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Long-Term Agricultural Management Effects on Soil Carbon

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This is the twelfth note in a series of Soil Quality-Agronomy technical notes on the effects of land management on soil quality.

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Sequestration of carbon in soil has attracted attention recently because of its potential to mitigate global warming (Lal et al., 1999). However, soil carbon (C) is also valuable because of its beneficial effects on crop productivity and soil quality. Soil C is the most important soil quality indicator because of its role in other biological, chemical, and physical processes. Long-term experiments have shown the benefits of manure, adequate fertilization, and crop rotations on soil C. However, even with manure and crop rotations, conventional cropping systems generally result in a steady decline of soil C. The rate and magnitude will be affected by cropping sequence, tillage system, soils, climate, and temperature (Reeves, 1997).

Soil organic matter is about 58% carbon. Soil organic matter conversions can be made by taking soil C values in this technical note and dividing by 0.58 or multiplying by 1.72.

This technical note will examine (1) carbon dynamics in long-term cropping experiments and (2) the combined effect of conservation tillage and high biomass crop rotations on soil C. Together, these studies demonstrate the importance of reducing tillage and increasing biomass inputs.

LONG-TERM ROTATION EXPERIMENTS

Morrow Plots

Long-term rotation results are some of the best records of agricultural effects on soil C. The Morrow Plots in Illinois, established in 1876, are the oldest continuous agricultural experimental plots in the United States. Records from the Morrow experiment show consistent decrease in crop yields of monoculture corn compared to corn-oat-legume rotation. In 1944, soil C was analyzed in the plots and in the sod border surrounding the Morrow Plots (Table 1). Assuming soil C in the border was representative of the original soil C in 1876, soil C has been substantially degraded even under best management practices.

Sanborn Field

The long-term plots at Sanborn Field, Missouri (begun in 1888) show similar trends as the Morrow Plots. After 100 years of continuous cropping, soil C under continuous corn averaged 0.58% C without amendments, 1.1% C with N-P-K fertilizer applications, and 1.3% C with annual applications of 6 tons of barnyard manure/acre. Similar treatments with continuous wheat show 0.81, 1.28, and 1.6% C, respectively (Brown, 1993).

Magruder Plots

The Magruder Plots long-term continuous wheat study in Oklahoma began in 1892 (Webb et al., 1980). Soil C declined rapidly during the first 35 years and somewhat slower during the next 52 years as a steady state was approached. One of the significant lessons from the Magruder Plots is that, even with manure additions, soil C levels are not sustainable under monoculture wheat with tillage (Table 2).

Pendleton, OR

A long-term study of wheat-fallow systems was started near Pendleton, Oregon in 1931. The fields had been previously cropped since the 1880's. As yields declined, annual cropping had given way to wheat-fallow systems. The nine treatments in the study were 10 tons/acre of manure; one ton/acre of pea vine residue; 0, 40, and 80 lbs/acre of nitrogen with and without spring burning of straw; and 0 lbs N/acre with fall burning of straw. Soil C is still declining from 1931 levels in all treatments at depths down to 12 inches except the manure treatment. There is little evidence that stationary levels will be reached in the future. Although the manure treatment is not losing soil C, tillage and the fallow period are probably preventing any gains in soil C.

Table 1. Crop rotation and manure effects on soil C in the Morrow Plots, University of Illinois. Sampled in 1944 (Odell et al., 1982). Sample depth was 6 and 2/3 inches.

Crop rotation and amendment	Organic C (Tons/acre)
Eastern sod border (no treatment)	37.8
Western sod border (no treatment)	32.0
Corn-oats-clover with manure, lime and phosphorus	31.2
Continuous corn (no amendments)	16.6

Table 2. Soil C trends in monoculture wheat at the Magruder Plots, Oklahoma State University (Webb et al., 1980).

Treatment	1892 Original Soil C%	1927 Soil C%	1979 Soil C%
Unfertilized wheat	2.0	1.0	0.64
Wheat with manure applications	2.0	1.6	0.87

Can soil carbon levels be maintained with tillage?

In Iowa it was shown that if enough corn residue was produced (5,352 lbs/acre) and turned under with a moldboard plow, soil C could be maintained on a Typic Hapludoll (Larson et al., 1972). However, after years of continuous corn, the level of soil C in this study was maintained near an equilibrium of only 1.8% C (Reeves, 1997). Soil C of similar native prairie soils is approximately 4% (Robinson et al., 1996). Even in the Pendleton example, where 10 tons of manure were added annually without straw burning, tillage prevented major gains in soil C. The effect of tillage on soils in cool wet climates is less than on soils in warm wet climates.

