SOIL CARBON AND NITROGEN CHANGES IN A LONG TERM CROPPING SYSTEMS STUDY

D. R. Christenson[1]

ABSTRACT

Conserving soil C and N appears to a reasonable objective in the choice of a cropping system. Many long-term studies have been conducted where the effects of rotation or cropping system on soil C, N and other nutrients have been evaluated. A cropping systems study was initiated in 1972 on Michigan's lake bed area to 1) evaluate how often sugar beet and dry bean could be grown in a rotation and 2) determine how much crop residue needed to be returned to the soil to maintain productivity.

Soil samples were taken at the initiation of the study, and after 9 and 19 years for carbon and nitrogen analysis. Soil carbon declined in all systems including those with greater than 50% corn in the rotation. In the first 9 years of the study, the rate of decline ranged from 0.38% per year for corn-corn-navy bean-sugar beet to 1.50% per year for navy bean-sugar beet. The change in the second 10 years ranged from a loss of 0.21% per year for oat-alfalfa-navy bean-sugar beet to a gain of 0.28% per year for the corn-corn-corn-sugar beet. This suggests that a new equilibrium is being established which may be unique for each system.

Soil nitrogen declined for all systems including a oat-alfalfa-navy bean-sugar beet system. Alfalfa was grown only 4 times during the course of the study and in combination with navy beans fixed an estimated 355 lb N/acre. Cropping systems with corn showed a positive nitrogen balance, primarily due to application of fertilizer nitrogen.

There was no relationship between carbon loss and economic return. The results suggest that strategies under convention tillage which conserve soil carbon may not be in the farmers best interest economically. Strategies to conserve soil carbon with reduced tillage for the production of dry beans and sugar beets merit additional research.

INTRODUCTION

Long term cropping systems and crop rotation research is important in helping understand how these systems affect crop yields, yield stability, and soil physical and biological properties. Since the beneficial effects of forage legumes on soil properties are recognized, most long term rotation studies include forage legumes. Studies commonly include evaluation of soil N and C, but P and S are also included as part of various investigations (Larson et al., 1972). Cropping systems that conserve soil C and N often increase crop yields

---

[1] Professor and Extension Specialist, Crop and Soil Sciences Department, Michigan State University, East Lansing, MI 48824. Presented at the 1994 North Central Extension-Industry Soil Fertility Conference, St. Louis, MO

because they promote the formation of stable aggregates and in turn increase capillary pore space (Robertson, 1952).

An experiment was established in 1972 on a Misteguay silty clay soil (Aeric Haplaquept) at the Saginaw Valley Bean and Beet Research Farm. Included in the rationale for this study was the need to include cropping systems which reflected the change from livestock to cash crop farming systems. The initial goals of the study were to: 1) evaluate how often dry bean and sugar beets could be grown in a rotation and 2) evaluate how much organic matter needed to be returned to the soil to maintain soil productivity. The objective of this paper is to evaluate changes in soil C and N concentration in the plow layer for six of the 12 cropping systems after 9 and 19 years of cropping.

METHODS

The general management for the experiment included fall plowing, field cultivation in the spring, recommended rates of fertilizer and herbicide, and planting in 30 inch rows. Nitrogen was broadcast at planting. A starter fertilizer containing P and micronutrients was used. Additional details of the management of the study are reported by Christenson et. al (1991).

Soil samples (20 cores/plot) to a depth of 9 inches were taken from the same experimental units in the spring of 1972, 1981 and 1991. The samples were dried, ground and stored in sealed containers. Oxidizable carbon was determined by the Walkley-Black (WBC) method (Schulte, 1988). These values were converted to total soil organic C using a recovery factor of 77% (Walkley and Black, 1934). Total soil N was determined using the Kjeldahl method (Bremner, 1965). Mean differences were tested using the Duncan's New Multiple Range test.

RESULTS

The amount of crop residue returned to the soil was estimated based on considerations formulated by Lucas et al. (1977). These estimates and the amount of fertilizer N applied are given in Table 1. Crop residues returned between 1972 and 1990 ranged from 31 tons/acre for the navy bean-sugar beet system to 85 tons/acre for the corn-corn-corn-sugar beet system. Nitrogen applied ranged from 550 lb/acre for the oats-alfalfa-navy bean-sugar beet system to 2035 lb/acre for the corn-corn-corn-sugar beet system.

Carbon

At the initiation of the experiment in 1972 soil C was not significantly different among cropping systems (Table 2). After 9 years of cropping under the different systems, there were significant differences in soil C due to cropping system. The O-A-NB-SB, NB-SB and O-NB-SB systems lost a significantly larger amount of soil C than the C-C-C-SB system. None of the six systems showed a significant increase in soil C. However, cropping systems containing corn resulted in up to 10% more soil C than those systems without corn.

