Soil Organic Matter Dynamics
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Adding large amounts of organic matter to mineral soils increases the rate of water infiltration, improves the ease of root penetration, increases soil buffering capacity, increases microbial activity, decreases soil bulk density and serves as a source of plant nutrients. Farming practices, however, have depleted most soils to less than 50 percent of their native organic matter content. Under most situations once a soil is depleted of its humus, it is a long-time program to build it up again. In fact it is not practical to return to the native levels.

To help understand soil humus changes, organic matter losses and additions must be compared. Losses include humus decay and soil erosion. Additions are any source of biomass material. This report summarizes field trial results on the addition of farm manures to soils and the soil humus changes one might expect as related to cropping practices and soil management.

Changes in soil organic matter due to soil management are difficult to determine with short term experiments. Variability in soil sampling and chemical analyses are sufficiently great so that they mask actual changes. For example, a variation between duplicate analyses of only 0.1 percent soil humus represents about 2,500 pounds per acre, 8 inches deep, a value greater than most annual additions. With long-time field experiments, meaningful values can be obtained. Such experiments, however, are costly and researchers lose interest because of the time factor.

About the only place in the Midwest where longtime trials on cropping and soil management can be observed are the Morrow plots at the University of Illinois and the Sanford plots at the University of Missouri. In the Morrow plots, soil organic matter content ranged from 3.1 percent for a continuous corn to 4.9 percent for a corn, oats, clover rotation (1). These differences reflect changes from 1886 to 1953. Current trials at the Sanford plots show about 1.3 percent organic matter for continuous corn, 1.9 percent for alfalfa and 2.5 percent for timothy.

Michigan does not have any long-time field trials where one can observe soil humus changes as related to soil management. A nine-year study, however, was made on a corn, field bean, barley, and two years of alfalfa rotation (5). This study was carried out at the Ferden Farm on a Sims Clay loam (1.5 c soil). The soil organic matter content at the start was 4.8 percent. Because of this high value, even with the good rotation, the soil was losing 1,200 pounds of soil humus annually.

Attempts were made to improve organic matter content by various amendments. Six years after 40 tons of sawdust were applied, the organic matter content was 0.6 percent higher than the check. Thus, for 40 tons of material, about 6 tons of soil humus were still present. This increase may not appear large, but when compared with the organic carbon changes, it amounts to about 20 percent of that applied, a value considered unusually high.

Soil organic nitrogen changes were compared in 1958 for two rotations that had been initiated in 1941 at the Ferden Farm (13). One rotation selected was typical for a livestock program and included corn, sugar beets, barley and two years of alfalfa-brome. Ten tons of farm manure per acre were applied to the corn during each of the four completed cycles of the rotation. The soil organic nitrogen in 1958 tested 4,100 pounds per acre. The second rotation was a cash crop system of corn, sugar beets, barley, field beans and wheat. The soil tested 3,700 pounds of organic nitrogen. These values indicate the soil organic matter was about 71,000 and 64,000 pounds per acre, respectively. Based upon the 18-year period, the difference in change averaged about 390 pounds per year. A valid criticism of these comparisons is that they do not apply to present day agricultural practices. For example, in the livestock rotation, the corn yields averaged 68 bushels per acre and the cash crop 39 bushels per acre.

Experimental Procedure for the Manure Plots

Manure plots were established in 1963 on a Metea loamy sand soil (3/2a soil) at East Lansing on the Michigan State University Farm. The experimental design was a split-block where each replication was divided into grain and silage areas. In 1974, the north half of each plot was irrigated. Progress results have been published (14, 15).

Two treatments consisted of N-P-K mineral fertilizer — one at low P-K and the second at high P-K rates. Additional treatments were manure from the loose housing beef barns which was applied annually at the rates of 10, 20 and 30 tons per acre. The manure contained about 500 pounds of dry organic matter per ton. Figure 1 illustrates the effect of 30 tons of manure on the soil color after 14 years.

Soil samples were collected from the plow layer October, 1976. At this location, the plow layer is about eight inches deep. In the calculations, the soil was estimated to weigh 2.5 million pounds per acre. The organic matter was determined from total carbon analysis using a high frequency induction furnace. A factor of 1.72 was used to convert carbon values to soil organic matter. The soil organic matter levels are compared with those reported in 1968 (15).

Results of Manure Trials

The data in Tables 1 and 2 report the yields and soil organic matter content for corn silage and grain. Yield differences were not great without irrigation. With irrigation, the yield for plots receiving 10 tons of manure per acre was noticeably less than for other treatments. Corn with this treatment was visibly nitrogen deficient. Data in Table 2 indicate that chemically fertilized plots had a rather stable soil organic matter content of about 2.0 percent. Manure treatments showed somewhat higher soil organic matter levels in 1976 as compared to 1968. As expected, the changes for the first six years

Table 1 Soil organic matter changes as related to fertilizer and manure treatment for a Metea loamy sand growing silage corn.

Annual Treatment	Silage Yield T/A		% Soil Organic Matter	
$N-P_2O_5-K_2O$-Manure	No Irrigation	Irrigation		
Lb/A - Tons/A	1963-1973	1974-1976	1968(a)	1976
160-40-40-0	13.5	23.3	2.05	1.63
160-190-190-O	15.0	24.5	2.05	1.70
10-40-40-10 T	14.3	19.6	2.12	2.07
10-40-40-20 T	14.8	23.5	2.28	2.20
10-40-40-30 T	15.6	23.9	2.96	2.83
LSD (.05)	0.7	2.0	-----	0.4

(a) Combined analysis of three replications.

