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ABSTRACT

LONG-TERM EFFECTS OF TILLAGE ON THE RETENTION AND TRANSPORT OF SOIL WATER

Quantitative measurements were made of the physical and chemical properties of two virgin prairie soils, Crowley and Jay, that remain in their native Arkansas environments and of similar soils that had been tilled extensively. Comparisons were made of soil properties at several depths. When compared with the tilled soils the virgin soils had higher organic matter contents, saturated hydraulic conductivities and water retained at several applied pressures. Bulk densities and hydraulic resistances were lower in the virgin soils. For the Crowley silt loam, values of pH and elemental contents of the virgin soil were higher than those of the tilled soil.

Determinations also were made of the effects of a 14-year addition of winter cover crops on a Dubbs-Dundee soil in continuous cotton production. In general, the winter cover crops tended to increase hydraulic conductivity, porosity and organic matter content. These results indicated that the detrimental effects of long-term tillage on soil hydraulic properties could partially be overcome with the planting of these crops during the winter. However, the rate of improvement in the hydraulic properties was not dramatic.

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INTRODUCTION

Traditionally, agriculture has been the base of the economy of Arkansas. During the turn of this century, the dominant philosophy of many farmers was to grow as much cotton as possible and sell it for whatever price it would bring (Duvall, 1973). At the same time, in flat and swampy areas in eastern Arkansas where cotton, corn and other grains were not well suited, rice production was introduced. Extensive production of soybeans came in later years (Von Steen and Brantner, 1981).

Production of these agronomic crops was possible with extensive tillage of the soil. Tillage was necessary for seedbed preparation, weed control and for increased aeration. Over the years, many tillage operations using either moldboard plows, disks or chisels, or a combination of disk-chisels or disk-cultivators have been used within a growing season. As a result of the varied equipment required and the numerous trips over the field, tillage of agronomic crops such as cotton, rice and soybeans is one of the major production costs and requires extensive amounts of equipment, fuel, time and maintenance.

Several reasons are usually expressed by farmers as to why tillage of the soil is necessary. These reasons center around providing a soil environment that optimizes crop growth and development. Examples include: controlling weeds; the need to cover surface residues for decomposition; the aesthetic value provided by emerging seedlings in a totally clean soil surface environment; improved aeration of the soil possibly necessary due to compaction created by heavy equipment as a result of many passes over wet soil; pest control through the covering of crop residues in short crop rotations or sequences; leveling or shaping of the field by plowing and disking needed after cultivation or harvesting operations during periods of heavy rainfall creating unfavorable conditions; incorporation of fertilizers and other soil amendments; increase in soil temperature; stimulation of root growth; and tradition developed from years of successful production by using implements and practices accepted and unchallenged by either the scientific or the farm community. All of these reasons for tillage have validity when one considers alternatives or options available to the farmer at that time. The crop production demands were met using these proven methods until the need for food and fiber associated with World War II, which placed great stress on world soil resources (Phillips, 1984). Industrialization, population explosions and economic changes continued to increase demands on land resources with predictable further expansions and demands for more food and fiber.

A. Purpose and Objectives

The purpose and objectives of this study were as follows: (i) to determine the relationships between duration of tillage and the retention and transport of water in three soils in Arkansas, and (ii) to evaluate the effects of potential management practices on the ability of one of these soils to retain and transmit water.

B. Related Research or Activities

There is general agreement that on a short-term basis, tillage is beneficial in crop production to some degree (Baver et al., 1973).

Moderate amounts of tillage maintain the upper layers of the soil in an aggregated state, which facilitates adequate aeration and infiltration of water for the crop development. Modern tillage practices, however, have imposed a considerable traffic load on these aggregated beds. In response to the vehicular loads, the soil aggregates have been either crushed and/or reoriented, which causes the aggregated bed to become compacted and less favorable to crop growth. The reported detrimental effects of tillage-caused compaction on crop establishment and yields often cannot be alleviated by natural forces or further tillage operations. Extensive tillage over long periods of time tends to reduce soil productivity by the development of compacted layers and reductions in the soil organic matter content (Bouma and Hole, 1971). These factors in turn reduce the transmission and retention of water in the soil near the surface. Many biological systems have the capacity to regenerate after substantial change has taken place. Most soil systems differ, however, in that they develop their characteristics over thousands of years (Foss and Moran, 1984). Since tillage primarily effects the surface 15 cm of soil, loss of productive surface soils may expose unfavorable subsurface soil materials. This loss is, therefore, a somewhat permanent change from the standpoint of our civilization.

There have been several recent studies conducted that compare virgin soils with similar soils that have been cultivated. Bauer and Black (1981) in North Dakota indicated that as virgin grasslands were put under cultivation, organic carbon and total N concentrations declined rapidly during the initial ten years of cultivation. Decline continued until an equilibrium level was reached after approximately 40 years in cultivation. Their results showed that the equilibrium concentrations can be affected by tillage practice. Tillage practices emphasizing stubble mulching over conventional tillage management had higher carbon and nitrogen concentrations. Bulk density of the surface to the 30 cm depth ranged from 7 to 20 percent higher in the cropland than in the virgin grasslands. Scott et al. (1983) in Arkansas showed that virgin Dubbs and Sharkey soils contained higher organic matter contents and volumes of water retained at all pressures, had lower bulk densities and were darker in color than similar soils that had been extensively cultivated. Skidmore et al. (1975) in Kansas compared the physical properties of a Keith silt loam when in a buffalograss pasture and an adjacent field which had been in cultivation for 60 years. They found a greater stability of the aggregates and much lower bulk densities in the pasture as compared with the cultivated field. The infiltration rates of water were seven times higher in the pasture than in the cultivated field. Hadas (1987) found the tensile strength of aggregated samples in a cultivated field was greater than that of samples taken from a virgin soil site of the same soil. Internal strength of the basic soil aggregation units was quadrupled under cultivation as compared to that determined from virgin samples. These finding suggest that cultivation and traffic-caused compaction affect to a greater extent the basic smaller structural units of the soil and less so for the larger aggregation units.

METHODS AND PROCEDURES

The *in situ* physical properties of soils from three locations in Arkansas were determined. Two of the sampling sites were located on virgin prairies which had been managed with haying operations over the years. Characterization of the third site compared the physical status of a soil in continuous cotton with that of continuous cotton with winter cover crops.

A. Sampling of the Crowley Site

The Crowley soil was sampled on May 14, 1985 and on April 24, 1986 at the Sam Konecny farm near Slovak. There were two sampling sites at this location: an area in virgin prairie and another area in production of rice or soybeans or wheat. The virgin area is preserved and managed by the Arkansas Natural Heritage Commission. According to the Lonoke and Prairie County Soil Survey (USDA, 1981), four soil series are found within the virgin prairie and nearby areas. These soils, which are Crowley, Calloway, Loring and Stuttgart, are somewhat similar in that they have silt loam textures near the soil surface and are classified as Alfisols. They differ primarily in their drainage characteristics and texture of the B horizon. Crowley and Stuttgart soils, which are poorly drained and moderately well drained, respectively, were formed in loamy windblown material underlain by clayey alluvium. The Calloway and Loring soils are somewhat poorly drained and moderately well drained soils formed in loamy windblown and alluvial sediments. All of these soils are wet and have slow water permeability. In general, they are well suited to production of cultivated crops such as soybeans, wheat and rice.