Thus, long-term studies show that continuous tillage and row crop production reduce soil C from the levels under native vegetation. After soil C has been reduced to a lower equilibrium level, the lower C level can be maintained under conventional tillage if the amount of C returned from amendments and residues equals or exceeds that lost to decomposition.

CONSERVATION TILLAGE

The long-term experiments reviewed above compared several crop rotations and fertility treatments under conventional tillage. This section will review other long-term studies that document carbon changes under conservation tillage systems. They show that conservation tillage alone will slow the decomposition of soil C, but not stop or reverse the loss of C. To increase the level or sequester soil C, sources of C from crop residues, cover crops, and/or manures must be added.

Canada

In semi-arid Saskatchewan, on a silt loam soil, soil C increased under no-till continuous wheat but showed no gains in a wheat-fallow system (Campbell et al., 1995). There were no significant differences between tillage systems under the wheat-fallow system. However, on a related 11-year study on a clay soil (Campbell et al., 1996), cropping frequency did not affect soil C. Soil C increased under no-till to a depth of 6 inches on both the continuous wheat and the wheat-fallow system (4,465 lbs/acre over 11 years). The conventional tillage continuous wheat treatment also showed increases in soil C to a depth of 6 inches (1786 lbs/acre over 11 years). Only the conventional wheat-fallow system (using sweep cultivator and rodweeder with three cultivations during fallow) showed no increase in soil C in the clay soil. Most of the increase in soil C came during excellent growing seasons the last four years of the study. It was speculated that the soil's high clay content and good growing conditions explained the lack of soil C differences between cropping frequencies.

South Central Texas

In south-central Texas, cropping intensity increased soil C under no-tillage systems but not under conventional tillage (Franzluebbers et al., 1994). Cropping intensity was defined as the fraction-year the crop was grown:

- Continuous wheat = 0.5 year
- Wheat-soybean double crop = 0.65 year, and
- Wheat-soybean-sorghum rotation = 0.88 year

After 9 years under no-till, the soil C levels increased by 9% in the continuous wheat system, 22% in the wheat-soybean system, and 30% in the wheat-soybean-sorghum system. Soil C levels did not increase under conventional tillage, regardless of cropping intensity.

Crossville, Alabama

In Alabama on a fine sandy loam soil, a 10-year study was conducted comparing conservation tillage to conventional tillage with crop rotations of (1) continuous corn with wheat cover crop, (2) continuous soybean with wheat cover crop, and (3) corn with wheat cover crop and soybean with wheat cover crop. Beginning soil C at 0-6 inches was 0.58% (Table 3) on land that had been cropped for many years (Edwards et al., 1988)

Soil C increased from 0.58% C to 0.90% C (8,309 to 11,499 lbs/acre) in the top 4 inches in no-tillage cropping systems – a 55 % increase compared to the soil C in conventional tillage cropping systems. In this study, the key to maintaining soil C in conventional tillage systems and increasing soil C in no-till systems was the use of a cover crop. Rotations with corn in the rotation also increased soil C in humid areas with high decomposition rates.

Table 3. Soil C by depth with different tillage and crop rotations after 10 years in Crossville, AL (Edwards et al., 1992).

Crop rotation	Soil depth (inches)	Conventional till (Soil C %)	No-till (Soil C%)
Soybean w/wheat cover crop	0-2	0.57	0.93
	2-4	0.56	0.88
	4-6	0.58	0.58
	0-6	0.57	0.80
Corn w/wheat cover crop	0-2	0.62	1.20
	2-4	0.62	1.06
	4-6	0.58	0.63
	0-6	0.61	0.96
Corn w/wheat cover-soybean-wheat cover crop	0-2	0.59	1.07
	2-4	0.58	0.93
	4-6	0.52	0.51
	0-6	0.56	0.84

Pierre, South Dakota

Since 1987, research at the Dakota Lakes Research Farm at Pierre, South Dakota have shown that crop diversity and crop intensity have major impacts on soil C levels. The study compared several rotation systems. This note will focus on three of the several rotation systems. The three no-till systems are: (1) a wheat–fallow system, (2) a three year rotation (winter wheat–corn–pea), and (3) a four-year rotation (spring wheat–winter wheat–corn–sunflower). In 1994, a dry year, the three-year rotation yielded four bushels/acre of wheat better than the wheat-fallow system. The four-year rotation produced five bushels/acre of wheat more than the wheat–fallow system. In 1995, a wet year, the three- and four-year rotations respectively produced 10 and 6 bushels/acre more wheat than the wheat–fallow system (Beck et al., 1998). Another rotation with a three year break between wheat crops (winter wheat–corn–soybean–field pea) yielded 14 bushels more than the wheat–fallow system. Cool and wet seasons intensify the yield advantage of the longer rotations, especially in no-till systems. Reeves (1997) substantiated the advantages of crop rotations by reviewing several studies showing that crop diversity and rotations were more effective at enhancing productivity in no-till than conventional tillage because the rotations reduced disease in humid regions and enhanced water use efficiency in semi-arid regions.

