RATE OF SOIL CARBON LOSS RESULTING FROM TILLAGE

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Abstract
Land management practices can have major impacts on soil carbon (C) levels. A 5-year study was conducted to evaluate soil C levels with different management practices and to ascertain the rate at which C is lost due to tillage. At the North Appalachian Experimental Watershed near Coshocton, Ohio (USA), multi-year conventional tillage (moldboard plowing followed by disking) with corn (*Zea mays* L), first year plow with corn, meadow, and multi-year no-till corn with and without manure were evaluated. After the first year of conventional tillage, total C in the 0-2.5 cm soil layer (3.5 Mg C/ha) was only 41 and 46% of the C in the 0-2.5 soil layer of multi-year no-till corn (8.6 Mg C/ha) and meadow (7.7 Mg C/ha) areas, respectively. However, in the 0-30 cm soil layer, C levels were similar for first year tillage, no-till, and meadow (41.7, 41.4, and 39.4 Mg C/ha, respectively). The results indicated that one year of conventional tillage greatly altered the distribution of C within the plow layer but did not have a detectable affect on total C within the plow layer. After 5 years of tillage, however, soil C amounts and concentrations were similar to those in the multi-year plowed soil.

Additional Keywords: soil carbon, carbon sequestration, carbon loss

Introduction
Soil carbon (C) can improve soil quality by increasing water holding capacity (Hudson, 1994) and water infiltration rate (Bruce et al., 1995) and by reducing pesticide adsorption (Stevenson, 1972) and erosion (West et al., 1991). By storing C, soils can also be a sink for atmospheric CO_2-C (Campbell et al., 1995) and offset CO_2 emissions, which is relevant to global change issues (Lal et al., 1998). Management practices can have major impacts on soil C levels, losses, and gains. Because tillage aerates soil and allows greater C mineralization (Eghball et al., 1994), levels of soil C and tillage are related. The rate of change of soil C with tillage or reduction of tillage is still uncertain. The objective of this study was to assess the level of soil C under different management practices, which included tillage over different lengths of time, and to evaluate the rate at which soil C losses occurred with tillage.

Materials and Methods
Field Site
At the North Appalachian Experimental Watershed research station (NAEW) near Coshocton, Ohio (USA), there is a site where five different management practices are in use on adjacent areas within a single mapping unit of one soil type. The soil at this site is in the Rayne Series (Soil Taxonomy, fine-loamy, mixed, mesic, Typic Hapludult; FAO, Dystric Luvisol), and formed in residuum from acid silty shale, siltstone, or fine-grained sandstone (Kelley et al., 1975). These silt loam soils occupy ridge tops in east central Ohio with 2 to 12% slopes. The five management practices used in this comparison were: long-term (1964-2002) consecutive no-till corn (weeds were controlled by herbicides) with approximately 14 Mg ha-1 beef cattle manure (wet weight) added each year along with 180 kg N ha-1 inorganic fertilizer [NT-manure]; long-term (1970-2002) consecutive no-till with no manure (nutrients were applied as inorganic fertilizer only) [NT]; conventional tillage corn (mold-board plow followed by disking from 1984 through 2002) [Plow]; conventionally tilled corn (first year was 1998) [Newplow]; and an ungrazed orchardgrass (*Dactylis glomerate* L.) meadow from which hay was made (1979-2002) [Meadow]. Usual plow depth was approximately 20 cm.

Soil samples were collected in the spring of five consecutive years beginning in 1998 prior to spring tillage and/or planting, e.g. first year plow samples in collected in 1998 were from an area plowed in 1997. Samples were taken to a depth of 30 cm using a hydraulically driven sampler. Five cores (2.5 cm diameter) were taken randomly from summit positions within each management practice. Cores were sectioned in increments of 0-2.5, 2.5-7.5, 7.5-15, 15-22.5, and 22.5-30 cm for bulk density estimates and C content calculations. Bulk density was estimated by using air dry weight of the soil in a specified length of column.

Analysis
Total C was determined by a dry combustion method (using a Perkin Elmer model PE 2400 Series II CHN analyser). Values presented are average concentrations and quantities from five cores taken at each sampling area.

