THE EFFECT OF CROPPING SYSTEMS AND SOIL TREATMENTS ON CERTAIN PHYSICAL AND CHEMICAL PROPERTIES OF A CLAYPAN SOIL

by

DAVID DANIEL NEHER

B. S., Kansas State College
of Agriculture and Applied Science, 1946

A THESIS

submitted in partial fulfillment of the

requirements for the degree of

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1948

Table of Contents

INTRODUCTION

Men have observed for many years that certain soil treatments and cropping systems have distinct effects upon certain chemical and physical properties of the soil. Also, investigators have been attempting to determine the effect of various factors on the physical and chemical properties of the soil. The plan of this investigation was to determine how cropping systems and soil treatment influence the total nitrogen content, organic carbon content, carbon-nitrogen ratio, the presence of water-stable aggregates and the moisture equivalent values of the soil and in turn how one factor relates to another.

AREA STUDIED

The soil samples used in this investigation were taken from the Columbus Experiment Field. This station is located on the farm of Mrs. W. H. Shaffer, one mile west and three miles north of the Columbus High School, Columbus, Kansas.

The Columbus Experiment Field was organized in 1924 in cooperation with the late Mr. W. H. Shaffer. The land involved was divided into a number of series. Series A through F were used in this particular problem. Each series was 396 feet long and 132 feet wide with 25 feet between each series for a roadway. Within each series there were 12 one-tenth acre plots measuring 132 feet east and west and 33 feet north and south. The series were lettered from east to west while the plots were numbered from north to south.

The soil on the station is, for the most part, Cherokee silt loam which has a white ashy surface soil, a very heavy, dark gray, subsurface and an impervious, drab-colored subsoil which is flecked with red, yellow, and gray. The field is nearly level, the drainage being mostly toward the northwest corner. The area from which the samples were taken occurs in the northeast corner of the experiment field.

In 1925, alfalfa was established on Series F (Appendix, Table 8), and was followed by Series E, B, D, C, and A, in that order. In the fall of 1945, alfalfa was established on Series A for the first time since the experiment field was organized. The alfalfa was left on each of the other series for five years unless the stand failed before then. A rotation of corn, soybeans, flax, wheat, and oats with sweet clover followed the alfalfa. Only one stand of alfalfa has ever occurred on each series. There never has been a legume grown on Plot 10 of any series. This plot had the sweet clover omitted from the oats and had redtop grown in the place of alfalfa. Starting with the year of 1946, a mixture of redtop and brome grass was grown on Plot 10 of the series where alfalfa was grown. Sorghums were substituted for the soybeans on Plot 10 in each series when soybeans were grown.

Of the 12 different plots in each series, only Plots 1, 6, 7, 10, 11, and 12 were sampled. The amounts of fertilizer materials added to each plot have changed somewhat through the years but the nature of the treatment has remained essentially the same. Plot 1 has received only lime when needed so as to keep the soil at about a neutral reaction. All other plots, except Plot 12, have received the same lime treatment. No lime has ever been added to Plot 12. Plot 6 also received eight tons of manure per acre before seeding alfalfa and before the flax stubble was plowed under. Plot 7 received the same treatment as Plot 6 along with the following applications of 20 percent superphosphate per acre: 40 pounds on corn, 80 pounds on oats, 80 pounds on wheat, 120 pounds on alfalfa, and 40 pounds on the flax. The treatment for Plots 10 and 11 differ from Plot 7 in that they received no manure. Plot 12 received no treatment of any kind. Table 1 gives the crops grown and the soil treatments applied on each of the plots during the two-year period prior to the sampling of the area.

COLLECTION AND PREPARATION OF SAMPLES

Nine samples were taken, more or less at random from one end of the plot to the other, with a spade to a depth of about six inches. Each sample was passed through a one-half inch hail screen, then put into a waxed pasteboard container and numbered. No attempt was made to separate anything from the sample. These samples were left in the containers for three days before they were spread in the laboratory to become air dry. A two-week period elapsed before any analyses were started. The soil samples were stored in the laboratory where all of the analytical work was done. Analyses were made on each individual sample. Only the samples taken in the fall of 1946 were used in this investigation.

Table 1. Crops grown and soil treatments, on per acre bases, for the two-year period prior to the time of sampling.

Year	Series	Plots 1	6	7	10	11	12
1946	A	Alfalfa 1½T lime	Alfalfa 1½T lime	Alfalfa 1½T lime	Redtop & brome 1½T lime	Alfalfa 1½T lime	Alfalfa
			8T manure				
				120 lbs. 20% superphosphate			
	B	Flax	Flax	Flax	Flax	Flax	Flax
				40 lbs. of superphosphate			
	C	Corn	Corn	Corn	Corn	Corn	Corn
				40 lbs. 20% superphosphate			
	D	Oats &* Sw. Cl.	Oats & Sw. Cl.	Oats & Sw. Cl.	Oats	Oats & Sw. Cl.	Oats & Sw. Cl.
				80 lbs. 20% superphosphate			
	E	Soybeans	Soybeans	Soybeans	Sorghums	Soybeans	Soybeans
				40 lbs. 20% superphosphate			
	F	Wheat	Wheat	Wheat	Wheat	Wheat	Wheat
			8T manure				
				80 lbs. 20% superphosphate			
1945	A	Oats & Sw. Cl.	Oats & Sw. Cl.	Oats & Sw. Cl.	Oats	Oats & Sw. Cl.	Oats & Sw. Cl.
	B	Soybeans	Soybeans	Soybeans	Sorghums	Soybeans	Soybeans
				40 lbs. 20% superphosphate			
	C	Alfalfa	Alfalfa	Alfalfa	Alfalfa	Alfalfa	Alfalfa
	D	Wheat	Wheat	Wheat	Wheat	Wheat	Wheat
			8T manure				
				80 lbs. 20% superphosphate			
	E	Corn	Corn	Corn	Corn	Corn	Corn
				40 lbs. 20% superphosphate			
	F	Flax	Flax	Flax	Flax	Flax	Flax
				40 lbs. 20% superphosphate			

*Sw. Cl. indicates sweet clover throughout the tables.

REVIEW OF LITERATURE

Moisture Equivalents

Some of the early work done in soil science research was with regard to the moisture equivalent values of the soil. Briggs and McLane (12, 13) were among the outstanding early workers. The procedure which they established was basically that which was still being used by investigators during the time of this investigation. During this early period of investigation, Briggs and McLane (12) defined moisture equivalent as the amount of moisture retained in the soil, 10 mm. deep in the moisture equivalent box, after being centrifuged at 1000 times the force of gravity for 40 minutes. Later investigations on certain factors affecting moisture equivalent values and best methods to use in making the determinations were made by Veihmeyer, Oserkowsky and Teeter (61). These investigators found that, for the most part, the procedure of Briggs and McLane (12) was sound and reliable. As more modern equipment became available to research workers, higher speeds with greater centrifugal forces, were tried in making moisture equivalent determinations. Olmstead (46) did some work with high-speed centrifuges. However, for the most part, the recommendations made by Veihmeyer, Oserkowsky and Teeter (61), with small modifications, are still used in many soil science research laboratories.

Briggs and McLane (13), Coile (17), Joseph and Martin (30), Russell (52) and Olmstead (46) propose that the moisture equivalent value of a soil is influenced by the texture of that soil. The moisture equivalent value becomes greater as the texture becomes finer, according to these investigators. If the texture is kept constant then other factors may be involved. Such investigators as Briggs and McLane (12), Coile (17), Gyeel (25), Joseph and Martin (30), Russell (52), and Stauffer (57) have shown that increased organic matter brought about an increase in the moisture equivalent value of the soil. A number of investigators have indicated that the application of lime on the soil caused the moisture equivalent to increase while others suggested that the moisture equivalent value did not change. McHenry and Rhoades (37) and Russell (52) found that an addition of lime to the soil increased the moisture equivalent value. According to these investigators, this increase was probably due in part to the moisture retained by the calcium carbonate and in part to a greater degree of aggregation. Also it may have been due to the dispersing effect of the calcium on the soil. Alderfer and Merkle (3), Baver and Hall (6), Martin and Waksman (35), and Myers (40) have actually proved that calcium-saturated colloids in the soil are more easily dispersed than are the same colloids when carrying considerable adsorbed hydrogen. This dispersed condition of the soil colloids may have caused the moisture equivalent of that soil to be higher. Elson and Lutz (23) suggested that the addition of calcium through superphosphate may result in some breakdown of the physical condition of the soil. From the data that these investigators have gathered, it would seem that calcium should directly increase the moisture equivalent of the soil through its dispersing effect on the soil, and indirectly cause the moisture equivalent value to be increased by the increased production of organic matter.

The crop grown may also have some effect on the moisture equivalent value. Stauffer (57) found that corn and oats in a fertilized and limed legume rotation gave a higher moisture equivalent value than the unfertilized continuous corn rotation.

