A STUDY OF METHODS FOR MEASURING SOIL PHYSICAL CONDITIONS

by

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INTRODUCTION

Man has long studied the soil in its use for plant production. Early experimenters were concerned primarily with its effect on plants. However, as knowledge of the basic sciences became more widespread, investigators began studying the soil as a natural body to determine its inherent properties.

The soil proved to vary markedly from place to place perhaps even more than the climate and plant life did. Facts learned in one area often did not apply in another. General principles were sought and tested. Gradually it became recognized that the different chemical, physical, and microbiological properties of each soil, together with its unique climate, called for separate considerations in developing maximum plant growth.

In the Great Plains Region major emphasis was placed on soil fertility and erosion control. Later studies concentrated on the soil moisture regime with investigations of tillage, mulch, and irrigation practices. More recent studies in this area have investigated the physical properties of the soil.

Although serious research in the field of Soil Physics has been under way for at least thirty years, there is still much to be done toward developing standard investigative techniques.

The Kansas State Experiment Station at Manhattan in conjunction with the North Central Committee on Soil Structure and Organic Matter made a preliminary study of several methods for measuring soil physical condition. The purpose of this study was to compare the several methods with each other, and to test their effectiveness in determining the physical condition of a soil as affected by long term rotation experiments on the experiment station at Manhattan.

LITERATURE REVIEW

In the early 1800's Schubler in Germany began studying the physical aspects of the soil. He made many observations of basic importance. Later in the century Schumacher published a book "Die Physick" which included much of Schubler's findings on soil physics. By the end of the century Wollny had made extensive studies in soil physics most of which were published in the journal he edited or in his monograph on factors influencing soil physical conditions. For this work Baver (5) called him the "Father of Soil Physics."

During the first quarter of the 20th century there was little interest in investigating the physical properties of soils (5). However, during the past 30 years many investigators (23) (28) (32) (39) (43) have studied the soil as a natural body. Some have found that the soil physical properties often have profound influence on plant production (6) (7) (29).

This line of investigation is essential, but it is also essential to find out what the physical properties of the soil are, why they are that way, and how they can best be measured or characterized. Once the physical properties are determined and correctly measured then a given soil can be properly identified as an individual natural body.

As early as 1860 Hilgard (Kellogg, 25) expressed the idea that soils differed in many respects and should be treated as separate bodies. The results of Russian workers under V. V. Dokuchaev about 1870 even more clearly pointed out the individualism of soils. The Russian concepts finally reached American workers when Marbut translated Stremme's German account of Dokuchaev's and his students' activities (Kellogg, 25).

By the end of the second decade in the 20th century several workers had concluded that the structure of the soil was the most important physical property affecting plant and water relations. In an attempt to evaluate soil structure Tiulin (47) in Russia, Yoder (53) in America, and others (8) (9) devised ways of measuring the distribution of water stable aggregates in the soil. About this same time investigations were underway in Russia (48) Europe (24), and America (4) (26) on the porosity of the soil as another measure of structure. Chepil in Canada and later in the United States (11) (13) developed a rotary sieve to determine dry aggregate distribution and mechanical stability. Martinson and Olmstead (30) developed a clod crushing strength technique for further information on mechanical stability of dry aggregates.

Aggregate Analysis By Wet Sieving

The technique of sieving a soil sample in water to determine the distribution of water stable aggregates and measure the extent of their stability is very widely used but with greatly differing methods. One of the first wet sieving experiments was conducted by Tiulin (47) in an effort to show why some soils retained their crumb structure against strong rains or heavy tilling while others did not. His method consisted of wetting a 50 gram sample of soil by capillarity for 30 minutes then placing it in a nest of three sieves (1.0, 0.5, and 0.25 mm) which were standing in a bucket of water with the top sieve half submerged. The nest of sieves was then dunked in the water 30 times. The aggregates remaining on each sieve were dried to constant weight, corrected for primary particles, and expressed as percent of the whole sample.

Yoder (53) developed a machine for sieving five samples simultaneously in nests of six sieves (5, 2, 1, 0.5, 0.25, and 0.10 mm) wherein a 50 gram sample of the air dry soil was placed directly on the top sieve and the whole nest was was given thirty $1\frac{1}{4}$-inch strokes under water per minute for 30 minutes. Each sieve was placed in a 6-inch Petri dish, dried at 110° C, weighed and expressed as percent of the sample. This method has been modified in numerous ways but is basically the one most commonly used at present.

Russell and Feng (41) found that the rank of different soils in order of decreasing stability changed with the length of sieving time. They characterized the aggregates by the initial stability indicated by a brief sieving time and the rate of disintegration indicated by the slope of the regression of the log of the weight of soil left on the sieve against the log of the sieving time in seconds. Russell (40) gives a review of other methods of wet sieving in his excellent review and discussion of soil structure.

Opinion on the importance of the pretreatment of the sample before sieving seems to vary. Tiulin (47) wet his samples by capillary action, Yoder (53) commenced sieving with air dry samples, Russell and Feng (41) found no significant difference in sample presoaking time. Nijaawan and Olmstead (33) compared 16 different pretreatments on the Munjor silty clay loam and the Geary silt loam. They found that immersion of the dry aggregates was too drastic for that soil. Also, aggregation could be reduced to almost any desired level by end-over-end shaking. Cernuda et al (10) found that the initial soil moisture condition had considerable influence on the slaking and destruction with water drops of the soil aggregates. Henin (19) (21) experimented with soaking aggregates in various organic liquids before sieving in water. He demonstrated that the slaking of the aggregate is greatly reduced when wet in a vacuum, and is greatly increased when the soil air is replaced by a noncompressable atmosphere such as a liquid. Dutt (14) experimented with sieving in various organic liquids and various surface tensions in water. Some additional literature review is given in Soils and Fertilizers (37).

The time of sampling for aggregate analysis is of considerable importance for data that is to be compared. Alderfer (2) (3) studied the effect of season on the aggregation of the Hagerstown soil. He found considerable variation with the season, particularly with the moisture cycle. He concluded that seasonal variations had greater effect on aggregation than fertility treatments, and that the soil moisture content, when sampled, had the greatest effect. Chepil (12) and Slater and Hopp (44) agreed with Alderfer that alternate freezing and thawing decreased aggregation during the winter with a subsequent recovery during the spring and summer. Puri and Rai (36) investigated the effects of dispersing and drying and concluded that water stability was an inherent property of the aggregates based on their mechanical composition and was not subject to seasonal change.

Another factor of great variation among workers is the method of expressing the results of aggregate analysis. In most cases these differences result from differences in wet sieving equipment or procedure used. Tiulin (47) used the percent aggregates greater than 0.25 mm. Yoder (53) used complete size distribution curves and tables. Puri and Puri (35) used the ratios of mechanical analysis, mean diameter, standard deviation, and Shoklitsch number before dispersion to the same factor after dispersion of the soil sample. Retzer and Russell (38) developed a coefficient of aggregation and Alderfer and Merkle (3) used a stability index based on aggregates greater than 0.2 mm. Henin (20) reported the percent aggregation greater than 0.2 mm using only one sieve whereas Mijhawan and Olmstead (33) also reported aggregates greater than 0.2 mm but used four sieves. Russell and Feng (41) as mentioned earlier used the initial stability indicated by the "y" intercept of the regression of the log of the weight of soil left on the sieve against the log of the oscillation time in seconds, and the slope of the line.

In 1934 Affleck (1) developed the equation of probability distribution for homogeneous material broken into particles by a random process. He indicated the soil is composed of several homogeneous materials and the sum of these curves would characterize the breakdown of the soil as a whole. Evans (16) affirmed homogeneous material curves experimentally with quartz, hornblende, and orthoclase feldspar.