Table 2 Soil organic matter changes as related to fertilizer and manure treatment for a Metea loamy sand growing corn (grain).

Annual Treatment	Bu/A		% Soil Organic Matter	
$N-P_2O_5-K_2O$-Manure	No Irrigation	Irrigation		
Lb/A -- Tons/A	1963-1973	1974-1976	1968(a)	1976
160-40-40-0	85	141	1.98	2.03
160-190-190-0	78	147	2.07	1.97
10-40-40-10 T	83	129	2.10	2.13
10-40-40-20 T	83	143	2.38	2.40
10-40-40-30 T	82	147	2.63	2.83
LSD (.05)	5	11	-----	0.4

(a) Combined analysis of three replications.

Fig. 1 Visual differences in soil appearance where manure was applied annually from 1963 to 1976. Treatments from front to back are: none, 30 tons, none and 20 tons per acre.

were greater than those for the next eight years of treatment. In chemically fertilized plots harvested for silage (Table 1), humus content declined about 0.4 percent between 1968 and 1976. The total change was about 10,000 pounds of humus or an average loss of about 725 pounds carbon per acre per year.

A comparison of averages for all plots which received manure, with the average for all plots which received only chemical fertilizer does reveal definite trends. The average rates of gain in humus due to manure on plots harvested for grain over the two time periods in Table 4 can be resolved into the smooth curve of Figure 2. From this curve, it can be estimated that in the first year of application each ton of manure increased soil humus about 100 pounds per acre. This represents a 20 percent recovery when comparing dry matter in the manure with soil humus produced.

A more reliable comparison of the recovery should probably be based upon carbon recovery. If so, then the first year recovery was about 30 percent of that applied. From 1968 to 1976 the increase in soil humus in plots harvested for grain was about 5 percent of that applied in manure (Table 4).

Soil erosion losses by wind and water were probably negligible for this research site. Large decreases in organic matter content in chemically fertilized silage plots from 1968 to 1976 (Tables 1 and 3) were due mainly to humus decay rates which exceeded the annual production of humus from roots, stubble, exudates, etc. By contrast, organic matter levels in chemically fertilized grain plots where stover was returned appeared to be approaching a steady state (Tables 2 and 4).

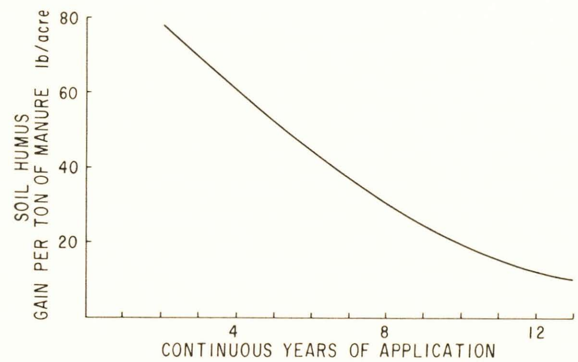

Fig. 2 Pounds of soil humus gain per ton of manure applied to a Metea loamy sand testing 2.0 percent organic matter--Average for the 10,20 and 30 ton application rates.

Under steady-state conditions, the annual production of humus from crop residues or manure is equal to the annual rate of humus decay. Assuming steady-state,

Table 3 Changes in the soil organic matter content of a Metea loamy sand for 1968 and 1976 for the manure treatments. Calculated from data in Table 1 (corn silage).

Manure	Soil Organic Matter	Increase from Manure	Increase per Ton of Applied Manure (over none)		
Tons/A/Year	Lb/Acre(a)	Lb/Acre O.M.	As Pounds of soil organic matter	As Pounds of soil carbon	% of applied carbon(b)
None					
1968	51250	------			
1976	41750	------			
Change		-9500			
10 Tons					
1968	53000	1750	29	17	8.5
1976	51750	10000	71	41	21.5
Change		8250	103	60	30.0
20 Tons					
1968	57000	5750	48	28	14.0
1976	55000	13250	47	27	13.5
Change		7500	47	27	13.5
30 Tons					
1968	74000	22750	126	73	36.5
1976	70750	29000	69	40	20.0
Change		6250	26	15	7.5
Average 10-20-30T					
1968	61330	10080	84	49	24.5
1976	59170	17420	62	36	18.0
Change		7340	46	27	13.5

(a) Assumes the plow layer weighs 2.5 million pounds of soil.
(b) Assumes each ton of manure contains 200 pounds of organic carbon and the soil humus is 58 percent carbon.

Table 4 Change in the soil organic matter content of a Metea loamy sand for 1968 and 1976 for the manure treatments. Calculated from data in Table 2 (Corn grain).

Manure	Soil Organic Manure	Increase from Manure	Increase per Ton of Applied Manure (over none)		
Tons/A/Year	Lb/Acre(a)	Lb/Acre O.M.	As Pounds of soil organic matter	As Pounds of soil carbon	% of applied carbon(b)
None					
1968	50625	------	------	------	------
1976	50000	------	------	------	------
Change		-625			
10 Tons					
1968	52500	1875	31	18	9.0
1976	53250	3250	23	13	6.5
Change		1375	17	10	5.0
20 Tons					
1968	59500	8875	74	43	21.5
1976	60000	10000	36	21	10.5
Change		1125	4	2	1.0
30 Tons					
1968	65750	15125	84	49	24.5
1976	70750	20750	49	28	14.1
Change		5625	18	10	5.0
Average 10-20-30T					
1968	59250	8625	72	42	21.0
1976	61330	11330	40	23	11.5
Change		2705	17	10	5.0