Water-Stable Aggregates

For many years, field observations have indicated that some crops, when removed from the land, left the soil loose and friable while other crops seemed to cause no changes. Still other crops caused the soil to become hard and cloddy. Most of this knowledge is based purely on qualitative observations in the field. Numerous investigators have developed quantitative measures that might be used in the laboratory to determine the physical characteristics of the soil. To mention a few, Baver and Rhoades (7) have worked on the elutriation method, Bouyoucos (10) has worked with slaking and wet-sieving methods. He has also done some work with the hydrometer. A wet-sieve method is described by Nichols (44). With all of the methods developed there is still lack of a good acceptable method. Work done by Nijhawan and Olmstead (45) showed that methods used may be in error since pre-wetting by vacuum or by capillarity gave much higher results. Bouyoucos (11) was of the opinion that the ordinary structure of the soil as seen in the field is not the ultimate, natural structure of the soil. He said that this field structure is changeable, temporary, accidental, and artificial. He suggested that "gentle, but quite vigorous," slaking of the soil particles and granules in a large quantity of water does not decrease their original, natural size.

Within one method of determining water-stable aggregates, there are other factors that tend to determine the quantity of water-stable aggregates in the soil. Browning (14) found that an application of organic matter to a soil of relatively poor physical condition materially improved the soil structure. Browning and Milam (15, 16) and Martin and Waksman (34, 35) obtained results which indicated that organic material that decomposed rapidly increased the aggregation, causing it to reach a maximum within 20 to 30 days and then a gradual decrease occurred. Resistant materials decayed slower and had a longer lasting effect. Bogachuk and Kurapov (9), Elson (22), and Weldon and Hide (62) did work which suggested that as the organic matter content of the soil decreased, so did the degree of aggregation of the soil. Work by Alderfer and Merkle (3) indicated that even light applications of manure produced structural improvement of the soil. A significant correlation was obtained by these investigators for organic matter and aggregation. Hide and Metzger (26, 27), Ilmenev (28), and Woodruff (64) have done work which indicated that the more aggregared the soil is the higher is the organic carbon content. On the other hand, Browning (14) and Bertramson and Rhoades (8) found that organic matter may or may not affect the physical properties of a soil. Browning (14) found that applications of organic matter to soils which had large amounts of either active inorganic colloids, or organic colloids, did not show an appreciable change in aggregation Rost and Rowles (51) concluded that clay and organic matter are limiting aggregation factors. In most of the soils they investigated, they found that humus rapidly lost its effect after the soil contained 2 to 2.5 percent or more humus. Work done by Ackerman and Myers (1) on a claypan soil indicated that there is no correlation between water-stable aggregates and organic matter content. Retzer and Russell (49), Rogers (50), and Stauffer, Muckenhirn, and Odell (58) found no simple relationship between the total organic carbon and the degree of aggregation of field soils. McHenry and Russell (38) observed that undecomposed organic matter reduced aggregation. They concluded that incubation of the organic material is first necessary before improved aggregation will result.

Johnston, Browning, and Russell (29) found that the size of distribution of soil aggregates may be influenced materially by the cropping system, with the greatest number of larger sized aggregates in bluegrass followed by red clover, oats, rotation corn, and continuous corn, respectively. Ackerman and Myers (1) found that alfalfa brought about marked improvement of the soil structure but this improvement disappeared within three years after the alfalfa sod was broken. Elson (20, 21, 22) reported that continuous corn or wheat reduced the aggregation of the soil. The manuring of continuous corn or wheat caused an increase in aggregation. In a rotation with corn, wheat and white clover, with no manures or fertilizers, the aggregation under each crop was not significantly different. When manure and fertilizer were used, the white clover gave the best aggregation. Hide and Metzger (27) found that wheat and sweet clover produced similar results but alfalfa produced increased aggregation. Unexpectedly, grass sods caused lower aggregation than did many other crops. Russell (52) reported that Russian workers have found that two or three years of grass sod are essential before improvement in structure is noticeable. Van Doren and Stauffer (60) found that corn provided for better aggregation of the soil than will soybeans. Myers and Myers (43) also found that a legume rotation will cause a better physical condition in the soil than a nonlegume rotation.

Investigations made by Martin and Waksman (35) revealed that alfalfa and straw were more effective than manure, which in turn was more effective than peat and lignin, in establishing aggregates. Kolodny and Neal (31) have done work which suggested that any condition causing the soil to dry thoroughly would be effective in structural attainment. The desiccating effect on the soil of grass sods produces the necessary alternate wetting and drying which is effective in structural attainment. They also stated that any factors operating in the soil which tend to prevent the wetting of the colloidal interface will help to prevent dispersion. A protective coating of organic matter or entrapped air is effective. Desiccated humus tends to be hydrophobic and thus resists dispersion. Clay colloids are hydrophillic and thus tend to disperse.

Biological activity in the soil has its effect on the soil structure. McCalla (36), Myers and McCalla (42) and Peele and Beale (48) found that biological decomposition caused increased stability of the soil structural units, but this effect was only temporary and apparently remained only as long as the biological by-products lasted. Under the conditions of his experiment, Dawson (18) found no relationship between microbial population on one hand and soil aggregation or crop yield on the other. Myers and McCalla (42) found that in no instance did maximum aggregation coincide with maximum bacterial numbers but lagged behind the bacterial numbers during both the growth and the death phases. Such investigators as Geltzer (24), Martin (33), Myers and McCalla (42), and Peele (47) have gathered data which indicated that bacteria were associated with the aggregation of soil particles in so far as they are responsible for the accumulation of certain metabolic products that function as cementing materials. Dawson (18) also reported that where fungi were involved, the mycelium played an important role in soil aggregation.

There has been a great amount of work done by such investigators as Alderfer and Merkle (3), Browning and Milam (15, 16), Martin and Waksman (34, 35), and Myers (40, 41) which suggested that lime with decomposing organic material caused improved aggregation of the soil, while lime alone had little effect or possibly produced a decrease in aggregation. Alderfer and Merkle (3) also collected data which indicated that lime with commercial inorganic fertilizers, gave no improvement in structural stability.

Data have been collected by Baver and Hall (6), Elson and Lutz (23), and Myers (40) which indicated that calcium colloids are more readily dispersed in water than hydrogen colloids. Myers (40) found that calcium or hydrogen-saturated organic colloids were several times more effective in cementing sand particles into water-stable aggregates than were the corresponding inorganic colloids. An interesting piece of work done by Elson and Lutz (23) indicated that the addition of calcium to the soil through superphosphate resulted in decreased aggregation. This was apparently due to the formation of calcium humates. They found that hydrogen and sesquioxide humates increased aggregation regardless of the amount of organic matter, thus indicating that the total amount of organic matter is not as important as the condition of humus in causing aggregation. Lutz (32) proposes that iron may serve as a flocculating agent as well as a cementing agent in the soil.

The methods used in determining water-stable aggregates will influence the amount of aggregates found within different size groups. According to such investigators as Baver and Rhoades (7), Elson (20), Nijhawan and Olmstead (45), and Russell (52), air drying of the soil before making the aggregate analysis will cause the percentage of water-stable aggregates to be lower. They reported that restoration of the moisture by capillary or vacuum wetting of the soil before analysis was made tended to correct this situation. Elson (20), Myers and McCalla (42), Sideri (55), and Woodburn (63), pointed out that it appeared as though drying destroyed the aggregating effect of the water films. Alderfer (2) suggested that the season of the year when the soil samples were taken may influence the degree of aggregation.

Organic Carbon and Total Nitrogen

Investigators in soil science are in general agreement that any soil treatment or cropping system that will cause succeeding crops to grow more abundantly will also cause the organic carbon content of the soil producing such crops to be at a higher level than a soil producing crops that are not so abundant in growth. It is also generally accepted that as the organic carbon content of the soil goes up so does the nitrogen content but not necessarily at the same rate. Such authorities as Ackerman and Myers (1), Bogachuk and Kurapov (9), Metzger (39), Rogers (50), and Salter (53) have collected data which indicated that an application of lime on soils deficient in calcium, or acid in reaction, caused improved plant growth, particularly in the case of the legumes. Work by Browning (14) and Hide and Metzger (26, 27) gave added proof to the accepted belief that cultivation over the years causes a reduction of organic carbon and total nitrogen content of the soil. Dean (19) has shown that the nitrogen content of a soil did not increase in as great proportions as did the organic carbon content.

