CONTINUOUS CONSERVATION TILLAGE: EFFECTS ON SOIL DENSITY, SOIL C AND N IN THE PRIME ROOTING ZONE

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ABSTRACT

This study reports the results of sampling soil within a field experiment at CEFS, the Cherry Farm, Goldsboro, North Carolina. The experiment tested effects of six years of conservation tillage *with* cover crops, contrasted with chisel plow/disk tillage *without* cover crops, under three crop rotations. In April, 2003 two sets of undisturbed core samples were collected from six mapped soil areas, at depth increments of 0-2 and 2-5 inches, replicated four times. One set was used for soil bulk density; the other provided soil carbon and total nitrogen contents. The study found strong and consistent inverse correlations between soil carbon content and bulk density. Under conservation tillage the surface two inches generally sustained suitable density for root activities. However, at 2-5 inches density approached or exceeded 1.6 g cm-3. Given the textures involved, this density likely would affect root growth, especially under non-ideal, wet/cool or dry/hard conditions. This would be especially important for crop establishment within this prime rooting zone. This low carbon/high-density problem was less likely for soils containing the influences of more silt with less sand. It was greater when corn, peanut and cotton were grown compared to producing soybean or wheat/soybean with corn. This study revealed increased carbon sequestration from the conservation tillage systems used, along with increased total N content in the surface five inches of soil. Conservation tillage as practiced helped to reduce the "greenhouse effect" and lessened N leaching losses, holding more of these elements within the topsoil.

INTRODUCTION

The use of continuous conservation tillage has become an important practice for many farmers, and for some, an essential one. Through improved equipment and technology of recent years it has provided increased production efficiency, allowing them to use much less labor and fuel per acre. This has allowed them to expand acreage, thereby gaining economies of scale in the use of their labor, capital and management. Many farm operations have accepted and benefited from financial incentive programs in support of one or more components of conservation tillage concepts and technology offered by federal, state and local agencies, as well as by agricultural input suppliers having similar environmental interests. To these agencies and suppliers the use of continuous conservation tillage is a preferred approach toward their assigned missions and their business objectives. It promises proven benefits in the prevention of soil erosion and protection of the quality of our natural resources, including soil, water, air and wildlife habitat.

When weather conditions are reasonably good, most farmers are quite content with crop performance and yields under conservation tillage. However, slow early seedling growth is sometimes observed when the no-till planting method is used, particularly in some field conditions and in the first few years of its continued use. This may occur in certain fields or portions of fields, and it may be more obvious only in certain seasons. Not having a contrasting area under a differing tillage method to serve as reference, it often is very difficult for farmers to know the degree of yield limitation that may be present in such problem areas.

In a long-term experiment conducted at the Center for Environmental Farming Systems (CEFS) near Goldsboro, North Carolina, slow early crop growth under the conservation tillage treatments was often noted. The replicated study included contrasting conventional tillage treatments for each crop and rotation. In that study crop yields under conservation tillage were generally only equal, and often slightly inferior, compared to the conventional tillage treatments. This situation offered the opportunity to monitor soil impacts from six years of continuous conservation tillage. The results reported here are based on soil samples collected in the spring of 2003 from selected areas within that study.

MATERIALS AND METHODS

The above mentioned, large-scale field experiment was begun at CEFS in 1995, and was designed to compare the long-term effects of continuous conservation tillage in contrast to annual conventional tillage. This was a systems study in which specific crop rotations and tillage methods were tested using farm-scale field equipment. The study included 16 treatments, each considered a system composed of a crop rotation and tillage method. Individual plots were 2/3 acre in size, and each treatment was replicated four times. The total experimental area including access aisles covered approximately 50 acres.

The rotations included corn/full season soybean, corn-wheat/double cropped soybean, and corn/peanut/cotton. In the conservation tillage treatments a cover crop was planted each fall and killed with Roundup herbicide as late as possible pending planting of the spring crop. Throughout the study, commercial fertilizers and pesticides were carefully applied as needed, using labeled products, rates and timing as recommended by NC Cooperative Extension Service. An exception to this was that in later years no insecticide was applied in the corn/full season soybean rotation for insects attacking corn seedlings, this to facilitate a related study of beneficial nematodes in that rotation.

