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ACCUMULATION OF ORGANIC MATTER IN SOIL UNDER LONG-TERM CONSERVATION MANAGEMENT

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Abstract

The influence of tillage, type of winter cover crop and N fertilizer rate on accumulation of organic C was measured in a field study established in 1987 on a Gigger silt loam in northern Louisiana. The percentage of soil organic matter was greater under notill than surface till, and greater in systems using a planted wheat winter cover rather than a cover of volunteer weeds. Notill systems contained a greater proportion of organic C in their surface 0-3" whereas surface tillage resulted in a more even distribution throughout the surface 0-6". Increasing the amount of fertilizer N applied to cotton from 45 to 90 lbs/acre/yr decreased organic matter in systems employing surface till or a volunteer winter cover, and increased accumulation in systems using notill or a wheat cover. In many instances the amount of organic C accumulated per acre was less than suggested by the differences in soil organic matter percentage because soil bulk density tended to decrease as organic matter increased. A combination of notill, a wheat winter cover and 90 lbs N/acre/yr resulted in the greatest accumulation of organic C in the surface 12"(4.7 tons C/acre). The lowest accumulation (3.9 tons C/acre) occurred using a combination of notill, a cover a volunteer winter weeds and 90 lbs N, though accumulation in this system was not significantly different than those in systems employing surface tillage. These findings suggest that the accumulation of soil organic matter in cotton production systems in the mid-south can not be reliably predicted solely by tillage system, cover crop or N fertilizer rate. Rather, organic C accumulation depends on the specific combination of these management factors. After 17 years, the difference between the highest C accumulation and the lowest in the surface 6" of soil was only 0.8 ton C/acre, or ~ 80 lbs C/acre/yr.

Introduction

There is widespread concern that rising levels of CO_2 in the atmosphere contributed primarily by the burning of fossil fuels are causing sea level rise and unfavorable climatic change on a global scale (Prentice, 2001). In 1997, the United Nations Framework Convention on Climate Change drafted the Kyoto Protocol requesting that all nations agree reduce overall emissions of CO_2 and other greenhouse gases by at least 5% below 1990 levels in the commitment period 2008 to 2012. This commitment becomes effective in Feb 2005.

Under the Kyoto Protocol, the U.S. was required to reduce its emissions to 93% of 1990 emissions. U.S. emissions of CO_2-C have increased about 18% since 1990, and therefore the US has withdrawn it commitment to a target considered unachievable. The US is the only major industrial nation that has failed to sign the Kyoto Protocol since Russia signed in Dec 2005. Even so, the US Energy Policy Act of 2003 (S.2095) proposes to reduce emissions of greenhouse gases through conservation, develop of alternative energy sources and enhanced carbon sequestration.

C sequestration involves the capture and secure storage of atmospheric CO_2 as organic forms such as trees and soil organic matter, or as mineral forms such as carbonates. The rationale underlying C sequestration is to enable the continued use of fossil fuels while reducing the atmospheric burden of CO_2, thereby mitigating global climate change. Emissions trading permitted under a revision of the Kyoto Protocol has led to an international market for carbon credits granted to reforestation and other restoration projects that enhance C sequestration. The US Energy Policy Act of 2003 also promises incentives for C sequestration in the foreseeable future.

About a third of the >30% increase in atmospheric CO_2 that has occurred in the last century has been attributed land use, primarily deforestation and the oxidation of soil organic matter caused by tillage of arable lands. Programs to encourage the use of notill, cover crops and other conservation management practices are being discussed as a means of not only offsetting the contribution of tillage, but also of enhancing sequestration through the buildup of soil organic matter. Measured rates of soil C sequestration through adoption of conservation management practices range from 44 to 893 lbs/acre/year (Lal, 2004). The global potential for sequestration as soil organic matter through conservation practices could offset one-fourth to one-third of the annual increase in atmospheric CO_2. The cumulative potential of soil C sequestration over 25–50 years has been estimated to be 10-20 times that annual increase in atmospheric CO_2 (Lal, 2004).

Conservation management systems, especially those using a combination of notill and a planted or volunteer winter cover crop, have proven a cost-efficient strategy for controlling surface erosion and minimizing the impact of cultivation on nearby surface water quality in the mid-South (Boquet et al., 1997). Despite the benefits of conservation management to soil quality and the surrounding environment, many cotton producers have been reluctant to adopt these systems because of initial equipment investments and other concerns. Programs that provide an economic reward for the C sequestered as soil organic carbon accumulated under conservation management may provide sufficient incentive for more widespread adaptation. The amount of the reward would undoubtedly depend upon the amount of C sequestered as soil organic matter.