Van Bavel (51) characterized the aggregation state of the soil by plotting the mean weight-diameter of the aggregates graphically. Youker and McGuinness (54) developed a rapid method of determining the mean weight-diameter by machine calculation. This has the advantage of avoiding much of the personal bias in plotting graphs. Schaller and Stockinger (42) compared five methods of expressing aggregation data: mean weight-diameter, % aggregates > 2.0 mm, % aggregates > 1.0 mm, % aggregates > 0.25 mm, and geometric mean diameter. They concluded that the geometric mean diameter gave better replicability. Mazurak (31) used the geometric mean diameter. In 1956 Gardner (18) tested several sets of data and concluded that the aggregates were log-normally distributed and advised using the log geometric mean diameter found by plotting the aggregate distribution on log-normal graph paper.

Porosity

Russell (40) maintained that a knowledge of soil pore-space was necessary for a proper understanding of the part played by structure in the soil's productivity. According to Baver (5), the porosity of a soil may be defined as that percentage of the volume of the soil which is not occupied by its solid particles. Leamer and Lutz (26) recognized that the pore space of a soil directly controls the movement of air and water in the soil, which in turn directly affects other soil properties and plant growth.

Tiulin (48) stated that Dojarenko showed the air and water regime depended on capillary and non-capillary pores in the soil. Russell (40) stated that the earliest workers, including Dojarenko, usually defined capillary pore-space as the weight of water held by a cylinder of soil when wetted by capillarity from underneath. He suggested that it was preferable to measure capillary pore-space when the soil is holding its maximum amount of water against free drainage. Tiulin objected to using water to determine the soil pore-space because certain soils would swell and change the ratio of capillary to non-capillary pore-space. He suggested using xylol.

Some workers (34) (49) (52) developed pycnometers for determining total pore-space. The equipment Page (34) used would also determine the percent capillary pores. He concluded that the pycnometer was the best method of determining pore-space of soils having a low total porosity. Tanner's sonic pycnometer[1] is the most récent development in this type of equipment.

However, most routine porosity determinations are made with equipment which uses the tension of a water column to drain the soil pores from the saturated condition. The size of pores drained is determined by the length of the water column used. By 1940 Leamer and Lutz (26) had developed a laboratory device for measuring pore size distribution by this method. From their studies they concluded that percolation and aeration are dependent on pore size rather than the amount of pore-space, and that there was no relationship between effective porosity and total pore-space. About a year later a new device was introduced by Leamer and Shaw (27). Its main features were simplicity of design and accommodation of a large number of samples at one time. This equipment was adopted in many laboratories for routine porosity measurements. Jamison and Reed (22) built tension tables of asbestos which proved to be more durable than the blotter paper used by Leamer and Shaw. Tanner *et al* (46) described a simple, durable tension plate built of porous alundum which also proved to be

[1]Reported at the meeting of the North Central Committee on Soil Structure and Organic Matter in Lincoln in 1958.

durable.

Baver (6) indicated that the soil porosity was directly related to the amount and stability of the soil granules. Feng and Browning (17) derived a soil "stability factor" from the relationship of the volume of water drained at 50 cm tension (essentially the non-capillary porosity) and the stability of the soil aggregates. However, Strickling (45) concluded there was no relation between soil aggregate porosity and stability, or that the relationship was obscured.

Aggregate Analysis By Dry Sieving

In an effort to study the physical condition of the soil as indicated by the aggregates in their natural condition various sieving techniques have been tried. By 1943 Chepil and Bisal (13) in Canada had developed a rotary sieve to determine the size distribution of the soil clods or aggregates in the dry state. Later in Kansas Chepil (11) developed another rotary sieve with improved features. He maintained that the rotary sieve eliminated the objectionable features of flat sieving such as: 1. operator bias, 2. clogging of holes in finer sieves, 3. limited sample size, and 4. excessive clod disintegration. Edwards (15) built a similar rotary sieve designed to handle larger samples and larger clods. He mentioned the additional advantage of it being less laborious than hand sieving.

Clod Crushing Strength

Martinson and Olmstead (30) developed a method for determining the hardness of natural clods. They investigated clod hardness at various moisture percentages and soil depths and compared it with moisture content, bulk density, moisture equivalent, water stable aggregation and total nitrogen. Hardness was measured by the force necessary to crush the clod calculated in ounces of force per gram of clod. They concluded that additional study of the method would be necessary to determine the factors that determine aggregate strength. However, crushing strength did correlate highly with moisture percentage and significantly with bulk density. In general the crushing strength was least in the plow layer of small grains, highest in intertilled crops, and intermediate in rotations containing both types of crops. Crushing strength increased with sample depth, and decreased with increase of nitrogen.

EXPERIMENTAL PLAN

The Kansas State Experiment Station entered a project to study the following methods of evaluating soil physical conditions: Aggregate stability by the Yoder wet sieving method, dry aggregate distribution and mechanical stability by Chepil's rotary sieving method, soil porosity with Uhland cores, and clod crushing strength by the Martinson and Olmstead method. An evaluation was made of their relative effectiveness in measuring soil physical condition and of their correlation with crop yield.

By these five methods an attempt was made to detect effects of 1. crop rotation, 2. fertility treatments, and 3. season, on the soil physical condition at the surface and subsurface depths. The results were checked for correlation with each other and with crop yields.

The soil samples were taken from the long time Soil Fertility Project on the Agronomy Farm at Manhattan. This project was laid out systematically on an unnamed silt loam terrace soil having a loess cap formerly called Geary. Of the rotations studied in this experiment Series II and IV were in a 16-year rotation: Alfalfa (four years), corn, wheat, wheat (twelve years). Series II was in wheat after wheat with eleven years after alfalfa. Series IV was in wheat after corn with seven years after alfalfa. Series V was in a 3-year rotation: Corn, soybean hay, wheat. It was in wheat after soybeans.

In each series the plots selected for sampling were: 5---check, 6---complete fertilizer, 7---superphosphate each year plus manure just before corn in the 16-year rotation, and manure only in the 3-year rotation, 8---check. Five samples were taken from each plot. Two depths were sampled at each site for the porosity and wet sieving determinations. The sample sites were in a row down the middle of the plot to avoid disturbing the plant growth along each side of the plot where the yields were taken. The plots were not laid out on the contour so the five sample sites were assumed to cover slope and position differences.

In this study no attempt was made to show the changes in soil physical condition caused by cropping over the forty-year project life because no samples were taken initially for references. However, it was assumed that the plots in each rotation were essentially alike in the beginning so any difference between them was an effect of treatment. It was further assumed that there actually were differences between the plots and part of the problem was to determine if these five methods of analyzing soil physical condition are sensitive enough to show the differences.

The following overall plan was used to make the above evaluations.

1. Appropriate soil samples were taken from each plot in the fall.
2. The porosity analysis was run immediately after sampling.
3. Samples for wet sieving aggregate analysis were passed through a ½-inch-mesh screen while field moist. They were then air dried and sieved to sub out the 2.00 to 4.76 mm fraction. These subsamples were stored in ½-pint cartons.
4. The samples for dry sieving aggregate analysis and for clod

crushing strength were dried at 80 degrees centigrade. These samples were dry sieved immediately after drying.

5. The clod size necessary for the crushing strength determination were separated and stored in $\frac{1}{2}$-pint cartons.
6. The wet sieving and crushing strength analyses were made as time permitted.
7. The entire process was repeated in the spring.

Ideally all samples to be compared should be taken the same day, however, because of the number of samples required for this study they couldn't all be taken the same day. The first samples were taken in the very dry wheat seed-bed condition resulting from the shortage of rainfall in the early fall. Before the sampling was completed the apparent physical condition of the surface soil was changed markedly by rain. New samples were taken from previously sampled plots and all sampling was completed before any more rain fell and before any freezing occurred. The fall sampling period was from November 19 to December 3, 1956. The spring sampling period was the last week in April and the first week in May, 1957. Earlier spring sampling was prevented by frequent precipitation and slow drying of the surface soil.