Where soybean, peanut or cotton was to be planted the cover crop was allowed to advance well into head formation before it was killed. No additional fertilizer nitrogen was applied to the cover crops. The cover crop in the first four years was wheat, until a problem developed with Hessian fly, which appeared to have over-wintered in the cover crop residue to then cause losses in the plots with wheat as grain. In the fifth and sixth years oat served as the cover crop in all conservation tillage plots.

In the first year of the study (1995) much attention was given to assurance throughout the experimental area of an optimum level of soil pH and available phosphorus. The area was divided via a grid into approximately five-acre areas, and each was sampled and treated separately, following the standard soil test recommendations. In the first year all crops were established in their assigned plots, although all were planted using conventional tillage. This involved use of a chisel plow, followed by tillage with a finishing disk and field cultivator. Conventional tillage was chosen the first season in order to assure proper incorporation of lime and phosphorus, and thus to facilitate continuous conservation tillage afterward. From that point onward all treatments and crop rotations were installed according to the plans specified in Table 1. It is important to realize that for practical purposes the crop sequence and cultural practices of any given plot within the experiment simulate a given field of a farmer's operation, where a standard rotation and tillage method is continually followed.

Following six complete years of the project (the 1996 through 2001 seasons), the study was modified. The individual plots locations were maintained, but much of the detailed original design aspects of the treatments were halted. The no till method was continued in planting the conservation tillage treatments. However, the differing rotations were dropped, and in 2002 the entire area was planted in soybean. The conventional tillage plots were planted following the standard chisel/disk preparation. A cover crop had been planted the preceding fall. The same procedures were used in 2003, except that corn was the sole crop throughout the study area, and there was no cover crop planted into the conservation tilled plots. Therefore the spring 2003 sampling that has provided the results reported herein is presented to document the results of six continuous years of the planned, contrasting tillage and rotations. However, the reader should note that the effects of six years of planned treatments probably had begun to diminish by the time sampling was done, because of the period of one summer and a winter in which the ongoing effects of the original plan for cover crops and differing crop rotations had been discontinued.

The entire area of this experiment lies near the Neuse River, and even closer to its tributary, the Little River. The soils throughout the area are subject to flooding, and belong within the taxonomic great group Hapludults. Typically these soils are quite spatially variable, which is the case throughout this experimental area. Commonly there are two or even three mapped soil areas within a plot area of 0.67 acre. Fortunately a detailed soil map has been developed and recorded in our GIS database.

Since the individual plots remained marked by corner posts, and these were easily located on the soil map, it was very feasible to choose sample areas of a given mapped soil within plots having chosen cultural system histories. In April 2003, just prior to any fertilization or preparatory tillage for the summer crop, 24 such study areas were chosen for soil sampling. Each of these areas represented a given mapped soil, along with its respective six-year history of the selected crop rotation and continuous tillage system. Within each area four replicate sites were sampled, each representing that combination of soil map unit and cultural system. In all cases sample areas were selected at about 8 inches beside the evident previous crop row, this to avoid the unusual local effects of recent root masses on soil bulk density, and the related contributions to soil carbon and nitrogen. Further, sites were chosen to avoid sampling the compacted areas of recent wheel tracks, especially those made by harvesting equipment.

In all cases the surface soil was sampled at depth increments of approximately the 0 to 2 inches and 2 to 5 inches. The thickness of these depth increments was accurate, because all samples were collected with a standard, undisturbed soil core sampler, using internal rings of 3 inches diameter. This core sampling procedure was modified by using a ring of 2-inch thickness for the upper sample, followed by the standard ring of 3-inch thickness for the second depth increment. However, the upper edge of these depth increments was approximate, judged to have been within a half-inch of the stated depths of 0 or 2 inches. This was necessary because in using the core sampler a small thickness of the surface soil must be removed in order to insure an exact and flat surface at the top of sample. Furthermore, the second depth increment cannot be taken directly beneath the surface sample because of the disturbance caused by a shovel, which is usually required to remove the upper sample. Therefore, an adjacent small excavation to approximately 2-inch depth was made with a small shovel, and the second depth sample was begun within that excavated area.

