Changes in an Ohio Prairie Soil as the Result of Cultivation[1]

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ABSTRACT. A comparison between an undisturbed soil and an adjacent soil which has been under cultivation for 100 to 150 years showed significant differences in chemical, physical, and morphological properties. Additions of fertilizer and agricultural lime to the cultivated site significantly increased the amount of P and Ca in the surface and upper subsurface horizons. Available K increased in only the surface horizon. The addition of agricultural lime significantly increased the pH of the surface of the cultivated site to 6.7 compared to the undisturbed site which had a pH of 5.8. Organic C content of the surface horizon decreased as much as 58% in the cultivated site compared to the undisturbed site. Loss of organic C can be attributed to 1) enhanced microbial activity brought about by increased aeration of the surface horizon by tillage, and 2) deep plowing which can mix lower carbon subsurface materials into the surface. Alterations in the physical characteristics of the surface horizon were illustrated by change from a porous, moderate granular type structure in the uncultivated surface to a more massive, weak subangular blocky structure in the cultivated surface. Bulk density values also bore out this difference with a 16% increase in the cultivated surface horizon. The subsurface horizon exhibited similar trends. These physical changes can be attributed to tillage operations and loss of organic binding agents. The undisturbed site was classified as a Mollic Hapludalf, a soil influenced by prairie vegetation; the cultivated soil was classified as a Typic Hapludalf, having lost the properties associated with prairie vegetation. Thus, cultivation has also altered the taxonomic classification of the soil.

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INTRODUCTION

Vegetative cover in Ohio, when first settled, was primarily forest. There were, however, numerous prairie areas in western Ohio that were dominated by various species of grasses such as big bluestem (*Andropogon gerardi*) and little bluestem (*A. scoparius*) in the well drained portions of the landscape and by giant reed grass (*Phragmites communis*) in the lower, wet areas (Gordon 1969). The extension of the prairies of the Great Plains into Indiana and Ohio has been documented and is known as the Prairie Peninsula (Transeau, 1935).

During the last 150 years the forests of central Ohio have been cleared, and the prairies plowed. Man has influenced soil properties by the addition of chemicals and fertilizers, the removal of natural vegetation, and by

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tilling the soil. The influence of cultivation on the chemical and physical properties of the soil has received limited study in Ohio. Because of the large percentage of Ohio's land base under cultivation, it is useful to evaluate these soil changes and relate them to past and future management practices.

Despite intensive use of our soil resource, there are small areas in Ohio where soil-forming processes have not been affected greatly by man. These areas are usually limited to old woodlots, borders of cemeteries and railroad tracks, wildlife preserves, and small tracts of private land. Though rare, such areas can be used as an index to study the impact of man, particularly cultivation, on soil properties. This type of research is not unique. Other studies have compared undisturbed soils to sites that have been subjected to a variety of agricultural practices (Saulter and Green 1933, Stauffer et al. 1940, Odell 1982). However, most of these studies are concerned with the effects of soil amendments on productivity rather than how the amendments affect soil chemical and physical properties.

Pedogenic processes, both chemical and physical, are modified by agronomic practice. These modifications vary with the type of crop grown and method and duration of tillage operations. The chemical changes include variation in available nutrients, soil acidity, and loss of organic carbon (C). As expected, yearly crop removal without addition of fertilizers significantly reduces the amount of available nitrogen (N), phosphorus (P), and potassium (K) (Jenny 1933, Stauffer et al. 1940, Odell 1982). The amount of nutrient reduction is dependent on soil type and crop grown; however the addition of fertilizers may result in an overall increase of available P and K in the surface horizon compared to an untreated soil (Albrecht 1938, Odell 1982). The addition of agricultural liming materials can increase available calcium (Ca) and magnesium (Mg), as well as increase the pH of the surface ploy layer (Stauffer et al. 1940, Odell 1982).