(a) Assumes the plow layer weighs 2.5 million pounds of soil.
(b) Assumes each ton of manure contains 200 pounds of organic carbon and the soil humus is 58 percent carbon.

humus decay rate in chemically fertilized plots harvested for grain can be estimated by the following calculation:

$$\frac{10{,}000 \text{ lb. plant residue} \times 0.20 \text{ (Humus production factor)}}{2{,}500{,}000 \text{ lb. soil/acre} \times 0.02 \text{ (soil organic matter)}} = 0.04 \text{ decay rate.}$$

Similar calculations for the 30 ton manure treatment show a seven percent decay rate. These rates are high as compared to most agricultural situations in Michigan because the soil is well drained and aerated. This would tend to indicate that this soil has not reached a steady state. Irrigation was initiated in 1974 which may also accelerate humus decay.

Soil Humus Model

Many factors affect soil humus levels. Lucas, Holtman and Connor (8) presented a model, Figure 3, that points out the major factors. Many of the assumptions were based on research results found with radioisotope carbon studies at the Rothamsted Research Center at Harpenden, England (6,7). On an annual basis, the temperature and rainfall averages are similar to mid-Michigan. At this same location, the English workers have also measured humus changes on several contrasting soil management practices. Fortunately to measure the small cumulative effects, the Rothamsted staff has sampled and preserved soils collected periodically from plots started as early as 1843. In that year plots were planted to continuous wheat. The soil tested 1.6 percent soil organic matter. The present value on the unfertilized plot is essentially the same. The treatment receiving 14 tons of farm manure per acre annually now contains 4.6 percent organic matter.[1] In contrast to what appears to be taking place in the Michigan manure trials, those in England showed definite increases for over 60 years.

In another trial at Rothamsted, a small tract of land has been kept bare since 1870. At the start the soil tested 2.4 percent organic matter. One hundred years later the bare soil tested 1.4 percent. The depletion rate was about 1.1 percent annually for the first 20 years and about 0.4 percent during the last 30 years. These values help us understand what to expect in soil humas decay rates under contrasting organic matter addition rates.

Another trial at Rothamsted shows the rate of soil organic matter buildup with native plants. Two areas

[1] Obtained from lecture notes prepared by D.S. Jenkinson.

in 1882 were fenced off and left to naturally regenerate plant cover. One area has developed into a mixed woodland with a sparse ground flora; the other area has been rogued annually to remove woody species. It consists of coarse grasses and a mixture of about 40 dicotyledonous species (3). Both areas have had a net gain of about 40,000 pounds of soil humus per acre in the top 9 inches of soil, an annual increase of 500 pounds per acre.

Dart and Day (3) have studied the nitrogen balance on these sites. (The organic matter to nitrogen ratio in these soils is about 18 to 1.)
They find that most of the gain in nitrogen is from non-symbiotic nitrogen fixation. Their calculations place a minimum annual fixation at 44 pounds of nitrogen per acre for the wooded site and 35 pounds for the grass-weed area. This fixation is much higher than most short-term experiments have indicated.

The model in Figure 3 attempts to portray the input and outgo factors related to soil humus levels. To use the model, we have made certain assumptions. These are:

1) All manure and plant residues upon decomposition leave a residue of 30 percent in the form of soil organic carbon.
2) Humus in recently bare land is estimated to decompose at an annual rate of:
   a) 2.5 percent for a loam, clay loam soil
   b) 3.5 percent for a sandy loam
   c) 4.5 percent for a loamy sand.
3) Soil weight is assumed to be 2 million pounds per acre. If higher weights are used, then the annual