At each of these replicate sample sites two sets of samples at each depth increment were collected. The one set was used to determine soil bulk density, by standard oven drying of the samples. The second set of samples was used for determination of soil carbon and total soil nitrogen contents. These samples were kept at field moisture and cool temperature, stored inside sealed plastic bags for several weeks until the laboratory analyses were performed. These soil samples were then air-dried and crushed to pass through a 2 mm sieve. Total carbon and nitrogen contents were determined by dry combustion using a Perkin Elmer/Series II 2400 analyzer (Nelson and Sommers, 1982).

A portion of one of the replicate samples from each study area was used to determine the soil texture for that area of soil. Particle-size distribution was determined using the USDA classification system. Samples were pretreated with hydrogen peroxide for organic matter removal prior to sedimentation analysis. Clay and silt contents were determined using the hydrometer method. (Gee and Bauder, 1986)

Standard one-inch soil cores were also taken from the four replica sites, and these were combined as a composite to provide a single soil fertility sample representing each study area. The samples were analyzed by the Agronomic Division, North Carolina Department of Agriculture and Consumer Services (data not shown).

Statistical analyses were done, including analysis of variance and tests for correlations between soil bulk density and soil carbon content, and between soil carbon and soil nitrogen contents. (SAS) This permitted testing for differences between the tillage treatments at the same depth increment, and between depth increments for the same tillage system. For three of the soils it was also possible to test for differences between crop rotations.

RESULTS AND DISCUSSION

Mapped areas of six soils were chosen for study within the experiment. Although there were several more soils within the overall experimental area, the six were chosen because these were present in all versions of the tillage systems tested, and for three of those soils the areas were adequate to permit sampling and contrast for two or even three of the crop rotations in the study. Although time and analytical resources were limited, this selection of soils allowed the study of all forms of tested tillage, these giving ten differing combinations of soil and crop rotation, each at the depth increments of 0-2 and 2-5 inches. Table 2 presents the means of soil bulk density and the contents of soil C and N for the rotation or rotations tested, and for each of the six soils. The taxonomic classification of the soils is included. The soil “Newbegun” currently is in the status of “proposed,” because it is under formal review for use on soils currently being mapped in this state. Statistical significance of difference between the two sample depths for each variable, for each form of tillage and each soil is shown. Significance is indicated where there was 90% or greater certainty, although in most cases the certainty level was much higher.

Soil Density Concerns

Bulk density was significantly greater at the 2 to 5 inch depth for seven of the ten comparisons under conservation tillage, and for eight of those comparisons under chisel plow/disk tillage without cover crops. However, of more importance is the fact that under conventional tillage the density at both depths will be lessened before planting each spring, whereas with continuous no till planting there is no plan for loosening in the seedbed zone, because we assume the density and porosity to be suitable for plant growth. A recent agency soil quality publication (USDA-NRCS, 2003) lists ideal soil bulk densities of <1.4 for sandy loam, loam, sandy clay loam, and clay loam textures. It stated that root growth “may be affected” beginning at the density of 1.60 for sandy clay loam, loam and clay loam;

at 1.63 for sandy loam and at 1.69 for loamy sand and sand textures. (Note: All expressions of soil bulk density will refer to units of gram cm -3.) This indicates that for a given level of root restriction a slightly higher bulk density can be tolerated in the more coarse-textured soils.

In this study the average density within the surface 2-inch depth under conservation tillage was nearly ideal, given the textures of the soils included. The exceptions to this statement were for the State soil when corn/peanut/cotton rotation was grown and for the Dogue soil under all three rotations. Unfortunately however, under conservation tillage the density at the 2-5 inch depth approached or exceeded that which would affect root growth in all soils except the Newbegun and the Yeopim. Textural analyses of samples from this study revealed that the Newbegun and Yeopim soils have about 50% silt and 30% sand (making them of silt loam texture), whereas the other soils studied were approximately 50% sand and 30% silt (fitting the standard for loam or sandy loam textures).