The sampling procedures in the virgin prairie initially involved the careful removal of the above-ground cover from the soil surface from an area having dimensions of approximately 0.6 m by 0.6 m. Undisturbed cores of soil were taken at 5 cm increments to the 30 cm soil depth. At each depth, there were four replicates of samples taken, resulting in 24 cores in the virgin prairie. Disturbed soil samples for chemical analyses were also taken at each depth interval at this site. Undisturbed cores were also taken from the cultivated site which was located approximately 150 m away. Since the cultivated site had recently been plowed, only the three depths below 15 cm were sampled at this time. The two 5-cm depth increments near the soil surface were sampled on April 24, 1986, when the field was under wheat production. At this same time, from both the virgin and tilled sites, 10 cm length undisturbed core samples were obtained for the determination of hydraulic conductivities by the falling-head method.

B. Sampling of the Jay Site

The second site of virgin prairie was located immediately west of the Siloam Springs airport on Arkansas Highway 59. The area is owned by Mr. Truee Rice, who reported that the land has not been cultivated since 1902, when his dad purchased the property. Recently, the land has been used for hay and has not been burned. The soil at the sampling site is a Jay silt loam and contains a considerable number of mounds. Extensive evidences of burrows exists around the soil mounds.

The Jay soils are moderately well drained, nearly level soils on broad uplands of the Springfield plateau (USDA, 1977). These soils formed in loamy material overlying cherty limestone. The native vegetation was tall prairie grasses. Jay soils have moderate fertility, slow permeability and medium water capacity. They are easy to till and can be cultivated over a wide range of soil moisture contents.

Undisturbed samples of soil were taken of the 0 to 5, 5 to 10, and 10 to 15-cm depth intervals. There were at least five core samples per depth. No samples were taken of an adjacent cultivated site since Mr. Rice does not own that property.

C. Sampling of the Dubbs-Dundee Site

The third site sampled was located on the Delta Branch Experiment Station near Clarkedale. The site had been in continuous cotton since 1973 and had, for the most part, been in cotton research for 30 years. Samples of soil were taken on November 11, 1985 within a research experiment in which the objective was to determine the influence of cover crops grown during the winter and early spring on continuous production of cotton. The samples were taken in the row of treatments having (i) continuous cotton with no cover crops and with 3 lb/A/yr of cotoran (a herbicide), (ii) continuous cotton with cover crops and with 3 lb/A/yr of cotoran, and (iii) continuous cotton with cover crops and with no cotoran applied. This sampling scheme allowed for comparisons of soil properties with and without cover crops during the winter, as well as, with and without the annual application of the herbicide cotoran.

The soil at the site was in a Dubbs-Dundee association. Dubbs soils are well drained and have moderate permeability, whereas, Dundee soils are somewhat poorly drained and have moderately slow permeability. Both soils have silt loam Ap horizons and were formed in stratified beds of loamy sediments. They are well suited to cotton production, are moderate to high in natural fertility and moderate to low in organic matter contents. Usually, the Dundee soils occur in the lower landscape positions and the Dubbs soils occur in the higher lying areas. About 96 percent of the Dubbs-Dundee association is in cultivation (USDA, 1974).

Undisturbed cores of soil were taken from the 0 to 5, 5 to 10, and 10 to 15-cm depth intervals. In addition, undisturbed cores having 10-cm core lengths were taken from the soil surface for the determination of hydraulic conductivities by the falling-head method.

D. Determination of the Soil Physical and Chemical Properties

The undisturbed soil core samples were brought to the laboratory for analyses of selected soil physical and chemical properties. The length and diameter of these cylindrical cores were 5 and 6 cm, respectively. Soil physical properties determined included saturated hydraulic conductivity by the constant-head method, soil water retention at pressures of 10, 20, 30, 50, 80, 100 and 1500 kPa, bulk density and organic matter content. These determinations were made according to the standard procedures published in Black et al. (1965). The organic matter contents were determined by a variation of the Walkley-Black method with ferrous ammonium sulfate substituted for ferrous sulfate. The organic matter content was determined by titration. Soil chemical properties determined included pH, and elemental contents of N, K, P, Ca, Mg and Na. The elemental contents were determined by the Soil Testing Laboratory at the University of Arkansas, Fayetteville.

In some cases, the saturated hydraulic conductivity was determined by the falling-head technique (Black et al., 1965). The length and diameter of these cylindrical undisturbed cores were 10 and 8.4 cm, respectively. These falling-head cores of soil were, therefore, twice as long as the other cores.

E. Statistical Analyses

The experimental data were subjected to several statistical analyses. For example, the water retention results were modeled with several mathematical equations that contained curve fit parameters. These parameters were used not only to describe the data but to determine the influence of cultivation and/or management on soil water retention. In addition, linear regressions were made between organic matter content and the dependent variables bulk density and plant extractable water.

PRINCIPAL FINDINGS AND SIGNIFICANCE

A. Crowley Results

Quantitative comparisons of the physical properties of the virgin and tilled Crowley soils are presented in Tables 1 and 2. These results show that tillage associated with the production of rice, soybeans and wheat during the last 37 years has detrimentally affected several physical properties of the Crowley soil and that these effects were greatest in the 0 to 5-cm depth increment. For example, in the 0 to 5-cm depth increment, the organic matter content and hydraulic conductivity of the virgin soil was approximately 2.6 and 128 times greater than that in the tilled soil, respectively. Bulk density, which is an indicator of compaction, was lower in the virgin soil at all depths. When considering the 0 to 30 cm as the soil profile, the virgin soil contained 1.7

Table 1. Organic matter contents, hydraulic conductivities and bulk densities of the virgin and cultivated Crowley soils.

Tillage Condition	Depth Interval	Organic Matter	Hydraulic Conductivity[1]	Bulk Density
	cm	%	cm hr^{-1}	g cm^{-3}
Virgin	0 - 5	4.5	7.67	1.08
	5 - 10	2.6	7.46	1.21
	10 - 15	2.6	1.37	1.21
	15 - 20	1.6	3.55	1.25
	20 - 25	1.5	1.44	1.25
	25 - 30	1.1	4.74	1.29
Cultivated	0 - 5[2]	1.7	0.06	1.31
	5 - 10[2]	1.7	0.06	1.35
	10 - 15	1.6	0.84	1.58
	15 - 20	1.4	0.10	1.59
	20 - 25	0.9	0.35	1.56
	25 - 30	0.6	3.05	1.48

[1] The natural logarithm of these core values were averaged.