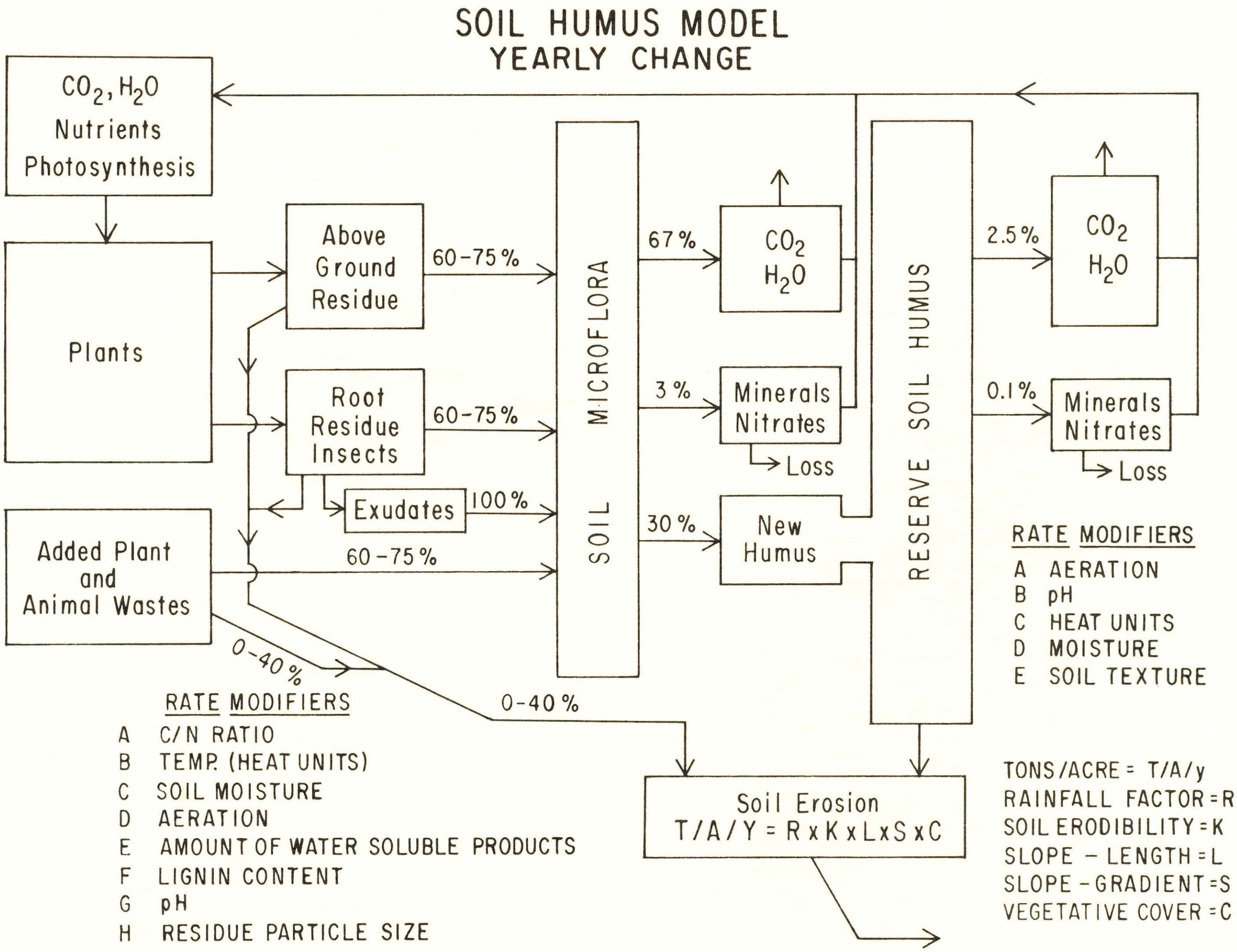

Fig. 3 **Soil humus model--yearly change.**

decay rate is reduced.

4) Most of the soil erosion factors apply to the Universal Soil Erosion Equation (16) for a loam soil in mid-Michigan. The values are: soil erodibility index of 0.32, "R" value of 100, slope and length factor of 0.3 (2% slope, 200 feet length) and the cropping-management values prepared by the Soil Conservation Service.
5) The organic matter content in eroded sediments is 50 percent greater than that in the field soil. This increase is necessary because humus is low in density and has small particle size.
6) Plant carbon from root turnover, exudates and insects is estimated at 150 percent of the amount for root weights at harvest.

Soil Organic Sources

During the process of plant decay to humus, there is an enrichment in the carbon content. Carbon is the element commonly used by chemists to follow the organic changes in plants and soils. For this reason, data in Table 5 and Figures 4-6 are reported as organic carbon. A factor of 1.72 is used to convert soil carbon to soil organic matter.

There is extensive information about the amount of above-ground plant residue but little on root production, exudates and other sources of plant carbon. At harvest, root weights for plants in humid areas range from 15 to 30 percent of the total plant residue. These amounts do not include turnover of root material dur-