Preliminary analyses indicated negligible inorganic C; therefore, the soil total C values reported in this paper would be similar to SOC values frequently reported in the literature.

Results and Discussion

Analysis of soil samples taken in Spring 1998 showed that soil C in the 0-30 cm depth was greatest for the long-term no-till that received manure [NT-manure] (66.0 Mg/ha). This was followed by Meadow (39.4 Mg/ha), no-till without manure [NT] (41.4 Mg/ha), and first year of plowed meadow [Newplow] (41.7 Mg/ha). The lowest level of C was in the area that had been conventionally tilled for 15 consecutive years [Plow] (34.8 Mg/ha) (Table 1 and Fig. 1). Throughout the 5-year data reporting period (1998-2002), NT-manure always had the greatest amount of C in the 0-30 cm depth, and the Plow area always had the lowest amount of C. The amounts of C for the NT, Meadow and Newplow were within one standard deviation of each other in 1998 and 1999, and they were separated from the NT-manure and Plow. Soil C amounts in the 0-30 cm depths were greater for all management practices in 2002 than in 1998, although not necessarily by a unit of standard deviation (Table 1). With this limited data set, consistent trends were difficult to identify (Fig. 1). The C amounts in the Meadow were consistently similar to or greater than the no-till without manure (NT). This is consistent with the values reported by Owens and Hothem (1999) in comparing Total C amounts of pastures at different fertility levels with a corn-soybean rotation using no-till.

Table 1. Total soil carbon in the 0-30 cm depth for five management practices over five years (Mg C/ha±Std Dev)

Management	Spring 1998	Spring 1999	Spring 2000	Spring 2001	Spring 2002
NT-manure	66.0±8.6	71.9±10.3	59.9±5.0	70.8±2.5	71.5±5.6
Meadow	39.4±3.9	49.0± 3.7	54.0±8.2	60.7±3.8	51.6±3.5
NT	41.4±5.2	44.6± 2.8	43.5±3.0	46.4±4.2	43.6±2.0
Newplow	41.7±2.2	43.6± 1.2	37.7±3.8	45.1±2.9	46.0±8.9
Plow	34.8±2.3	34.5± 2.0	35.3±2.5	42.8±2.2	44.9±2.4

The C levels in the 0-30 cm soil depths for the Newplow and the Plow treatments were considerably different (more than 3 units of standard deviation) following the first two years of tillage in the Newplow (Fig. 1). After the third year of moldboard plowing (2000), the differences were within a single standard deviation (Table 1). Even though there is annual variation in the soil C levels in the NT, the soil C of the other 4 treatments were compared to it based on the premise that it has been in the practice long enough to have stable C levels (Fig. 2). This presentation of the data also illustrates the similarity of C levels between 3 years of tillage (Newplow in 2000) and 18 years of tillage (Plow in 2000). The increase in measured C for both tillage practices in 2001 and 2002 is not currently well understood. Bulk density measurements varied more greatly than did soil C concentrations and had higher values after 2000 for the 0-15 cm layers.

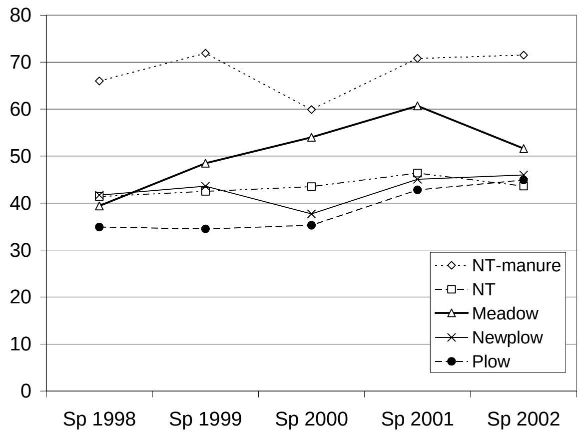

Figure 1. Comparison of total soil carbon in the 0-30 cm depth for five management practices during the data reporting period.