METHODS AND RESULTS

Porosity

The soil porosity determinations were made first because the soil cores had to be processed before they dried out. The samples were taken from five sites spaced at equidistant intervals down the center of plots 5, 6, 7, and 8 in each of the Series II, IV, and V. Each site was soaked with five inches of water applied in an 18 inch length of stovepipe 8 inches in diameter forced into the soil an inch or so. Two to three days elapsed between the disappearance of the water on the surface and the time of sampling. The moisture content of the soil at this time was approximately at field capacity. In the fall the surface and subsurface samples were taken at the same time without further watering. In the spring the surface samples were taken as before, then the holes were filled with water and allowed to soak another two or three days before the subsurface samples were taken. This eliminated the swelling of occasional subsurface samples.

At each sampling site an undisturbed soil core three inches long by three inches in diameter was taken vertically with a Uhland Soil Sampler (50). In the fall the samples were taken at the arbitrarily selected depths of 1 to 4 inches and 8 to 11 inches. It was desired to get one core from the plow layer and another below the plow layer. However, it was noticed while taking the fall samples that the 8 to 11 inch depth was sometimes wholly within the A horizon, sometimes partly in the A and partly in the B, and sometimes wholly within the B horizon. This tended to introduce more variation in porosity than the treatments did, so the spring subsurface samples were taken in the top three inches of the B horizon.

While in the field the samples were trimmed on top and bottom just enough to fit them into a pint carton for transporting to the laboratory. As soon as the samples were brought to the laboratory they were trimmed flush with the brass sleeves with a knife or thin-bladed spatula. The core was trimmed on the bottom first and a square of 4-ply cheesecloth or a single thickness of cotton muslin was placed over the core and held snugly with a number 64 rubber band stretched around twice. The core was then tipped up and the top was trimmed. If a chunk fell out or if the sample in the core became visibly disturbed it was discarded and a new sample was taken. Care was taken to mark which end of the sample was up in the field and this was the top during the porosity determination.

After the samples were trimmed they were placed in a pan and about one half inch of distilled water containing 30 ppm of Dowcide "B"[1] was added. The cores were wetted by capillarity until the top appeared soaked, then more Dowcide "B" solution was added to come up as near the top of the cores as possible without washing over. When the cores had soaked up to equilibrium weight (one to three days) their weight was recorded and they were placed on the tension plates in the constant temperature room. During the weighing each sample was removed from the pan of water and set on the scale with only a few seconds of draining time. The draining time was the same for all samples. As the samples were removed from the pan for weighing, more water was added to keep the level the same. A Toledo Laboratory Scale model 4636 was used for all weighings throughout the porosity determination.

The soil cores were placed on porous plates and drained at a tension of 60 cm of water until they were at constant weight. The first weight check was made after 24 hours and the equilibrium point was chosen where there was less than 3 g loss in eight hours. While on the porous plates the cores were covered with sheets of plastic to prevent evaporation from the surface. The plates were checked periodically to make sure the water column remained unbroken and tension was still being applied.

The tension plate apparatus was constructed similar to that suggested by Tanner, _et al_ (46). The porous alundum plates had to be washed quite thoroughly after each run to prevent clogging of the pores. Each of the 5 plates used held 8 cores thus allowing all 40 samples from each series to be run simultaneously.

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[1] 85% Sodium Trichlorophenate, 15% inert. Dow Chemical Company.

The percent macropores or non-capillary pore-space was calculated by obtaining the difference between the saturated weight and the equilibrium weight at 60 cm tension then dividing by the volume of the core. This value was used as the statistic in the analysis of variance. Preliminary studies indicated tremendous and consistent differences between surface soils and subsoils therefore the data for these layers were analyzed separately.

Table 1. Average percent by volume of pores drained at 60 cm tension Soil Fertility Project, Manhattan, Kansas. Fall 1956 and spring 1957.

Plot and treatment	Season	Series (Rotation and tillage) II 16-yr. plow	IV 16-yr. disc	V 3-yr. disc
		surface soils		
5. Check	fall	18.97	16.75	12.61
	spring	19.22	16.69	14.28
6. NPK	fall	13.30	17.59	23.14
	spring	14.22	17.04	13.64
7. Manure + P	fall	16.63	19.80	21.01
	spring	16.63	21.41	11.68
8. Check	fall	17.15	20.72	18.25
	spring	15.02	14.62	13.30
		subsurface soils		
5. Check	fall	15.71	12.95	14.10
	spring	10.30	9.73	7.77
6. NPK	fall	14.16	11.28	12.95
	spring	9.67	8.06	10.82
7. Manure + P	fall	15.08	12.82	12.72
	spring	10.65	9.67	6.68
8. Check	fall	13.53	12.72	14.34
	spring	11.91	10.65	8.75

The average percent macropores for fertility treatments, rotation and tillage, sample depth, and season are presented in Table 1. These data show consistant differences between the surface and subsurface samples. Among the surface samples there are no consistant differences between treatments, rotations, or seasons. The analysis of variance in Table 2 indicates an interaction between treatments and rotations. Tables 3 and 4 reveal where actual differences were found by the $LSD_{.05}$.

Of the 48 comparisons made in Table 3 only 13 were declared significant. Most of these were somewhat isolated cases with insufficient consistency to show a trend. In the case of the differences between rotations on plot 5 in the fall surface samples there seems to be no logical explanation especially since the other plots don't show similar effects. In Table 4 only 14 out of 72 comparisons were declared significant. It is observed that plot 6 on Series II had fewer macropores in the fall than any other plot. On Series V in the fall plot 5 had the lowest percent macropores. Neither of these conditions remained in the spring. However, by that time, plot 7 on Series IV appeared to have the highest percent macropores. In each case on Table 4 each plot is compared only with the other plots of the same rotation. The situations where differences were found were not consistant enough to have any meaning.

Thus if one assumes that actual differences between plots or rotations were developed over the years then the porosity determination as run in this experiment is not an effective way of detecting them. The nature of the differences in this assumption is described as the effective physical condition of the soil. Percent macropores is only one index of physical condition and its failure to show differences in this experiment does not prove that the determination itself is not valid or accurate. It is possible that the actual differences in physical condition exist in some other soil characteristic.

There are three possible sources of error in the percent macropore determination which may be of considerable importance. The Uhland Soil Sampler was

Table 2. Analysis of variance of percent Macropores. Soil Fertility Project, Manhattan, Kansas.

	TSS	DF	MS	F
Surface soils, Fall 1956				
Series (Rotations & tillage)	65.74	2	32.87	6.89**
Treatments	81.01	3	27.00	5.66**
Series X Treatments	366.51	6	61.08	12.81***
Replication	36.68	4	9.17	1.92^{ns}
Error	209.81	44	4.77	
Surface soils, Spring 1957				
Series (Rotation & tillage)	189.64	2	94.82	13.77***
Treatments	64.29	3	21.43	3.11*
Series X Treatments	149.46	6	24.91	3.62**
Replications	15.73	4	3.93	0.57^{ns}
Error	303.02	44	6.89	
Subsurface soils, Fall 1956				
Series (Rotation & tillage)	47.22	2	23.61	3.91*
Treatments	15.95	3	5.32	0.88^{ns}
Series X Treatments	17.16	6	2.86	0.47^{ns}
Replications	24.85	4	8.21	1.36^{ns}
Error	265.51	44	6.03	
Subsurface soils, Spring 1957				
Series (Rotation & tillage)	45.21	2	22.61	8.07**
Treatments	17.48	3	5.83	2.08^{ns}
Series X Treatments	59.88	6	9.98	3.56**
Replications	14.31	4	3.58	1.28^{ns}
Error	123.26	44	2.80	

Table 3. Significance of differences in percent macropores between series by treatment.