The above trends were still apparent after 19 years of cropping (Table 2). Soil C losses were greatest for the NB-SB, O-NB-SB and O-A-NB-SB and least for the systems which contained corn. Only 25% of the rotation had alfalfa grown compared to 50-67% for corn. It is apparent that alfalfa grown in this manner does not maintain soil C similar to corn grown more frequently.

The rate of disappearance of soil C was faster in the first 9 years than in the second 10 years or averaged over the course of the 19 years of this study (Table 3). This fits with the general understanding of the effect of cropping systems on soil organic C where carbon is lost more rapidly in the first years after a change in the cultivation pattern. The data suggest that these cropping systems may be reaching a new equilibrium with respect to C. This new equilibrium concentration may be unique for each cropping system or type of system. However, the duration of the study is insufficient to substantiate that a new equilibrium exists.

Nitrogen

After 19 years of cropping, soil N concentration was highest in the C-SB and C-C-C-SB systems which had received large amounts of fertilizer N from commercial sources (Table 4). Conversely, soil N was lowest in the NB-SB and O-NB-SB systems which had received less applied N over the course of the study. The O-A-NB-SB system was intermediate receiving less fertilizer N than systems containing corn.

Nitrogen balance was calculated by subtracting the N added from the N removed. N added was the total from fertilizer plus that fixed by navy beans and alfalfa. Nitrogen fixed by legumes was conservatively estimated at 35 lb/acre for navy beans (Piha and Munns, 1987) and 45 lb/acre for alfalfa (Hesterman, 1992), respectively. Nitrogen removed was the total of the loss of soil N (Table 4) plus crop removal. Nitrogen removed by crops was estimated based on a number of sources summarized by Christenson et al. (1992).

The majority of the N lost from the system was from crop removal (Table 5). Corn removed 50 to 75% of the total in those cropping systems containing corn, reflecting the proportion of the system devoted to this crop. N removed by the NB-SB and O-NB-SB systems was less than systems containing corn. The O-A-NB-SB system lost the most N over the course of the study. There was less fertilizer nitrogen added in this system than those containing corn. Nitrogen fixed by legumes was a modest 355 lb/acre. Alfalfa was grown 4 and navy beans 5 times during the course of this study. One of the initial questions in this study was to evaluate the effect of a single year of alfalfa on nitrogen balance. It is obvious that alfalfa grown in this manner does not add sufficient quantities of N to equal removal from this system.

Relationship Between Yield, Organic Matter and Economic Return

One of the initial goals was to determine the how much organic matter needed to be returned to the soil to maintain the yield of navy bean and sugar beet. There is not a good relationship between C conservation and yield of the two crops (Table 6) For example, navy bean in the navy bean-sugar beet system yielded 16.3 cwt/acre and an associated carbon loss of 2.2 g/kg. The oat-alfalfa-navy bean-sugar beet system yielded 19.5 cwt/acre of navy beans with an associated carbon loss of 2.0 g/kg. Similar results were obtained for sugar beet in the corn-corn-corn-sugar beet system (loss of 0.3 g/kg and 24.7 t/acre) and oat-alfalfa-navy bean-sugar beet (loss of 2.0 g/kg and 26.8 t/acre). We also see different cropping systems being advantageous for the production of beans and beets. This prompted an economic approach for the evaluation of cropping systems. Annual net return to land and unallocated resources (ANR) was calculated by subtracting production costs from gross return for each cropping system.

Data in Table 6 shows a comparison of ANR to loss of carbon for 6 cropping systems. The NB-SB system has the largest carbon loss, but has the highest ANR, while the C-C-C-SB system had the lowest carbon loss, but also had a much lower ANR. There are factors other than carbon conservation which control yield of these crops in these systems. Using an economic measurement is useful in evaluation of these systems. Additional consideration of this aspect of this study is given in Christenson et al. (1995).

SUMMARY

Nitrogen and C concentrations in this soil declined for all systems even though forage legumes and corn were included in the rotation. Where corn was grown over 50% of the time, C concentration declined less than where a one year stand of alfalfa was included. The rate of decline in soil C was more rapid in the first 9 than in the second 10 years. This suggests that a new equilibrium is being established. The data further suggest that the new equilibrium level may be unique for each cropping system or type of system.

The combination of alfalfa and navy bean did not add sufficient N to the soil to equal removal. Fertilizer N applied to the C-SB and C-C-C-SB systems resulted in a net gain of 35-57 lb N/acre over the course of the study.

