EFFECT OF TILLAGE MANAGEMENT ON SOIL ORGANIC CARBON AND NITROGEN

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Organic matter is a soil component that both directly and indirectly affects soil productivity. It is the major source of soil nitrogen, contains as much as 65 percent of the total soil phosphorus, and also contains significant amounts of sulfur and other nutrients essential for plant growth. Carbon is used by soil microorganisms as a source of metabolic energy to change nutrient availability and soil structure. Soil organic matter affects other soil properties such as cation exchange capacity, water infiltration rate, and water holding capacity. It also affects pesticide persistence.

Organic matter content of grassland soils is inherently high before cultivation begins. When these soils are brought under cultivation, the organic matter content declines. The decline is most rapid during the first 10 years, as shown in Figure 1, then proceeds at a slower rate, and eventually tends toward an apparent equilibrium (Hill, 1954; Hobbs and Brown, 1965). This apparent equilibrium level is determined by the quantity of organic residue returned and rate of residue decomposition, less the quantity of residue decomposition products lost by different pathways, notably erosion. The apparent equilibrium level will vary with crop sequences (Haas et al., 1957), type and amount of crop residue returned (Black, 1973; Larson et al., 1972), and tillage practices (Unger, 1968).

Annual changes in soil organic matter content are small and virtually impossible to detect. Cropping, tillage, or management treatments must be repeated several years before any changes become large enough to measure.

Wind erosion is a serious problem in semiarid regions on fields which are not protected by a vegetative cover. Stubble mulching will control erosion, but farm operators are skeptical that any yield advantage will be obtained with stubble mulching on an annual basis, much less of obtaining any long term benefits to the soil.

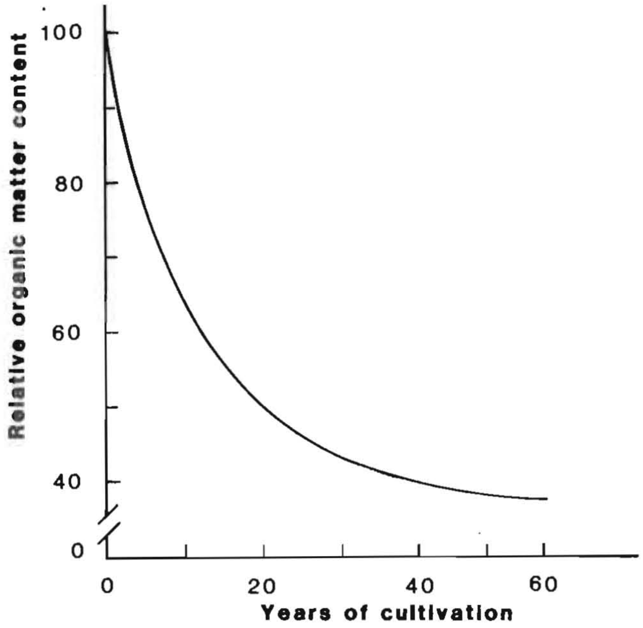

Fig. 1. CHANGE IN SOIL ORGANIC MATTER CONTENT WITH YEARS OF CULTIVATION

The effect of stubble mulching and conventional tillage on soil properties was compared on farm units in Grant County, North Dakota. The operators of one farm unit had used stubble mulching continuously for 25 years. They used a tillage implement to undercut the soil being summerfallowed that incorporated 5 percent or less of the residue with each operation. The adjacent neighbor's fields were summerfallowed with conventional tillage implements. There was little, if any, residue on their summerfallow at the end of the summer. Next to the croplands were grazed/hayed virgin grasslands which we also sampled. This was an opportunity to evaluate the effects of cultivation on soil properties.

METHODS AND MATERIALS

The soil properties measured were organic carbon, total nitrogen, and bulk density. (Organic carbon and total nitrogen are part of the organic matter; bulk densi-

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ty is the weight of soil per unit volume). Samples were taken in the fall of 1979 from 12 fields on which stubble mulching was used, 12 fields on which conventional tillage was used, and 12 grazed/hayed virgin grasslands. The 24 cultivated fields had all been cropped in 1979. Of the 12 fields within each management system, samples were taken on moderately coarse (sandy) textured soils in four fields; from medium textured (loamy) soils in four fields; and from moderately fine or fine (clayey) textured soils in four fields. A Soil Conservation Service soil scientist selected the sampling sites on the basis of uniformity within soil series, using standard soil classification techniques.

Samples were taken with a 3-inch diameter soil corer to 18 inches. The soil cores were divided into segments at the 1 to 3, 3 to 6, 6 to 12, and 12 to 18-inch depths.

Crop history, tillage, and other management information were obtained from interviews with the landowner cooperators by the Soil Conservation Service District Conservationist. Each cooperator responded to an identical set of questions, and the responses are summarized in Table 1. Neither green nor barnyard manure was applied to cropland nor barnyard manure to the grassland.