Treatment and season	Series (Rotations & tillage) Diff. II-IV	Diff. II-V	Diff IV-V	Series "F" values by treatment
	Surface Soil			
5 fall	+2.22*	+6.36*	+4.14*	26.05***
spring	ns	ns	ns	3.58 ns
6 fall	-4.29 ns	-9.84*	-5.55*	13.71**
spring	ns	ns	ns	2.05 ns
7 fall	ns	ns	ns	4.05 ns
spring	-3.78 ns	+4.95 ns	+9.73*	9.94**
8 fall	ns	ns	ns	3.52 ns
spring	ns	ns	ns	1.16 ns
	Subsurface Soil			
5 fall	+2.76	ns	ns	3.91*
spring	ns	ns	ns	3.90 ns
6 fall	+2.88*	ns	ns	3.91*
spring	ns	ns	ns	2.07 ns
7 fall	+2.26*	ns	ns	3.91*
spring	+0.98 ns	+3.97*	+2.99*	5.18*
8 fall	ns	ns	ns	ns
spring	+1.26 ns	+3.16*	+1.90*	8.57*

Table 4. Significance of differences in percent macropores between treatments by Series.

Series and season	Treatments: Diff. 5-6	Diff. 5-7	Diff. 5-8	Diff. 6-7	Diff. 6-8	Diff. 7-8	Treatment "F" values by series
				Surface Soil			
II fall	+5.67*[1]	+2.34 ns	+1.82 ns	-3.33*	-3.85*	-0.52 ns	6.02**
spring	+5.00*	+2.59 ns	+4.20*	-2.41 ns	-0.80 ns	+1.61 ns	4.03*
IV fall	ns	ns	ns	ns	ns	ns	1.73 ns
spring	-0.35 ns	-4.71*	+2.07 ns	-4.37*	+2.42 ns	+6.79*	6.64**
V fall	-10.53*	-8.40*	-5.64*	+1.13 ns	+4.89*	+2.76 ns	15.70**
spring	ns	ns	ns	ns	ns	ns	1.64 ns
				Subsurface Soil			
II fall	ns	ns	ns	ns	ns	ns	0.88 ns
spring	ns	ns	ns	ns	ns	ns	1.74 ns
IV fall	ns	ns	ns	ns	ns	ns	0.88 ns
spring	ns	ns	ns	ns	ns	ns	1.88 ns
V fall	ns	ns	ns	ns	ns	ns	0.88 ns
spring	-3.05*	+1.09 ns	-0.98 ns	+4.14*	+2.07 ns	-2.07 ns	6.74**

[1] Single asterisk, *, indicates that difference value was found significant by the $LSD_{.05}$.
"ns" indicates that difference value was found not significant by the $LSD_{.05}$.
Double asterisk, **, on the "F" values indicates significance at the 0.01 level by the "F" test, and a single asterisk on these values indicates significance at the 0.05 level by the "F" test.

designed to extract a sample of known volume that could be handled without disturbing its natural structure. But in loose soils at field capacity there is often an appreciable amount of compaction of the sample. This increases the bulk density and changes the porosity characteristics. Also, failure to have the soil at the sampling site wetted to field capacity may result in a significant amount of swelling of the core sample when it is saturated. This changes the porosity characteristics somewhat. The third problem is failure to achieve saturation of the soil core. This results in low values for percent macropores and total porosity. The saturation weight of the core can be calculated if the specific gravity of the soil is known, but this was not done in this experiment. These sources of error cannot be eliminated by merely handling all samples alike because they act differently on different soils. Other possible sources of error, such as temperature changes and excessive microorganism growth in the cores, are more easily controlled.

The correlation of the percent macropores with the average yield of wheat from 1909 to 1956 was tested. The correlation coefficient was +0.002 which was not significant. The long time yield average was used to reduce the effect of annual climate. The effect of climate was increased by the fact that each rotation treatment combination was not in the same crop each year.

The correlations of the percent macropores with size distribution of dry aggregates, stability of wet aggregates, and clod crushing strength were also tested. The latter correlation was the only significant one; the correlation coefficient was -0.581. More study is necessary to determine how the coherence of dry clods as measured by the crushing strength determination is related to the soil porosity.

Aggregate Analysis By Dry Sieving

The dry aggregate-size distribution was determined by Chepil's rotary sieve method (11). The samples were taken from five sites spaced at equidistant intervals down the middle of plots 5, 6, 7, and 8 in each of the Series II, IV, and V. Four to 10 kilograms of the 0 to 3-inch depth were scooped up and placed in a large, shallow pan with a minimum of disturbance. These samples were taken when the surface soil was dry to reduce breakdown of the clods in handling. All the samples were taken the same day in the fall, no samples were taken in the spring because of wet conditions.

To dry the large samples uniformly in a reasonable length of time they were placed in a large oven at 80°C for 6 to 12 hours. After drying they were stored in the lab. About half of the sample was used for the clod crushing strength determination. The other half was again divided roughly into halves and each half was run through the rotary sieve to separate out the aggregate sizes > 19.1, 19.1 - 6.4, 6.4 - 2.0, 2.0 - 0.84, 0.84 - 0.42, and < 0.42 mm. Those fractions were then weighed to the nearest gram to give the dry aggregate size distribution by weight. The fractions > 0.84 were recombined without mixing and run through a second rotary sieve to determine the coherence or mechanical stability of the dry aggregates.

The sum of the weights of the fractions after the first sieving is the weight of the soil that went through the sieve at once. The percent oversize of each fraction and the total weight > 0.84 cm were calculated. The percent loss by second sieving of the fractions > 0.84 cm was used as the statistic to evaluate mechanical stability of the dry aggregates. The geometric mean diameter was used as the statistic to evaluate the differences between dry aggregate distribution. To obtain this, the percent oversize was plotted against the diameter of the smallest size in the fraction on log-probability paper. The value where the line crossed the 50% mark was used as the statistic. Some of the errors involved in determining and using this value are discussed later in the section on aggregate analysis by wet sieving.

A summary of the average geometric mean diameters of the dry aggregates is given in Table 5. These data show a remarkable (and significant) difference between the plowed and disced plots (compare Series II with IV and V). It was observed at the time of sampling that the disced areas were covered with smaller and less stable clods than the plowed area. The differences between series were highly significant as indicated by the analysis of variance in Table 6, however, the $LSD_{.05}$ points out that the differences are probably due to tillage. The 16-year rotation which was plowed had larger aggregates than the 16-year rotation which was disced or the 3-year rotation which was disced. The differences between the disced rotations were not significant.

The analysis of variance also indicates a significant difference between treatments. Plot 7 which received manure and phosphate had larger aggregates than any of the other plots, and plots 5, 6, and 8 did not differ according to the $LSD_{.05}$. There was no apparent difference between any of them in the field at the time of sampling.

This method appears to be very satisfactory for use on this soil. Of all the methods tested it is the least laborious and simplest to run. A relatively large number of samples may be taken at a time and processed with a minimum of personal bias. It takes a large oven to dry many samples at a time but thorough air drying would suffice. The results show that it detected smaller soil differences than any of the other methods. There was no correlation between dry aggregate size distribution and any of the other determinations made. The physical differences measured by this method did not correlate with yields as shown by the low coefficient, +0.012.

The coherence or mechanical stability of the dry aggregates was evaluated by running the fractions > 0.84 mm through a second rotary sieve and com-

Table 5. Average size of dry aggregates in surface soils expressed as geometric mean diameter. Soil Fertility Project, Manhattan, Kansas. Fall, 1956.

Plot and treatment	Series (Rotation and tillage)			Average
	16-yr. plow	16-yr. disc	3-yr. disc	
5 Check	4.29	0.79	1.12	2.07
6 NPK	4.37	0.75	1.19	2.10
7 Manure + P	5.98	0.89	1.51	2.79
8 Check	5.22	0.96	0.88	2.35
Average	4.96	0.85	1.17	2.33

Table 6. Analysis of variance of dry aggregates. Soil Fertility Project, Manhattan, Kansas. Fall, 1956.