[2] Sampled in April 1986 when the field was in wheat.

Table 2. Water retained by the virgin and cultivated Crowley soils.

Tillage Condition	Depth Interval	Water Retained at Applied Pressure (kPa)								
		0	5	10	20	35	50	80	100	1500
	cm	$cm\ cm^{-3}$								
Virgin	0 - 5	.594	.526	.500	.479	.465	.387	.376	.340	.149
	5 - 10	.545	.434	.414	.380	.366	.318	.277	.263	.163
	10 - 15	.544	.403	.383	.357	.347	.335	.326	.318	.148
	15 - 20	.529	.380	.358	.326	.299	.269	.261	.249	.158
	20 - 25	.527	.382	.379	.331	.320	.294	.287	.282	.171
	25 - 30	.515	.364	.348	.315	.290	.258	.253	.247	.175
Cultivated	0 - 5	.505	.383	.372	.356	.350	.337	.311	.305	.127
	5 - 10	.493	.405	.396	.379	.374	.363	.348	.342	.136
	10 - 15	.404	.366	.361	.347	.339	.328	.316	.311	.200
	15 - 20	.402	.368	.362	.355	.346	.341	.332	.325	.235
	20 - 25	.416	.381	.373	.361	.353	.345	.339	.330	.257
	25 - 30	.448	.368	.360	.342	.322	.306	.275	.256	.197

and 1.4 times more organic matter on a weight and volume basis, respectively, had a saturated hydraulic conductivity which was 49 times higher, and a bulk density that was 0.8 times as high as compared with the tilled soil.

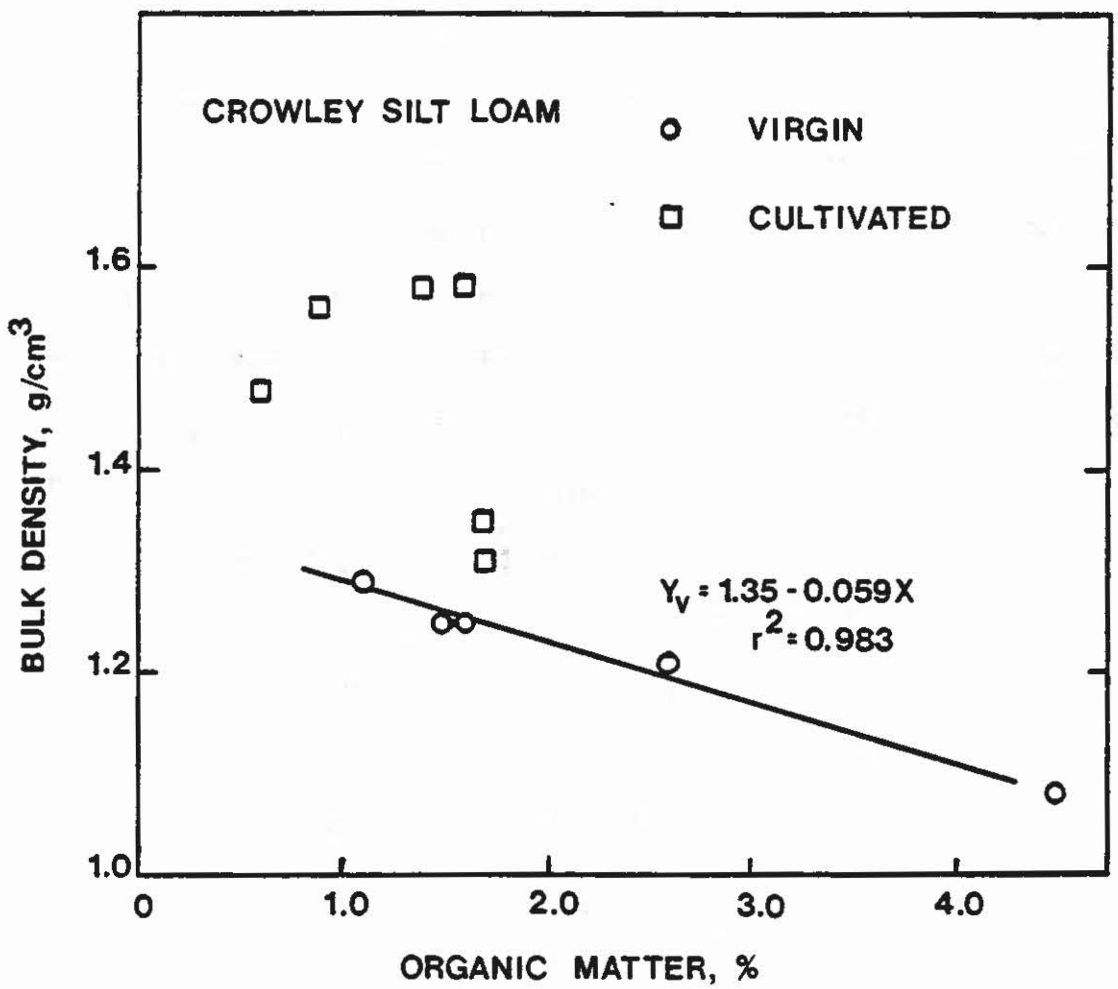
The thickness of each depth increment divided by the saturated hydraulic conductivity is known as the hydraulic resistance. For these two sites, the average resistance to flow of water in the surface 30 cm was 1.82 +/- 1.38 and 39.76 +/- 37.81 in the virgin and tilled sites, respectively. Therefore, the tilled soil profile had a resistance to flow of water that was 21.8 times greater than in the virgin soil profile. Variability of the hydraulic resistance also was greater in the tilled profile. The greatest differences in hydraulic resistance between the two sites was found in the 0 - 5 and 5 - 10-cm depth increments where the average resistance to flow of water was 126 times higher in the tilled soil.

Saturated hydraulic conductivities (Ksat) also were determined by the falling-head method during the second sampling of the sites in April 1986. From these larger cores, Ksat values were 2.69 and 0.27 cm hr^{-1} for the virgin and tilled soils, respectively. These falling-head Ksat results indicated that the rate of movement of water through the virgin Crowley was an order of magnitude faster than through the tilled soil. Since organic matter acts as a binding agent for aggregation, the higher organic matter contents of the virgin Crowley soil contributed to the greater structure of the soil, which resulted in greater transmission rates and lower compaction.