The loss of organic C is a well recognized result of cultivation. When soil aeration is improved by cultivation, microbial populations are stimulated which results in an increased rate of organic matter decomposition (Jenny 1933, Albrecht 1938, USDA 1957). In addition, deep plowing may result in mixing of low organic matter subsoil with the surface horizon, thus lowering the organic matter content in the plow layer by dilution. The rate of loss of organic C (and N) depends largely on agronomic practices. Organic C and N contents decrease at a rapid rate initially and then continue to decrease at a slower rate (Jenny 1933, Low 1972). Addition of manure or the use of a crop rotation scheme that returns large amounts of organic matter to the soil have been shown to minimize losses (Saulter and Green 1933, Albrecht 1938, Low 1972, Jenkinson and Rayner 1977, Odell 1982). The addition of fertilizers tends to reduce the rate of C loss depending on rate of fertilizer addition and crop grown (Stauffer et al. 1940, Davidson et al. 1967, Steinhardt and Norton 1979, Odell 1982). Where soils have been row-cropped continuously and only mineral fertilizers applied, surface horizons have been shown to lose 30 to 50 percent or more of their original organic matter content (Jenny 1933, Saulter and Green 1933, Albrecht 1938, Low 1972, Steinhardt and Norton 1979, Odell 1982). The amount of organic matter lost from a cultivated soil to which no amendments have been added has been estimated to be as high as 75 percent over a 25-year period (Low 1972).

The physical properties most affected by cultivation are soil structure and bulk density. Soil structure is defined as the arrangement of aggregated soil particles and the pore space between them (Low 1972). Degradation of soil structure often occurs with cultivation and is commonly accompanied by an increase in bulk density. These changes have been attributed to a number of factors: 1) the practice of monocultural row cropping which promotes organic matter loss, 2) low rates of addition of soil organic matter such as manure or crop residues, 3) artificial drainage that alters the natural water table and results in greater aeration, and 4) untimely cultivation, especially in wet weather (Jenny 1933, Low 1972, Blake et al. 1976, Steinhardt and Norton 1979). In addition, the use of heavy tillage equipment also may cause a zone of compaction known as a "plow pan" which occurs within or just below the plow layer (Blake et al. 1976) Soil structure and bulk density are important soil properties that affect water infiltration and hydraulic conductivity. Consequently, deterioration of soil structure and increased bulk density slows seedling emergence and root growth.

MATERIALS AND METHODS

An uncultivated 5-ha prairie site located on a privately-owned farm in western Madison County, Ohio was chosen for the study area (Fig. 1). The site has been designated informally as the W. Pearl King Prairie Grove, and is an area designated by Transeau (1935) as an outlier of the Prairie Peninsula. The vegetation growing on the site was identified and classified by Knoop (1985) as a tallgrass prairie containing more than 25 prairie indicator species, as suggested by Cusick and Troutman (1978), and a grove of large mixed oak trees. *Sporobolus heterolepis* (dropseed), which is an endangered species in Ohio and susceptible to soil disturbance, was identified at the site, suggesting that the study area has never been cultivated (King 1981). The presence of several large bur oak trees (*Quercus macrocarpa*) more than 1 m in diameter and estimated to be more than 300 years old (Knoop 1985) also suggests that the site has not been disturbed by cultivation. The owner, now in her eighties, has no recollection of tillage or cropping in the study area. Aerial photos taken by the Soil Conservation Service in November 1941, June 1952, and October 1971 were examined, and field boundaries appear to have remained in the same positions since 1941. None of the photos indicate any cropping in the field.

Adjoining the prairie is a cultivated field which has been tilled for an estimated 100 to 150 years. The sample sites were located within a single soil mapping unit that extended across a fence line and included both cultivated and uncultivated land (Fig. 2). The map unit was identified as Crosby-Lewisburg silt loams, 2 to 6% slopes (Gerken and Sherzinger 1981). The records of the current manager indicate a corn-soybean rotation in the cultivated portion since 1971. In the fall of 1981, when site selection and sampling took place, the field was in soybeans.

