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Effect of soil compaction on organic carbon amounts and distribution, South-Central Iowa

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"Capsule": *The effects of 150 years soil compaction were to alter soil carbon pools by limiting new additions of organic matter to the soil and limiting vegetative production.*

Abstract

Soils on the Mormon Trail have been compacted for over 150 years. Bulk density, carbon, and nitrogen samples were taken in 5-cm increments to 20 cm. Bulk density was determined using rings of known volume; total carbon and nitrogen with a LECO CHN-600. Total above ground biomass (AGB) samples were collected by clipping vegetation within a 0.25 m^2 frame and were analyzed for carbon. Statistical comparisons were made using a *t*-test ($\alpha = 0.05$). Bulk density was higher in the on-trail soils from 5 to 20 cm; soil carbon and C/N ratios were higher in the off-trail soils from 10 to 20 cm. AGB and AGB carbon is significantly less on the trail. Results indicate the compacted layer on the trail alters the soil carbon pool by limiting additions of fresh organic matter to the soil, limiting vegetative production, and by "pooling" carbon additions in the upper 10 cm of the soil.

Keywords: Carbon sequestration; Soil compaction; Trails

1. Introduction

Many scientists, as well as the public sector, now believe that anthropogenic additions of CO_2 to the atmosphere are contributing to a rise in global mean surface temperatures, a phenomenon known as the "greenhouse effect" (Mosier, 1998; Bluemle et al., 1999). The realization that increasing the organic matter content of soils can effectively remove CO_2 from the atmosphere has made carbon sequestration an important research topic in soil science in recent years (Hakamata et al., 1997; Paustian et al., 1997; Batjes, 1998; Lal et al., 1998b; Mosier, 1998). Despite the recent surge in carbon sequestration research, there are still many gaps in our knowledge of this important topic (Greenland, 1998; Lal et al., 1998a; Smith, 1999). As we attempt to model soil carbon sequestration, it is important to understand how various soil properties affect soil carbon pools and carbon distribution within the soil. The effect of soil compaction on carbon pools and carbon distribution in the soil is one area that has received limited attention, even though frequent cultivation by heavy machinery has made soil compaction one of the most important problems in modern mechanized agriculture (Plaster, 1997; DeNeve and Hofman, 2000). Therefore, it is important that the effect of compaction on soil carbon content is studied as policy makers consider using soil as a carbon sink in response to increasing atmospheric CO_2 levels.

The portion of the Mormon Trail that ran through southern Iowa was used from 1846 until approximately 1853, during a portion of the United States' westward expansion (Kimball, 1997). After that time, the portion of the trail that passes through Iowa received little use as large parts of Clarke County were tilled or fenced off (Chowdhery, 1989). Brevik and Fenton (1999) have demonstrated that soils along a portion of the Mormon Trail in south central Iowa are still compacted nearly 150 years after the compacting process ceased. Therefore, preserved portions of old trails such as those used during westward expansion may provide an opportunity to observe the effects of compaction on soil organic carbon (SOC) amounts and distribution over a relatively long time span. One such preserved section near Murray, Iowa was used for this study (Fig. 1). The objective of the study was to determine whether or not the compaction along the trail appears to be influencing SOC distribution.

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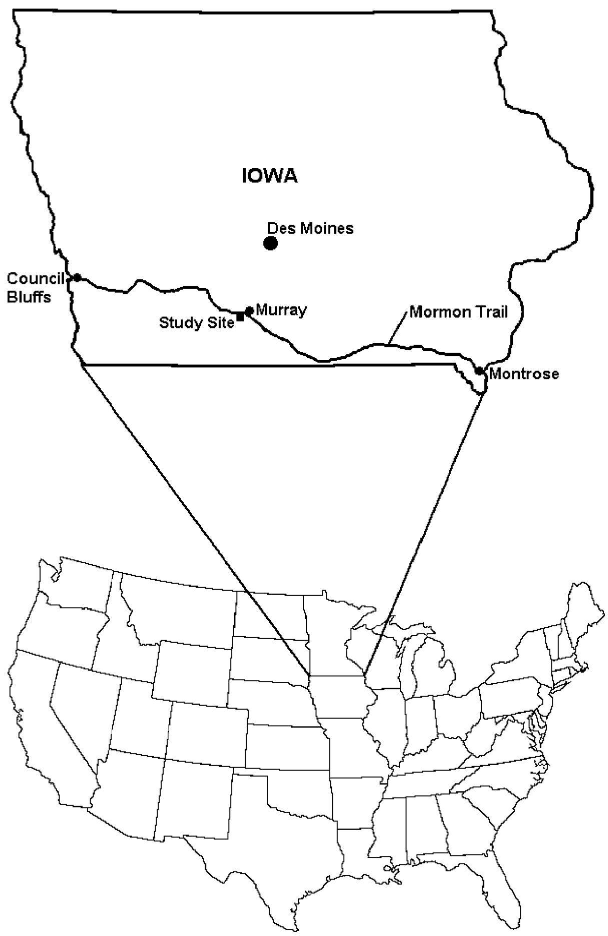

Fig. 1. The Mormon Trail through southern Iowa, and the location of the study site.