The primary sequence in cropland management was alternate wheat-fallow (Table 1). Summerfallow tillage on the stubble mulched fields consisted of two or three sweep operations with 32-inch blades. Occasionally, herbicides were used to control weeds instead of sweep tillage to assist in maintaining crop residue cover. On the conventionally tilled cropland, summerfallow tillage varied with operators; the initial operation was with either a chisel plow, moldboard plow, oneway or tandem disk, or duckfoot. At one site, the initial operation was with 6-foot sweeps. Succeeding operations, usually two to three, were with sweeps, duckfoot, or oneway or tandem disk. At most conventional till sites, a major portion of the residues was incorporated during the first operation.

In both the stubble mulch and conventional tillage systems, almost all operators used a moldboard plow-packer-pony press drill in tandem for spring seeding.

RESULTS AND DISCUSSION

The organic carbon (organic carbon × 1.7 = organic matter) and total nitrogen concentrations, average to 18 inches, were higher under stubble mulch than conventional tillage on moderately coarse and fine-textured soils (Table 2). In the moderately coarse-textured, stubble mulched fields, the organic carbon concentration was 44 percent higher than under the conventional tillage management. In fine textured soils it was 13 percent higher. This difference in carbon and nitrogen concentration between the two management systems is attributed to better erosion control with stubble mulching. Some of the difference in concentration could have resulted from higher crop yields under stubble mulch on the fine-textured soils (Table 1), but the larger amount of residue produced on these soils would not account for the difference. Moderately coarse and fine-textured soils are the most susceptible to wind erosion and benefit the most from residues retained on thee surface during the fallow period.

The organic carbon and nitrogen concentrations did not differ on medium-textured soils, for two principal reasons. First, the conventionally tilled medium-textured soils were summerfallowed 22 percent of the years and the stubble mulched soils were summerfallowed 48 percent of the years. The potential for erosion on conventionally tilled fields is much reduced when a vegetative cover is present, as compared to summerfallow management. Also, more total vegetation was returned to the soil in this cropping sequence. Second, medium-textured soils are generally less susceptible to wind erosion than either moderately coarse or fine-textured soils because these soils form a higher proportion of nonerodible sized aggregates.

Table 1. Management and cropping history at field locations.

Management	Texture	Crop		Small grain[6] yield	Fertilizer[7]	
		Small grain	Fallow		N	P
		percent of years		pounds/acre	total pounds/acre	
Stubble mulch	Mod. coarse[1]	43	41	1143	335	389
	Medium[2]	51	48	1634	265	432
	Fine[2]	49	50	2027	225	405
Conventional	Mod. coarse[3]	58	41	1143	303	133
	Medium[4]	47	22	1607	335	353
	Fine[5]	51	27	1687	303	275
Grassland	Mod. coarse	—	—	—	0	0
	Medium	—	—	—	0	0
	Fine	—	—	—	0	0

[1] 16 percent in alfalfa

[2] 1 percent in sunflowers

[3] 1 percent in alfalfa

[4] 21 percent in alfalfa, 9 percent in corn silage, 17 percent sunflowers.

[5] 5 percent alfalfa, 10 percent corn silage, 1 percent sunflowers.

[6] Average crop yield.

[7] Total applied over the 25-year period.

Table 2. Organic carbon (C) and total nitrogen (N) concentration to 18 inches as affected by management and soil texture.

Management	Texture			Average
	Mod. coarse	Medium	Fine	
	percent organic C by weight			
Stubble mulch	1.14	1.33	2.03	1.50
Conventional	0.79	1.36	1.79	1.31
Average	0.96	1.34	1.91	
	percent N by weight			
Stubble mulch	0.141	0.161	0.220	0.174
Conventional	0.106	0.157	0.201	0.155
Average	0.124	0.159	0.211	

L.S.D. (0.05) for organic C. Texture (T) = 0.46; management (M) = 0.13; T × M = 0.22.
L.S.D. (0.05) for total N. Texture (T) = 0.039; Management (M) = 0.016; M × T = NS.

Table 3. Organic carbon and total nitrogen content as affected by soil texture under two tillage management systems.

Texture	Management			
	Organic carbon (C)		Total nitrogen (N)	
	Stubble mulch	Conventional	Stubble mulch	Conventional
	pounds per acre[1]			
Moderately coarse	57025	42140	7190	5715
Medium	61063	63750	7615	7487
Fine	91528	83466	10134	9603
Average	69872	63118	8313	7602

[1] To 18 inches.

The stubble mulched fields, to a depth of 18 inches, had about 6750 pounds per acre more total carbon (11,475 pounds per acre organic matter) than the conventionally tilled fields (Table 3). Based on the 25-year period over which these changes occurred, the average carbon change was about 270 pounds per acre per year. This outcome lends support to the premise that most, if not all, of the difference in organic carbon resulting from method of tillage management was due to erosion.