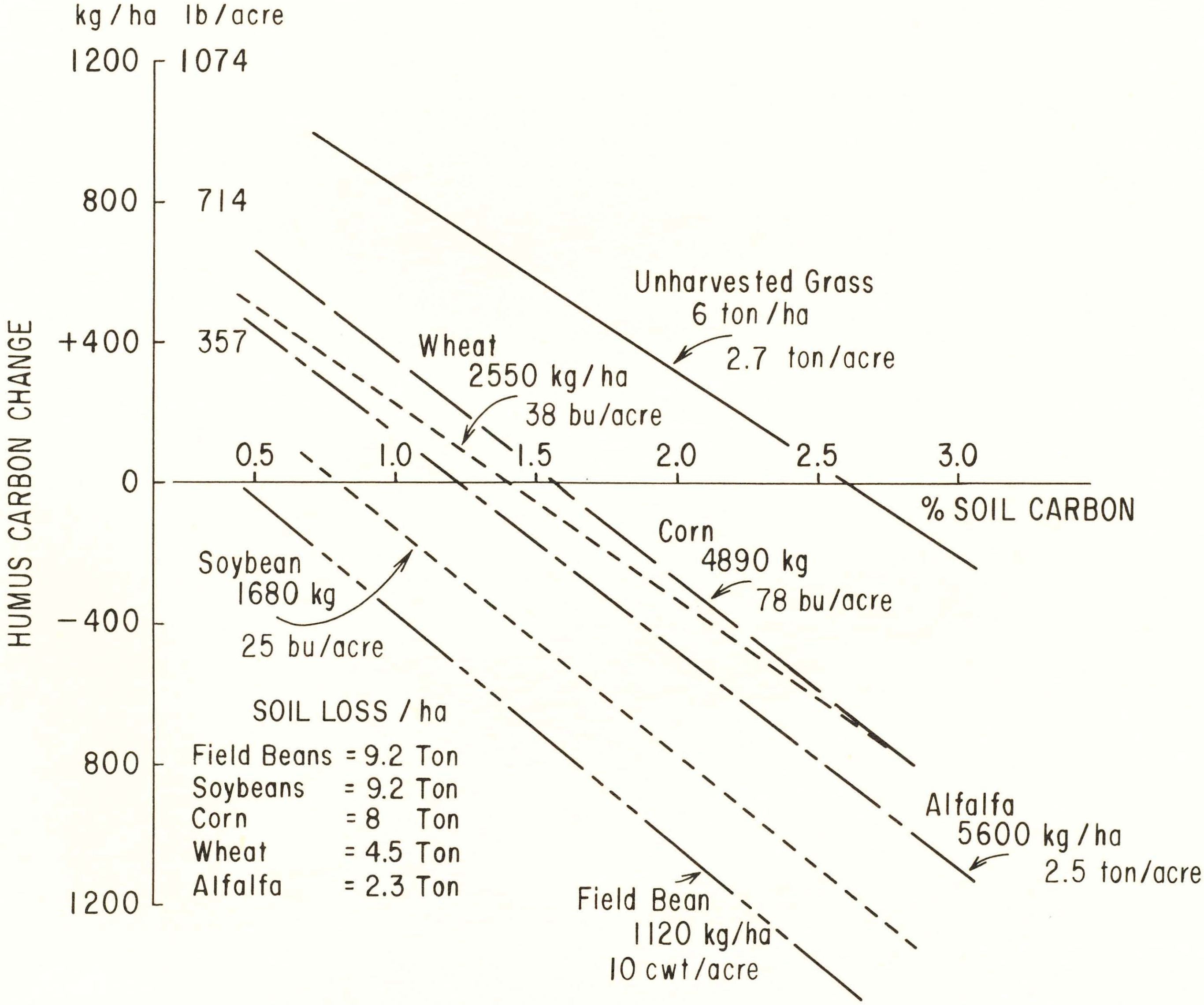

Fig. 4 **Yearly soil humus changes as related to the crop grown and the soil carbon content. (Average yields for Michigan)**

ing the growing period and exudate materials from both tops and roots. Other carbon sources overlooked are weeds, birds, insects and algae. Data in Table 5 attempt to account for the source of soil carbon for field crops. Note that the values for field beans yielding 15 cwt per acre return only the equivalent of 340 pounds of soil carbon while corn returns 1110 pounds. These differences reflect soil organic matter changes. The relationships shown in Figure 4 are based upon average yields for crops grown in Michigan. The line for unharvested grass is used as a reference for natural conditions. The horizontal line designated as "% soil carbon" represents the content for the plow layer.

For a particular situation, illustrated in Figures 4,5,6, where the crop line and soil line intersect, the point is called the steady-state value. If the soil carbon content is less than the steady-state value, the change in humus content is positive. In the region where the humus is negative (below the soil line), the steady-state level is approached from the opposite direction. As the steady-state level is approached from above or below, the annual change becomes smaller and smaller providing

Table 5 Estimated soil organic carbon production for several field crops. (Plant carbon times 0.3 equals soil organic carbon production.)

Source	Corn		Soybeans	
	100 bu/A	8270 kg/ha	32 bu/A	2150 kg/ha
Top Residue	725(b)	812	380	426
Roots (a)	155	174	70	78
Others (a)	230	258	110	123
Total	1110	1244	560	627
	Wheat		Field Beans	
0403	45 bu/A	3025 kg/ha	15 cwt/A	1680 kg/ha
Straw	540	605	240	269
Roots	120	134	40	45
Others	180	202	60	67
Total	840	941	340	381
	Alfalfa - 1st Year		Alfalfa - 2nd Year	
	4T/A	8960 kg/ha	4T/A	8960 kg/ha
Top residue	180	202	180	202
Roots	310	347	240	269
Others	470	526	360	403
Total	960	1075	780	874

(a) Roots include only the amount at harvest. "Others" include root turnover exudates, insects, etc.

(b) Pounds of Soil Carbon Produced.