The relationships between organic matter content, saturated hydraulic conductivity and bulk density were determined with regression techniques. Most of these regressions were not significant and are presented in Appendix Table 1. For the virgin soil, however, a linear relationship was found between bulk density and organic matter content with a slope of -0.059 g cm^{-3} $\%^{-1}$ of organic matter (Figure 1). The high coefficient of determination (r^2 = 0.983) indicates that organic matter was a significant factor in determining the soil compaction and structure at the virgin site. Structure and compaction of the soil are important in the determination of the magnitude of the porosity. For the cultivated soil, no relationship was found between bulk density and organic matter content, as indicated by the low coefficient of determination (0.155). In the cultivated soil, bulk density varied from 1.31 to 1.59 g cm^{-3}, while the organic matter content varied from 1.7 to 0.6 percent. The higher bulk densities and lower organic matter contents in this soil indicate that factors other than organic matter were involved in determining the magnitude of the bulk density in the cultivated soil. Therefore, it appears that the loss of organic matter as a result of cultivation results in other factors besides organic matter content alone determining the bulk densities. These factors include the occurrence of traffic loads from tillage.

The retention of water varied with tillage condition and with soil depth (Table 2). In the 0 to 5 cm depth increment, the virgin soil retained greater amounts of water at all applied pressures, despite the lower bulk density, than in the cultivated soil. This can be attributed

Figure 1. Relationship between bulk density and organic matter content of the virgin and cultivated Crowley silt loam.



to the considerably greater organic matter content of the virgin soil at the surface (4.5 percent) as compared with the tilled soil (1.7 percent). Additions of organic matter are known to increase soil water retention (MacRae and Mehuys, 1985). However, as depth in the profile increased and as the soil become unsaturated, greater amounts of water retained were found in the tilled soil (Figures 2 and 3). The organic matter contents at these lower depths in the two soils were closely related, however, the tilled soil was compacted to a much greater extent. Therefore, at the lower depths the greater compaction of the tilled soil had a greater influence on water retention than did the slightly greater organic matter contents of the virgin soil.

At saturation, the mean profile (0 to 30 cm) water retained was 0.542 and 0.445 cm^3 cm^{-3} for the virgin and tilled site, respectively. This difference of 0.097 cm^3 cm^{-3} of water represents a significant decrease in the ability of the tilled soil to store water. On a unit surface area of soil basis, this amounts to a storage loss due to tillage of 2.9 cm of water in the surface 30 cm. This is a large loss of water and indicates that long-term tillage has reduced the volume of water that the soil can contain.

The soil water retention results were modeled with the equation

$$O_v = a + b \ln P \qquad [1]$$

where O_v is the volumetric soil water content (cm^3 cm^{-3}), P is the applied pressure (kPa), and a and b are the intercept and slope of the regression lines, respectively. All of the replications were used in determining the regression parameters. The results, which are summarized

Figure 2. Water retention curves of the virgin and cultivated Crowley silt loam between the surface and 15 cm depth in the profile.

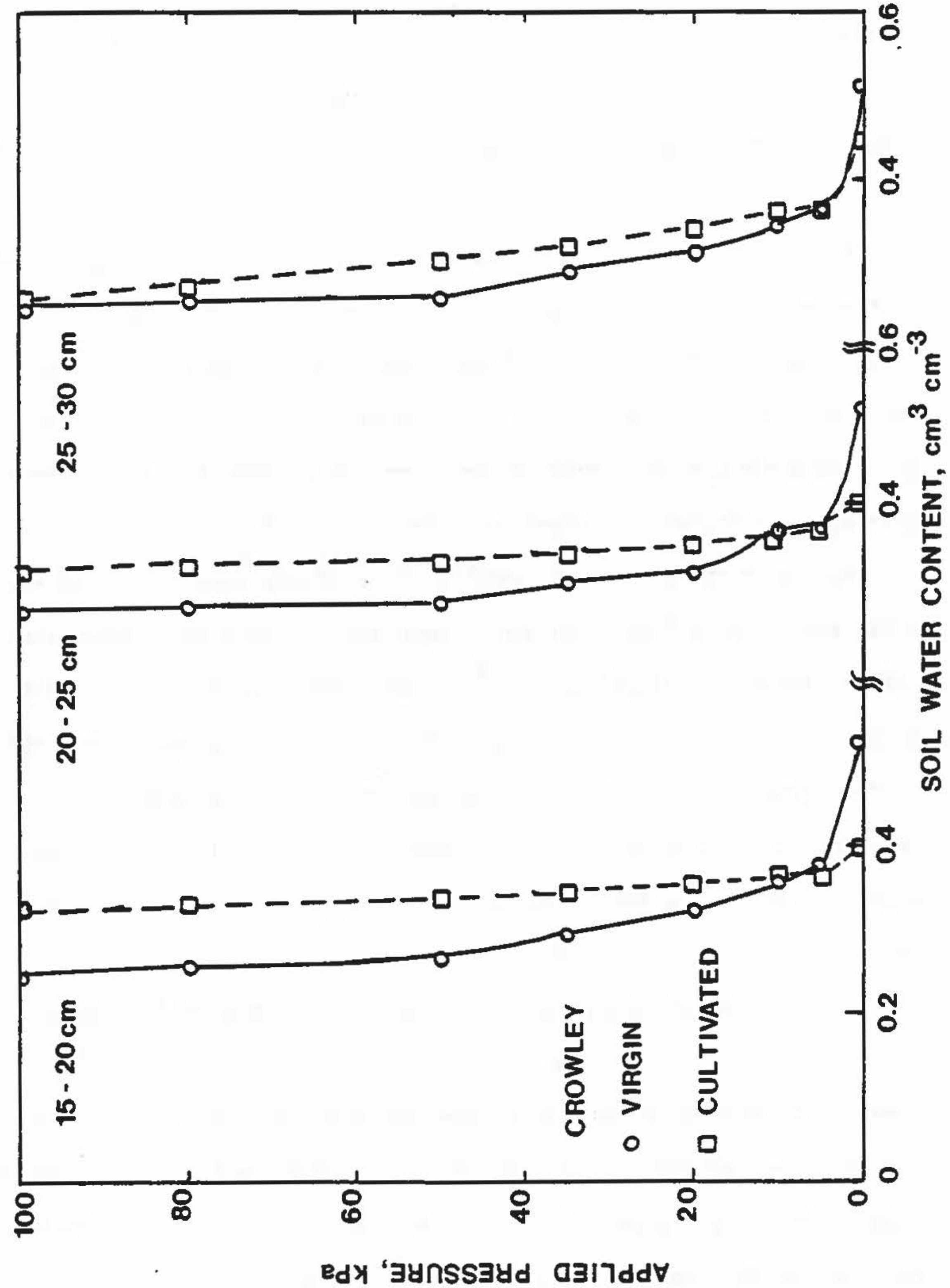
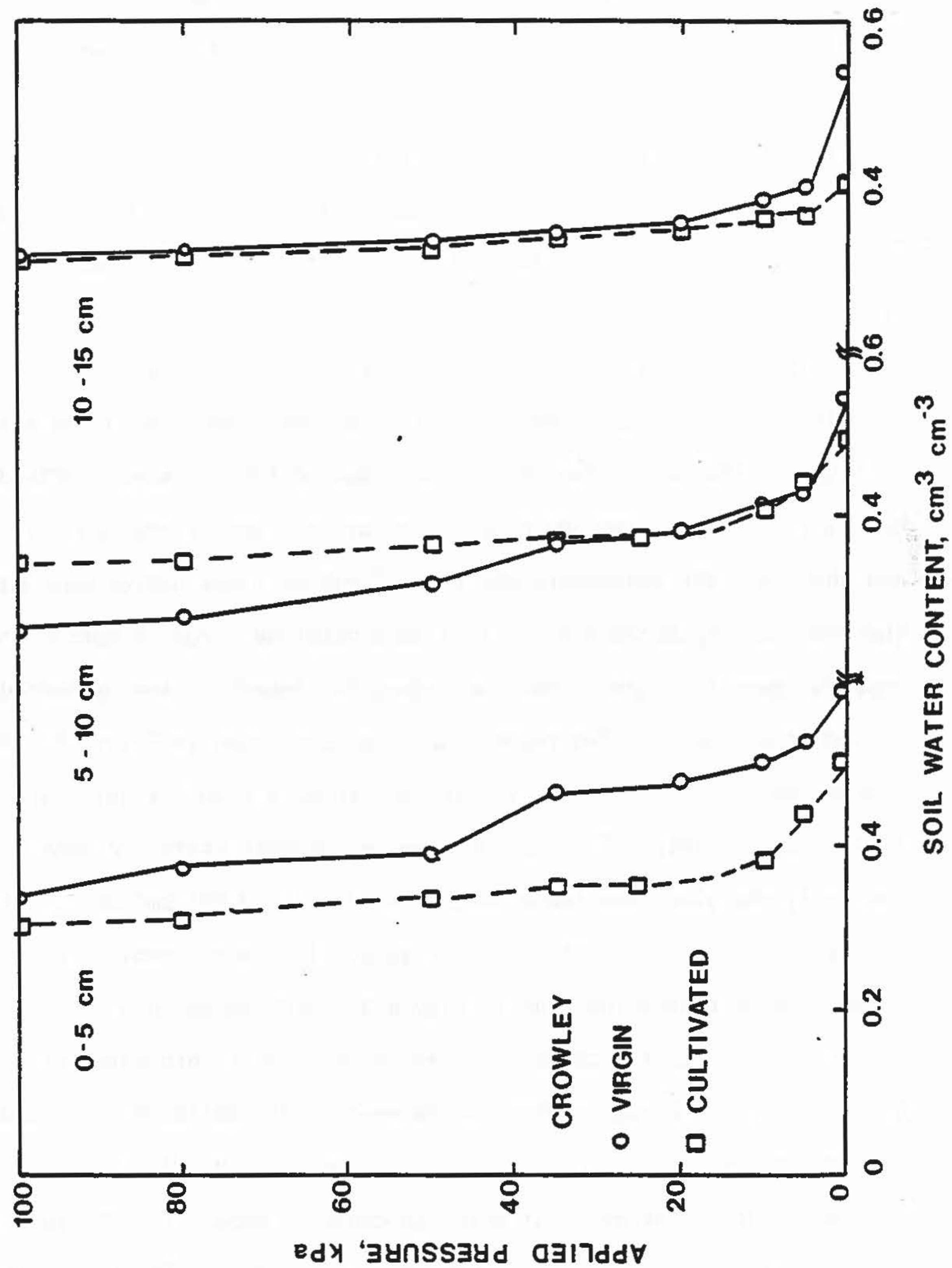