The reasons for this hypothesis are: First: the average small grain yield difference between tillage management systems was about 122 pounds per acre per year, or a total difference over the 25-year period of about 3050 pounds per acre. At a wheat grain yield of about 1600 pounds per acre, the straw weight will be about double the grain weight (Bauer and Zubriski, 1978). Over the 25-year period, the amount of residue produced and returned to the land under the stubble mulch tillage system was about 6116 pounds per acre more than on the conventionally tilled.

Second: Research by researchers in other states show that only about 5 to 8 percent by weight of the organic residues returned to the soil in the form of crop stubble and barnyard manure becomes a part of the soil organic carbon. The remainder is dissipated largely as carbon dioxide by microbial activity. Eight percent of 6116 pounds per acre (the greater amount of residue produced by the stubble mulch over the conventional system) is only about 489 pounds per acre, the amount from the residue ending up in the soil organic carbon. This quantity accounts for only 7 percent of the total 6750 pounds of carbon per acre difference, average of all textures, that existed between the tillage management systems.

Rebuilding soil organic matter levels in cultivated soils under dryland agriculture in this area is a very slow process. How slow it is can be illustrated with the differences in organic carbon content between the stubble mulched and conventionally tilled moderately coarse-textured soils (Table 3). To make up the difference of 14885 pounds per acre of organic carbon that now exists between the stubble mulched and conventionally tilled fields would require adding about 94 tons per acre more residue on the conventionally tilled than the stubble mulched fields. (This is the amount needed if it is assumed that 8 percent of the residue weight ends up as soil organic matter). If the quantity of residues added to these moderately coarse-textured soils in the conventionally tilled fields were doubled over the average of the past 25 years, to about 6390 pounds per acre, and if the residues returned to the stubble mulched fields were the same as in the past 25 years and the soil organic carbon level did not change, it would take 59 crop years to bring the organic carbon level of the conventionally tilled fields to the same level now present in the stubble mulch fields. If the amount of residues returned to the conventionally tilled fields were increased by 50 percent, it would take 120 crop years.

In reality, the difference in organic matter level of the moderately coarse-textured soils between the two systems will widen if the current management is maintained. This is likely to occur for two reasons. First, the opportunity for erosion is much greater under the conventional tillage than the stubble mulch. Second, productivity of the conventionally tilled fields is already lower, so the amount of residue returned will also be lower than will be returned to the stubble mulched fields. However, productivity of the conventionally tilled soils can be brought to the level of the stubble mulched with nitrogen fertilizer.

The stubble mulched fields also averaged 711 pounds per acre more total nitrogen than the conventionally tilled fields. The difference was greatest in moderately coarse-textured soils, initially having the smallest amount. The difference could have been larger had not the conventionally tilled fields received about 118 pounds per acre more fertilizer nitrogen than the stubble mulched over the 25-year period (Table 1). The largest difference in total nitrogen, 1474 punds per acre, occurred on moderately coarse-textured soils (Table 3). Over a period of 25 years this amounts to a loss of about 59 pounds per acre per year from the conventionally tilled soils compared to stubble mulching.

Considering the cost of nitrogen from fertilizer at the price of 15^{c} per pound, this is a loss of $8.85 per acre per year. Over a period of 25 years, the dollar value of nitrogen loss per acre, about $221, was only about $100 less than the 1981 estimated average per acre cropland value in the southwest farming area of North Dakota (Johnson, 1982).

On fine-textured soils, the total nitrogen content was 530 pounds per acre higher in stubble mulched than conventionally tilled fields, about a third less than in moderately coarse-textured soils. Nevertheless, the average loss of about 21 pounds per acre per year over the 25-year period is equivalent to an amount of fertilizer nitrogen (N) many area farmers consider too costly to apply annually.

Bulk densities were higher on the cropland than the grassland (Table 4). For individual depths to 12 inches averaged over textures, the differences ranged from 7 to 14 percent. The largest difference occurred on the moderately coarse-textured soils; on these the cropland bulk density was 20 percent higher than on the grassland. There was no difference in bulk density between the stubble mulched and conventional tillage cropland.

The change in bulk density with cropping is due to an associated decrease in organic carbon concentration. In soils of the same texture, Davidson et al. (1967) showed that soil bulk density is inversely related to soil organic matter content. However, after about 70 years of tillage and cropping of these fields even with the associated loss of organic matter, there is no reason to suspect that water and root penetration are restricted.