Two complete profiles within the same mapping unit approximately 30 m apart and on similar landscape positions were sampled. One was located in the prairie, and the other in the cultivated field (Fig. 2). Both profiles are well-drained soils developed in late Wisconsinan loam till. The cultivated pedon is classified as a member of the Lewisburg series which is a Typic Hapludalf (Soil Survey Staff 1975). The uncultivated pedon has a dark surface horizon and is classified as a taxadjunct of the Lewisburg series (Mollic Hapludalf). Standard descriptions and sampling procedures outlined by the Soil Survey Manual (Soil Survey Staff 1951) were followed, and all horizons were sampled for chemical and physical characterization. In addition, bulk density samples were taken in triplicate from the top three horizons and from the parent materials at each sampling site.

Ten additional sites between the two main profiles were sampled with a hydraulic probe (Fig. 2). Bulk density clods were taken from

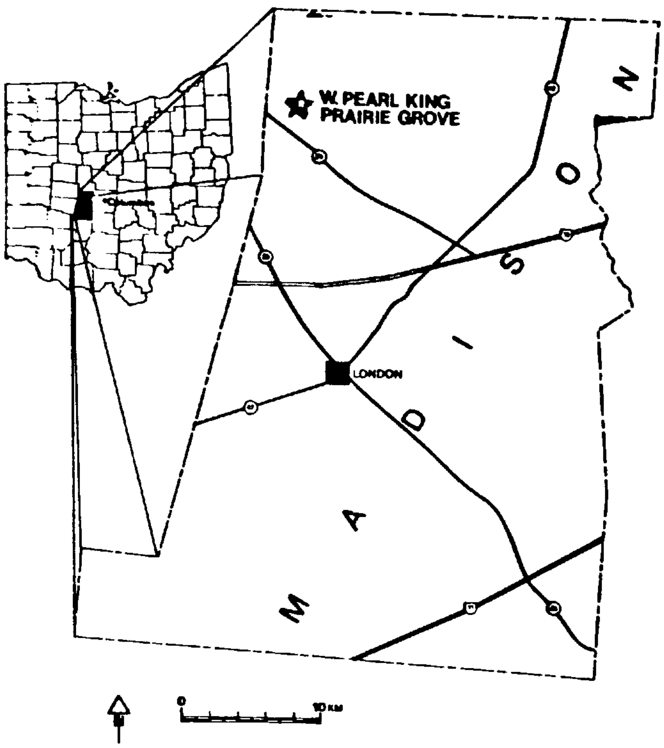

FIGURE 1. Location of W. Pearl King Prairie Grove study site.

each of the paired cores taken at each site. The 15-23-cm section was used to represent the lower part of the A horizons, and the 31-38-cm section to represent the B horizons. It was impractical to sample the 0-12-cm portion of the A horizon owing to the friable nature of the surface layer. Samples for chemical analysis were also collected from the transect cores.

The organic carbon content was determined by the Walkley-Black (1934) method. The pH was determined with a 1:1 soil to distilled water mix and measured by a standard glass electrode pH meter