2. Materials and methods

The soil at the study site is Sharpsburg with 2–5% slopes. The Sharpsburg is classified as Fine, montmorillonitic, mesic Typic Argiudolls. It is a moderately well drained soil that formed in loess on narrow convex ridge tops and side slopes on uplands. The native vegetation is tall prairie grass (Chowdhery, 1989). The study site has never been tilled, but has been used as pasture (R. Jackson, personal communication). We investigated the site to determine if cattle may use the preserved Mormon Trail as a preferential travel route, but found abundant modern trails indicating that other routes are preferred. The landowner also reported that he had never observed cattle preferentially using the preserved Mormon Trail as a travel route (R. Jackson, personal communication).

The top 20 cm of eight pedons were sampled for bulk density, total carbon, nitrogen, and particle size analyses. Three pedons were in the Mormon Trail and five alongside the trail, with each trail pedon being paired with one or two control pedons located approximately 3 m off the trail. Bulk density samples were collected in 5 cm depth increments in each of the eight sampled pedons, with two bulk density samples being taken from each 5 cm increment. Bulk soil samples were then collected from each 5 cm increment for laboratory analysis and stored in sealed and labeled Ziplock® bags. Total aboveground biomass (AGB) samples were collected at six paired sites by clipping all vegetation within a 0.25 m^2 guide.

Bulk density was determined using rings of known volume (each ring is approximately 60 cm^3) to collect soil cores that were then dried at 105°C for 24 h (Soil Survey Staff, 1996). Total soil carbon and nitrogen content were determined with a LECO CHN-600 using the total combustion technique (Soil Survey Staff, 1996). Two C and N samples were analyzed for each depth increment in each pedon. The Sharpsburg soils sampled for this study have been leached free of carbonates (pH is about 6.0; Chowdhery, 1989); therefore total carbon is assumed to also represent SOC. The C/N ratio was determined by dividing total carbon by total nitrogen. Bulk density values were multiplied by the percent SOC, determined from the corresponding pedon and depth increments, to obtain the mass of SOC per unit volume of soil. Particle size analysis was done with a sieve and pipette method (Walter et al., 1978). AGB was determined on a dry weight basis by drying the AGB samples for 24 h at 70 °C in an oven with a circulation fan. Total carbon in the AGB samples, on a percentage basis, was determined by the total combustion technique using a LECO CHN-600. Total mass of carbon associated with the AGB samples were determined by multiplying percent carbon by the oven dry AGB. Statistical analysis of the various sample means was done using *t*-tests with the statistical package imbedded in Microsoft Excel 97. The null hypothesis for each comparison is that the off-trail values are greater than the on-trail values they are being compared with, with the exception of bulk density where that is reversed. All statistical comparisons were done at the 5% level of significance.

3. Results

Particle size analysis was used as a check to confirm that each of the sites used for the study fell within the same particle size class, thereby assuring that similar soils were being compared. All soils sampled for and reported in this study fell within the silty clay loam range, which is the expected particle size class for the upper 20 cm of the Sharpsburg soil series (Chowdhery, 1989).

Mean bulk density values in the on-trail soils are higher than in the off-trail soils at all depth intervals (Table 1), and these differences are statistically significant from the 5–10 cm interval down. Tests for SOC show no significant differences between the on-trail and off-trail sites from 0–10 cm, but from 10 to 20 cm SOC levels are significantly higher in the off-trail soils (Table 2). Likewise, the C/N ratios for the on-trail versus off-trail soils are not statistically different in the 0–10 cm interval, but are significantly higher in the off-trail soils below 10 cm (Table 3). Table 4 shows the mean SOC content, given in kg SOC per m^3, for each of the sampled intervals and the P values from the *t*-tests comparing on-trail with off-trail SOC values. As with the SOC percentages and the C/N ratios, there is no significant difference between the on-trail and off-trail SOC levels in the 0–10 cm intervals, but SOC levels are significantly higher in the off-trail soils from 10 to 20 cm. Both AGB and the amount of carbon associated with the AGB are significantly higher off the trail than on it (Table 5; Fig. 2).