Figure 3. Water retention curves of the virgin and cultivated Crowley silt loam between the 15 cm and 30 cm depths.



in Table 3, show that excellent fits with the model were obtained on the virgin soil. The fit of the model on the tilled water retention was not as good. In general, the slopes and intercepts were lower with the tilled soil water retention curves than with the virgin soil water retention curves. This indicates that the virgin soil had higher water contents near saturation and was more responsive to changes in pressure than the tilled soil.

Plant available water in the surface 30 cm was estimated by subtracting from the water retained at 10 kPa (the upper limit) the water retained at 1500 kPa. The thought was that 10 kPa represents "field capacity", or the upper drainage limit for this poorly drained soil, and that 1500 kPa represents the lower limit of plant extractable water. The relationship between plant available water and organic matter content is shown in Figure 4 and the regression equations are presented in Appendix Table 1. Two regression lines are shown in Figure 4. The regression analysis with the virgin soil shows a highly significant linear relationship. For each one percent organic matter content in the soil, the plant available water increased by 0.051 $cm^3\ cm^{-3}$. All of the data from the virgin and cultivated sites were combined and used in the second regression line in Figure 4, which shows that each one percent organic matter content increased plant available water by 0.056 $cm^3\ cm^{-3}$. Linear regression between plant available water and organic matter content in the tilled soil was nonsignificant.

A comparison by depth of selected chemical properties for the virgin and tilled Crowley soils is presented in Table 4. These results

Table 3. A summary of the parameters of the fit of the model to the soil water retention curves of the Crowley soil.

Tillage Condition	Soil Depth	Intercept	Standard Error	Slope	Standard Error	Coefficient of Determination
	cm	cm^3 cm^{-3}		kPa^{-1}		
Virgin	0 - 5	0.570	0.0128	-0.047	0.0032	0.831
	5 - 10	0.487	0.0067	-0.044	0.0017	0.941
	10 - 15	0.472	0.0065	-0.040	0.0016	0.931
	15 - 20	0.444	0.0020	-0.042	0.0005	0.994
	20 - 25	0.451	0.0035	-0.040	0.0009	0.979
	25 - 30	0.428	0.0019	-0.040	0.0005	0.994
Tilled	0 - 5	0.467	0.0070	-0.038	0.0018	0.902
	5 - 10	0.473	0.0090	-0.034	0.0023	0.820
	10 - 15	0.469	0.0080	-0.042	0.0020	0.913
	15 - 20	0.402	0.0098	-0.023	0.0024	0.663
	20 - 25	0.412	0.0090	-0.023	0.0023	0.706
	25 - 30	0.413	0.0063	-0.032	0.0018	0.908

Figure 4. Relationships between plant available water and organic matter content for the Crowley soil.