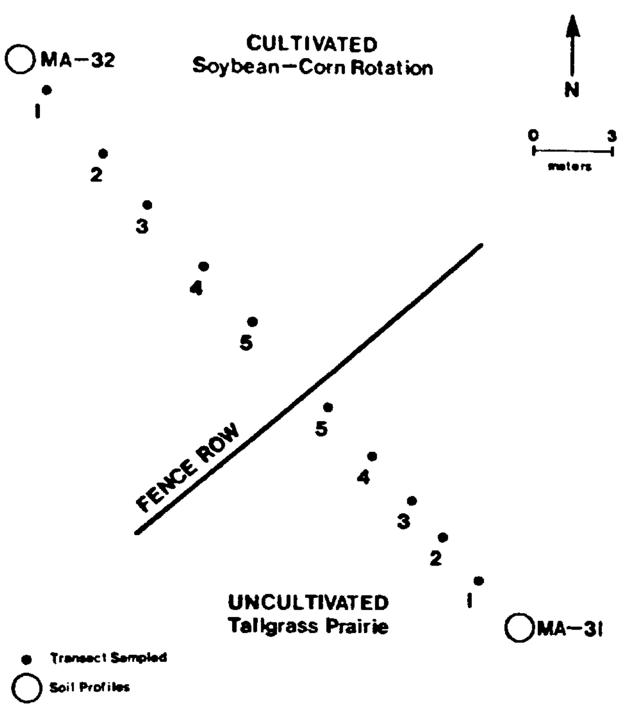

FIGURE 2. Location of sample sites and transect from the virgin tallgrass prairie to the cultivated farm field.

(Peech 1965). The fertility parameters measured included available P, K, Ca and Mg. These analyses were performed at the Research and Extension Analytical Laboratory (REAL) of the Ohio Agricultural Research and Development Center, Wooster, Ohio.

Bulk density determinations were made with the saran-coated clod method of Brasher et al. (1965) as modified and described by the Ohio State Physical Characterization Laboratory Manual. Density measurements were made at the moisture contents of ⅓ bar and oven-dry (110C to constant weight). Soil textures were estimated in the field and determined in the laboratory by the pipet method (Steele and Bradfield 1934).

RESULTS AND DISCUSSION

To assess the effects of cultivation, it is necessary to compare the soils formed in the same parent material and on the same landscape position. The study sites were selected with these criteria in mind. The field description and laboratory data from the lower B and C horizons indicated that the two soils are very similar (Tables 1-3). It was assumed, therefore, that the parent material at both sites at the onset of soil formation was similar. Differences were noted, however, in the upper horizons and can be attributed to cultivation practices.

The morphology of the uncultivated prairie site (MA-31, Table 1) suggested influence by prairie grass vegetation (Hole and Nielsen 1976, Steiger 1981). The surface horizon color was a very dark grayish brown (10YR 3/2) and the structure was medium granular. A clear, smooth boundary separated it from an underlying transition horizon (BA) that had a bright color (yellowish brown, 10YR 5/4). The bright color suggests the presence of a zone of eluviation. A clay enriched, argillic horizon (Bt) was evidenced by clay films on structural aggregates. There was no indication from the morphology or laboratory data that the soil has ever been cultivated.

The surface and transition horizons of the prairie site can be contrasted with those of similar depth in the cultivated profile (MA-32, Table 1). The surface horizon of the cultivated soil was a lighter brown (10YR 4/3) than the uncultivated surface horizon (10YR 3/2) which can be attributed to the loss of organic matter and to mixing of the surface and subsurface horizons during plowing. Organic C content in the surface horizon (Ap) of the cultivated profile was 1.13%, whereas the content of the uncultivated surface horizon was 2.71 (Table 2). This represents a 58% decrease owing to cultivation. The mean organic C values of the 15-23-cm deep transect samples from the two areas differed by 35%. These results are in agreement with the findings of Low (1972) and Saulter and Green (1933) in which similar comparisons were made. The decrease can be attributed to increased aeration and enhanced microbiological activity, coupled with dilution by mixing of subsurface horizons during cultivation.

The structure of the cultivated surface was weak, subangular blocky tending toward massive, whereas the uncultivated surface had granular aggregates that were moderately expressed (Table 1). The two horizons below the surface of each site had subangular blocky structure; however, the prairie site exhibited a stronger grade of structure. The loss of structure was associated with an increase in bulk density (Table 3). The surface of the uncultivated profile at 1/3 bar moisture content had a bulk density of 1.28 g/cm^3, whereas the cultivated site was 1.49 g/cm^3, or a 16.4% increase. The mean bulk

TABLE 1.
Soil profile descriptions.