Although the effects tended to be in the same direction, some crops caused a different effect on the soil with different soil treatments. Stauffer (57) and Stauffer, Muckenhirn, and Odell (58) found that an unfertilized continuous corn plot was lower in organic carbon than the fertilized corn, oats and clover rotation. Metzger (39) found that alfalfa on a previously cultivated soil increased the nitrogen and carbon content of the soil in spite of the fact that the top growth was removed for hay. He also found that manured plots and fertilized plots contained more nitrogen and organic carbon than the untreated plots because of the increased crop residue. Applications of lime held the nitrogen and organic carbon to the level of the manured and fertilized plots. During the time of their experiment, Johnston, Browning and Russell (29) found that continuous corn reduced the organic matter content of the soil from 3.39 percent in 1931 to 2.86 percent in 1942. They found no significant differences in the organic matter content under bluegrass or a rotation of corn, oats and clover during the time of the investigation. Salter and Green (54) have estimated that a single year's cropping to the various crops has increased or decreased the organic carbon content of the soils in Ohio by the following percentages of the total organic carbon present in the soil: corn, -3.12; wheat, -1.44; oats, -1.41; hay in 5-year rotation (timothy predominating), +1.36; hay in 3-year clover rotation, +3.25. The corresponding values for nitrogen are: corn, -2.97; wheat, -1.56; oats, -1.45; hay in 5-year rotation, +0.64; hay in 3-year rotation, +2.87. They also found that residues from the corn crop were of little value in conserving soil nitrogen or organic matter, residues from oats were notably effective, and residues from wheat crops were intermediate in value. These investigators estimated that about one-half of the nitrogen and organic carbon conserved during 32 years in the soil of a liberally manured plot in the five-year rotation, was due to residues from the larger crops grown. The applications of the manure left residues which probably account for the remainder of the organic carbon and nitrogen conserved.

Carbon-nitrogen Ratio

The fact that the carbon-nitrogen ratio widens with increased annual rainfall or decreased annual temperature is general knowledge among soils investigators. Decreasing temperature has the same effect as increased altitude. Dean (19) observed these facts in his investigations of Hawaiian soils. Salter (53) generalized on some well-known facts when he wrote that a carbon-nitrogen ratio wider than 10 to 1 caused the loss of organic carbon from the soil and that when the ratio was narrower than 10 to 1 there tended to be a saving of organic carbon or a loss of nitrogen. Metzger (39) found that wheat maintained a wider carbon-nitrogen ratio than did alfalfa in the same soil. Hide and Metzger (27) reported that the carbon-nitrogen ratio was wider in well-aggregated soil fractions than in the poorly aggregated fraction. Elson (21) obtained information which indicated that the carbon-nitrogen ratio was not significantly different from sample to sample. This information was in agreement with Rost and Rowles (51) who found that, although organic matter was positively correlated with soil aggregation, there was no correlation between the carbon-nitrogen ratio and aggregation.

STATISTICAL METHODS USED

Since the experimental plots used in this investigation are arranged systematically, the validity of the analysis of variance is questionable. Therefore a number of comparative observations were necessarily made. A correlation of the various factors investigated seemingly was justified. Procedures used for the statistical analysis of the data were taken from Snedecor (56).

EXPERIMENTAL PROCEDURES AND RESULTS

Moisture Equivalents

The moisture equivalent determinations were made during the summer months of 1947. The temperature of the laboratory during the time of the actual determinations, with three exceptions, ranged from 32° to 39° C.

The procedure used for making the moisture equivalent determinations was very similar to the one Veihmeyer, Oserkowsky and Tester (61) recommended. Since soils laboratories vary in equipment, a number of minor variations from the old accepted standard procedure have resulted. Thus the procedure used for making the moisture equivalents is given in detail.

Each sample, after having been air dried and put in storage for six months, was crushed so as to pass a 10-mesh sieve. Any sand or gravel which would not pass this sieve was discarded. After passing the 10-mesh sieve, the coarser material was crushed, mechanically, still further, taking care not to pulverize the soil. This added crushing was done for the purpose of decreasing the size of the pore spaces in the sample to a more favorable size when the soil was placed in the centrifuge boxes.

The bottoms of the centrifuge boxes were carefully covered with squares of thin filter paper which were just a fraction larger than the bottoms of the boxes. This oversize in filter paper was an added insurance against the loss of soil. The boxes were then filled with enough air-dry soil so that the combined weights of filter paper and oven-dry soil would be approximately

30 grams. The air-dry soil carried between one and one and a half percent moisture on the oven-dry bases. Care was exercised in keeping the fine and coarse soil uniformly mixed throughout the sample. The surface was then smoothed with a specially prepared block of wood so that the curvature of the sample surface would be approximately the same as the curvature of the centrifuge bowl. There were eight soil samples in a set plus their respective duplicates.

Each set of samples was placed in a flat glass vessel and enough distilled water was added to just cover the soil in the boxes. These samples were allowed to stand over night in the water and were permitted to drain two to four hours the next morning before centrifuging.

The samples were so arranged in the centrifuge that the duplicates were opposite each other. This served to keep the centrifuge balanced. The samples were then centrifuged for 40 minutes at a force 1000 times that of gravity. The centrifuge was brought to the desired speed in approximately two minutes.

The centrifuge used was an early model of the International Instrument Company. A Frahm, vibrating reed, Tachometer, mounted on the base of the centrifuge was used to determine the speed of the centrifuge. The speed was regulated by a hand-manipulated rheostat which was mounted next to the centrifuge.

After centrifuging, the samples, including the boxes and filter papers, were immediately placed in a humidor, taken to a Torsion Balance and weighed to the nearest .01 gram. The samples were then placed in an oven and dried over night at 105° C. After cooling in a desiccator, the samples were weighed. The moisture equivalent (percent moisture on the oven-dry basee) was calculated by the following equation:

Moisture equivalent =

$$\frac{\text{wt. of box and wet sample} - \text{wt. of box and dry sample}}{\text{wt. of dry sample and box} - \text{wt. of box}} \times 100.$$

This equation includes the filter paper as soil. According to work done by Olmstead (46), results are probably most accurate if the filter paper is included as soil. This is done because it is very difficult to determine the amount of water the filter paper contains when the centrifuging is over. The filter paper probably contains more water after the centrifuge is stopped than before the centrifuge starts to slow down. The weight of the filter pore was only about 0.16 gram.

Only the average moisture equivalent value for each plot of each series (Table 2) was recorded in this investigation.

Table 2. Mean moisture equivalent value of each plot of each series. (Each value represents the average of nine samples.)

Series	Plots						Av.
	1	6	7	10	11	12	
A	20.62	19.64	20.41	21.19	21.28	21.39	20.76
B	21.94	20.88	20.90	19.70	20.60	19.90	20.65
C	23.03	20.71	21.32	20.92	20.05	20.01	21.01
D	20.86	22.13	21.69	20.90	20.33	19.79	20.95
E	23.08	22.77	22.75	21.10	21.06	20.38	21.86
F	22.54	22.73	22.90	21.11	20.58	19.97	21.64

An examination of Table 2 and Fig. 1 revealed a number of interesting facts. First of all it was observed that the average

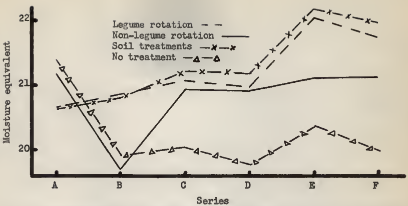

Fig. 1. A comparison of moisture equivalent values of soils under a legume rotation with a non-legume rotation and also a comparison of soils receiving treatments (such as lime, manure, etc.) with soils receiving no treatments.

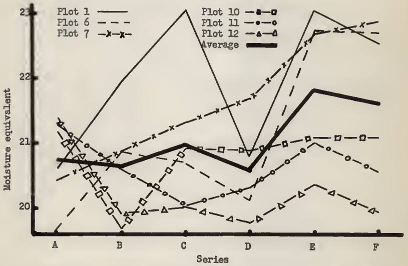

Fig. 2. A plot to plot comparison of moisture equivalent values in each series.

moisture equivalent value of all of the plots in each series with a legume rotation had a higher moisture equivalent than the nonlegume plot of each series, with but one exception. The differences between the legume and the nonlegume rotations are not statistically significant. (Appendix, Table 9.) A comparison of the no-treatment plot of each series with the plots receiving some sort of treatment is very similar to the previous comparison except that the differences were statistically significant. (Appendix, Table 10.)

In both comparisons in Series A, the results were just opposite those which most investigators have reported. The reason for these results was quickly answered by determining the organic carbon content of each plot. Plot 12 of Series A proved to be higher in organic carbon (Table 4) than any other plot of the series. Table 7 indicated that the correlation between organic carbon and moisture equivalent was highly significant statistically in a positive direction.

An analysis of variance (Appendix, Table 8a) showed a highly significant interaction between crops and soil treatments, and a highly significant difference between soil treatments.