The primary goal of this study was to determine the amount of C sequestered as soil organic matter in long-term (17 year) cotton plots under notill management with planted wheat cover crops by comparison to the amounts in surface-tilled plots using a winter cover of volunteer weeds. The ability of higher rates of N fertilization to increase soil organic matter were also assessed.

Methodology

Study site: Soil and plant samples were collected in Spring 2004 from plots in a long-term conservation tillage experiment established in 1987 on a Gigger silt loam soil (fine-silty, mixed, thermic Typic Fragidaulf) at the Macon Ridge Research Station, Winnsboro LA. This study area contains a large number of tillage systems and winter cover crop combinations in a randomized complete block design. For the current study, a factorial combination of tillage (surface tillage vs. no till), winter cover crop (wheat and volunteer vegetation) and rate of N fertilizer (45 and 90 lbs N/A) was selected. Each treatment combination is replicated four times in 4-row (40” spacing) plots each 50 feet in length.

Tillage practices: The surface tilled plots are disked twice in early April and twice in late April each year. After final disking, plots are bedded with disk hippers. A reel and harrow bed conditioner is used for final seedbed preparation. No seedbed preparation is used in the no-till plots though ripple coulters are mounted ahead of each planter unit for planting.

Cover crops: Wheat covers are established by broadcasting wheat seed (90 lbs/A) into standing cotton stalks between mid-October and early-November each year. Cotton stalks are shredded with a rotary mover after seeding wheat. Stalks are shredded at the same time in plots where covers consist of volunteer winter weeds.

N fertilizers: In late May of each year since 1997, 45 or 90 lbs N/A is injected as 32% UAN solution with knife outlets positioned approximately 3 inches deep and 10 inches from the drill. Prior to 1997, all plots received annual injections of 75 lbs N/A.

Sampling: Soil samples were collected immediately prior to planting. Each sample consisted of two composite samples (0-3”, 3-6”, or 6-12”) of 5 cores each collected at 8” intervals along transects perpendicular to rows. Soil samples were air-dried, crushed, and re-dried in a fan-forced oven (105 ^{o}C; 48 h). Additional cores were collected at 0-3”, 3-6” and 6-12” for bulk density measurements using a 12” AMS core sampler fitted with four brass rings (3” x 2” dia.) for removal of largely undisturbed soil cores.

Analyses: Total organic C was determined in 150-225 mg oven-dried soil samples using a CE Model 1112 CN Soil Analyzer. Duplicate samples were treated with 1 N HCl and re-dried prior to analysis to determine organic C content. The pH of samples ranged from 5.3 to 6.4, and statistical analysis comparing HCl-treated and untreated samples confirmed that carbonates were below detectable levels. Where the differences between samples were >4%, an additional pair of samples was analyzed to ensure that no carbonate was present and to minimize analytical error. Results of all analyses were averaged to obtain the most accurate estimate of organic C for each sample. Bulk density was determined by dividing the oven-dry soil weight by the volume of the brass ring used to collect the sample.

Statistical analyses were performed using the GLM procedure of Statistica (StatSoft, 2003). ANOVA assumed a randomized complete block design with a factorial combination of treatments.

Results and Discussion

The effects of various tillage systems, cover crops and cotton N fertilizer rates on the amount of soil organic matter accumulated were clearly evident in the surface 0-3". Organic matter in the surface layer ranged from 1.44 % with a combination of surface till, volunteer weed cover and 45 lbs of N to as much as 2.01% with a combination of notill, wheat cover and 90 lbs of N (Table 1). More than 2% organic matter is unusually high for cultivated silt loam soils of the Macon Ridge area of Louisiana, and the accumulation of this amount of organic matter underscores the potential of conservation management to improve these highly erosive soils. A planted winter wheat cover crop resulted in greater accumulation of organic matter in the surface 0-3" than a volunteer cover under both tillage systems. The benefit of a wheat cover was most evident when notill management was employed. While notill and a higher rate of N both tended to increase organic matter in the surface 0-3", these results were not statistically significant ($p = 0.05$).

Table 1. Soil organic matter (SOM) accumulation expressed as a percentage of soil solids at various depths in soils under different management systems for 17 years. Organic matter was calculated by multiplying the amount of organic C (g/kg) measured by a conversion factor of 0.178.