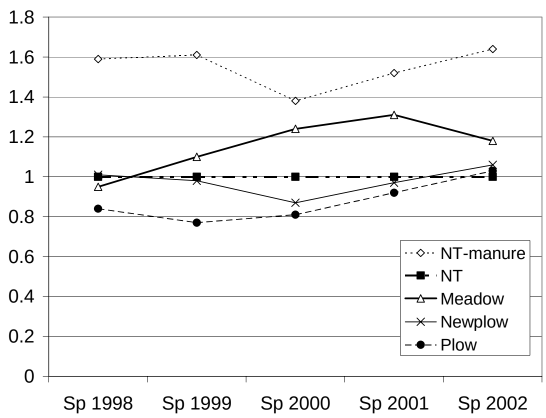

Figure 2. Ratio of total soil carbon in the 0-30 cm depth of four management practices to the 0-30 cm NT.

The distribution of C in the soil profile varies with the treatment. The no-till and meadow treatments have greater amounts of C near the surface (Fig. 3) while the tillage treatments have greater amounts of C lower in the tillage layer. In the Spring 1998 samples (Fig. 3 – left), the treatments without tillage had more C in the 2.5-7.5 cm layer and more than twice the amount of C in the 0-2.5 cm layer than the tillage treatments. There was more C in the 15-22.5 cm layer on the tillage treatments than in the NT or meadow treatments, and more C in the 7.5-15 cm layer of the Newplow than NT or Meadow treatments. With the greater length of tillage, C was less in the 7.5-15 cm layer of the Plow than the Newplow. Similar observations can be made for the Spring 2002 data (Fig. 3 – right), although the contrasts are not always as distinct. Because of the manure additions, the NT-manure has more C throughout the "tillage layers" (0-22.5 cm) than any of the other treatments. Below the 22.5 cm C amounts are similar across treatments.

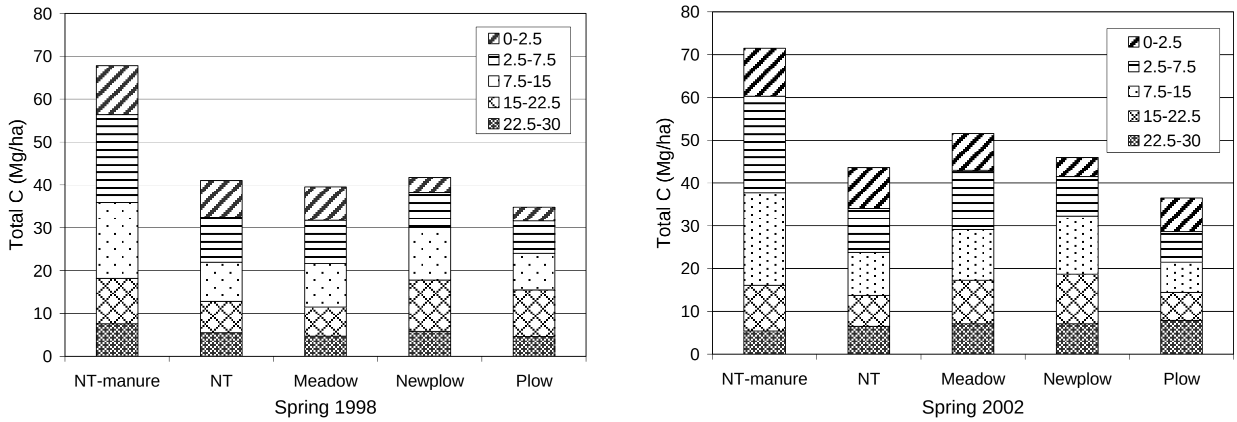

Figure 3. Total soil carbon by layer within the 0-30 cm soil depth for the five management practices for Spring 1998 (left) and Spring 2002 (right).