A comparison of the two plots which differed only in superphosphate treatment (Plots 6 and 7 of Fig. 2) indicated that the use of superphosphate seemed to slightly increase the moisture equivalent value of the soil. A glance at Fig. 8 indicated that the organic carbon content of the same two plots compared about the same as did the moisture equivalent values. The variations between the plots were not statistically different. As some workers (23) have suggested, the extra calcium added to the plot through the use of superphosphate (Table 1) may have caused this difference between the moisture equivalent values of the two plots. However, the amount of calcium added would be relatively small compared to the amount added to both of the plots in the form of 1½ tons of limestone per acre only the fall before the samples were taken. The difference was probably due to the increased plant residues which were produced as the result of the addition of an essential plant nutrient, phosphorus, which is known to be highly deficient in Southeast Kansas soils.

A comparison of Plot 12, the no-treatment plot, with Plot 1, the plot receiving only lime, showed that, with exception of Series A, the use of lime had certainly maintained a higher moisture equivalent value. These higher moisture equivalent values were probably due to a generally higher level of organic matter (Fig. 8), and to the direct effect of the lime. The lime had been on this series only one year since the last application. The comparison of Plots 1 and 12 might be somewhat questionable, since they are located on opposite ends of each series.

In a general way, it may be said that any of the soil treatments used in this investigation raised the moisture equivalent as compared to no soil treatment (Plot 12). Figure 2 indicated in general that the treatments of Plots 1 and 7 resulted in a generally higher moisture equivalent than the treatments of Plots 10, 11, and 12. These differences may be due either to soil treatments or to crop. With the exception of the series on which the alfalfa occurred, the crop changed on each plot every year. This made it impossible to successfully ascertain the individual effect of crops on the moisture equivalent values. Series C was in alfalfa the four years prior to 1946, yet the moisture equivalent values of that series were not distinctly different from any other series with the possible exception of Series F. Series F had not had alfalfa on it since 1929 (Appendix, Table 8). The last year for sweet clover to occur on this series was in 1942.

The unusually high moisture equivalent values in Plots 6 and 7 in Series F may have been due to the eight tons per acre application of manure (Table 1) made on the wheat series just before it was plowed. The situation in Series E could not be explained on the same basis as was Series F because the last application of manure made on Series E was in the fall of 1942. Series A and D received equal applications of manure in the fall of 1943 and 1944, respectively. The situation in Series E, like the one previously mentioned in Series A, could not be satisfactorily answered from data collected in this investigation. It was true that the organic carbon content of these plots was also generally high, but as to why the carbon content was so high can not logically be answered here.

Water-Stable Aggregates

The procedure used to make the determinations was the one described by Nichols (44) with one variation. A mechanical analysis was not made. Therefore, the different groups of separates of the mechanical analysis were not subtracted from the respective separate groups of the aggregate analysis.

The water-stable aggregate determinations were made during the early part of 1947. Each of the 324 samples was analyzed in duplicate and the average of these duplicates was recorded for statistical interpretation. Only the aggregated fraction of the sample larger than 0.20 mm. was used in this study. Tiulin (59) suggested that the aggregates larger than 0.25 mm. are responsible for favorable structural relationships in the soil.

Only the average aggregation of each plot of each series (Table 3) is recorded in this paper. These values were used for the comparisons which were made. An analysis of variance was not applied to these data, however. An analysis of variance (Appendix, Table 11) was made on the entire 324 samples.

Table 3. Mean percentage of water-stable aggregates larger than 0.20 mm. (Each value represents the average of each respective plot.)

Series	Plots						Av.
	1	6	7	10	11	12	
A	18.54	17.81	19.65	24.54	21.90	25.16	21.27
B	24.85	23.36	27.01	31.37	23.23	21.62	25.24
C	30.97	27.67	26.80	26.64	28.48	32.66	28.87
D	36.42	29.60	26.24	22.72	24.06	23.29	27.06
E	25.86	25.08	21.90	18.15	23.74	21.56	22.71
F	26.78	22.53	24.97	22.71	26.39	22.22	24.27

The analysis of variance of the 324 samples suggested that there was a significant difference between the soil series. Since the crops changed every year on each series (Appendix, Table 8), it could not justly be said that the significant difference was between crops. Since the crops were not grown on the same area during successive years, with the exception of alfalfa, it was difficult to satisfactorily explain why some of the series were sig-

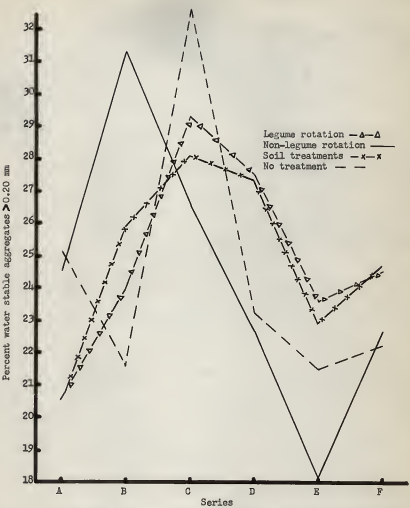

Fig. 3. A comparison of aggregation in soils under a legume rotation with non-legume rotation and also a comparison of soils receiving treatments (such as lime, manure, etc.) with soils receiving no treatments.

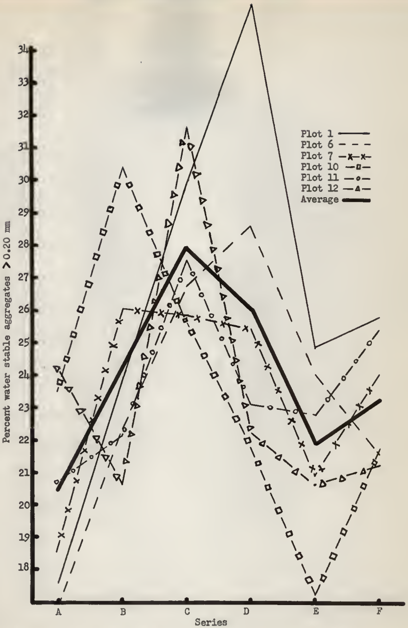

Fig. 4. A plot to plot comparison of aggregation in each series.

nificantly different in water-stable aggregates larger than 0.20 mm. Although alfalfa had been removed from Series C for one year, there seemed to be a residual effect of the alfalfa on the soil (Fig. 4). Series D had the second highest percentage of water-stable aggregates larger than 0.20 mm. Series D had been in alfalfa for a three-year period previous to Series C. The series with the next highest water-stable aggregates, Series B, had been in alfalfa the four-year period before Series D. Whether this condition in Series B was due to the alfalfa crop which was plowed up in 1938 may be questionable, since it is the general thought of many investigators that an improved structural condition of the soil due to alfalfa will be apparent only about three years after the alfalfa is plowed under. On the basis of this assumption, it may be doubtful that the condition in either Series B or D was due to the residual effect of the earlier alfalfa crops. The lower aggregation in Series A and E may have been due, in part, to the intensive cultivation the plots of each series received during the year and a half previous to the date of sampling.

Another possible reason for the lower aggregation of the soil in Series A may have been due to the lime added the year before. The fall before sampling, Series A, with the exception of Plot 12, received a ton and a half application of finely ground limestone per acre. This lime may have directly caused some dispersion of the soil aggregates. Plot 10 indicated that it was as highly aggregated as the plot receiving no lime (Plot 12). This would suggest that the lime had no effect. Plot 10 was in brome grass and redtop, while Plot 12 was in alfalfa, although at sampling time it appeared that much of the alfalfa was being replaced by wild grasses.

Plot 10 of Series E gave a very low result compared to the average of any of the other plots of the rest of the series. This condition may be explained in part by the fact that the sorghum crop, substituted for soybeans on the nonlegume plot, was killed early in the growing season by chinchbugs. Due to dry weather, reseeding was not possible and thus the plot was essentially under a period of summer fallow during the remainder of the summer. The summer fallow would probably have tended to destroy the water-stable aggregates of the soil.

A comparison of the water-stable aggregates of all of the plots receiving a legume rotation in each series with the nonlegume rotation (Fig. 3) showed no statistically significant differences (Appendix, Table 12). Further examination of Fig. 3 would suggest that within Series A and B alone, the percent water-stable aggregates was higher in the nonlegume plots than in the legume rotation. Ordinarily, one would expect the legume rotation to be most highly aggregated. Series C, D, E, and F within themselves had a higher degree of aggregation in the legume rotation than in the nonlegume rotation. A comparison of the plot receiving no soil treatment, Plot 12, with all of the plots receiving some sort of treatment, as lime, manure, superphosphate, etc., showed that there were no consistent significant differences in any of the series (Appendix, Table 13).

The analysis of variance (Appendix, Table 11), indicated a highly significant interaction. Since there were no plots with a continuously grown crop, it was not possible to decide just where the interaction occurred. Perhaps the lack of consistent differences in degree of aggregation between crop rotations or soil treatments could be explained by interaction. It was found that the degree of aggregation correlated with none of the factors studied in this investigation, with the exception of the carbon-nitrogen ratio (Table 7). The soils investigated were probably too high in either organic matter or active inorganic colloids, or both, to show a significant correlation between percent organic carbon and percent water-stable aggregates larger than 0.20 mm. There was, however, an indication of a negative correlation (Table 7) between aggregation and the carbon-nitrogen ratio. This indicated that as the carbon-nitrogen ratio became wider the percent of aggregated soil became smaller, thus suggesting that it was the end productes of decomposed carbonaceous materials which were responsible for improved aggregation and not the more carbonaceous organic materials.