With the assumption of a constant density for mineral soil particles of 2.65 gram cm –3, it is possible to determine useful estimates of total soil porosity for stated levels of soil bulk density. Using this approach, the above-stated benchmark densities for differing textures show that "ideal" total pore volume for sandy loam, sandy clay loam, loam, and clay loam would be a minimum of about 47 volume percent. For these same textures the loss of less than 1/5 of this porosity would "affect root growth," and loss of about a 1/3 of it would "restrict" root growth. For loamy sand and sand textures, the range is even more narrow; the loss of 1/12 total pore volume would "affect" and 1/5 would "restrict" root growth. It can be argued that porosity under conservation tillage culture may favor root growth and aeration because it may offer more continuous and more large-sized pore spaces.

However, based on the reality of constant density of mineral soil particles, these comparisons illustrate that quite small density changes may be quite detrimental to the soil porosity so necessary for healthy root systems. This is especially critical in the surface five inches as studied here, because this certainly is the prime zone of root development during early crop growth and establishment.

Similar bulk densities have been found by other workers studying tillage pans and how these limit root development and crop growth in soils of the southeastern states. Kashirad, et al, (1967) studied the tillage pan layers in the Norfolk, Red Bay, Orangeburg and Lakeland soils in many cropped fields in Florida. The pan layers in all of these soils were more sandy than in the soils studied here, (mostly sandy loam, loamy sand and sand textures) and the average densities within the pan layers were 1.63, 1.59, 1.65 and 1.63, respectively, for the soils named above. In those crop fields studied they reported that root growth "either did not penetrate the tillage pan or was constricted within the pan as shown by the lack of secondary roots, as compared to those in the soil above or below the pan a zone."

Kamprath, et al. (1978), in a study of the Norfolk and Wagram soils in North Carolina, a multi-year study that revealed significant soybean yield increases in response to deep tillage, in three seasons of the four tested, reported that in the zones of maximum mechanical impedance the bulk density of the dense, compacted pan layer was 1.65 to 1.67 for the Norfolk soil and 1.67 to 1.73 for the Wagram soil. In the Wagram soil the texture of the pan zone was more sandy than that of the Norfolk, probably loamy sand. Loosening the compacted zone by deep tillage significantly increased soybean root dry weight in the zone. Vepraskas, et al, studied soil physical properties and other factors affecting the root growth and yield response to subsoiling by tobacco in many fields in North Carolina. They found that the presence of a zone of soil bulk density of 1.63 or greater was one of two soil factors useful in predicting the responsiveness of soils to subsoiling for tobacco.

The Soil Carbon/Bulk Density Relationship

The correlation coefficients between these variables were consistent, strong and negative. The correlation coefficient for 80 samples from conservation-tilled plots was (-) 0.758; the same for the 80 samples from plots annually stirred by a chisel plow and disk was (-) 0.664. Note that this was found for 80 samples grouped across both sample depths, and for all soils and all rotations. These high correlations were found even though soil density usually differed greatly between sample depths for both tillage treatments. For both forms of tillage these correlation coefficients were statistically significant at >1:10,000. Correlation coefficients for the six individual soils, combining the values from both depths and the rotations sampled, were similarly strong and inverse, even though there many fewer samples per comparison. These were statistically significant at 90 percent or greater certainty for all six soils under conservation tillage and for three of the six soils under conventional tillage management. *Since the soil texture from the two sample depths was generally very similar, the strength and consistency of these inverse correlations strongly urge the conclusion that soil carbon content largely controlled soil bulk density, at the depths and under the conditions sampled in this study.* The soil carbon contents shown in Table 2 also often demonstrate significantly less carbon at 2-5 inches compared to the surface two-inch increment. *These statistical correlations suggest that if soil carbon content is adequately high, soil bulk density will be sustained at a desirable level for crop root growth and activity.*

Even with six years of strong conservation tillage emphasis in this study, that of producing a wheat or oat cover crop and conserving all crop residues, soil carbon content dropped to the range of 6/10 to 3/4 percent at this second depth, except for the more silty Newbegun and Yeopim soils, which sustained soil carbon at 8/10 to 1%, along with maintaining a satisfactory density at this depth. In fact, for conservation-tilled plots, soil carbon at the second sample depth was *statistically significantly less* than the chisel plow/disk plots in five of the ten combinations of soil and rotation compared. Also, for the more sandy soils studied the corn/peanut/cotton rotation resulted in lower soil carbon and higher bulk density, compared to rotations including soybean or wheat/soybean. Again, this was not apparent in the more silty Newbegun soil. Since soil carbon content appeared to control soil density, it is apparent that in the other four more sandy textured soils, it would be desirable either to mechanically loosen the soil in the prime root zone, or to successfully establish higher carbon content to at least 5 inches depth through some more effective choice of cover crops and management of cover and crop residues.