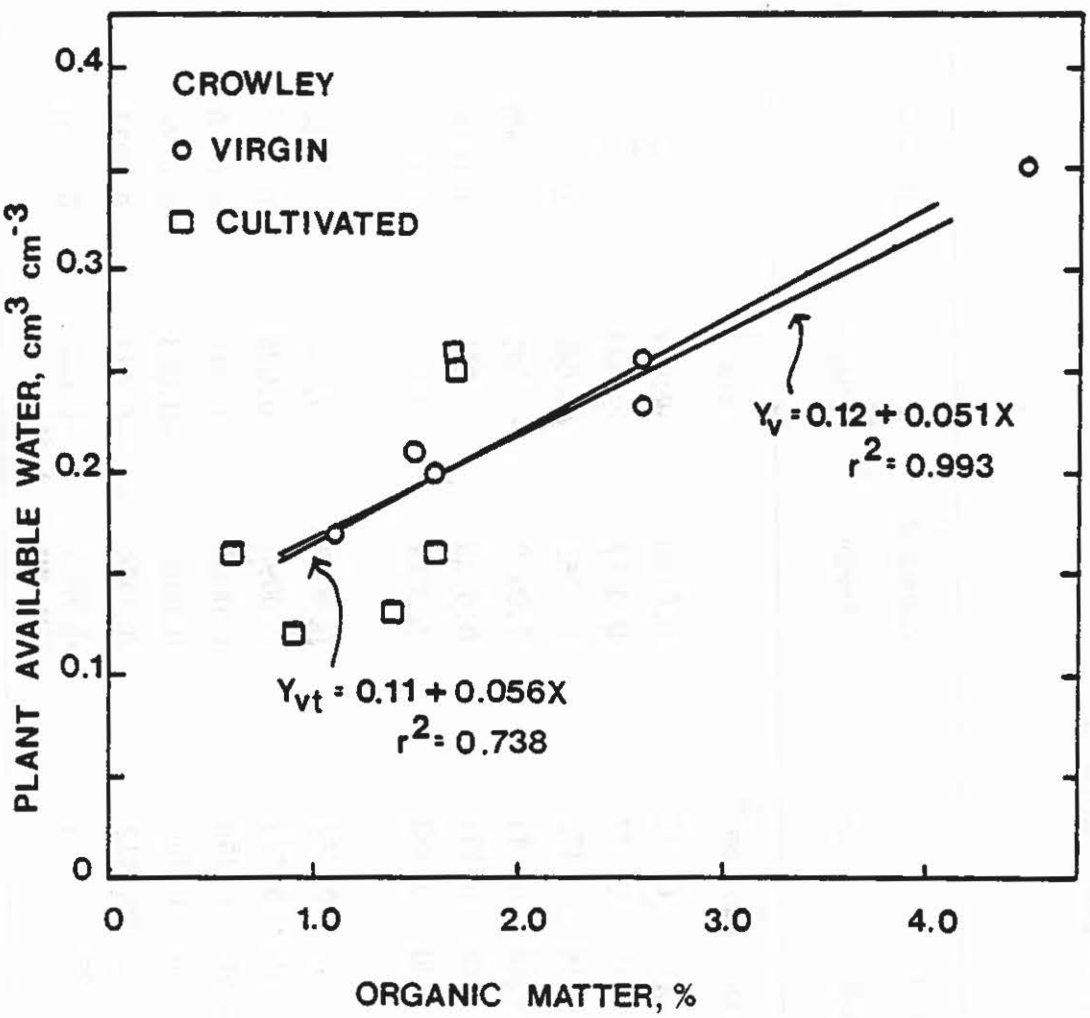


Table 4. Selected chemical contents of the virgin and tilled Crowley soils.

Tillage Condition	Depth Interval	pH	P	K	Ca	Na	Mg	Electrical Conductivity
			Soil Test Values					
	cm			kg ha^{-1}				umhos cm^{-1}
Virgin	0 - 5	4.6	11	78	448	179	34	84
	5 - 10	4.7	7	45	448	157	34	55
	10 - 15	4.7	3	45	336	190	34	65
	15 - 20	4.7	7	34	336	168	34	55
	20 - 25	4.8	6	34	336	213	34	50
	25 - 30	4.8	3	34	336	202	34	50
Tilled	0 - 5	5.3	45	157	1568	190	347	86
	5 - 10	5.3	46	168	1680	202	347	100
	10 - 15	5.4	45	157	1792	190	358	85
	15 - 20	5.3	34	78	1680	224	336	85
	20 - 25	5.8	7	45	1904	258	414	95
	25 - 30	5.1	9	45	784	258	190	95

show that the Crowley soil in its native or virgin state is relatively infertile and that long-term tillage along with the associated crop management practices such as fertilization and deposition of $CaCO_3$ from irrigation water have increased the pH and elemental contents. No significant difference was found in the electrical conductivity in which all values are considered to be in the low range. Therefore, from a soil chemical view, tillage associated with the production of rice, soybeans and wheat has tended to increase the chemical fertility of the Crowley soil.

These results show that long-term tillage of the Crowley soil has lowered its organic matter content, saturated hydraulic conductivity, saturated soil water content and plant available water. Tillage and the associated crop management activities have increased the compaction, hydraulic resistance and elemental content. Retention of water was dependent on the applied pressure, organic matter content and bulk density.

B. Jay Results

Summaries of the physical properties of the Jay soil are presented in Tables 5 and 6. Since there was no cultivated Jay soil for comparison, these data can be compared with the results of Thiesse (1984), who determined several physical properties of Captina soils. Captina soils have similar textures in the surface as the Jay and were formed in loamy material overlying cherty limestone or siltstone. They have slow permeabilities primarily because of a fragipan in the lower parts of the profile. Captina soils are found in the Ozarks on broad uplands

Table 5. Organic matter contents, saturated hydraulic conductivities and bulk densities of the virgin Jay soil and the similar but extensively cultivated soil, Captina.

Soil	Depth Interval	Organic Matter	Hydraulic Conductivity	Bulk Density
	cm	%	cm hr^{-1}	g cm^{-3}
Jay	0 - 5	4.2	25.6	1.08
	5 - 10	4.0	8.0	1.05
	10 - 15	3.4	1.8	1.26
Captina	0 - 5	2.5	1.4	1.28
	10 - 15	0.9	1.2	1.38

and ridges. These soils were some of the first to be cultivated in the Ozark plateau region.

In both soils, the highest organic matter contents and saturated hydraulic conductivities were found in the 0 to 5-cm depth interval (Table 5). The Ksat of 25.6 cm hr^{-1} in the virgin soil indicates that this layer can rapidly transmit water. Values of Ksat declined with depth in both soils. The resistance to flow of water for the three depths in the virgin Jay was 3.6 hr; for the two depths in the cultivated Captina, the resistance was 7.7 hr. When the same two depths were compared, the results indicated that the resistance to transport of water was more than 2.5 times higher in the cultivated soil as compared with the virgin soil. As a rule, the extensively cultivated Captina had higher bulk densities and lower Ksats and organic matter

Table 6. Water retained at three depths by the virgin Jay soil and the similar but extensively cultivated soil, Captina.

Depth	Water Retained at Applied Pressure (kPa)									
Interval	0	5	10	15	20	30	50	80	100	1500
cm					cm^3 cm^{-3}					
Jay										
0 - 5	.593	.461	.397	.378	.367	.332	.306	.257	.246	.083
5 - 10	.604	.416	.353	.338	.328	.301	.281	.253	.247	.077
10 - 15	.525	.427	.377	.362	.353	.323	.294	.258	.251	.093
Captina										
0 - 5	.537	.450	.406	.393	.363	.333	.306	-	.266	-
10 - 15	.479	.381	.350	.336	.314	.291	.263	-	.225	-

contents as compared with the virgin Jay soil. The relationship between bulk density (BD) and organic matter content (OM) for the results in Table 5 could be described with the regression equation

$$BD = 1.494 - 0.0948\ OM \qquad [2]$$

where the coefficient of determination was 0.827. This linear equation shows that compaction of the layers near the soil surface was indirectly correlated with the organic matter content of these layers. A similar result was found with the Crowley soil.