Organic Carbon and Total Nitrogen

The organic carbon determinations were made by the Schollenberger method, using the reduction of chromic acid as outlined by Allison (4). The results recorded in this paper were the average percents of organic carbon for each plot of each series studied (Table 4).

The total nitrogen determination followed the Gunning-Hibbard procedure (5) but was modified according to the steps of previous work done by Metzger (39). As for the carbon determinations, only the average percent nitrogen content of each plot of each series was recorded in this investigation (Table 5).

The analysis of variance (Appendix, Tables 17 & 14) for organic carbon and total nitrogen was made on the 324-sample determinations made. These 324 determinations are not recorded in this paper.

It was found that the total nitrogen and the organic carbon content of the samples had a very high positive correlation (Table 7). Thus it seemed proper to discuss both total nitrogen and organic carbon together.

Table 4. Percent organic carbon in each plot of each series. (Each value represents the average of nine samples.)

Series	Plots						Av.
	1	6	7	10	11	12	
A	1.09	1.29	1.34	1.26	1.32	1.38	1.28
B	1.18	1.38	1.32	1.16	1.34	1.20	1.27
C	1.38	1.33	1.33	1.06	1.14	1.09	1.22
D	1.23	1.45	1.35	1.14	1.18	1.14	1.25
E	1.36	1.37	1.38	1.11	1.22	1.14	1.26
F	1.14	1.31	1.33	1.15	1.22	1.16	1.22

Table 5. Percent total nitrogen in each plot of each series. (Each value represents the average of nine samples.)

Series	Plots						Av.
	1	6	7	10	11	12	
A	.094	.108	.111	.101	.113	.118	.107
B	.105	.118	.116	.098	.114	.110	.110
C	.123	.119	.115	.097	.109	.097	.110
D	.112	.125	.120	.102	.110	.102	.112
E	.114	.116	.116	.094	.109	.104	.109
F	.105	.118	.117	.099	.105	.104	.108

An analysis of variance (Appendix, Tables 14 & 17) for both total nitrogen and organic carbon indicated that there were no significant differences between the respective series. There were, however, highly significant interactions. The differences between soil

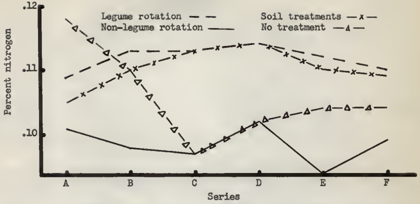

Fig. 5. A comparison of the percent nitrogen in soils under a legume rotation with a non-legume rotation and also a comparison of soils receiving treatments, (such as lime, manure, etc.), with soils receiving no treatment.

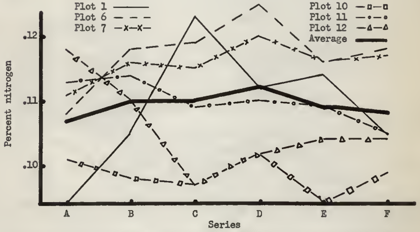

Fig. 6. A plot to plot comparison of the percent nitrogen in each series.

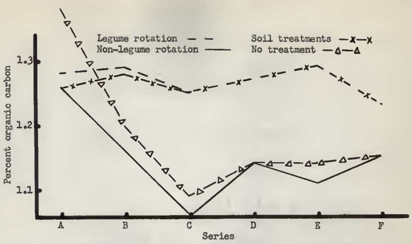

Fig. 7. A comparison of the organic carbon contents of soils under a legume rotation with a non-legume rotation and also a comparison of soils receiving treatments, (such as lime, manure, etc.), with soils receiving no treatment.

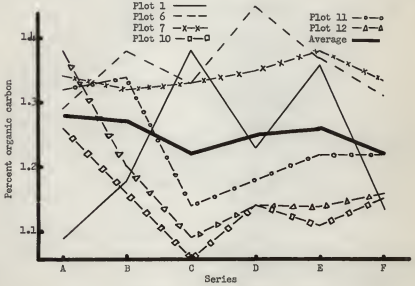

Fig. 8. A plot to plot comparison of organic carbon contents in each series.

treatments were also highly significant. An examination of Figs. 6 and 8 illustrated very well that soil treatments did influence the percent nitrogen and organic carbon carried in the soil. Plot 10, the nonlegume rotation plot, carried the least amount of nitrogen and organic carbon of any plot of any series other than Series A. Within Series A, Plot 1, the lime plot on which a legume rotation was followed, carried the least nitrogen and organic carbon of that series. Why this condition occurred could not be satisfactorily explained in this investigation. It would seem that Plot 1 of Series A would have been in much better condition for the production of organic matter than Plot 10 of the same series. Plot 12 of each series followed along very well with Plot 10, which indicated that a legume rotation without some soil treatment was very little more effective than the soil treatments without a legume rotation. This suggested that the two were needed together in order to keep the organic carbon and total nitrogen content of the soil relatively high, thus explaining the highly significant interaction.

A study of Figs. 6 and 8 showed that Plot 12 of Series A, which was in alfalfa at the time of sampling, was higher in total nitrogen and organic carbon than any other plot in that series. It could have been possible that Plot 12 was in such a condition that microbial activity was hindered and thus organic materials were conserved rather than being decomposed. But if such a condition existed in Series A, then the same would have been expected in each of the other series, unless it would be due to the alfalfa which was on Series A for the first time since the experiment station was organized.

An analysis of variance (Appendix, Tables 15 and 18) indicated that a legume rotation will maintain the total nitrogen and organic carbon content of the soil at a significantly higher level than a nonlegume rotation. Also it was indicated that fertilized and limed soils would remain higher in total nitrogen and organic carbon content than a soil which received neither lime nor fertilizer (Appendix, Tables 16 and 19).

Carbon-nitrogen Ratio

The carbon-nitrogen ratios recorded in this investigation were arrived at by first dividing each of the 324 organic carbon determinations by their respective 324 total nitrogen determinations. From these values, the average value for each plot of each series was calculated and recorded in Table 6.

Table 6. Average carbon-nitrogen ratio of each plot of each series. (Each value represents the average of nine samples.)

Series	Plots						Av.
	1	6	7	10	11	12	
A	11.63	11.70	12.03	12.54	11.65	11.69	11.91
B	11.24	11.65	11.38	11.83	11.76	10.93	11.47
C	11.30	11.17	11.59	10.83	10.48	11.11	11.08
D	10.95	11.59	11.21	11.24	10.76	11.12	11.15
E	11.99	11.82	11.93	11.83	11.20	10.97	11.62
F	10.80	11.12	11.38	11.64	11.64	11.23	11.30

An analysis of variance (Appendix, Table 20) indicated that the carbon-nitrogen ratio was significantly different between soil series. There was also a significant interaction. An examination of Fig. 9 indicated that, with the exception of Series C, the non-

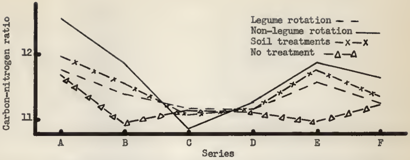

Fig. 9. A comparison of carbon-nitrogen ratios in soils under a legume rotation with a non-legume rotation and also a comparison of soils receiving treatments, (such as lime, manure, etc.), with soils receiving no treatment.

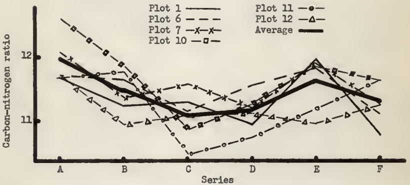

Fig. 10. A plot to plot comparison of carbon-nitrogen ratios in each series.

legume rotation has a wider carbon-nitrogen ratio than did the legume rotation. The differences between the two rotations were statistically significant (Appendix, Table 21). The plots under a legume rotation probably produced materials which were, on the average, less carbonaceous than the organic materials produced on the nonlegume rotation. A comparison of Plot 10 with Plot 11 illustrated the same general difference. With the exception of Series C, all of the plots which received lime, manure or superphosphate, or some combination of these treatments (Fig. 9), had a wider carbon-nitrogen ratio than the no-treatment plot, Plot 12, of each series. The difference between these two groups of treatments was also statistically significant (Appendix, Table 22). There seemed to be no good explanation as to why the no-treatment plots should have a narrower carbon-nitrogen ratio than the average of the plots which received lime, manure or fertilizer treatment. There was a significant positive correlation between the carbon-nitrogen ratio and the organic carbon content (Table 7), which indicated that as the organic carbon content of the soil became lower, the carbon-nitrogen ratio became narrower.