Tillage	Cover	N rate	0-3"	3-6"	6-12"	0-6"	0-12"
		lbs/acre	----------------------------		% SOM	--------------------------------	
ST	Wheat	45	1.60	1.14	0.70	1.37	1.04
ST	Wheat	90	1.69	1.03	0.68	1.36	1.02
ST	Volunteer	45	1.44	1.18	0.65	1.31	0.98
ST	Volunteer	90	1.52	1.10	0.59	1.31	0.95
NT	Wheat	45	1.79	0.82	0.60	1.31	0.95
NT	Wheat	90	2.01	0.97	0.61	1.49	1.05
NT	Volunteer	45	1.63	0.99	0.68	1.31	1.00
NT	Volunteer	90	1.54	0.91	0.70	1.22	0.96
ST	Wheat	--	1.64	1.08	0.69	1.36	1.03
ST	Volunteer	--	1.48	1.14	0.62	1.31	0.96
NT	Wheat	--	1.90	0.90	0.60	1.40	1.00
NT	Volunteer	--	1.58	0.95	0.69	1.27	0.98
ST	--	--	1.56	1.11	0.66	1.34	1.00
NT	--	--	1.74	0.92	0.65	1.33	0.99
--	Wheat	--	1.77	0.99	0.65	1.38	1.01
--	Volunteer	--	1.53	1.04	0.66	1.29	0.97
--	--	45	1.62	1.03	0.66	1.32	0.99
--	--	90	1.69	1.00	0.65	1.35	1.00

The amount of organic matter in the underlying layer (3-6") was about 20% greater with spring surface tillage than with notill (Table 1). This result is not entirely surprising since surface till results in mechanical mixing of the surface 6" whereas notill relies on the actions of soil organisms and other natural processes to mix surface layers. Organic matter was significantly higher in the 3-6" depth with a cover of volunteer winter weeds than with a planted wheat cover, presumably because a wheat cover positions a greater proportion of its biomass at the surface tillage was to not sufficient to completely homogenize the surface 0-6". When the amounts of organic matter in the surface 0-3" and 3-6" layers were averaged, the differences among management systems were less dramatic, but significant treatment effects remained evident. Organic matter averaged from 1.22% to 1.40% in the 0-6" zone. Surprisingly, the lowest amount of organic matter was found in a notill system with a weed winter cover and a higher rate of N applied to the cotton crop. This finding suggests that use of notill alone does not ensure an increase the C content of soils.

Most estimates of C sequestration presume that significant changes in soil organic matter occur only in the surface 6", and therefore restrict measurements to this layer to minimize costs. To ensure that conservation management practices in this study did not significantly influence C accumulation at greater depths in this study, the organic C content from 6-12" was also measured. Increasing the organic matter content and soil structure at depth is particularly important for this soil because Gigger silt loams tend to develop hardpans in this layer. Table 1 shows trends, but no clear differences were evident in the accumulation of soil organic matter below 6". Most differences in organic matter percentage could be attributed to differences in bulk density.

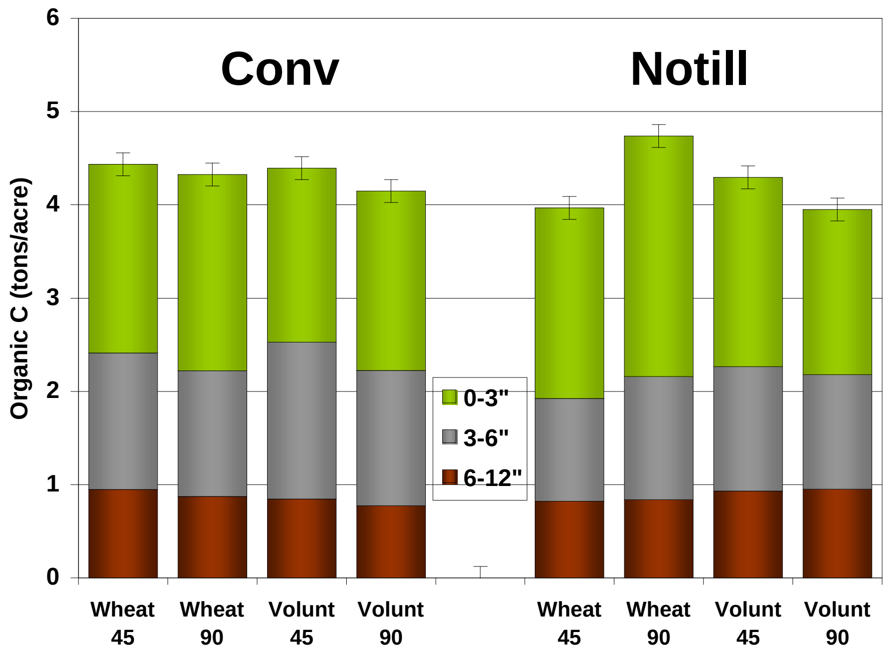

Figure 1. Amount of C sequestered (tons/acre) as organic matter in soils under various conservation management systems for 17 years.