The water retention results of the Jay and Captina soils are presented in Table 6. At saturation, the virgin Jay contained about 5 percent more water than the cultivated Captina. This was primarily due to its lower bulk density and higher organic matter contents. As the applied pressure increased, both soils retained less amounts of water. At 100 kPa and in the 0 to 5-cm depth interval, the virgin Jay contained about 2 percent more water than the extensively cultivated Captina. In the 10 to 15-cm depth interval, the Captina soil retained 2.6 percent more water than the Jay at this same pressure. This difference in water retained at the two depths can be attributed to the greater compaction (i.e., higher bulk density) of the Captina soil.

For the Jay and Captina soils the water retention results were also fit to equation [1] and the results are presented in Table 7 and Appendix Table 2. Excellent fits of the regression model to the experimental data were obtained. As soil depth increased, the slope of the equation decreased, which indicated that the water retention curves were less sensitive to changes in pressure. When all of the Jay data were combined,

Table 7. A summary of the parameters of the fit of the mathematical model to the soil water retention curves of the virgin Jay and the extensively cultivated Captina soils.

Soil Depth	Intercept	Standard Error	Slope	Standard Error	Coefficient of Determination
cm	$cm^3\ cm^{-3}$		kPa^{-1}		
Jay					
0 - 5	.505	.0028	-.0561	.0007	.987
5 - 10	.488	.0016	-.0544	.0004	.996
10 - 15	.468	.0049	-.0455	.0013	.944
Captina					
0 - 5	.482		-.0406		.919
10 - 15	.422		-.0377		.943

Table 8. Selected chemical contents at three depths of the virgin Jay soil.

Depth Interval	pH	P	K	Ca	Na	Mg	Electrical Conductivity
		Soil Test Values					
cm			$kg\ ha^{-1}$				$umhos\ cm^{-1}$
0 - 5	4.8	42	235	1568	190	302	200
5 - 10	4.7	34	190	1680	190	246	200
10 - 15	4.6	33	90	1344	179	224	200

the regression model that best fits the water retention results was

$$\theta_v = 0.487 - 0.052 \, \text{LnP} \qquad [3]$$

with a coefficient of determination of 0.970.

A comparison of the effects of cultivation on the similar soil, Captina, can be shown with the results of Thiesse (1984). The modeling results show that the extensively cultivated Captina soil had a lower intercept, which is an indication of a lower volume of water retained in a unit volume of soil near saturation. The lower slopes of the Captina regression model indicate that this soil was much less sensitive to changes in applied pressure than the virgin Jay soil. A similar result was found by comparing the virgin and cultivated Crowley soils.

Soil chemical analyses of the Jay soil are presented in Table 8. These results indicate that the native fertility of this prairie soil is moderately low. Values of pH as well as the P content were low.

C. Dubbs-Dundee Results

Summaries of the physical properties of the Dubbs-Dundee soil are presented in Tables 9 and 10. These data were obtained in order to determine the effects of winter cover crops on the transmission and retention of water in a soil that had been extensively cultivated. Research plots from three treatments of continuous cotton for 14 years were sampled: (i) continuous cotton with rye and vetch as winter cover crops and no herbicide cotoran, (ii) continuous cotton with rye and vetch as winter cover crops and with 3.3 kgha^{-1} cotoran applied during the last four years, and (iii) continuous cotton with no winter

Table 9. Organic matter, saturated hydraulic conductivities and bulk densities of the Dubbs-Dundee soil in the three treatments.

Treatment	Herbicide	Depth Interval	Organic Matter	Hydraulic Conductivity	Bulk Density
	$kgha^{-1}$	cm	%	$cmhr^{-1}$	gcm^{3}
Rye/Vetch	0	0 - 5	1.9	3.46	1.26
		5 - 10	1.3	4.49	1.29
		10 - 15	0.9	5.13	1.34
Rye/Vetch	3.3	0 - 5	1.8	5.62	1.22
		5 - 10	1.5	2.90	1.33
		10 - 15	1.1	2.97	1.33
Cultivated	3.3	0 - 5	1.4	2.08	1.28
		5 - 10	1.1	2.31	1.39
		10 - 15	1.1	1.43	1.39

Table 10. Water retention of the Dubbs-Dundee soil at the three depths and treatments.

Tillage	Depth Interval	Water Retained at the Applied Pressure 0	5	10	15	20	30	50	80	1500
					$cm^3\ cm^{-3}$					
Rye/Vetch	0 - 5	.525	.433	.396	.363	.347	.333	.307	.285	.053
(0 herb.)	5 - 10	.513	.419	.388	.362	.359	.332	.284	.273	.077
	10 - 15	.494	.391	.366	.342	.339	.312	.279	.260	.098
Rye/Vetch	0 - 5	.540	.446	.407	.373	.370	.334	.309	.290	.071
(3 herb.)	5 - 10	.498	.392	.358	.331	.322	.302	.286	.279	.067
	10 - 15	.498	.423	.388	.358	.339	.305	.267	.251	.077
Check	0 - 5	.517	.411	.375	.346	.329	.296	.268	.255	.070
	5 - 10	.476	.396	.378	.358	.357	.350	.339	.338	.081
	10 - 15	.476	.407	.378	.353	.336	.300	.261	.238	.088

cover crops but with cotoran applied at the recommended rate. The purpose of the sampling of the plots with and without cotoran was to determine if annual applications during the last four years affected the retention and transmission of water in the soil.

The organic matter contents were typical of those silt loam soils that have been extensively cultivated in eastern Arkansas (Table 9). As expected, the highest organic matter contents were found in the 0 - 5-cm depth increment. There seemed to be no difference in organic matter content due to winter cover treatment.

The average saturated hydraulic conductivities, determined by the constant-head method, were about 50 percent lower in the plots that had no winter cover. These results indicate that under continuous cotton production, the addition of winter cover such as rye and vetch increased the ability of the soil to transmit water under saturated conditions. Average Ksats from the plots with winter cover and cotoran were only about 12 percent lower than those with winter cover. Although not significantly different, this reduction may be due to the effects of cotoran on the microorganism population and, in particular, the earthworms. Earthworms are known to increase the sizes of pores near the soil surface.

Saturated hydraulic conductivities also were determined by the falling-head method and averaged 1.53, 0.83 and .27 cm hr^{-1} in the rye/vetch with no herbicide, rye/vetch with herbicide and no winter cover crops, respectively. Therefore, in these larger cores, the soil planted to winter cover crops had values of Ksat that were 5.5 and 3.0 times higher than those in continuous cultivation of cotton. The plots of continuous cotton but with no cotoran had values of Ksat that were 1.8 times higher than that with the herbicide. This indicates that the trend found with the smaller cores in the steady-state experiment was more evident in the larger cores, i.e., the application of the herbicide reduced the Ksat.