A comparison of the nonlegume plot, which received lime and superphosphate, with the no-treatment plot, which had a legume rotation (Fig. 9), indicated that the no-treatment plot had a narrower carbon-nitrogen ratio than the nonlegume plots. This difference was, in general, the same difference found in the organic carbon comparisons (Fig. 8).

CORRELATION OF EXPERIMENTAL DATA

All of the calculations used in making the correlation determinations for this investigation are recorded in Table 7. The data for these calculations were taken from Tables 2, 3, 4, 5, and 6. Since there were 36 different values for each factor studied, the degrees of freedom used for the correlations were 34. Therefore, to be statistically significant at the 10, 5, 1, or 0.1 percent levels, the significant correlation values were at least 0.279, 0.330, 0.424, or 0.526, respectively.

The water-stable aggregates correlated only with the carbon-nitrogen ratio and this was only at about the 7 percent level (Table 7). This correlation was negative, thus it indicated that as the carbon-nitrogen ratio became wider, the degree of aggregation decreased. This correlation indicated that perhaps aggregation is more dependent upon the humus and the end products of microbial activity in the soil than upon the more carbonaceous organic materials.

The moisture equivalent values indicated a positive correlation with the organic carbon and the total nitrogen contents of the soil (Table 7). This positive correlation would be expected, since organic matter has a very high affinity for water. Therefore, with increases in organic carbon and total nitrogen of the soil, which occurred with an increase in organic matter, there were increases in the amounts of water held in the soil. The moisture equivalent values were probably dependent upon the organic matter content of the soil. The organic matter content was probably not dependent upon the moisture equivalent values of the soil.

The correlation between organic carbon and total nitrogen was positive and highly significant. The correlation indicated that as the organic carbon content of the soil increased, so did the total nitrogen content. It was known by many earlier investigators, that as more and more organic materials were produced, the amount of organic carbon produced was increased. Since nitrogen was needed for plant and animal growth, the total amount of nitrogen used was also increased.

The organic carbon content was significantly and positively correlated with the carbon-nitrogen ratio. Such a correlation indicated that as the organic carbon content of the soil increased, the carbon-nitrogen ratio became wider. Such a relationship would have occurred if conditions were such that microbial activity was hindered, thus decreasing the rate of decomposition of organic materials. Therefore, with reduced microbial activity, organic material tended to accumulate, resulting in a higher organic carbon content of the soil, as well as a wider carbon-nitrogen ratio. The total nitrogen content of the soil did not correlate with the carbon-nitrogen ratio. This was probably due to the fact that the relative nitrogen increases were much smaller than the organic carbon increases.

SUMMARY

This study included the determination of water-stable aggregates, moisture equivalent values, the percentage organic carbon

Table 7. Correlation values of the factors investigated.

Factors correlated	Correlation values			
	Moisture equivalent values	Organic carbon content	Total nitrogen content	Carbon-nitrogen ratio
Water-stable aggregate values	0.1216	0.0753	0.2318	-0.3088[1]
Moisture equivalent values		0.5222**	0.5092**	0.1564
Organic carbon content			0.9022**	0.4468**
Total nitrogen content				0.0177

[1] Significant at about the 7 percent level.
** Significant at or above the 1 percent level.

and total nitrogen content, and the carbon-nitrogen ratio of a claypan soil under cultivation in Southeastern Kansas.

Soil treatments proved to give highly significant differences in the moisture equivalent values of the soil. Soils receiving fertilizers or lime had higher moisture equivalent values than the soils receiving no lime or fertilizers.

The moisture equivalent values had a highly significant positive correlation with the organic carbon content of the soil. The use of manure appeared not to have significantly changed the moisture equivalent values of the soil. There was some evidence that a legume rotation caused higher moisture equivalent values. Moisture equivalent values did not correlate with the carbon-nitrogen ratios. The use of superphosphate tended to increase the moisture equivalent values of the soil. The use of legumes without any kind of soil treatment, or the use of lime and superphosphate without legumes did not increase the moisture equivalent values of the soil, but the two used together tended to increase the moisture equivalent values.

Differences in the degree of aggregation, apparently due to the kinds of crops previously grown, proved to be highly significant.

Alfalfa appeared to have caused an increase in the degree of aggregation of the soil. The residual effect of alfalfa on the degree of aggregation appeared to last over a period of time as long as eight years.

The treatment of the soil under similar crops with superphosphate, manure or lime apparently caused no significant differences in the degree of aggregation.

The correlation of aggregation with carbon-nitrogen ratio was significant at about the 7 percent level and was negative. There were no significant correlations between aggregation and moisture equivalent values, organic carbon content or total nitrogen content.

The total nitrogen and organic carbon content proved to be higher in legume rotations than in the nonlegume rotation. These values also proved to be lower under a legume rotation receiving no soil treatment than under legume rotation receiving soil treatments.

The correlation between organic carbon and total nitrogen was positive and highly significant. Also the organic carbon content of the soil gave a significant positive correlation with the carbon-nitrogen ratio of the soil. There was not a significant correlation between the carbon-nitrogen ratio of the soil and the total nitrogen content of the soil.

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to Dr. H. E. Myers who outlined the studies; to Asst. Prof. F. W. Smith, his major instructor, who gave helpful suggestions in research technique; to Dr. L. B. Olmstead for his valuable suggestions in the making of physical analytical determinations, and also for the use of his equipment; and to Dr. H. H. Laude and Dr. H. C. Fryer for their advice in the statistical analysis.

BIBLIOGRAPHY

(1) Ackerman, F. G. and H. E. Myers.
Some factors influencing aggregation of claypan soils. Soil Sci., 55:405-413. 1943.

(2) Alderfer, R. B.
Seasonal variability in the aggregation of Hagerstown silt loam. Soil Sci., 62:151-168. 1946.

(3) Alderfer, R. B. and F. G. Merkle.
The measurement of structural stability and permeability and the influence of soil treatments upon these properties. Soil Sci., 51:201-212. 1941.

(4) Allison, L. E.
Organic soil carbon by reduction of chromic acid. Soil Sci., 40:311-320. 1935.

(5) Association of Official Agricultural Chemists.
Official and tentative methods of analysis. Assoc. Offic. Agr. Chemists. Washington, D. C. 5th ed. 757 p. 1940.

(6) Baver, L. D. and N. S. Hall.
Colloidal properties of soil organic matter. Missouri Agr. Expt. Sta. Res. Bul. 267. (Cited by Elson and Lutz in Soil Sci. 50:265-275. 1940.)

(7) Baver, L. D. and H. F. Rhoades.
Aggregate analysis as an aid in the study of soil structure relationships. Amer. Soc. Agron. Jour. 24: 920-930. 1932.

(8) Bertramson, B. R. and H. F. Rhoades.
The effects of cropping and manure applications on some physical properties of a heavy soil in Eastern Nebraska. Soil Sci. Soc. Amer. Proc. 3:32-36. 1938.

(9) Bogachuk, G. K. and I. A. Kurapov.
Changes in the physical chemical properties of the soil under continuous culture of sugar beets and under a system of crop rotations. Chemistion Socialistic Agr. (U.S.S.R.). 8:80-86. 1937. (Cited in Chem. Abs. 32:3070. 1938.)

(10) Bouyoucos, G. J.
A method for making mechanical analysis of the ultimate natural structure of soils. Soil Sci. 40:481-485. 1935.

(11) Bouyoucos, G. J.
The ultimate natural structure of soils. Soil Sci. 28:27-37. 1929.

(12) Briggs, L. J. and J. W. McLane.
Moisture equivalent determinations and their applications. Amer. Soc. Agron. Proc. 2:138-147. 1910.

(13) Briggs, L. J. and J. W. McLane.
The moisture equivalent of soils. U. S. Dept. Agr. Bur. Soils Bul. 45:1-23. 1927.

(14) Browning, G. M.
Changes in the erodibility of soils brought about by the application of organic matter. Soil Sci. Soc. of Amer. Proc. 2:85-86. 1937.

(15) Browning, G. M. and F. M. Milam.
Effect of different types of organic materials and lime on soil aggregation. Soil Sci. 57:91-106. 1944.

(16) Browning, G. M. and F. M. Milam.
Rate of application of organic matter in relation to soil aggregation. Soil Sci. Soc. of Amer. 6:96-97. 1941.

(17) Coile, T. E.
Effect of incorporated organic matter on the moisture equivalent and wilting percentage values of soils. (Abstract.) Soil Sci. Soc. of Amer. Proc. 3:43-44. 1938.

(18) Dawson, R. C.
Effect of crop residues on soil micropopulations, aggregation, and fertility under Maryland conditions. Soil Sci. Soc. Amer. Proc. 10:180-184. 1945.