The Soil Carbon/Soil Nitrogen Relationship

As expected, total contents of soil nitrogen and carbon were closely related. Since the soil samples were collected prior to any spring fertilization and following wet conditions of the fall and winter, nearly all of the measured nitrogen was probably associated with the soil biota and organic matter. The correlation coefficients between soil C and N contents were very highly significant at 0.92 and 0.86 for all 80 samples from both the conservation tillage treatment and the chisel/disk treatment, respectively. This is also shown in Table 2, where N contents often were significantly less at the second sample depth, and there was always less N content where peanut and cotton were produced in the rotation instead of soybean or wheat/soybean. Again, the N content differences by depth and rotation were less apparent in the more silty Newbegun soil.

Measured Carbon Sequestration and Nitrogen Capture

Since the original field study was designed to include replicated plots of contrasting tillage systems, and the present research included equal sample numbers from these comparable treatments, it was possible to estimate the impact of the tillage treatments on carbon and nitrogen present in the soil.

For each sample depth and each soil and rotation tested, the average contents of these elements per acre-five inch depth were determined. These were compared for the conservation tillage and chisel/disk tillage systems. This was done by simple subtraction of mean computed values, based on the mean concentrations of C and N, which were multiplied by the respective mean bulk densities. As a result some variation can occur for a given comparison, since these values are subject to any unusual variability for either of the components being multiplied together.

Shown in Table 3 are the results of these estimates. In the case of carbon, when the value shown is positive, this can be referred to as "carbon sequestration" by six years of the conservation tillage system applied. (Further, some of this affect may have diminished because in the crop season preceding sampling, no cover crops nor planned rotations had been included.) This information is of much current interest because it confirms that the conservation tillage system used, through its consumption of substantially greater quantities of carbon dioxide in photosynthesis and the careful residue management applied, in most comparisons did in fact make a greater contribution to soil C, and has thereby reduced atmospheric "greenhouse gases" resulting largely from our societal use of fossil fuels.

The nitrogen values shown in Table 3, when positive, also indicate increased capture of nitrogen through the conservation tillage system used, in comparison to the chisel/disk tillage without cover crops. Since equal fertilization was applied to plots under both forms of tillage, this increased N held in the soil is primarily that from applied fertilizers and the symbiotic N fixed by the soybean and peanut crops grown. *This additional captured nitrogen is not readily susceptible to leaching loss and potential groundwater contamination--another contribution to the benefit of society. Although this additional soil N resulting from the use of conservation tillage is not immediately plant available, surely over time much of it will enter the plant-available pool. This suggests the need to plan future studies to test the opportunity for some reduction in plant fertilizer nitrogen requirement for comparable yields under long-term conservation tillage management.*

CONCLUSIONS

After six years of continuous conservation tillage soil bulk density within the surface two inches was generally sustained at an adequate level for root activities. However, just below, at 2-5 inches, soil density approached or exceeded 1.6 gram cm –3, a level considered to unfavorably affect root growth and activity because of inadequate soil pore volume, given the soil textures involved. During wet periods this would slow air and water exchange, while during dry conditions it may present excessive soil hardness for ideal root growth and normal expansion of root systems.

Soil bulk density was strongly and inversely related to soil carbon content. Based on this fact, the above concern may be considered one of low soil C/high soil density just below the soil surface, this within the prime zone of root growth for crop establishment. The problem may require some form of row-zone loosening, and/or achievement of deeper soil C deposition via changes in cover crop choice and management. Further study is needed to predict or determine where this is needed and the preferred solutions to it.