	TSS	DF	MS	F
Series (Rotations & tillage)	419.009	2	209.504	273.82***
Treatments	13.719	3	4.573	5.98**
Series X Treatments	7.662	6	1.277	1.69 ns
Replications	4.409	4	1.102	1.44 ns
Error	79.566	104	0.765	

Significance of differences in dry aggregate size

between series $LSD_{.05}$ = 0.38		between treatments $LSD_{.05}$ = 0.45			
Diff. II-IV	+4.11*	Diff. 5-6	-0.01 ns	Diff. 6-7	-0.69*
Diff. II-V	+2.79*	Diff. 5-7	-0.70*	Diff. 6-8	-0.25 ns
Diff. IV-V	-0.32 ns	Diff. 5-8	-0.28 ns	Diff. 7-8	+0.44**

puting the percent loss from the first sieving. The stable aggregates would break down less by the abrasive action of the second sieving than the unstable ones. The results of this test are compiled in Table 7. These data show large, consistant differences between series, but very little difference between treatments. This is in agreement with the analysis of variance in Table 8, which indicates the treatment differences were not significant. It is interesting to note that according to the $LSD_{.01}$ all three series differ from each other. Series II (16-year plow) was the most stable; Series V (3-year disc) was next; and Series IV (16-year disc) was the least stable. A discussion of these results is given in the following section on clod crushing strength.

Clod Crushing Strength

The clod crushing strength determination was made according to the method of Martinson and Olmstead (30). Sampling information was given in the discussion of aggregate analysis by dry sieving. After the sample was dried it was screened to separate out the clod size that would pass through a ½-inch square hole but not through a ½-inch round hole. Flat clods were discarded since they do not crush suddenly but merely mash and crumble. At least 40 clods were taken from each sample. They were stored in ½-pint cartons until ready to test.

Each clod was weighed on a Fisher Gram-atic Balance which made it simple to record the weight to the tenth of a milligram although a tenth of a gram would be sufficiently accurate. The crushing apparatus was the same one used by Martinson and Olmstead. A small aluminum moisture can lid was placed on the crushing platform and the scale was zeroed. Each clod was placed on the lid in its most stable position directly under the crushing shaft. The crush-

Table 7. Average percent breakdown of dry aggregates larger than 0.84 mm on passing through a second rotary sieve. Soil Fertility Project, Manhattan, Kansas. Fall, 1956.

Plot and treatment	Series (Rotation and tillage)			Average
	II 16-yr. plow	IV 16-yr. disc	V 3-yr. disc	
5 Check	12.05	27.95	17.61	19.20
6 NPK	11.01	28.02	17.46	18.83
7 Manure + P	10.20	27.36	15.50	17.69
8 Check	10.92	25.06	20.47	18.82
Average	11.04	27.10	17.76	18.63

Table 8. Analysis of variance of percent breakdown of dry aggregates larger than 0.84 mm on passing through a second rotary sieve. Soil Fertility Project, Manhattan, Kansas. Fall, 1956.

	TSS	DF	MS	F
Series (Rotations & tillage)	5198.268	2	2599.134	131.14***
Treatments	38.793	3	12.931	0.65 ns
Series X Treatments	162.038	6	27.006	1.36 ns
Replications	139.326	4	34.832	1.76 ns
Error	872.003	44	19.818	

Significance of differences between series. $LSD_{.01}$ = 3.50

Diff. II-IV = -16.06** Diff. II-V = -6.72** Diff. IV-V = +9.34** ing force was applied uniformly at moderate speed until the clod collapsed or crushed sufficiently to cause the scale needle to jump sharply back from the reading needle. Many clods would crack, then with a little more force they would crush completely. In such cases the reading for the complete shattering was recorded. The reading needle was read to the nearest ounce then returned to zero. Clods requiring more than the full scale reading of 400 ounces were recorded as 400 ounces. Those clods which tended to mash or crumple slowly without any sudden shattering were discarded.

The ounces of crushing force per gram weight of the clod was used as the crushing strength of the clod. The average crushing strength of 40 clods was used as the statistic for the sample in the analysis of variance. The average crushing strengths are given in Table 9 and the analysis of variance is in Table 10. This method also finds differences between series, but the differences between the treatments were judged insignificant by the "F" test.

It was noticed that the crushing strength of Series IV samples was relatively low with essentially no difference between treatments in contrast to the other two rotations where the crushing strength was about 30% higher with considerable difference between some treatments. Apparently some factor reduced the crushing strength of the clods in Series IV to the point that differences between treatments was obliterated. The dry sieving data revealed that Series IV also had the smallest aggregates and the least stable ones. These results together with subsequent visual observations in the field indicate that the average size and coherence of the dry aggregates were determined largely by the type of tillage and the moisture content of the soil at the time of tillage. Differences caused by the fertility treatments or the actual crop sequence in the rotations can be obliterated by tillage. However, part of the difference between rotations was attributed to the crops because

Table 9. Average aggregate crushing strength (ounces per gram) of soils in the Soil Fertility Project, Manhattan, Kansas. Fall, 1956.

Plot and treatment	Series (Rotation and tillage)			Average
	II 16-yr. plow	IV 16-yr. disc	V 3-yr. disc	
5 Check	79.8	70.9	98.0	82.9
6 NPK	91.1	70.1	82.9	81.4
7 Manure + P	105.1	70.1	93.7	89.6
8 Check	95.2	70.3	90.9	86.2
Average	92.8	70.4	91.4	85.0

Table 10. Analysis of variance of average aggregate crushing strength of soils in the Soil Fertility Project, Manhattan, Kansas. Fall, 1956.

	TSS	DF	MS	F
Series (Rotations and Tillage)	5987.0	2	2996.5	19.51**
Treatments	608.2	3	202.7	1.32 ns
Series X Treatments	1668.6	6	278.1	1.81 ns
Replications	260.7	4	45.2	0.29 ns
Error	6757.2	44	153.6	

Significance of differences between rotations. $LSD_{.01} = 10.54$

Diff. II-IV = +21.86** Diff. II-V = +1.41 ns Diff. IV-V = -20.45**

Table 11. Tillage notes. Soil Fertility Project, Manhattan, Kansas. 1956.

Date	Tillage
	Rotation II
July 15	Wheat stubble on all plots was plowed under.
August	All plots disced once.
September	All plots disced once.
October 8	All plots were harrowed.
October 11	All plots were seeded to wheat. Plots were dry and cloddy.
	Rotation IV
September	Cornstalks on all plots were chopped and disced.
October 11	All plots were seeded to wheat. Plots were not harrowed because of the trashy surface.
	Rotation V
September	Soybean stubble on all plots was disced twice.
October 8	All plots were harrowed.
October 11	All plots were seeded to wheat.

Series IV and V were tilled at essentially the same moisture content. The tillage notes in Table 11 show that Series V was harrowed and Series IV was not which should tend to give the former smaller aggregates. The fact that Series V has larger and more stable aggregates than Series IV is attributed to the additional protective effect of the close-drilled soybeans (for hay) during the rains on V in contrast to the open, intertilled corn on IV. Series II had even larger and more stable aggregates because it was plowed at a higher moisture content resulting in large clods with considerable puddled surface area which weathered during the summer to leave the more resistant clods on the surface.

The average dry aggregate crushing strength correlated negatively with the percent macropores. The correlation coefficient of -0.581 was significant at the 1 percent level. More study will be necessary to determine what factors of soil porosity affect coherence. The crushing strength results also correlated with mechanical stability of the aggregates > 0.84 mm evaluated by second sieving. This was expected since both methods test coherence of the aggregates. The correlation coefficient was -0.54 which was highly significant. The correlation was negative because the second sieving test was evaluated by the percent of the sample that broke down. Thus high coherence gave a high value for crushing strength but a low percent breakdown by second sieving.