(19) Dean, L. A.
The effect of rainfall on carbon and nitrogen contents, and carbon-nitrogen ratios of Hawaiian soils. Soil Sci. Soc. Amer. Proc. 2:455-459. 1937.

(20) Elson, J.
A comparison of the effect of certain cropping and fertilizer and manuring practices on soil aggregation of Dunmore silt loam. Soil Sci. 50:339-353. 1940.

(21) Elson, J.
A comparison of the effect of fertilizer and manure, organic matter, and carbon-nitrogen ratio on water-stable soil aggregates. Soil Sci. Soc. Amer. Proc. 6:86-90. 1941.

(22) Elson, J.
A 4-year study of the effects of crop, lime, manure, and fertilizer on macro-aggregation of Dunmore silt loam. Soil Sci. Soc. Amer. Proc. 8:87-90. 1943.

(23) Elson, J. and L. F. Lutz.
Factors affecting aggregation of Cecil soils and effect of aggregation on runoff erosion. Soil Sci. 50:265-275. 1940.

(24) Geltzer, F. Y.
The role of organic matter in soil structure. Chem. Soc. Agr. 8:53-63. 1937. (Cited in Chem. Abs. 32:3070. 1938.)

(25) Gysel, L. W.
The forest humus layers of Ohio. Soil Sci. 60:213. 1945.

(26) Hide, J. O. and W. H. Metzger.
Effect of certain crops and soil treatments on soil aggregation and the distribution of organic matter in relation to aggregate size. Amer. Soc. Agron. Jour. 30: 833-843. 1938.

(27) Hide, J. O. and W. H. Metzger.
Soil aggregation as affected by certain crops and organic materials and some chemical properties associated with aggregation. Soil Sci. Soc. of Amer. Proc. 4:19-22. 1939.

(28) Ilmenev, S. I.
The effects of an oat crop, dung and lime on the aggregate composition of soils. (Cited in E. W. Russell, Soil Structure.)

(29) Johnston, J. R., G. M. Browning, and M. B. Russell.
The effect of cropping practices on aggregation, organic matter content and loss of soil and water in the Marshall silt loam. Soil Sci. Soc. Amer. Proc. 7:105-107. 1942.

(30) Joseph, A. F. and F. J. Martin.
The moisture equivalent of heavy soils. Jour. Agr. Sci. (England). 13:49. 1923.

(31) Kolodny, L. and O. R. Neal.
The use of microaggregation or dispersion measurements for following changes in soil structure. Soil Sci. Soc. of Amer. 6:91-95. 1941.

(32) Lutz, J. F.
The relation of free iron in the soil to aggregation. Soil Sci. Soc. Amer. Proc. 1:43-45. 1936.

(33) Martin, J. P.
Microorganisms and soil aggregation: I. Origin and nature of some of the aggregating substances. Soil Sci. 59:163-174. 1945.

(34) Martin, J. P. and S. A. Waksman.
Influence of microorganisms on soil aggregation and erosion. Soil Sci. 50:29-47. 1940.

(35) Martin, J. P. and S. A. Waksman.
Influence of microorganisms on soil aggregation and erosion. II. Soil Sci. 52:381-394. 1941.

(36) McCalla, T. M.
Influence of microorganisms and some organic substances on soil structure. Soil Sci. 59:287-297. 1945.

(37) McHenry, J. R. and H. F. Rhoades.
Influence of calcium carbonate content and exchangeable sodium calcium ratio on consistency constants, residual shrinkage, moisture equivalent, and hygroscopic coefficient of soils. Soil Sci. Soc. Amer. Proc. 7:42-47. 1942.

(38) McHenry, J. R. and M. B. Russell.
Elementary mechanics of aggregation of puddled materials. Soil Sci. Soc. Amer. Proc. 8:71-77. 1943.

(39) Metzger, W. H.
Nitrogen and organic carbon of soils as influenced by cropping systems and soil treatments. Kans. Agr. Expt. Sta. Tech. Bul. 45. 36 p. 1939.

(40) Myers, H. E.
Physicochemical reactions between organic and inorganic soil colloids as related to aggregate formation. Soil Sci. 44:351-359. 1937.

(41) Myers, H. E.
Some physico-chemical aspects of soil aggregates. Soil Sci. 52:469-480. 1941.

(42) Myers, H. E. and T. M. McCalla.
Changes in soil aggregation in relation to bacterial numbers, hydrogen-ion concentration, and length of time soil was kept moist. Soil Sci. 51:189-200. 1941.

(43) Myers, H. E. and H. C. Myers.
Soil aggregation as a factor in yields following alfalfa. Amer. Soc. Agron. Jour. 36:965-969. 1944.

(44) Nichols, M. L.
Letter No. 13 to project supervisors, Soil Cons. Service. Sept. 17, 1943.

(45) Nijhawan, S. D. and L. B. Olmstead.
The effect of sample pre-treatment upon soil aggregation in wet sieve analysis. Soil Sci. Soc. Amer. Proc. of 1947. (In press).

(46) Olmstead, L. B.
Some moisture relations of the soils from the erosion experiment stations. U. S. Dept. of Agr. Bur. of Chem. and Soils. Tech. Bul. No. 562. July, 1937.

(47) Peele, T. C.
Microbial activity in relation to soil aggregation. Amer. Soc. Agron. Jour. 32:204-212. 1940.

(48) Peele, T. C. and O. W. Beale.
Microbial activity and soil aggregate formation during the decomposition of organic matter. Soil Sci. Soc. Amer. Proc. 8:254-257. 1943.

(49) Retzer, J. L. and M. B. Russell.
Differences in the aggregation of a prairie and a gray-brown podzolic soil. Soil Sci. 52:47-58. 1941.

(50) Rogers, H. T.
The relation between soil reaction, erosion, and aggregation of silt and clay in Clarksville loam. Amer. Soc. Agron. Jour. 31:915-923. 1939.

(51) Rost, C. O. and C. A. Rowles.
A study of factors affecting the stability of soil aggregates. Soil Sci. Soc. Amer. Proc. 5:421-433. 1940.

(52) Russell, E. W.
Soil structure. Imp. Bur. Soil Sci. Tech. Comm. 37. 1938.

(53) Salter, F. J.
The carbon nitrogen ratio in relation to the accumulation of organic matter in soils. Soil Sci. 31:413-430. 1931.

(54) Salter, R. M. and T. C. Green.
Factors affecting the accumulation and loss of nitrogen and organic carbon in cropped soils. Amer. Soc. Agron. Jour. 25:622-630. 1933.

(55) Sideri, D. J.
On the formation of structure in soil II. Synthesis of aggregates on the bonds uniting clay with sand and clay with humus. Soil Sci. 42:461-479. 1936.

(56) Snedecor, G. W.
Statistical methods, 4th ed. The Collegiate Press, Ames, Iowa. 485 p. 1946.

(57) Stauffer, R. S.
Influence of soil management on some physical properties of a soil. Amer. Soc. Agron. Jour. 28:900-906. 1936.

(58) Stauffer, R. S., R. J. Muckenhirn, and R. T. Odell.
Organic carbon, pH, and aggregation of the soil of the Morrow plots as affected by type of cropping and manurial additions. Amer. Soc. Agron. Jour. 32:819-832. 1940.

(59) Tiulin, A. F.
Questions on soil structure. II. Aggregate analysis as a method for determining soil structure. Perm. Agr. Expt. Sta. Div. Agr. Chem. (Reprint). 2:77-122. 1928. (Quoted by Baver in Soil Physics.)

(60) Van Doren, C. A. and R. S. Stauffer.
Effect of crop and surface mulches on runoff, soil losses, and soil aggregation. Soil Sci. Soc. Amer. Proc. 8:97-101. 1943.

(61) Veihmeyer, F. J., J. Oserkowsky and K. B. Tester.
Some factors affecting the moisture equivalent of soils. Proc. First Inter. Cong. Soil Sci. 1:512-534. 1927.

(62) Weldon, T. A. and J. C. Hide.
Some chemical properties of soil organic matter and of sesquioxides associated with aggregation in soils. Soil Sci. 54:343-352. 1942.

(63) Woodburn, R.
Aggregation studies of Houston clay in Mississippi. Soil Sci. Soc. Amer. Proc. 9:30-36. 1944.

(64) Woodruff, C. M.
Variations in the state and stability of aggregation as a result of different methods of cropping. Soil Sci. Soc. Amer. Proc. 4:13-19. 1939.

APPENDIX

Table 8. The sequence of the crops grown upon each series* during the 20 years prior to the time of sampling.