Soil organic matter in Table 1 is expressed as a percentage of total dry solids. However, because the accumulation of organic matter tends to improve soil structure and porosity, it is likely that treatments that increase organic matter in soils also reduce their bulk densities. Estimating C sequestration from organic C concentration (g/kg) alone can be misleading because the total mass of soil decreases as structure improves and soil density decreases For that reason, estimates used to establish C sequestration values for soil organic matter are based on tons per acre rather than on the average concentration of organic C. The amount of soil C on an area basis is calculated by multiplying the measured C concentration by the mass of soil occupying an acre slice of soil. While a 6" acre slice of soil is often estimated to weight about 1000 tons, statistical analysis of the bulk densities of soils collected at various depths in this study showed a number of significant effects. Bulk densities increased with depth and were influenced by tillage system and type of cover crops. For example, while the bulk densities of notill soils were significantly lower in the surface 0-3" than surface-tilled plots, they were significantly higher in the 3-6" layer.

The tons of C/acre accumulated in the surface 12" under various management systems shown in Fig. 1 were calculated using the bulk density determined for each plot and soil depth. Even though the magnitude of some differences was less than when comparing organic matter percentages, a number of statistically significant treatment effects remained evident. Accumulations in the surface 12" ranged from 3.9 to 4.7 US tons/acre. The greatest C accumulation occurred using a combination of notill, wheat cover and 90 lbs N. Notill systems contained a greater proportion of organic C in their surface 0-3". In surface till systems, the amount of organic C was more evenly distributed throughout the surface 0-6". The proportional differences in total C accumulation between notill and surface tilled plots in the 3-6" layer were less than the differences in organic matter percentage because the average density of was substantially greater under notill than under surface till.

The surface till treatment used in this study does not include fall tillage and may be more appropriately call reduced till than conventional till. When this study was initiated in 1987, the field was heavily eroded and contained an average of only 0.44% organic matter in the surface 6". The amounts of organic matter measured in surface tilled plots with either a volunteer or wheat cover crop were nearly three times this amount, indicating an organic matter increase of nearly three fold. Using this standard, the amount of organic matter in surface 6" of the notill/wheat/90 N system was 3.4 times greater than when the experiments were initiated.

Some believe that increasing N rate to increase biomass results in greater accumulation of organic matter, while others argue that increasing N fertilizer application accelerates the rate and extent of decomposition and results in less accumulation. The main effect of N rate was not significant, but the interactions of N rate with tillage and the type of cover crop were significant. Increasing the amount of N applied annually to the cotton crop from 45 to 90 lbs N/acre decreased organic C accumulation in systems using surface till and volunteer winter covers. A higher N rate increased C accumulation in systems employing notill and a planted wheat cover crop.
The effects of management on the stability of organic matter and soil biomass were also studied (*data not shown*). In general, stability increased with depth and was greater under notill. A combination of notill and wheat cover resulted in the greatest accumulation of organic C measured as the amount of C remaining after refluxing samples in 6 N HCl for 16 h. While stability measurements are of value in interpreting data in recently established experiments, their meaning is difficult to interpret in longer-term studies such as that reported. Similarly, a number of significant treatment effects on microbial biomass were observed. However, the values obtained were likely dependent upon time of sampling and it is difficult to draw general conclusions regarding the impact of different management systems on the size of the soil microbial community.

Our findings suggest that the accumulation of soil organic matter in cotton production systems in the mid-south can not be predicted based solely on tillage system, cover crop or N fertilizer rate. Rather, organic C accumulation depends on the specific combination of these management factors. For example, a combination of notill, wheat winter cover and application of 90 lbs N/acre to cotton resulted in the greatest accumulation of soil organic matter in this study, whereas the lowest accumulation occurred with a combination of notill, a volunteer cover and 90 lbs of N. After 17 years, the difference between the highest accumulation and the lowest in the surface 12" was only 0.8 ton C/acre, or ~ 80 lbs C/acre/yr. This is substantially less than reported for conservation systems in other areas and it is unclear at present whether these differences are due to differences in climate and soils or to differences in experimental approach. Even so, the economic value of the C sequestered by conservation management on silt loam soils in the mid-south is not great in comparison.

Overall, this study indicates the economic value of the C sequestered as soil organic matter by conservation management on silt loam soils in the mid-south is not great.
The principal benefits of conservation management on the Macon Ridge appears to lie in the marked capacity to reduce soil erosion, thereby preserving soil productivity and reducing pollution of nearby surface waters. The estimated 10−40% reduction of present agricultural energy requirements incurred by

conservation tillage systems (Sauerbeck, 2001) may represent a greater reduction in the atmospheric burden of CO_2 that does the capacity of these systems to accumulate soil organic matter.

Citations

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