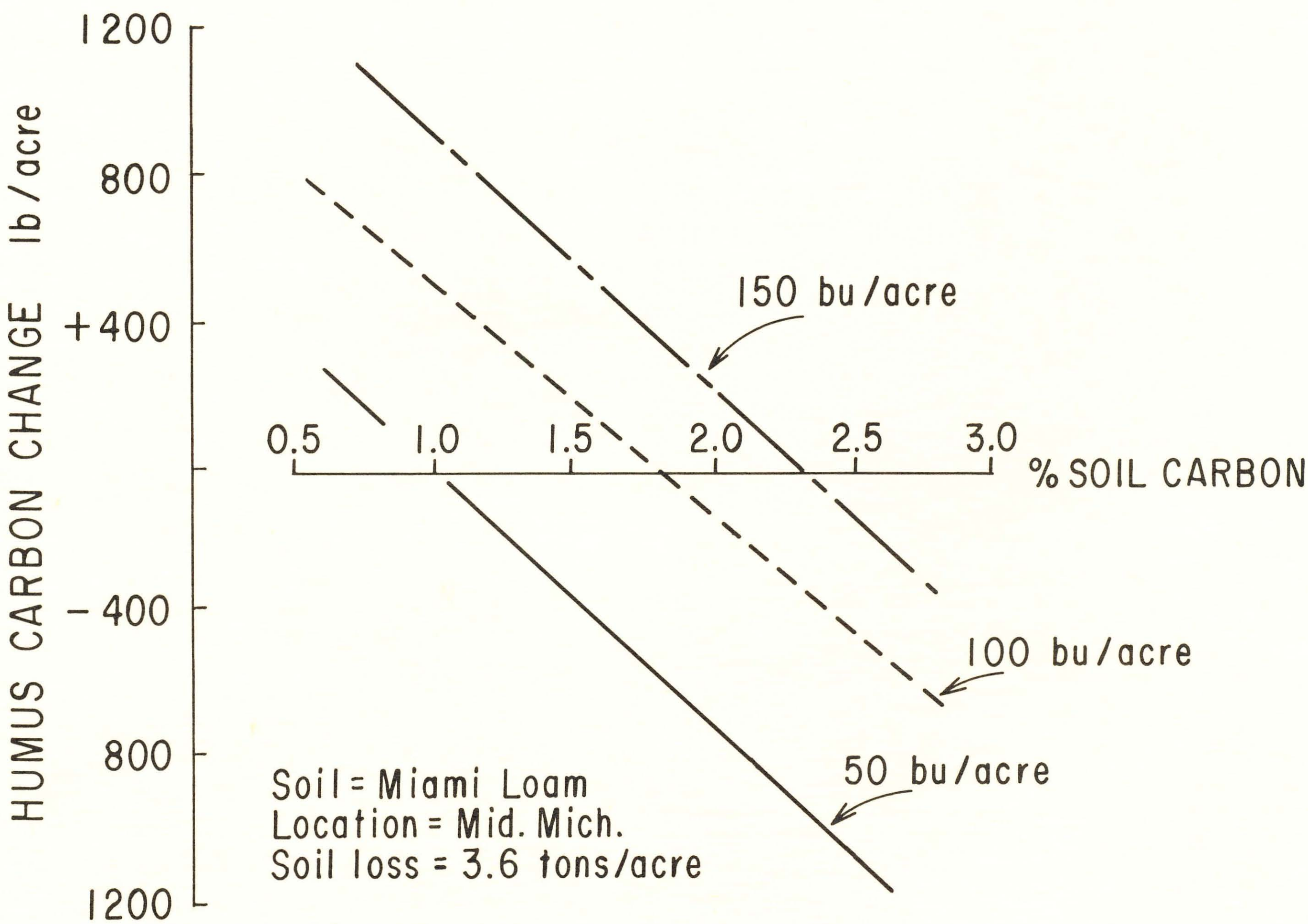

Fig. 5 Yearly soil humus changes as related to yield of corn and the soil carbon change.

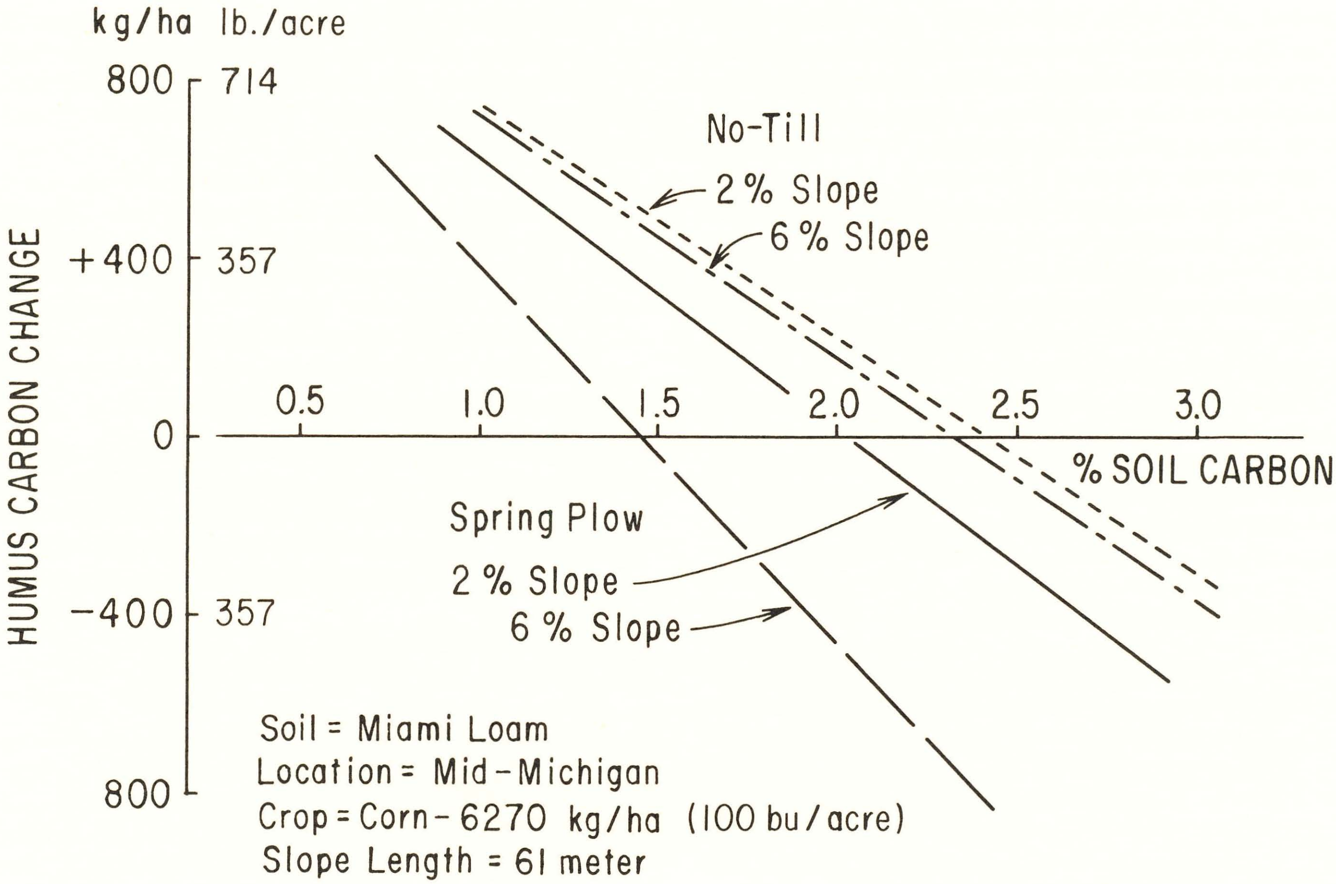

Fig. 6 **Yearly soil humus change as related to slope, tillage and the soil carbon content.**

inputs are held constant. For Michigan conditions, it could require over 75 years to reach a steady-state point (8).

