-till		3.7	5.2	3.6	4.8
	Corpus Christi	Corn/High fertilizer [c]	Corn/Low fertilizer [c]	Cotton/High fertilizer [c]	
Conventional		3.0	2.8	2.5	
Moldboard plow		2.9	3.0	2.5	
Chisel plow		2.9	2.9	2.2	
Minimum till		2.9	2.7	2.5	
No-till		2.1	1.9	1.7	

[a] Biomass inputs were estimated from grain and cotton lint harvested assuming a harvest index of 0.3 for wheat, 0.4 for grain sorghum, 0.5 for corn, and 0.5 for cotton.

[b] Biomass inputs from a corn/wheat/grain sorghum rotation.

[c] Corn plots biomass inputs from 8 years of corn and 7 years of cotton. Cotton plot biomass inputs from 7 years of corn and 8 years of cotton.

Table 10
Differences in soil organic C accumulation rate between no-till and other management systems

Tillage comparisons	Location	Soil organic C accumulation rate (kg C ha^{-1} yr^{-1})			
	Bushland	Wheat/Fertilized	Wheat/Not fertilized	Sorghum/fertilized	Sorghum/Not fertilized
NT[a] vs. SM		550	570	380	180
	Temple	Wheat/High fertilizer	Wheat/Low fetilizer	Corn/High fertilizer	Corn/Low fertilizer
NT vs. CP		−110	140	290	300
	Corpus Christi	Corn/High fertilizer	Corn/Low Fertilizer	Cotton/High fertilizer	
NT vs. MP		400	343	243	
NT vs. CP		243	50	521	
NT vs. MT		143	−150	164	
NT vs. CT		−157	−93	264	

[a] NT=No-till, SM=stubblemulch, CP=chisel plow, MP=moldboard plow, MT=minimum till, and CT=conventional till.

this study (Table 10). Rate of change in SOC due to no-till varied from an increase of 570 kg C ha^{-1} yr^{-1} with fertilized continuous wheat at Bushland to a net loss of 157 kg C ha^{-1} yr^{-1} compared with conventionally tilled corn with high fertilizer rates at Corpus Christi.

Comparisons of management systems among sites is confounded by differences in crop rotations and cropping systems. Soil C accumulation is affected by the amount of crop residue returned to the soil and by differences in the quality of the residues being returned. At Bushland, despite the larger amounts of residue returned to the soil with the continuous sorghum rotation (Table 9), the continuous wheat rotation resulted in greater SOC, indicating that the decomposition rate of plant residue was slower over the long term for the wheat compared to the grain sorghum. At Temple, wheat increased SOC in both no-till and chisel-tilled soils, but no-till maintained greater SOC levels through other phases of the crop rotation (Table 6). The decomposition rate of plant residue is dependent on several factors, including age, size, lignin content, and the C:N ratio of the residue (Parr and Papendick, 1978; Ghidey and Alberts, 1993). Changes in the plant structure even within a plant species such as wheat have been shown to alter the rate of microbial decomposition (Ball, 1991). Slower decomposition of wheat compared to corn and grain sorghum may have been due to differences in the residue nitrogen content, with wheat straw typically averaging 0.667% N, corn stover 1.111% N, and grain sorghum stover 1.083% N (Hansen, 1990). The lower nitrogen content of the wheat residue may result in N limitations to microbial decomposition resulting in slower decomposition compared to corn and grain sorghum residue.

Climatic effects on SOC sequestration were estimated by selecting the most similar crop and management system at each location, i.e., the fertilized corn crop at Temple and Corpus Christi and the fertilized grain sorghum crop at Bushland. Differences in annualized total SOC accumulation rates (ΔSOC) between no-till management and chisel plow management at Temple and Corpus Christi, and no-till and stubble-mulch management at Bushland was related to average annual temperature and rainfall. The results of this analysis were:

$$\Delta\mathrm{SOC}\,(\mathrm{kg\,C\,ha^{-1}\,yr^{-1}}) = -17.2\,[\mathrm{Annual\,Temp\,(^{\circ}C)}] + 619,\quad r^2 = 0.99$$

$$\Delta\mathrm{SOC}\,(\mathrm{kg\,C\,ha^{-1}\,yr^{-1}}) = -0.23\,[\mathrm{Rain\,(mm)}] + 455,\quad r^2 = 0.40$$

This implies that no-till is more effective in sequestering SOC in cooler and drier climates than in warmer and humid areas. This agrees with research results which indicate that no-till is more effective in sequestering SOC in the southeastern United States if a winter cover crop is included in the crop rotation or with double cropping (Hunt et al., 1996). However, these results should not be extrapolated to regions drier than Bushland. Bushland is near the lower rainfall limit for continuous cropping, and in practice, including fallow in the crop rotation is more common than continuous cropping in the Bushland region. Inclusion of fallow into the cropping system limits biomass returned to the soil and effectively prevents SOC sequestration (Potter et al., 1997). More rigorous testing of rainfall and temperature effects on SOC sequestration requires a wider range of variables than was available for this study and common management practices.

4. Conclusion

Soil organic C distribution and total mass were affected by long-term (>10 years) management systems at three locations studied across an 1100 km transect of Texas. No-tillage management resulted in greater SOC concentrations in the surface 0.07 m. Fertilization had little effect on C sequestration at all the sites studied. Across all three sites, SOC decreased with an increase in mean annual temperature.

Carbon can be sequestered in soil under Texas climatic conditions, but the amounts may be quite small. Sequestration of SOC varied among locations depending upon management system and climatic conditions. Crop rotation appears to have a significant effect on SOC. Organic C accumulated during one phase of the crop rotation may be lost if less biomass is produced in other phases of the rotation.

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