Horizon	Depth (cm)	Color (moist)	Textural class	Coarse fragments (%)	Structure	Boundary
			Uncultivated (MA-31)			
A	0-17	Very dark, grayish brown 10YR 3/2	Silt loam	0	Moderate, medium, granular	Gradual smooth
BA	17-28	Yellowish brown 10YR 5/4	Silt loam	0	Moderate, medium, subangular, blocky	Clear, smooth
Bt	28-46	Brown 7.5YR 4/4	Clay loam	2	Strong, medium, subangular, blocky	Clear, wavy
BC	46-61	Dark yellowish brown 10YR 4/4	Clay loam	10	Moderate, medium, subangular, blocky	Gradual, wavy
CB	61-79	Dark yellowish brown 10YR 4/4	Loam	25	Weak, medium, subangular, blocky	Gradual, wavy
C	79+	Yellowish brown 10YR 5/4	Loam	30	Massive	
			Cultivated (MA-32)			
Ap1	0-20	Dark brown 10YR 4/3	Silt loam	0	Weak, medium, subangular, blocky	Clear, smooth
Ap2	20-30	Dark brown 10YR 4/3	Silt loam	0	Moderate, medium, subangular, blocky	Abrupt, smooth
Bt1	30-43	Dark yellowish brown 10YR 4/4	Clay loam	5	Moderate, medium, subangular, blocky	Clear, smooth
Bt2	43-61	Dark yellowish brown 10YR 4/4	Clay loam	15	Weak, medium, subangular, blocky	Gradual, smooth
BC	61-76	Yellowish brown 10YR 5/4	Loam	15	Weak, medium, subangular, blocky	Gradual, smooth
C	76+	Yellowish brown 10YR 5/4	Loam	20	Massive	

density values of the 15-23-cm transect samples in the cultivated field were also higher than those of the uncultivated site, which further illustrates the loss of pore space owing to compaction during cultivation. Less difference in the transect bulk densities between the comparison plots may be attributed to compaction by machinery on a lane along the edge of the prairie area. The bulk densities of the subsurface horizons (Table 3) in the cultivated field were slightly higher than the uncultivated soil in the upper portion of the profile. The 31-38-cm depth core samples of the transect taken from the cultivated field were also higher than those of the uncultivated prairie indicating compaction to this depth. Bulk densities measured at oven-dry moisture contents follow trends similar to those at the ⅓ bar measurements (Table 3).

The data suggest that the physical effects of cultivation of the surface horizon are a deterioration of soil structure and an increase in bulk density. In the subsurface horizons of the cultivated soil, the bulk density was slightly higher than the uncultivated soil, and a deterioration of soil structure was evident. The cause of compaction (increased bulk density) and loss of structure in surface and subsurface horizons was related to the loss of organic binding agents described earlier and to tillage operations. These physical changes result in slower water movement and may hinder seed germination and root growth.

The fertility data showed some clear differences between cultivated and uncultivated soils, especially in the surface horizon. Available P, K, and Ca in the five cultivated transect surface samples were significantly higher ($P \leq 0.10$) than in the uncultivated surface samples (Table 2). Below the surface, only P was significantly ($P \leq 0.10$) different, although the mean values of K and Ca of the cultivated soil were higher than those of the uncultivated soil (Table 2). Available Mg shows no clear trend, when comparing the cultivated and uncultivated profiles. However, in the transect samples the mean values for the surface were significantly ($P \leq 0.10$) higher in the uncultivated samples.

The higher values of K and P were undoubtedly due to surface-applied fertilizers. Although these elements are not normally mobile in the soil, tillage and crop recycling may have increased their content below the surface. Higher available calcium in the cultivated field was due to the addition of agricultural liming materials. As part of the cultivated field management, agricultural lime was spread in 1970 and 1974. This is reflected in the pH values (Table 2) of the transect (15-23 cm). The cultivated field samples had a mean value of 6.7, which was

TABLE 2

Organic carbon, soil test, and pH values for the soil profiles. Mean values are given for the transect samples.