Crop Yields

We can increase soil humus amounts by returning more plant residue. The trend lines shown in Figure 5 illustrate how corn yields ranging from 50 to 150 bushels of grain per acre change the steady-state point. In the calculations, a 2.0 percent annual decay rate was assumed for 50 bushels, 2.5 percent for 100 bushels and 3.0 percent for the 150 bushel per acre crop.

Before 1950, the corn yields for Michigan averaged less than 40 bushels per acre. With continuous cropping at such yields, the soil organic matter depletion was extensive. If 10 tons of farm manure per acre were applied to the 100 bushel corn land, the change in soil humus is estimated to be similar to the 150 bushel per acre return. A 30 ton application of manure is estimated to have a steady-state point at 3.0 percent soil carbon and a decay rate of 4.0 percent annually. Harvesting corn for silage as compared to grain was found to lower soil humus content about 0.3 percent for a loamy sand (Tables 1 and 2, average of 1968 and 1976). For a loam soil, the estimate is 0.2 percent.

Soil Erosion

Soil erosion can be a major source of soil organic matter loss. The amount of loss is related to several factors. The Universal Soil Erosion Equation predicts those losses (16). Data in Figure 6 illustrate how slope and tillage modify soil carbon levels. The organic matter content of soil materials removed by erosion can more than double that found in the original soil material. In these calculations the eroded soil was estimated to contain 150 percent of the carbon content of the field soil.

As shown in Figure 6 the soil carbon content could range from 1.4 to 2.4 percent based upon soil erosion losses. Crop production was held constant at 100 bushels per acre. This yield could be difficult to maintain if soil humus is greatly depleted.

Rate Modifiers

Rate modifiers in organic matter decay include aeration, soil pH, heat, moisture and soil texture. Soils located in the warm moist tropics particularly show high humus decay. For every 10°C increase in temperature, the rate of biological activity about doubles. The decay loss can be compensated by means of greater plant carbon return. For example, in the Southern States, double cropping is practiced. In the tropical rain forests, the decay rate can exceed 15 percent annually. Fortunately for the humid tropics, the organic matter production can be five times greater than for the humid temperature zones (4, 12).

The amount of new humus produced in a soil greatly modifies the rate of decay. As noted for the barren soil in England, the rate after 100 years is 0.4 percent. New humus, on the other hand, is estimated to have about a 20 percent decay rate under Michigan climatic conditions. The proportion of old to new humus accounts for the great differences in the rate for different management practices.

Significance of Soil Organic Matter

Many agriculturists believe the loss of organic matter in soils is one of our major problems facing the industry (11). A low soil organic matter content can contribute to crusting and poor percolation, and seriously retard root growth. Some researchers have placed the critical bulk density at 1.3 gm/cc for loam and clay loam soils (9). Already most cultivated natural well-drained soils in Michigan exceed 1.4 gm/cc in the "A" horizon and 1.5 gm/cc in the "B" horizon. A good level of soil organic matter is one way to reduce bulk density.

Robertson[2] estimates it takes over 2.8 percent organic matter (1.6% carbon) for a loam soil to have less than 1.3 gm/cc of bulk density. To maintain such a level, it requires a return of over 8000 pounds of dry plant material annually. These estimates are based upon 3 tons of soil erosion per acre. Such amounts of plant residue return are particularly difficult when field beans, vegetables and sugar beets are grown. Harvesting corn for silage, burning straw or using farm residues for fuel purposes are other examples which contribute to low organic matter returns.

[2] Robertson, L.S. 1977. Dept. of Crop and Soil Sciences, Michigan State Univ. Unpublished data.

In many parts of the world erosion accounts for more of the soil humus loss than decay. Pimentel, et al. (10), reviewed some of the issues on energy and land constraints on food production. They cite Buchele (2) and state, "For the United States, as a whole, 3.6 billion metric tons of top soil are lost annually, that is, about 31 metric tons per hectare of cultivated land." On an acre basis this amounts to 14 tons. Assuming the field soil contains 2.5 percent soil organic matter and the eroded soil is 150 percent higher, then the average annual loss in the U.S. is over 1000 pounds of soil humus per acre. Our estimates show that this requires a return of about 5000 pounds of plant residue per acre.

Good soil aggregation is more than just raising the soil organic matter content. Aggregation is the result of chemical reactions on soils by polysaccharides and humic substances formed during decay and root activity. Grasses particularly develop good soil aggregation.

Summary

Soil organic matter dynamics are affected by many factors. Attempts have been made to predict the changes based upon manure application, cropping system, soil texture, erosion and tillage practices. The information should be helpful for those teaching soil science.

In the field trials, farm manure was applied at 0, 10, 20, and 30 tons per acre annually for 14 years to a Metea loamy sand soil. When corn grain was harvested, the soil ranged from 2.0 percent organic matter for the mineral fertilizer "control" treatment to 2.8 percent for the 30 ton manure treatment. Where the corn was harvested for silage, the range was 1.7 percent to 2.8 percent, respectively. Based upon the soil test results obtained in 1968 and in 1976, the manure treatments are now adding only small increases in the soil organic matter content.