Since the second sieving test can be made quickly and simply with the same sample used for dry aggregate distribution, it was considered to be more satisfactory for evaluating aggregate coherence than the clod crushing test. The former test is relatively free from personal bias since the whole sample is processed in two steps--sieving by machine and weighing. The clod crushing test is subject to considerable personal bias in the selection of suitable clods, positioning the clod for crushing, applying the crushing force, and deciding whether the crushing point was suitable or should be discarded. In selecting 40 clods to represent the sample, the flat, platy clods are discarded because they usually do not have a definite crushing point. In placing the clod under the shaft for crushing the operator has to decide which is the most stable position. The crushing force is applied by twisting a large knob by hand which is subject to variations in the rate the force is increased. There is also considerable variation in how the clods crush; some shattering completely and suddenly, others splitting once or twice before shattering, and others crumbling slowly.

Aggregate Analysis By Wet Sieving

The soil samples for the wet sieving aggregate analysis were taken at the same time as the porosity samples. About a pint of the moist soil was dug beside the porosity sample hole, the portions of the sample compacted by the spade were discarded and the sample was transported to the lab in a paper bag with minimum disturbance. Immediately upon reaching the lab the samples were gently sieved through a $\frac{1}{2}$-inch mesh hardware cloth screen and laid out to dry. When air dry the samples were sieved to separate out those aggregates between 2.00 and 4.76 mm in size. This fraction was stored in $\frac{1}{2}$-pint cartons until the analysis was made.

The wet sieving apparatus was similar in principle to that devised by Yoder (53). It consisted of a 1/12-horsepower motor with attached gear case which powered a crank that raised and lowered the sieves. The speed was non-adjustable at 34.5 strokes per minute. The length of stroke was 3/4 inches. Four nests of 5-inch sieves were run at once. Each nest consisted of four sieves of the following sizes: 2.00, 1.00, 0.50, and 0.25 mm. The bottom sieve was half-height. Each nest was submerged in a glass battery jar having a 6-inch inside diameter and 8½-inch inside height. These specifications were in accordance with the tentative method used by the Soil Conservation Service.[1]

Two 25-gram subsamples were taken from the dried aggregates (20 grams where the sample was small). One subsample was oven dried to determine the moisture content of the aggregates at the time of sieving. The other subsample was used for the sieving test. The four battery jars were nearly filled with distilled water at room temperature and the nests of sieves were immersed. The nests were tipped slightly and a hook-shaped glass tube was inserted under the bottom sieve to suck out any entrapped air. The position of the sieves was adjusted so the top sieve was at the top of the water when at the top of the stroke. The weighed subsample was distributed somewhat over the top sieve and the sieving started without any presoaking. An automatic timer stopped the machine after 30 minutes at which time the sieves were lifted out and allowed to drain. Each sieve was placed in a 6-inch Petri dish and oven dried at 105°C. When dry the aggregates on each sieve were brushed into the Petri dish and then into a small aluminum moisture can which was placed in a desiccator to cool. After cooling the contents of each sieve were weighed to the nearest 0.1 gram. The various fractions were dispersed and washed through the sieve on which they were collected to test for primary particles. There were no primary particles larger than 0.50 mm and an insignificant amount between 0.25 and 0.50 mm.

The net weight of each aggregate size class was found and the cumulative percent oversize was computed on the oven dry basis. These percents were

[1]Tentative Method of Determining Water-Stable Aggregates. Submitted by M. L. Nichols to all Soil Conservation Service project supervisors and cooperators. September 17, 1943.

plotted against size on log-probability graph paper[1] and the size value where the curve crossed the 50 percent line was recorded as the geometric mean diameter (according to Gardner (44)). This value was used as the statistic in the analysis of variance in the initial study. The validity of this figure is based on the premise that the logs of the sizes of the stable aggregate are normally distributed. When such is the case the curve resulting from plotting aggregate size against percent oversize on log-probability paper will be a straight line. Some representative curves are shown in Fig. 1.

It was observed that the subsoil curves did not form a straight line so for this study the geometric mean diameter was determined by drawing a straight line between the two points on each side of the 50 percent line. This ignores part of the data but with only four points it was difficult to draw a straight line that would adequately represent all the data without introducing additional variability. The curves for the topsoil data had to be extrapolated a considerable distance to cross the 50 percent line. This obviously introduced a great deal of error. To remedy this situation it would be necessary to separate finer fractions in order to plot points on both sides of the 50% line.

When it was observed that the data did not fit a log-normal distribution too well it was decided to compare the results of Gardner's technique with two other techniques of presenting wet sieving data. Accordingly, these same data were analyzed using for a statistic the mean weight-diameter determined by Van Bavel's graphical method (51) and by Youker and McGuiness's machine calculation method (54). The following results compare the three methods in detecting differences between rotations and treatments from the same wet sieving data. Table 12 compares the average aggregate size distribution determined by

[1]K. and E. 358-22. Probability Scale X 3-Cycle Log.