The NT-manure has the greatest soil C concentration above 15 cm of the 5 management practices (Fig. 4). The lowest concentrations of soil C occurred in the tillage practices with the longer term Plow being the lowest above 15 cm in Spring 1998 (Fig. 4 – left). After 5 years of tillage, the C concentration in the Newplow was very similar to the Plow practice through the entire 30 cm depth (Fig.4 – right). Soil C concentrations in the Meadow and NT were similar with the NT being slightly lower than the Meadow, especially in Spring 2002. The soil C concentrations in the Meadow and NT were greater than in the tillage practices above 7.5 cm, but below them in the 7.5-15 cm and 15-22.5 cm layers. This shows the inversion of C distribution in the tillage layer by use of the moldboard plow. Below the tillage layer, 22.5-30 cm, the soil C concentrations in all of the management practices were quite similar.

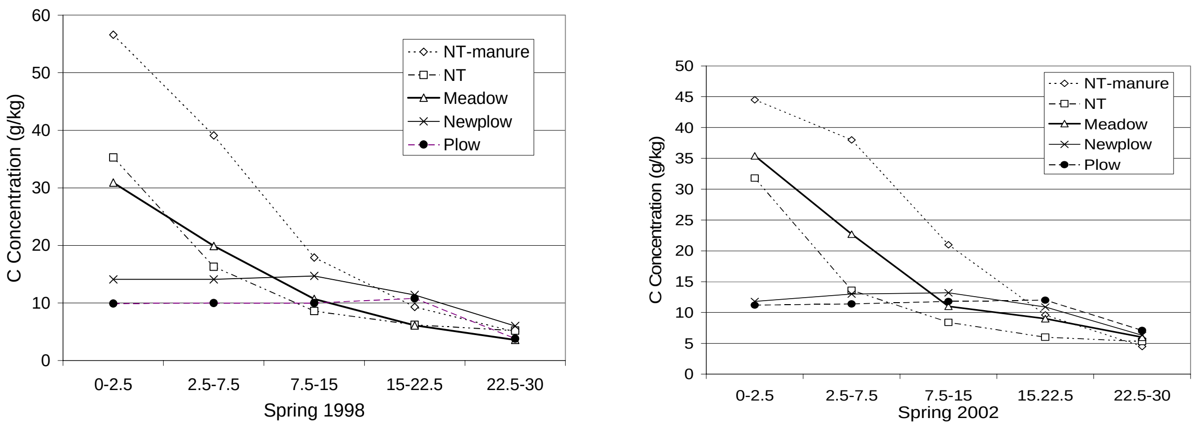

Figure 4. Total soil carbon concentrations with soil depth for the five management practices for Spring 1998 (left) and Spring 2002 (right).

Following the first year of tillage, there was not a measured difference in soil C in the 0-30 cm layer between the newly tilled and meadow practices. However, with continued annual tillage, the total soil C of the "newly" plowed treatment began to approach the levels measured in the multi-year plowed soil. After 5 years of tillage, the soil C concentrations at each depth in the top 30 cm of the soil profile were quite similar. After 3 years of tillage, the soil C amounts in the Newplow and the Plow were similar. Because of the variability of soil C values, of which variability of soil bulk density measurements are an important factor, it is difficult to calculate a meaningful rate of C loss resulting from tillage. Steps to reduce sampling variability, especially bulk density measurements are needed.

Although one year of tillage may not greatly reduce soil C, there can be other detrimental impacts to soil properties. On this same research site, Rhoton et al. (2002) compared runoff and soil loss from meadow and first year plow and observed large differences. They concluded that the beneficial effects of sod with respect of runoff and erosion can be lost within a short time period with the introduction of conventional tillage. Stockfisch et al. (1999) observed organic matter stratification in old minimum tilled soil. They concluded that a single plowing (inversion tillage) caused this stratification and accumulation of organic matter to be completely lost.

Conclusions

Comparison of soil C in the 0-30 cm depth under 5 different management practices showed that there was less soil C with major tillage than with no tillage or meadow. Meadow soil had more C than soil under long-term no-till, except when there were annual additions of manure. Soils which had been tilled for several consecutive years had the lowest levels of soil C of the 5 practices studied. Tillage by moldboard plowing redistributed the C within the plow layer by moving C from the surface to lower in the plow layer. Even though this study showed that after one year of tillage the total C in the soil did not change much, it also showed that multi-year tillage reduces soil C, and that this reduction occurs over a few years rather than occurring mostly with the first tillage.

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