The soil model of Lucas, Holtman and Connor (8) was used to predict changes in soil humus based upon average crop yields in Michigan for different corn yield levels and soil tillage practices.

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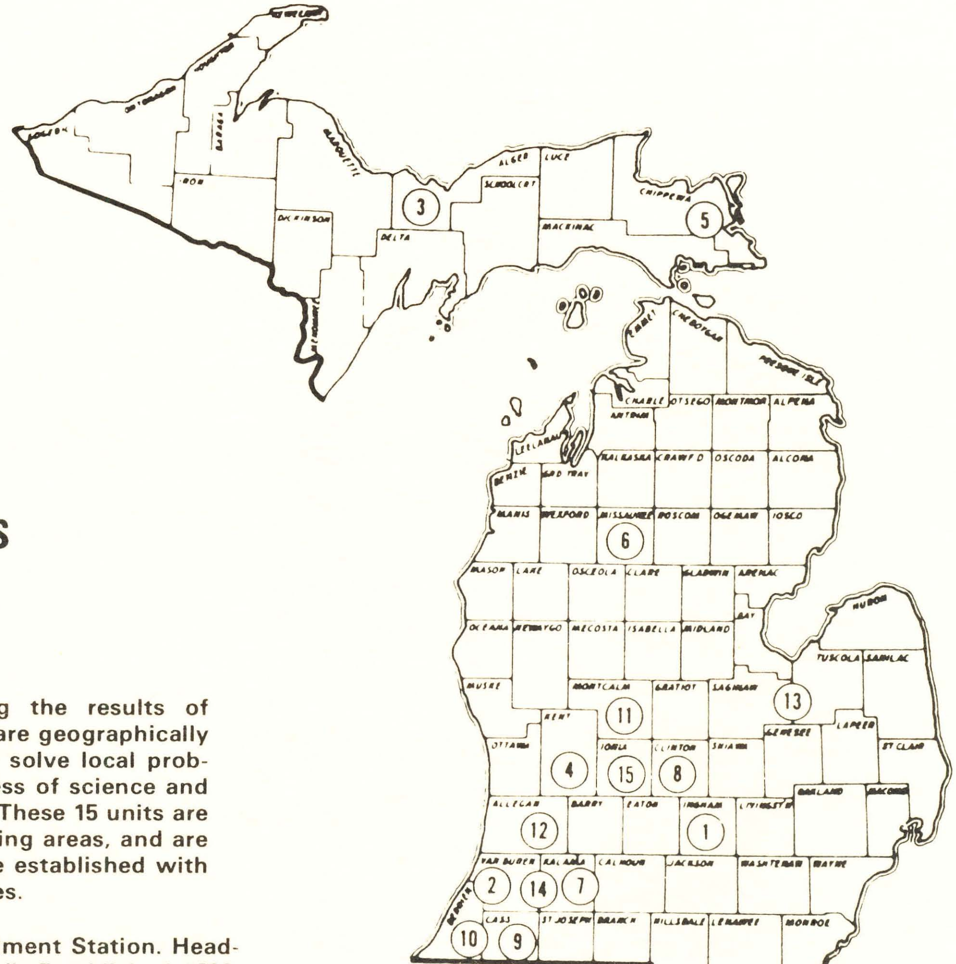

Outlying Field Research Stations

These research units bring the results of research to the users. They are geographically located in Michigan to help solve local problems, and develop a closeness of science and education to the producers. These 15 units are located in important producing areas, and are listed in the order they were established with brief descriptions of their roles.

(1) Michigan Agricultural Experiment Station. Headquarters, 101 Agriculture Hall. Established 1888. Research work in all phases of Michigan agriculture and related fields.

(2) South Haven Experiment Station, South Haven. Established 1890. Breeding peaches, blueberries, apricots. Small fruit management.

(3) Upper Peninsula Experiment Station, Chatham. Established 1907. Beef, dairy, soils and crops. In addition to the station proper, there is the Jim Wells Forest.

(4) Graham Horticultural Experiment Station, Grand Rapids. Established 1919. Varieties, orchard soil management, spray methods.

(5) Dunbar Forest Experiment Station, Sault Ste. Marie. Established 1925. Forest management.

(6) Lake City Experiment Station, Lake City. Established 1928. Breeding, feeding and management of beef cattle and fish pond production studies.

(7) W. K. Kellogg Biological Station Complex, Hickory Corners. Established 1928. Natural and managed systems: agricultural production, forestry and wildlife resources. Research, academic and public service programs.

(8) Muck Experimental Farm, Laingsburg. Plots established 1941. Crop production practices on organic soils.

(9) Fred Russ Forest, Cassopolis. Established 1942. Hardwood forest management.

(10) Sodus Horticultural Experiment Station, Sodus. Established 1954. Production of small fruit and vegetable crops. (land leased)

(11) Montcalm Experimental Farm, Entrican. Established 1966. Research on crops for processing, with special emphasis on potatoes. (land leased)

(12) Trevor Nichols Experimental Farm, Fennville. Established 1967. Studies related to fruit crop production with emphasis on pesticides research.

(13) Saginaw Valley Beet and Bean Research Farm, Saginaw. Established 1971, the farm is owned by the beet and bean industries and leased to MSU. Studies related to production of sugar beets and dry edible beans in rotation programs.

(14) Kalamazoo Orchard, Kalamazoo. Established 1974. Research on integrated pest control of fruit crops.

(15) Clarksville Horticultural Experiment Station, Clarksville. Purchased 1974. Plots established 1978. Research on all types of tree fruits, small fruits, vegetable crops and ornamental plants.

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