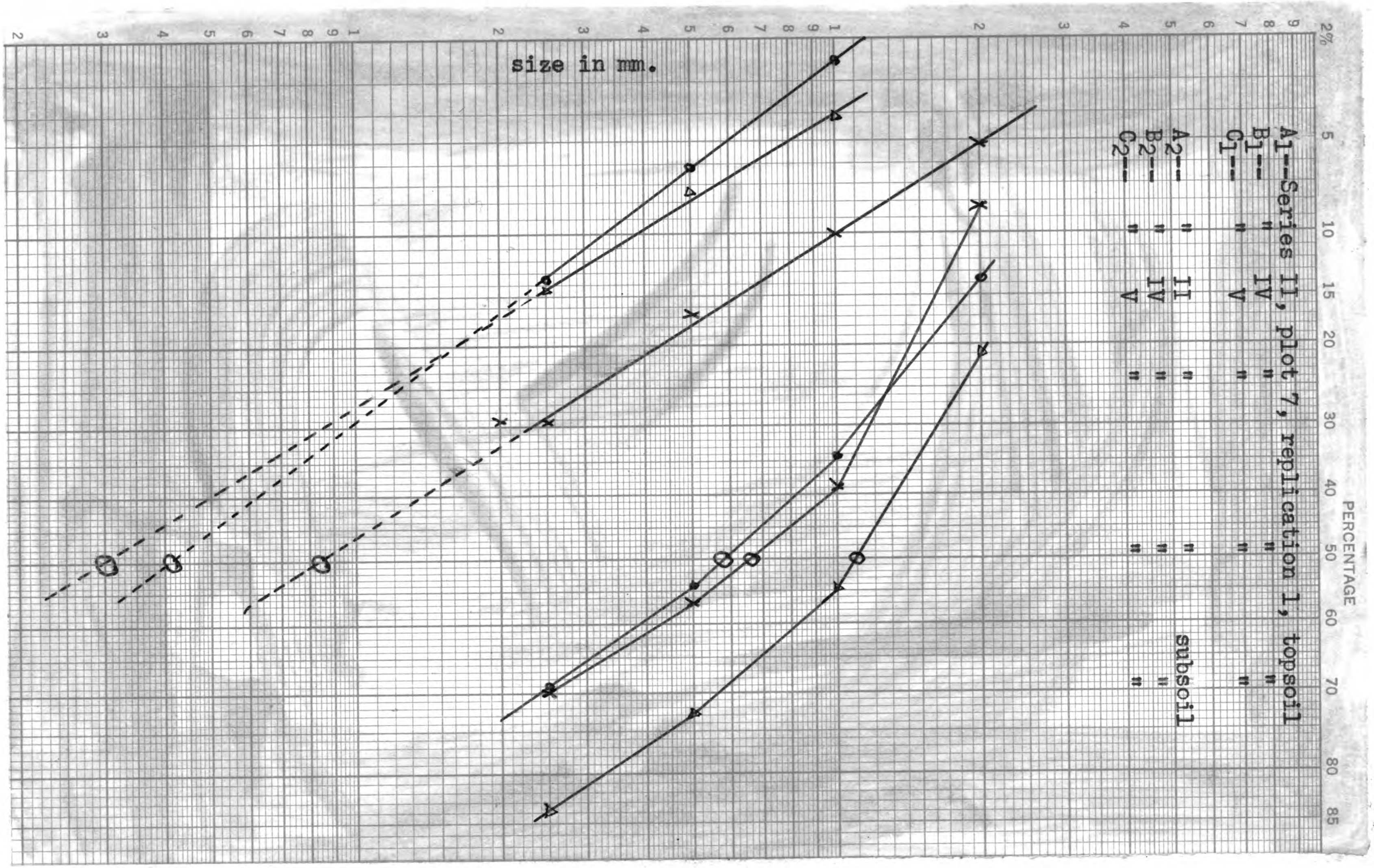

Fig. 1. Set of curves showing representative variation between rotations and between sample depths. The size where the curve crosses the 50% line is the geometric mean diameter.

all three methods. All three methods indicate that Series V has the least stable surface aggregates, but the methods differ in ranking the stability of Series II and IV. There is even less consistency in ranking the treatments. In comparing the stability of the subsurface samples all three methods agree on the following rank orders: Series V is more stable than Series IV which is more stable than Series II; treatment 8 is more stable than 5, which is more stable than 6, which is more stable than 7. However, these comparisons are merely indications based on the average aggregate size distributions. The analysis of variance for each method is given in Tables 13, 14 and 15. Gardner's method in Table 13 indicates no significant differences among the surface soils, but in all the other analyses there was a significant interaction between Series and Treatments.

Table 16 shows the differences between the means in all plots in all Series for the surface soils. Where the "F" value was significant the $LSD_{.05}$ was used to check for significant differences between the means. A comparison is made of the sensitivity of all three methods in detecting differences. The "F" value given is that for the Series X Treatments interaction, however, with Gardner's method the "F" was also insignificant for Series alone and for Treatments alone. Out of the 66 comparisons Van Bavel's method and the Youker & McGuinness method each found 26 significant. They differed in 4 cases but in each of those cases the other method was nearly significant.

Each plot in each series was compared with each of the other 11 plots. Series II is more stable than IV or V on plots 5, 6, and 7, and all three series are essentially the same on plot 8. Series IV is more stable than V on plot 5 but about the same as V on plots 6, 7, and 8. On Series II plots 5 and 6 are more stable than 7 and 8, but on Series IV plot 7 is more stable than 5 and 6, and on Series V plot 6 is more stable than 5 with little difference

Table 12. Average aggregate size distribution. Geometric mean diameter by Gardner's method, mean weight-diameter by Van Bavel's method, and mean weight-diameter by Youker and McGuinness' method. Samples taken from the Soil Fertility Project, Manhattan, Kansas. Fall, 1956.

Plot and treatment	Method	Series (Rotation and Tillage) II 16-yr. plow	IV 16-yr. disc	V 3-yr. disc	Average
		Surface Samples			
5 Check	G	0.031	0.041	0.029	0.033
	V B	0.33	0.27	0.18	0.26
	Y & M	0.34	0.26	0.19	0.26
6 NPK	G	0.054	0.043	0.045	0.048
	V B	0.34	0.28	0.28	0.30
	Y & M	0.37	0.29	0.28	0.31
7 Manure + P	G	0.048	0.052	0.044	0.048
	V B	0.23	0.35	0.24	0.27
	Y & M	0.23	0.25	0.24	0.24
8 Check	G	0.028	0.046	0.042	0.039
	V B	0.24	0.29	0.23	0.25
	Y & M	0.24	0.30	0.24	0.26
Average	G	0.040	0.045	0.040	0.042
	V B	0.28	0.30	0.23	0.27
	Y & M	0.30	0.28	0.24	0.27
		Subsurface Samples			
5 Check	G	0.96	0.90	0.58	0.81
	V B	1.29	1.05	0.90	1.08
	Y & M	1.32	1.14	1.00	1.15
6 NPK	G	0.69	0.82	0.88	0.81
	V B	1.06	1.04	1.08	1.06
	Y & M	1.12	1.13	1.18	1.14
7 Manure + P	G	0.58	0.77	1.02	0.79
	V B	0.90	0.98	1.22	1.03
	Y & M	0.98	1.09	1.31	1.13
8 Check	G	0.68	0.90	1.10	0.89
	V B	0.91	1.19	1.25	1.12
	Y & M	1.00	1.29	1.34	1.21
Average	G	0.73	0.85	0.90	0.83
	V B	1.04	1.06	1.11	1.07
	Y & M	1.10	1.16	1.21	1.16

Table 13. Analysis of variance of wet sieving aggregate analysis data using Gardner's geometric mean diameter. Soil Fertility Project, Manhattan, Kansas. Fall 1956.

	TSS	DF	MS	F
		Surface Soils		
Series (Rotations & Tillage)	0.000401	2	0.00020	0.75 ns
Treatments	0.002180	3	0.00072	2.72 ns
Series X Treatments	0.001467	6	0.00024	0.91 ns
Replications	0.000092	4	0.00002	0.09 ns
Error	0.011757	44	0.00027	
		Subsurface Soils		
Series (Rotations & Tillage)	0.29905	2	0.14952	4.44*
Treatments	0.04161	3	0.01383	0.41 ns
Series X Treatments	1.19906	6	0.19984	5.93**
Replications	0.25138	4	0.06284	1.21 ns
Error	1.48198	44	0.03368	

Table 14. Analysis of variance of wet sieving aggregate analysis data using Van Bavel's mean weight-diameter. Soil Fertility Project. Manhattan, Kansas. Fall, 1956.

	TSS	DF	MS	F
		Surface Soils		
Series (Rotations & Tillage)	0.04556	2	0.02278	9.34**
Treatments	0.01958	3	0.00653	2.68 ns
Series X Treatments	0.7490	6	0.01248	5.11**
Replications	0.00648	4	0.00162	0.66 ns
Error	0.10751	44	0.00244	
		Subsurface Soils		
Series (Rotations & Tillage)	0.05770	2	0.02885	1.72 ns
Treatments	0.05598	3	0.01866	1.12 ns
Series X Treatments	0.93411	6	0.15568	9.30**
Replications	0.19497	4	0.04849	2.90*
Error	0.73632	44	0.01673	

Table 15. Analysis of variance of wet sieving aggregate analysis data using Youker & McGuinness' mean weight-diameter. Soil Fertility Project, Manhattan, Kansas. Fall, 1956.

	TSS	DF	MS	F
		Surface Soils		
Series (Rotations & Tillage)	0.04783	2	0.02391	8.28**
Treatments	0.02815	3	0.00938	3.25**
Series X Treatments	0.08777	6	0.01463	5.07**
Replications	0.00602	4	0.00151	0.52 ns
Error	0.12703	44	0.00289	
		Subsurface Soils		
Series (Rotations & Tillage)	.098157	2	.049078	2.77 ns
Treatments	.061572	3	.020524	1.16 ns
Series X Treatments	.081243	6	.133540	7.53**
Replications	.171226	4	.042806	2.41 ns
Error	.780289	44	.017734	

Table 16. Wet sieving aggregate analysis data. Differences between the means in all plots in all series for the surface soils. The mean indicated by the column was subtracted from the mean indicated by the row to give the difference in the intersecting block. A comparison is made of Gardner's geometric mean diameter, Van Bavel's mean weight-diameter, and Youker and McGuinness' mean weight diameter. Soil Fertility Project. Manhattan, Kansas. Fall, 1956.