Soil textures with more silt (48-58%) and less sand (25-40%) influence maintained soil carbon at about 1 percent or greater, as well as bulk density suitable for crop growth. These soils were loam approaching silt loam in texture. The soils presenting the problem had less silt influence with more sand (25-45% silt, with an average of 52% sand). These soils were loam approaching sandy loam in texture. After six years of conservation tillage culture these soils maintained soil C content at the 2-5 inch depth at only about 0.8 percent or less.

The corn/peanut/cotton rotation was less soil carbon-friendly and more prone to high soil density than rotations including soybean or wheat and soybean. It is apparent that aggressive use of winter cover crops is especially important in such rotations.

Soil C and N contents were closely correlated. Because conservation tillage generally did increase soil C it also generally captured more N in the soil. Compared with chisel plow/disk culture without use of cover crops, conservation tillage generally did sequester more C from the atmosphere, where via residue conservation it was measured in the surface soil sampled. Also, generally more N was measured within the surface 5 inches of soil studied, indicating that there was reduced N loss and the associated probable groundwater contamination, provided by the six years of conservation tillage used. These are both benefits of importance our current society.

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Table 1. Details of the Tillage Systems Experiment, Center for Environmental Farming Systems (CEFS).

System	Crop Rotation	Tillage/Cover Crop	1995	1996	1997	1998	1999	2000	2001
A1	Corn/F. Season SB	No-Till--Yes	Corn	S'Bean	Corn	S'Bean	Corn	S'Bean	Corn
A2	Corn/F. Season SB	No-Till--Yes	S'Bean	Corn	S'Bean	Corn	S'Bean	Corn	S'Bean
A3	Corn/F. Season SB	Chisel Pl./Disk--No	Corn	S'Bean	Corn	S'Bean	Corn	S'Bean	Corn
A4	Corn/F. Season SB	Chisel Pl./Disk--No	S'Bean	Corn	S'Bean	Corn	S'Bean	Corn	S'Bean
A5	Corn/F. Season SB	Fall Chisel/Levl--Yes	Corn	S'Bean	Corn	S'Bean	Corn	S'Bean	Corn
A6	Corn/F. Season SB	Fall Chisel/Levl--Yes	S'Bean	Corn	S'Bean	Corn	S'Bean	Corn	S'Bean
B1	Corn-Wh/D. Cr. SB	No-Till--Wh. as Cvr/Grn.	Corn	Wh/SB	Corn	Wh/SB	Corn	Wh/SB	Corn
B2	Corn-Wh/D. Cr. SB	No-Till--Wh. as Cvr/Grn.	Wh/SB	Corn	Wh/SB	Corn	Wh/SB	Corn	Wh/SB
B3	Corn-Wh/D. Cr. SB	Ch.Pl./Disk--Wh. grain	Corn	Wh/SB	Corn	Wh/SB	Corn	Wh/SB	Corn
B4	Corn-Wh/D. Cr. SB	Ch.Pl./Disk--Wh. grain	Wh/SB	Corn	Wh/SB	Corn	Wh/SB	Corn	Wh/SB
C1	Corn/P'Nut/Cotton	No-Till--Yes	Corn	Peanut	Cotton	Corn	Peanut	Cotton	Corn
C2	Corn/P'Nut/Cotton	No-Till--Yes	Peanut	Cotton	Corn	Peanut	Cotton	Corn	Peanut
C3	Corn/P'Nut/Cotton	No-Till--Yes	Cotton	Corn	Peanut	Cotton	Corn	Peanut	Cotton
C4	Corn/P'Nut/Cotton	Chisel Pl./Disk--No	Corn	Peanut	Cotton	Corn	Peanut	Cotton	Corn
C5	Corn/P'Nut/Cotton	Chisel Pl./Disk--No	Peanut	Cotton	Corn	Peanut	Cotton	Corn	Peanut
C6	Corn/P'Nut/Cotton	Chisel Pl./Disk--No	Cotton	Corn	Peanut	Cotton	Corn	Peanut	Cotton

Shading indicates a Conservation Tillage Treatment--------

Table 2. Mean soil bulk density, carbon and total N contents, by soil, crop rotation, tillage system and sample depth, resulting from six years duration of the experiment at the Center for Environmental Farming Systems (CEFS).