Bulk densities increased with depth in the profile. As a general rule, the bulk densities were slightly higher in the continuous cotton without winter cover crops (1.35 g cm^{-3}) than in the plots with the cover crops (1.3 g cm^{-3}).

The relationship between bulk density and organic matter content in the Dubbs-Dundee soil was determined by regression to be

$$BD = 1.50 - 0.134\ OM \qquad [4]$$

with a coefficient of determination of 0.633. This r^2 indicated that organic matter alone could explain 63 percent of the variation in the variation of bulk density of the top 15 cm of soil.

Soil water retention results for the three treatments are presented in Table 10. Differences due to treatment were small and nonsignificant. There was, however, a tendency for the soil that had been in continuous cultivation of cotton to have slightly lower volumes of water retained to 80 kPa. The differences in water retained were not dramatic and indicates that the planting of winter cover crops and subsequent incorporation of the residues into the soil during the spring has not dramatically affected the volume of water retained by a unit volume of soil.

The results of the fitting of equation [1] to the experimental data are presented in Table 11. Based upon the values of the r^2, excellent fits to the experimental data were obtained. There were little differences in the intercepts and slopes that can be attributed to treatment affects. A summary of the data when combined across the three depths is presented in Appendix Table 3.

A summary of the soil chemical status of the three treatments is presented in Table 12. The results indicate that the soil has high fertility, which is due primarily to the annual applications of fertilizer for cotton production. No generalizations can be made concerning the effects of treatment on the chemical status of the soil since the plots were fertilized similarly.

CONCLUSIONS

This study was conducted to determine the effects of cultivation on soil physical and chemical properties. Two soils in their native environments were sampled and compared with similar soils that had been extensively cultivated. A decrease in the physical fertility of the soils was found due to tillage and the associated crop production practices. An improvement in the chemical fertility was found. The tilled soils had lower organic matter contents, lower Ksats, lower porosities, but higher bulk densities and hydraulic resistances. Linear relations were determined between organic matter content and the dependent variables bulk density and extractable water for the virgin soils.

The results of the analyses of the continuous cotton plots indicated that the addition of winter cover crops such as rye and vetch

Table 11. Summary of the fit of the mathematical model to the water retention of the Dubbs-Dundee soil.

Treatment	Depth Interval	Intercept	Standard Error	Slope	Standard Error	Coefficient of Determination
Rye/Vetch	0 - 5	.479	.0089	-.0482	.0024	.907
	5 - 10	.462	.0056	-.0461	.0015	.958
	10 - 15	.440	.0055	-.0410	.0014	.950
Rye/Vetch	0 - 5	.490	.0085	-.0485	.0022	.916
	5 - 10	.442	.0067	-.0433	.0018	.933
	10 - 15	.455	.0083	-.0448	.0022	.906
Cultivated	0 - 5	.456	.0062	-.0470	.0016	.950
	5 - 10	.450	.0112	-.0369	.0029	.784
	10 - 15	.437	.0077	-.0416	.0020	.907

Table 12. Summary of the chemical analyses of the Dubbs-Dundee soil at three depths and treatments.

Tillage	Depth Interval	pH	P	K	Ca	Na	Mg	Electrical Conductivity
				Soil Test Values				
				kg ha^{-1}				umhos cm^{-1}
Rye/Vetch	0 - 5	5.2	218	784	1792	246	325	82
(0 herb.)	5 - 10	5.3	159	224	2352	224	325	80
	10 - 15	5.7	87	202	3136	246	448	100
Rye/Vetch	0 - 5	5.6	214	818	1568	246	325	80
(3 herb.)	5 - 10	5.2	178	515	1904	168	336	120
	10 - 15	5.3	148	202	2464	190	482	304
Check	0 - 5	6.2	192	482	1792	146	403	75
	5 - 10	5.9	125	258	2464	157	381	62
	10 - 15	5.9	158	190	3024	179	414	70

increased the organic matter contents and Ksats and decreased the bulk density. Although the effects were not dramatic and rapid, this indicates that improvements in the soil physical status can be obtained over a number of years. These results also have implications on the volume of water available during the season for the growth of crops such as cotton. Higher values of Ksat indicate that the transmission coefficients of water through the soil near the surface are higher and this tends to reduce runoff from rainfall and irrigations. Therefore, more efficient use can be made of the water. Higher values of porosity indicate that the soil can store more of the water within a given input of water.

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APPENDICES

Appendix Table 1. A summary of the regression analyses of the virgin (v) and tilled (t) Crowley soils.

Relationships between Ksat (Y) and Organic Matter (X)

$Y_v = 1.081 + 1.463 X$ $\quad r^2 = 0.413$

$Y_t = 3.257 - 1.909 X$ $\quad r^2 = 0.570$

Relationships between Ksat (Y) and Bulk Density (X)

$Y_v = 29.707 - 20.852 X$ $\quad r^2 = 0.295$

$Y_t = -1.494 - 1.514 X$ $\quad r^2 = 0.025$

Relationships between Bulk Density (Y) and Organic Matter (X)

$Y_v = 1.347 - 0.0588 X$ $\quad r^2 = 0.983$

$Y_t = 1.615 - 0.1037 X$ $\quad r^2 = 0.155$

$Y_{vt} = 1.552 - 0.1153 X$ $\quad r^2 = 0.481$

Relationships between Plant Available Water (Y) and Organic Matter (X)

$Y_v = 0.122 + 0.051 X$ $\quad r^2 = 0.993$

$Y_t = 0.074 + 0.079 X$ $\quad r^2 = 0.369$

$Y_{vt} = 0.108 + 0.056 X$ $\quad r^2 = 0.738$

Appendix Table 2. A summary of the regression analyses of the virgin Jay.

Relationships between Ksat (Y) and Organic Matter (X)

$Y_v = 1.440 - 0.0167 X$ $\quad r^2 = 0.444$

$Y_{vt} = 1.367 - 0.0133 X$ $\quad r^2 = 0.359$

Relationships between Bulk Density (Y) and Organic Matter (X)

$Y_v = 2.11 - 0.2538 X$ $\quad r^2 = 0.866$

Appendix Table 3. Relationship between water retained and applied pressure combined across depths for the three treatments in the Dubbs-Dundee soil.

rye/vetch - no herbicide

$0_v = 0.460 - 0.045 \ln P$ $\quad r^2 = 0.928$

rye/vetch - 3.3 kg/ha of cotoron

$0_v = 0.462 - 0.046 \ln P$ $\quad r^2 = 0.902$

check

$0_v = 0.488 - 0.042 \ln P$ $\quad r^2 = 0.868$