Adopting strategies in conventional tillage which conserve soil carbon may not be in the farmers best interest for economical survival. Development of alternative strategies which conserve soil carbon and allow the grower to compete is worthy of additional research. Conservation tillage systems which reduce soil erosion and oxidation of carbon hold some promise. Incorporation of forage legumes into cropping systems without losing a cash crop may be advantageous.

REFERENCES

Bremner, J. M. Total nitrogen. In Methods of Soil Analysis. Amer. Soc. Agron., Madison, WI., 9, 1149, 1965.

Christenson, D. R. 1995. Soil organic matter in sugar beet and dry bean cropping systems in Michigan. In E. Paul (ed.) Soil Organic Matter in Temperate Agroecosystems: Concepts and Bench Mark Data. Lewis Publisher, Inc. Chelsea, MI. (In Press).

Christenson, D. R., Gallagher, R. S., Harrigan, T. M. and Black, J. R. 1995. Annual net return from twelve cropping systems containing sugar beet and navy bean. J. Prod. Agric. 8: (In Press).

Christenson, D. R., Warncke, D. D., Vitosh, M. L. Jacobs, L. W., and Dahl, J. G., Fertilizer recommendations for field crops in Michigan, Mich. State Univ. Coop. Ext. Bull., E-550A, 1992.

Christenson, D. R., Helsel, Z., Meints, V., Black, R., Hoskins, R., Wolak F., and Burkhardt, T., Agronomics and economics of some cropping systems for fine textured soils, Dry Bean Digest, 4 (2), 6, 1980.

Hesterman, O. B., Griffin, T. S., Williams, P. T., Harris, G. H., and Christenson, D. R., Forage legume-small grain intercrops: Nitrogen production and response of subsequent corn, J. Prod. Agric., 5, 340, 1992.

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

Lucas, R. E., Holtman, J. B., and Connor, L. J., Soil carbon dynamics and cropping practices, in Agriculture and Energy, Academic Press, Inc, 1977, 333.

Piha, M. I. and Munns, D. N., Nitrogen fixation capacity of field bean compared to other grain legumes, Agron. J. 79, 690, 1987.

Robertson, L. S., A study of the effects of seven systems of cropping upon yields and soil structure, Amer. Soc. Sugar Beet Tech., 7, 255, 1952.

Schulte, E. E., Recommended soil organic matter tests. Recommended chemical soil test procedures for the North Central Region, N. Dak. State Univ. Agric. Exp. Sta. Bull., 49, 29, 1988.

Walkley, A., and Black, I. A., An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method, Soil Sci., 37, 29, 1934.

Table 1. Estimated crop residues returned and fertilizer N applied to a cropping systems study conducted on a Misteguay silty clay soil.

Cropping System[†]	Residues[*] 1972-80	Residues[*] 1972-90	Nitrogen 1972-80	Nitrogen 1972-90
	- - - - - - - - - - - -	- - t/acre - -	- - - - - - - - - -	
C-SB	30	62	0.45	1.09
NB-SB	15	31	0.19	0.41
O-NB-SB	17	36	0.16	0.35
C-C-C-SB	40	85	0.48	1.02
C-C-NB-SB	26	57	0.36	0.78
O-A-NB-SB	20	42	0.12	0.28[‡]

[†] C = Corn, SB = Sugar Beet, NB = Navy Beans, O = Oats, A = Alfalfa.

[*] Estimated residue returned: Corn 4.5 ton/acre; Sugar beets, 2.0 ton/acre; Navy beans 1.6 tons/acre; Oats, 2.2 tons/acre; Alfalfa, 3.6 tons/acre (Lucas et al. 1977).

[‡] Does not include nitrogen contribution from alfalfa.

Table 2. Effect of cropping system on carbon concentration in a Misteguay silty clay soil after 9 and 19 years of cropping.

Cropping System[†]	Carbon 1972	Carbon 1981	Carbon 1991	Δ Carbon 72-81	Δ Carbon 81-91	Δ Carbon 72-91
	- - - - - -	- - - - - -	- - - - - - $g\ kg^{-1}$	- - - - - -	- - - - - -	- - - - - -
C-SB	16.8a[*]	15.4ab	15.6a	1.4abc	-0.2a	1.2ab
NB-SB	16.3a	14.1c	14.1c	2.2a	0.0a	2.2a
O-NB-SB	16.3a	14.2bc	14.2c	2.1a	0.0a	2.1a
C-C-C-SB	16.4a	15.7a	16.1a	0.7bc	-0.4a	0.3b
C-C-NB-SB	15.8a	15.3ab	15.3ab	0.5c	0.0a	0.5b
O-A-NB-SB	16.5a	14.7abc	14.4bc	1.7ab	0.3a	2.0a

[†] C = Corn, SB = Sugar Beet, NB = Navy Beans, O = Oats, A = Alfalfa.