	Soil Bulk Density ($g.cm^{-3}$)				**Soil Carbon (%)**				**Total Soil N (%)**			
	Cons.Till		Ch. P/Disk		Cons.Till		Ch. P/Disk		Cons.Till		Ch. P/Disk	
Crop Rotation	0-2 in.	2-5 in.	0-2 in.	2-5 in.	0-2 in.	2-5 in.	0-2 in.	2-5 in.	0-2 in.	2-5 in.	0-2 in.	2-5 in.
State Soil (fine-loamy, mixed Typic Hapludults)												
Corn/FS Soybean	1.444	1.583*	1.601	1.641	1.370	0.730*	0.945	0.723*	0.160	0.103*	0.115	0.095*
Corn/Peanut/Cotton	1.602	1.651	1.564	1.597*	1.025	0.585*	0.773	0.690	0.128	0.095	0.115	0.100*
Altavista Soil (fine-loamy, mixed Aquic Hapludults)												
Corn/Wheat/DC SB	1.464	1.623*	1.379	1.533*	1.188	0.758*	1.245	0.900*	0.158	0.110*	0.158	0.128*
Newbegun Soil (fine-silty, mixed Typic Hapludults)												
Corn/Wheat/DC SB	1.396	1.540*	1.320	1.501*	1.388	1.110	1.290	1.025*	0.173	0.153	0.163	0.140*
Corn/Peanut/Cotton	1.439	1.536	1.439	1.539*	1.353	1.003	1.090	1.113	0.163	0.138	0.143	0.143
Yeopim Soil (fine-silty, mixed Aquic Hapludults)												
Corn/F S Soybean	1.412	1.552*	1.305	1.530*	1.600	0.830*	1.110	0.943	0.188	0.118*	0.153	0.133*
McQueen Soil (clayey, mixed Typic Hapludults)												
Corn/F S Soybean	1.456	1.596*	1.415	1.508*	1.573	0.780*	1.018	0.918*	0.170	0.103*	0.115	0.105
Dogue Soil (clayey, mixed, Aquic Hapludults)												
Corn/F S Soybean	1.587	1.622	1.527	1.608	1.073	0.610*	0.963	0.785*	0.143	0.108*	0.125	0.110*
Corn/Wheat/DC SB	1.498	1.649*	1.438	1.617*	1.278	0.753*	1.068	0.773*	0.180	0.128*	0.130	0.100
Corn/Peanut/Cotton	1.530	1.653*	1.450	1.634*	1.010	0.653*	0.870	0.800	0.120	0.088*	0.125	0.118

*Indicates a difference at 90 percent or greater certainty between values for same variable (soil bulk density; soil C or Soil N) and for the same form of tillage (NT or CP/Disk) at differing soil sample depths.

Table 3. Differences in soil C and total soil N contents per acre-five inch resulting from six years of continuous conservation tillage with cover crops versus conventional tillage (chisel plow/disk) without cover crops for six soils and differing crop rotations in CEFS experiment.

Soil Name (Drn. Cl.)	Av. Sand	Av. Silt	Crop Rot'n	Diff. Soil C	Diff. Soil N
	%	%		------(Lbs/A-5 in.)------	
State (Well)	51.9	33.6	Corn/FS SB	+ 2,116	+ 201
State (Well)	"	"	Corn/Pnut/Cot	+ 1,093	+ 92
Altavista (Mod. Well)	44.8	38.4	Corn/FS SB	(-) 880	(-) 54
Newbegun (Well)	30.6	52.6	Corn/Wh-DC SB	+ 2,206	+ 287
Newbegun (Well)	"	"	Corn/Pnut/Cot	+ 637	+ 76
Yeopim (Mod. Well)	30.9	49.5	Corn/FS SB	+ 2,819	+ 123
McQueen (Well)	52.3	40.5	Corn/FS SB	+ 3,185	+ 421
Dogue (Mod. Well)	47.7	40.4	Corn/FS SB	(-) 800	+ 143
Dogue (Mod. Well)	"	"	Corn/Wh-DC SB	+ 1,730	+ 704
Dogue (Mod. Well)	"	"	Corn/Pnut/Cot	+ 185	(-) 311