4. Discussion

The 5–10 cm interval is an area of particularly high bulk density in the on-trail soils (Table 1), and it appears that the high bulk density layer from 5 to 10 cm is causing SOC to "pool" in the upper 10 cm of the on-trail soils while restricting additions of SOC below 10 cm (Tables 2 and 4). The C/N ratio (Table 3) indicates that the organic matter below 10 cm in the on-trail soils tends to be more decomposed than the organic matter in the same interval in the off-trail soils (Troeh and Thompson, 1993). These findings are consistent with recent work done on soils that have been compacted for several decades in North Dakota (Brevik, 2000). The SOC levels and C/N ratios indicate that the soils below the compacted layer in the on-trail locations are probably less active than the soils in the same interval of the off-trail locations in the sequestration of carbon. Therefore, it appears that the high bulk density layer in the on-trail soils is having a profound effect on SOC amounts, distribution, and degree of decomposition in the soils at this study site. Namely, the high bulk density layer has probably been preventing significant additions of fresh plant residues (Table 5), which become SOC, below the 5–10 cm interval of the on-trail soils. This caused new additions of SOC to "pool" at the surface of the high bulk density layer. This process has probably

Table 1
Mean bulk density values and statistics for the four depth intervals sampled in this study

Depth interval (cm)	Mean bulk density off trail (g/cm^3)	Standard deviation	Mean bulk density on trail (g/cm^3)	Standard deviation	*P* value	Significantly different
0–5	0.98	0.017	1.04	0.065	0.195	No
5–10	1.25	0.058	1.44	0.117	<0.001	Yes
10–15	1.20	0.105	1.34	0.111	0.013	Yes
15–20	1.22	0.109	1.37	0.043	0.003	Yes

Table 2
Mean carbon values and statistics for the four depth intervals sampled in this study

Depth interval (cm)	Mean carbon values off-trail (%)	Standard deviation	Mean carbon values on-trail (%)	Standard deviation	*P* value	Significantly different
0–5	5.19	1.42	5.71	1.65	0.250	No
5–10	3.52	0.59	2.75	0.25	0.051	No
10–15	2.77	0.06	1.60	0.15	<0.001	Yes
15–20	1.97	0.06	1.24	0.07	<0.001	Yes

Table 3
Mean C/N ratios and statistics for the four depth intervals sampled in this study

Depth interval (cm)	C/N ratios off-trail	Standard deviation	C/N ratios on-trail	Standard deviation	*P* value	Significantly different
0–5	10.17	0.87	10.17	0.48	0.500	No
5–10	9.46	1.01	9.43	0.82	0.480	No
10–15	10.00	0.97	8.58	1.26	0.028	Yes
15–20	9.50	1.30	7.86	0.81	0.023	Yes

Table 4
Mean kg C/m^3 of soil values and statistics for the depth intervals sampled in this study

Depth interval (cm)	Mean C values off-trail (kg C/m^3)	Standard deviation off-trail	Mean C values on-trail (kg C/m^3)	Standard deviation on-trail	*P* value	Significantly different
0–5	51.75	18.31	58.43	13.19	0.267	No
5–10	44.28	9.89	39.53	3.22	0.190	No
10–15	34.00	4.20	21.75	5.57	0.001	Yes
15–20	24.29	2.80	16.95	3.44	0.001	Yes

Table 5
Mean above ground biomass (AGB) values and the mean amount of carbon associated with that biomass

Item	Mean value off-trail (g/m^2)	Standard deviation	Mean value on-trail (g/m^2)	Standard deviation	*P* value	Significantly different
AGB	491.7	150.2	329.7	161.0	0.022	Yes
Carbon associated with the AGB	95.7	30.1	43.9	21.7	0.026	Yes

Fig. 2. A view looking west along the Mormon Trail at the study site, August, 1999. Note that soil compaction has lead to reduced forage growth in the trail, making the trail easily recognizable in late summer.

been occurring since the time of compaction, over 150 years ago.

Compaction is probably not the only difference between the on-trail and off-trail soils at this site. Because soil compaction can affect other soil properties, such as aeration, water content, and temperature, there are probably differences in soil microbial activity in the on-trail versus off-trail sites. However, the conditions that may lead to differences in microbial activity at this site can be traced back to one central variable, whether or not the soil was compacted by wagon traffic during the period the Mormon Trail was in use. For this reason, the differences found in soil carbon levels in the on-trail versus off-trail soils are attributed to soil compaction as opposed to other variables, such as differences in microbial activity.

5. Conclusions

The on-trail soils at this study site were compacted and have remained compacted, relative to the adjoining off-trail soils, for over 150 years. Both the on-trail and off-trail sites have the same soils and have had the same management practices applied to them during the time they have been used for agricultural purposes. Over this time, SOC has "pooled" in the upper 10 cm of the on-trail soils. C/N ratios indicate that the SOC found below 10 cm in the on-trail soils is probably more decomposed than the SOC found in the same interval of the off-trail soils. This indicates that there is probably less fresh organic matter being added below the 10 cm level in the on-trail versus off-trail soils, probably because the high bulk density layer found in the 5–10 cm interval in the on-trail soils restricts vegetative production in the on-trail soils. AGB samples also indicate that there might be less root mass available to be converted to SOC in the on-trail soils compared with the off-trail soils. Regardless of the possible effects of the high bulk density layer in the on-trail soils on the grass root systems, there is definitely less AGB to be added to the on-trail soils. As a whole, the results of this study indicate that less organic matter is added to and sequestered by the on-trail soils compared to the off-trail soils.

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