[*] Means followed by the same letter within a column are not significantly different, alpha = 0.05 (Duncan's new multiple range test).

Table 3. Effect of cropping system on the rate of carbon loss from a Misteguay silty clay soil after 9 and 19 years.

Cropping System	1972-1981	1981-1991	1972-1991
		%/year†	
C-SB	0.90abc‡	- 0.13a	0.37ab
NB-SB	1.53a	-0.05a	0.71a
O-NB-SB	1.42a	0.01a	0.68a
C-C-C-SB	0.45bc	- 0.28a	0.08b
C-C-NB-SB	0.38c	- 0.01a	0.18b
O-A-NB-SB	1.16ab	0.21a	0.66a

† %/year = $100(C_o - C_t)/(t * C_o)$; where: C_o = 1972 carbon, C_t = 1981 or 1991 carbon, t = time in years.

‡ Means followed by the same letter within a column are not significantly different, alpha = 0.05 (Duncan's new multiple range test).

Table 4. Soil N at the initiation of a cropping systems study and after 19 years of cropping on a Misteguay silty clay soil.

Cropping System	Total N Applied	Total Soil Nitrogen 1972	Total Soil Nitrogen 1991
	t/acre	- - - g kg^{-1} - - -	
C-SB	1.09	1.75a†	1.69ab
NB-SB	0.41	1.73a	1.60cd
O-NB-SB	0.35	1.64a	1.56d
C-C-C-SB	1.02	1.79a	1.73a
C-C-NB-SB	0.78	1.76a	1.65bc
O-A-NB-SB	0.28	1.72a	1.66abc

† Means followed by the same letter within a column are not significantly different, alpha = 0.05 (Duncan's new multiple range test).

Table 5. Nitrogen balance for six cropping systems after 19 years of cropping on a Misteguay silty clay soil.

Cropping System	N Removed			N Added			Difference[§]
	Soil N[†]	C.R.[*]	Total	Legume[‡]	Fert.	Total	
	lb/acre						
C-SB	130b[#]	2013	2144	-	2179	2179	- 35
NB-SB	260a	1538	1798	350	821	1171	627
O-NB-SB	155b	1354	1509	214	705	919	590
C-C-C-SB	130b	1848	1979	-	2036	2036	- 57
C-C-NB-SB	210a	1905	2115	179	1554	1733	382
O-A-NB-SB	255a	1829	2084	355	554	909	1175

[†] Nitrogen lost from decline in soil N (Table 4). Bulk density (1.30 g/cc).

[*] Crop Removal: Corn, 0.90 lb/bu; Sugar Beets, 4.0 lb/ton; Navy Beans, 3.6 lb/cwt; Oats, 0.62 lb/bu; Alfalfa, 45 lb/ton.

[‡] Nitrogen fixed: Navy beans = 35 lb/acre; Alfalfa = 45 lb/acre.

[§] Nitrogen removed minus nitrogen added.

[#] Means followed by the same letter within a column are not significantly different, alpha = 0.10 (Duncan's new multiple range test).

Table 6. Yield of navy beans and sugar beets (average of 1975-1990) and the associated carbon loss compared to the annual net return to land and unallocated resources (ANR) for a cropping systems study conducted on a Misteguay silty clay soil.

Cropping System[†]	Navy Bean Yield	Sugar Beet Yield	Carbon Loss	ANR
	cwt/acre	t/acre	g/kg	$/acre
C-SB	-	24.8b	1.2ab	319b
NB-SB	16.3b[‡]	25.3b	2.2a	392a
O-NB-SB	18.5b	25.2b	2.1a	255c
C-C-C-SB	-	24.7b	0.3b	166e
C-C-NB-SB	19.3a	25.4b	0.5b	229c
O-A-NB-SB	19.5a	26.8a	2.0a	204d

[†] C = Corn, SB = sugar beets, NB = navy beans, O = oats, A = alfalfa.

[‡] Means followed by the same letter within a column are not significantly different, alpha = 0.05 (Duncan's new multiple range test).

PROCEEDINGS OF THE TWENTY-FOURTH
NORTH CENTRAL EXTENSION-INDUSTRY
SOIL FERTILITY CONFERENCE

October 26-27, 1994

Holiday Inn St. Louis Airport

Bridgeton, Missouri

Volume 10

Program Chairman and Editor:

Dr. Maurice Vitosh
Michigan State University
Dept. of Crop and Soil Sciences
Plant and Soil Sciences Building
East Lansing, MI 48824-1325