CONCLUSION

Farmers may or may not see financial incentives to reduce greenhouse gases through C sequestration, but there will always be other benefits to improving soil C, including better productivity and soil quality. Soil C levels on continuously cropped land have dropped substantially over the past century. This decline is at least partially reversible while still keeping the land in agricultural production. Soil C levels can be increased through two types of land management practices: 1) increasing the input of organic matter by crop rotation systems, planting cover crops, applying manure, or improving annual productivity, and 2) reducing the loss of organic matter by controlling erosion and reducing tillage. Applying either of these two approaches can reduce or stop the loss of soil C associated with continuous cropping, but both approaches must (almost always) be used together to increase soil C levels. Climate is important in determining the rate of loss or gain of soil C. For example, in cool, humid climates it is not as critical to reduce tillage because cool temperatures reduce the loss of soil C and the adequate moisture allows high productivity. Conservationists should make it clear to their clients that increasing soil C is valuable and is practically feasible in agricultural situations. But to increase soil C, and not merely reduce the decline, most land managers must both reduce tillage and use crop rotations that increase annual productivity.

REFERENCES

Beck, D.L., J.L. Miller, and M.P. Hagny. 1998. Successful no-till on the Central and Northern Plains. www.dakotalakes.com/publications.htm.

Brown, J.R. 1993. Sanborn Field: A capsule of scientific agricultural history in central Missouri. Missouri Agric. Experiment Station, Columbia, MO.

Campbell, C.A., B.G. McConkey, R.P. Zentner, F.B. Selles, and D. Curtin. 1995. Carbon sequestration in a Brown Chernozem as affected by tillage and rotation. Can. J. Soil Sci. 75:449-458.

Campbell, C.A., B.G. McConkey, R.P. Zentner, F.B. Selles, and D. Curtin. 1996. Long-term effects of tillage and crop rotations on soil organic C and total N in a clay soil in southwestern Saskatchewan. Can. J. Soil Sci. 76:395-401.

Edwards, J.H., C.W. Wood, D.L. Thurlow, and M.E Ruf. 1992. Tillage and crop rotation effects on fertility status of a Hapludult. Soil Sci. Soc. Am. J. 56:1577-1582.

Edwards, J.H., D.L. Thurlow, and J.T. Eason. 1988. Influence of tillage and crop rotation on yields of corn, soybean, and wheat. Agron. J. 80:76-80.

Franzluebbers, A.J., F.M. Hons, and Z.A. Zuberer. 1994. Long-term changes in soil carbon and nitrogen pools in wheat management systems. Soil Sci. Soc. Am. J. 58:1639-1645.

Lal. R., R.F. Follet, J. Kimble, and C.V. Cole. 1999. Managing US cropland to sequester carbon in soil. J. Soil Water Conser. 54:374-381.

Larson, W.E., C.E.Clapp, W.H. Pierre, and Y.B. Morachan. 1972. Effects of increasing amounts of organic residues on continuous corn: II. Organic carbon, nitrogen, phosphorus, and sulfur. Agron J. 64:204-208.

Odell, R.T., W.M. Walker, L.V. Boone, and M.G. Oldham. 1982. The Morrow Plots: A century of learning. Agricultural Experiment Station, College of Agriculture, Univ. of Illinois Bull. 775, Urbana-Champaign, IL.

Reeves, D.W. 1997. The role of soil organic matter in maintaining soil quality in continuous cropping systems. Soil Tillage Res. 43:131-167.

Robinson, C.A., R.M. Cruse, and M. Ghaffarzadeh. 1996. Cropping system and nitrogen effects on Mollisol organic carbon. Soil Sci. Soc. Am. J. 60:264-269.

Webb, B.B., B.B. Tucker, and R.L. Westerman. 1980. The Magruder Plots: Taming the prairies through research. Agricultural Experimental Station, Oklahoma State Univ.