Year	Series					
	A	B	C	D	E	F
1946	Alfalfa	Flax	Corn	Oats & Sw. Cl.	Soybeans	Soybeans
1945	Oats & Sw. Cl.	Soybeans	Alfalfa	Wheat	Corn	Flax
1944	Wheat	Corn	Alfalfa	Flax	Oats & Sw. Cl.	Soybeans
1943	Flax	Oats & Sw. Cl.	Alfalfa	Soybeans	Wheat	Sorghum
1942	Soybeans	Oats	Alfalfa	Corn	Flax	Oats & Sw. Cl.
1941	Corn	Flax	Oats & Sw. Cl.	Alfalfa	Soybeans	Wheat
1940	Oats & Sw. Cl.	Soybeans	Wheat	Alfalfa	Corn	Flax
1939	Wheat	Corn	Flax	Alfalfa	Oats & Sw. Cl.	Soybeans
1938	Flax	Alfalfa	Soybeans	Oats & Sw. Cl.	Wheat	Corn
1937	Soybeans	Alfalfa	Corn	Wheat	Flax	Oats & Sw. Cl.
1936	Corn	Alfalfa	Oats & Sw. Cl.	Flax	Soybeans	Wheat
1935	Oats & Sw. Cl.	Alfalfa	Wheat	No Crop	Corn	Flax
1934	Wheat	Oats & Sw. Cl.	Flax	Corn	Alfalfa	Soybeans
1933	Flax	Wheat	Soybeans	Oats & Sw. Cl.	Alfalfa	Kafir
1932	Soybeans	Flax	Corn	Wheat	Alfalfa	Oats & Sw. Cl.
1931	Corn	Soybeans	Oats & Sw. Cl.	Flax	Alfalfa	Wheat
1930	Oats & Sw. Cl.	Corn	Wheat	Wheat	Alfalfa	Flax
1929	Kafir	Wheat	Wheat	Sw. Cl.	Oats	Alfalfa
1928	Wheat	Wheat	Sw. Cl.	Oats	Corn	Alfalfa
1927	Wheat	Sw. Cl.	Sw. Cl.	Corn	Wheat	Alfalfa
1926	Cowpeas	Oats & Sw. Cl.	Corn	Wheat	Wheat	Alfalfa

*At no time was there a legume grown on Plot 10 of any series. Redtop substituted for alfalfa up to 1946 when brome was also mixed with the redtop. Sorghums substituted for the soybeans. Before 1930, wheat or oats grew on Plot 10 when sweet clover was on the series. After 1929, the sweet clover was grown with the oats, thus it was omitted on Plot 10 during the season when oats and sweet clover were on the series.

Table 8a. An analysis of variance for the moisture equivalent of the 324 samples investigated.

Sources of variance	D/F	S.S.	Variance	Calculated "F"	Table "F" 5%	Table "F" 1%
Total	323	477.7490				
Between series	5	63.2107	12.64214	2.191	2.60	3.86
Between soil treatments	5	124.0701	24.81402	4.301	2.60	3.86
Interaction	25	144.2180	5.76872	11.360	1.61	1.95
Error	288	146.2502	0.50781			

Table 9. An analysis of variance for the moisture equivalent values of the 324 soil samples investigated, comparing the legume rotations with the nonlegume rotation.

Sources of variance	D/F	S.S.	Variance	Calculated "F"	Table "F" 5%	Table "F" 1%
Total	323	477.7490				
Legume vs. no legume	1	5.5420	5.5420	3.779	3.85	6.85
Error	322	472.2070	1.4665			

Table 10. An analysis of variance for moisture equivalent values of the 324 soil samples investigated comparing the soils receiving no treatment with soils receiving lime, manure or superphosphate or some combination of these.

Sources of variance	D/F	S.S.	Variance	Calculated "F"	Table "F"	
					5%	1%
Total	323	477.7490				
Treatment vs. no treatment	1	51.4931	51.4931	38.8979	3.85	6.85
Error	322	425.2559	1.3238			

Table 11. An analysis of variance for water-stable aggregates of the 324 soil samples investigated.

Sources of variance	D/F	S.S.	Variance	Calculated "F"	Table	
					"F" 5%	"F" 1%
Total	323	9895.3435				
Between series	5	2102.2600	420.4520	3.932	2.60	3.86
Between soil treatments	5	356.1386	71.2277	0.666	2.60	3.86
Interaction	25	2673.0563	106.9222	6.464	1.61	1.95
Error	288	4763.8886	16.5413			

Table 12. An analysis of variance for water-stable aggregates of the 324 soil samples investigated, comparing the legume rotations with the nonlegume rotation.

Sources of variance	D/F	S.S.	Variance	Calculated "F"	Table "F" 5%	Table "F" 1%
Total	323	9895.3435				
Legume vs. no legume	1	19.3804	19.3805	0.6319	3.85	6.85
Error	322	9875.9631	30.6707			

Table 13. An analysis of variance for water-stable aggregates of the 324 soil samples investigated, comparing soils receiving no treatment with soils receiving lime, manure, superphosphate or some combination of these.

Sources of variance	D/F	S.S.	Variance	Calculated "F"	Table "F" 5%	Table "F" 1%
Total	323	9895.3435				
Treatment vs. no treatment	1	15.1517	15.1517	0.4938	3.85	6.85
Error	322	9880.1918	30.6838			

Table 14. An analysis of variance for total nitrogen content of the 324 soil samples investigated.

Sources of variance	D/F	S.S.	Variance	Calculated "F"	Table "F"	
					5%	1%
Total	323	0.036247				
Between series	5	0.0007834	0.00015668	0.4593	2.60	3.86
Between soil treatments	5	0.0126321	0.00252643	7.4056	2.60	3.86
Interaction	25	0.0085288	0.00034115	6.8697	1.61	1.95
Error	288	0.014303	0.00004966			

Table 15. An analysis of variance for the total nitrogen content of the 324 soil samples investigated comparing the legume rotations with the nonlegume rotation.

Sources of variance	D/F	S.S.	Variance	Calculated "F"	Table "F"	
					5%	1%
Total	323	0.036247				
Legume vs. no legume	1	0.007696	0.007696	86.47	3.85	6.85
Error	322	0.028551	0.000089			

Table 16. An analysis of variance for the total nitrogen content of the 324 soil samples investigated, comparing soils receiving no treatment with soils receiving lime, manure, superphosphate or some combination of these.

Sources of variance	D/F	S.S.	Variance	Calculated "F"	Table "F"	
					5%	1%
Total	323	0.036247				
Treatment vs. no treatment	1	0.000700	0.000700	6.364	3.85	6.85
Error	322	0.035547	0.000110			

Table 17. An analysis of variance for the organic carbon content of the 324 soil samples investigated.

Sources of variance	D/F	S.S.	Variance	Calculated "F"	Table "F"	
					5%	1%
Total	323	5.8740				
Between series	5	0.1719	0.0344	0.053	2.60	3.86
Between soil treatments	5	1.8475	0.3695	5.693	2.60	3.86
Interaction	25	1.6235	0.0649	8.429	1.61	1.95
Error	288	2.2311	0.0077			

Table 18. An analysis of variance for the organic carbon content of the 324 soil samples investigated comparing the legume rotations with the nonlegume rotation.

Sources of variance	D/F	S.S.	Variance	Calculated "F"	Table "F" 5%	Table "F" 1%
Total	323	5.874				
Legume vs. no legume	1	0.672	0.672	42.00	3.85	6.85
Error	322	5.202	0.016			

Table 19. An analysis of variance for the organic carbon content of the 324 soil samples investigated, comparing soils receiving no treatment with soils receiving lime, manure, superphosphate or some combination of these.

Sources of variance	D/F	S.S.	Variance	Calculated "F"	Table "F" 5%	Table "F" 1%
Total	323	5.874				
Treatment vs. no treatment	1	0.254	0.254	14.941	3.85	6.85
Error	322	5.620	0.017			

Table 20. An analysis of variance for the carbon-nitrogen ratios of the 324 soil samples investigated.

Sources of variance	D/F	S.S.	Variance	Calculated "F"	Table "F"	
					5%	1%
Total	323	131.9748				
Between series	5	26.1406	5.2281	5.575	2.60	3.86
Between soil treatments	5	10.5848	2.1170	2.258	2.60	3.86
Interaction	25	23.4423	0.9377	3.761	1.61	1.95
Error	288	71.8071	0.2493			

Table 21. An analysis of variance for the carbon-nitrogen ratios of the 324 soil samples investigated comparing the legume rotations with the nonlegume rotation.

Sources of variance	D/F	S.S.	Variance	Calculated "F"	Table "F"	
					5%	1%
Total	323	131.975				
Legume vs. no legume	1	3.511	3.511	8.799	3.85	6.85
Error	322	128.464	0.399			

Table 22. An analysis of variance for the carbon-nitrogen ratios of the 324 soil samples investigated, comparing soils receiving no treatment with soils receiving lime, manure, superphosphate or some combination of these.

Sources of Variance	D/F	S.S.	Variance	Calculated "F"	Table "F"	
					5%	1%
Total	323	131.975				
Treatment vs. no treatment	1	3.912	3.912	9.804	3.85	6.85
Error	322	128.063	0.399			