Horizon	Depth (cm)	pH	CEC** (meg/100g)	Available nutrients (kg/ha) P	K	Ca	Mg	Organic Carbon (%)
				Uncultivated Site (MA-31)				
A	0-17	5.8	12	10	207	2755	532	2.71
BA	17-28	6.2	14	2	154	3640	1170	0.75
Bt	28-46	6.9	24	1	258	7134	2083	0.69
BC	46-61	7.7	21	1	155	6642	1555	--
CB	61-79	8.1	26	0	139	9834	1173	--
C	79-	8.1	25	0	118	9587	981	--
				Cultivated Site (MA-32)				
Ap1	0-20	6.6	11	53	194	3942	613	1.13
Ap2	20-30	6.6	13	27	195	4234	805	1.01
Bt1	30-43	6.8	24	4	177	7134	2106	0.85
Bt2	43-61	7.7	19	1	129	5678	1732	--
BC	61-76	8.1	25	0	113	9957	768	--
C	76-	8.2	24	0	125	9542	785	--
				Transect Samples				
Uncultivated	15-23	5.8*	12	4*	142*	2565*	833*	1.99*
	31-38	6.4	22	1*	231	5141	2145	0.83*
Cultivated	15-23	6.7	14	63	220	4648	707	1.29
	31-38	6.8	21	7	230	6070	1754	0.63

*Indicates mean values of the uncultivated variables that are significantly (t-test; $p \leq 0.10$) different from the corresponding cultivated variables.
**Cation exchange capacity.

significantly ($P \leq 0.10$) higher than the uncultivated samples which had a mean of 6.0. The 31-38-cm depth samples had a mean pH of 6.8 which was not significantly higher than the mean pH of the uncultivated site (6.4). Lower Mg values in the cultivated site may have been caused by plant utilization of the original Mg and the application of low Mg limestone.

In summary, cultivation and addition of soil amendments over the past 100 to 150 years have considerably changed the chemical, physical, and morphological properties of the soil. The uncultivated site has the properties of a soil influenced by prairie vegetation with a surface horizon that is slightly acidic, relatively high in organic matter, and a very dark grayish brown(10YR 3/2), and that has a well expressed granular structure (Steiger 1981, Fenton 1983). As a result of the prairie influence on this soil, it classifies as a Mollic intergrade of the Alfisol soil order. The cultivated site is classified however, in a Typic subgroup of the Alfisol order, having lost a portion of the original organic matter and thus its Mollic properties as a result of the long period of cultivation. The cultivated surface horizon has a nearly neutral pH (6.6), a relatively light color (brown, 10YR 4/3), a significantly ($P \leq 0.10$) lower organic matter content, and weaker structure than its uncultivated counterpart. Thus, the taxonomic classification of the soil has been altered by cultivation.

The addition of P and K fertilizers increased the availability of these elements in the surface horizon over and above the values measured in the undisturbed site. The addition of agricultural lime increased the pH and the available Ca of the cultivated site. In the subsurface horizon, with the exception of P, none of the soil test values from the cultivated site differed significantly from the undisturbed site. The addition of soil amendments to the cultivated site was not sufficient to maintain the original organic C content, which was found to be 58 to 35% lower than that of the uncultivated site.

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TABLE 3

Bulk density values for the profile samples. Mean values are given for the transect samples.

Horizon	Depth (cm)	Bulk density (g/cm^3)* 1/3 Bar	Oven-dry
	Uncultivated (MA-31)		
A	0-17	1.28	1.35
BA	17-28	1.54	1.60
Bt	28-46	1.58	1.64
CB	61-79	1.60	1.68
	Cultivated (MA-32)		
Ap1	0-20	1.49	1.55
Ap2	20-30	1.52	1.57
Bt1	30-43	1.51	1.57
BC	61-76	1.60	1.63
	Transect Samples		
Uncultivated	15-23	1.45	1.54
	31-38	1.46	1.56
Cultivated	15-23	1.50	1.56
	31-38	1.50	1.63

*Values represent triplicate determinations for MA-31 and MA-32 and duplicate determinations for transect samples.

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