Haas et al. (1957) compared soil organic carbon and total nitrogen concentrations in plots with various cropping sequences at field stations in the Great Plains to the concentrations in virgin grasslands on these stations or adjacent areas. (The samples were taken in 1947). The data in Table 5 are a comparison of the percentage change in organic carbon and total nitrogen due to cropping reported by Haas et al. with the percentage change we determined in the 1979 samples. The change in carbon and nitrogen due to cropping reported by Haas et al. was similar to change in the conventional tillage management system sampled in 1979. However, the change with the stubble mulch system was less. This is interpreted to mean that the croplands sampled by Haas et al. had reached organic matter equilibrium level after about 40 years of cropping. The stability in organic matter levels between 1947 and 1979 supports this conclusion. But of greater importance is that the apparent organic matter equilibrium level was higher with stubble mulching than with conventional tillage management still in use today. This outcome implies that the apparent soil organic matter equilibrium level can be altered by tillage practices, and that erosion control with stubble mulching over conventional tillage management is a major factor contributing to the difference of this level.

The validity of our interpretations of these data is based on two assumptions. First, that the cropland soil properties measured reflect the effect of management of the most recent 25 years and not that of conditions that

Table 4. Bulk density of cropland and grassland as affected by soil texture and soil depth.

	Soil depth (inches)				
Texture	0-3	3-6	6-12	12-18	Average
			grams per cubic centimeter		
			Cropland		
Mod. coarse	1.24	1.37	1.43	1.41	1.36
Medium	1.09	1.28	1.32	1.34	1.26
Fine	1.03	1.21	1.31	1.41	1.24
Average	1.12	1.29	1.35	1.39	
			Grassland		
Mod. coarse	1.03	1.26	1.32	1.39	1.25
Medium	1.01	1.19	1.23	1.33	1.19
Fine	0.91	1.12	1.22	1.34	1.15
Average	0.98	1.19	1.26	1.35	

L.S.D. (0.05) for cropland. Texture (T) = 0.07; Depth (D) = 0.04; and D × T = 0.06.

Table 5. Carbon and nitrogen losses under stubble mulch and conventional tillage based on 1979 samples from grasslands compared to losses at six northern Great Plains field stations reported by Haas et al. (1957).[1]

			Management[2]	
	Depth	**Haas**	**Stubble mulch**	**Conventional**
	inches		percent loss from virgin grassland	
Carbon	0-6	41	27	38
	6-12[3]	20	7	14
Nitrogen	0-6	34	23	33
	6-12[3]	16	5	10

[1] Two each of the 6 locations are in Montana, North Dakota and Wyoming. Soil texture was moderately coarse at 1, medium at 3, and moderately fine at 2 of these locations.

[2] Average of all soil textures.

[3] Locations included for the 6- to 12-inch depths are Mandan and Dickinson, ND, Havre, MT, and Archer, WY.

may have existed prior to the period, including a common original carbon and nitrogen base within textural groups. Second, that grassland soil properties were not substantially altered by erosion or livestock management and therefore reflect the native grassland condition when the land was settled.

LITERATURE CITED

Bauer, Armand, and Joseph C. Zubriski. 1978. **Hard red spring wheat straw yields in relation to grain yields.** Soil Sci. Soc. Am. J. 42:777-781.

Bauer, Armand and A. L. Black. 1981. **Soil carbon, nitrogen, and bulk density comparisons in two cropland tillage systems after 25 years and in virgin grassland.** Soil Sci. Soc. Am. J. 45:1166-1170.

Black, A. L. 1973. **Soil property changes associated with crop residue management in a wheat-fallow rotation.** Soil Sci. Soc. Am. Proc. 37:943-946.

Davidson, J. M., F. Gray, and D. I. Pinson. 1967. **Changes in organic matter and bulk density with depth under two cropping systems.** Agron. J. 59:375-378.

Haas, H. J., C. E. Evans, and E. F. Miles, 1957. **Nitrogen and carbon changes in Great Plains soils as influenced by cropping and soil treatments.** Tech. Bull. No. 1164, USDA. U. S. Government Printing Office, Washington, D.C.

Hill, K. W. 1954. **Wheat yields and soil fertility on the Canadian prairies after a half century of farming.** Soil Sci. Soc. Am. Proc. 18:182-184.

Hobbs, J. A., and Paul L. Brown. 1965. **Effects of cropping and management on nitrogen and organic carbon contents of a western Kansas soil.** Kansas Agr. Exp. Sta. Tech. Bull. No. 144.

Johnson, Jerome E. 1982. **Upward trend in 1981 farmland values.** North Dakota Agr. Exp. Sta. Farm Res. 39(4):8-13.

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.

Unger, Paul W. 1968. **Soil organic matter and nitrogen changes during 24 years of dryland wheat tillage and cropping practices.** Soil Sci. Soc. Am. Proc. 32:426-429.

Young, R. A., J. C. Zubriski, and E. B. Norum. 1960. **Influence of long-time fertility management practices on chemical and physical properties of a Fargo clay.** Soil Sci. Soc. Am. Proc. 24:124-128.