Plot	Method	II 6	II 7	II 8	IV 5	IV 6	IV 7	IV 8	V 5	V 6	V 7	V 8	$LSD_{.05}$	F
	Gardner	The "F" value was insignificant for all comparisons among the surface soils with this method, hence the LSD was not used.											---	0.91 ns
II 5	Van Bavel	-.0182 ns	+.1002 *	+.0881 *	+.0601 ns	+.0441 ns	-.0205 ns	+.0323 ns	+.1423 *	+.0497 ns	+.0871 *	+.0931 *	.0629	5.11 **
	Youker-McGuinness	-.0298 ns	+.1096 *	+.1014 *	+.1751 *	+.1501 ns	-.1089 ns	+.0391 ns	+.1511 *	+.0560 ns	+.1000 *	+.0998 *	.0685	5.07 **
	Gardner													
II 6	Van Bavel		+.1184 *	+.1063 *	+.0783 *	+.0623 *	-.0023 ns	+.0505 ns	+.1605 *	+.0679 *	+.1052 *	+.1113 *		
	Youker-McGuinness		+.1394 *	+.1312 *	+.1049 *	+.0799 *	+.0209 ns	+.0689 *	+.1809 *	+.0858 *	+.1298 *	+.1296 *		
	Gardner													
II 7	Van Bavel			-.0121 ns	-.0401 ns	-.0561 ns	-.1207 *	-.0679 *	+.0421 ns	-.0505 ns	-.0132 ns	-.0071 ns		
	Youker-McGuinness			-.0082 ns	-.0345 ns	-.0590 ns	-.1185 *	-.0705 *	+.0415 ns	-.0536 ns	-.0096 ns	-.0098 ns		
	Gardner													
II 8	Van Bavel				-.0280 ns	-.0440 ns	-.1086 *	-.0558 ns	+.0542 ns	-.0384 ns	-.0011 ns	+.0050 ns		
	Youker-McGuinness				-.0263 ns	-.0513 ns	-.1103 *	-.0623 ns	+.0497 ns	-.0454 ns	-.0014 ns	-.0016 ns		
	Gardner													
IV 5	Van Bavel					-.0160 ns	-.0806 *	-.0278 ns	+.0822 *	-.0104 ns	+.0269 ns	+.0330 ns		
	Youker-McGuinness					-.0250 ns	-.0840 *	-.0360 ns	+.0760 *	-.0191 ns	+.0249 ns	+.0246 ns		
	Gardner													
IV 6	Van Bavel						-.0646 *	-.0118 ns	+.0982 *	+.0056 ns	+.0429 ns	+.0490 ns		
	Youker-McGuinness						-.0590 ns	-.0110 ns	+.1010 *	+.0059 ns	+.0499 ns	+.0497 ns		
	Gardner													
IV 7	Van Bavel							+.0528 ns	+.1628 *	+.0702 *	+.1075 *	+.1136 *		
	Youker-McGuinness							+.0480 ns	+.1060 *	+.0649 ns?	+.1089 *	+.1087 *		
	Gardner													
IV 8	Van Bavel								+.1100 *	+.0174 ns	+.0547 ns	+.0608 ns		
	Youker-McGuinness								+.1120 *	+.0169 ns	+.0609 ns	+.0607 ns		
	Gardner													
V 5	Van Bavel									-.0926 *	-.0553 ns	-.0492 ns		
	Youker-McGuinness									-.0951 *	-.0511 ns	-.0513 ns		
	Gardner													
V 6	Van Bavel										+.0373 ns	+.0434 ns		
	Youker-McGuinness										+.0440 ns	+.0438 ns		
	Gardner													
V 7	Van Bavel											+.0061 ns		
	Youker-McGuinness											-.0002 ns		

Table 17. Wet sieving aggregate analysis data. Differences between the means in all plots in all series for the subsurface soils. The mean indicated by the column was subtracted from the mean indicated by the row to give the difference in the intersecting block. A comparison is made of Gardner's geometric mean diameter, Van Bavel's mean weight-diameter, and Youker and McGuinness' mean weight-diameter. Soil Fertility Project, Manhattan, Kansas. Fall, 1956.

Plot	Method	II 6	II 7	II 8	IV 5	IV 6	IV 7	IV 8	V 5	V 6	V 7	V 8	LSD$_{.05}$	F
	Gardner	+.270 *	+.384 *	+.290 *	+.086 ns	+.146 ns	+.190 ns	+.060 ns	+.380 *	+.082 ns	-.054 ns	-.138 ns	.2336	5.93**
II 5	Van Bavel	+.2271 *	+.3849 *	+.3817 *	+.2346 *	+.2523 *	+.3142 *	+.1021 ns	+.3847 *	+.2073 *	+.0688 ns	+.0352 ns	.1648	9.30**
	Youker-Mcguinness	+.2046 *	+.3460 *	+.3253 *	+.1825 *	+.1982 *	+.2302 *	+.0322 ns	+.3301 *	+.1632 ns?	+.0186 ns	-.0154 ns	.1697	7.53**
	Gardner		+.114 ns	+.020 ns	-.202 ns	-.124 ns	-.080 ns	-.210 ns	+.110 ns	+.188 ns	-.324 *	-.408 *		
II 6	Van Bavel		+.1578 ns	+.1546 ns	+.0075 ns	+.0252 ns	+.0871 ns	-.1250 ns	+.1576 ns	-.0198 ns	-.1572 ns	-.1918 *		
	Youker-McGuinness		+.1414 ns	+.1207 ns	-.0221 ns	-.0064 ns	-.0256 ns	-.1724 *	+.1255 ns	-.0423 ns	-.1860 *	-.2191 *		
	Gardner			-.094 ns	-.316 *	-.238 *	-.194 ns	-.324 *	-.004 ns	-.302 *	-.438 *	-.522 *		
II 7	Van Bavel			-.0032 ns	-.1503 ns	-.1326 ns	-.0707 ns	-.2828 *	-.0002 ns	-.1776 *	-.3150 *	-.3496 *		
	Youker-Mcguinness			-.0207 ns	-.1635 ns	-.1478 ns	-.1156 ns	-.3138 *	-.0159 ns	-.1837 *	-.3274 *	-.3650 *		
	Gardner				-.224 ns	-.146 ns	-.102 ns	-.232 *	+.088 ns	-.210 ns	-.346 *	-.430 *		
II 8	Van Bavel				-.1471 ns	-.1294 ns	-.0675 ns	-.2796 *	-.0030 ns	-.1744 *	-.3188 *	-.3463 *		
	Youker-McGuinness				-.1428 ns	-.1271 ns	-.0949 ns	-.2931 *	+.0068 ns	-.1630 ns?	-.3067 *	-.3398 *		
	Gardner					+.078 ns	+.122 ns	-.008 ns	+.312 *	+.014 ns	-.122 ns	-.206 ns		
IV 5	Van Bavel					+.0177 ns	+.0796 ns	-.1325 ns	+.1501 ns	-.0273 ns	-.1647 *	-.1970 *		
	Youker-Mcguinness					+.0157 ns	+.0479 ns	-.1503 *	+.1476 ns	-.0202 ns	-.1639 ns?	-.1970 *		
	Gardner						+.044 ns	-.086 ns	+.234 *	-.064 ns	-.200 ns	-.284 *		
IV 6	Van Bavel						+.0619 ns	-.1502 ns	+.1324 ns	-.0450 ns	-.1824 *	-.2170 *		
	Youker-Mcguinness						+.0322 ns	-.1660 ns	+.1319 ns	-.0359 ns	-.1796 *	-.2127 *		
	Gardner							-.130 ns	+.190 ns	-.108 ns	-.244 *	-.328 *		
IV 7	Van Bavel							-.2121 *	+.0705 ns	-.1069 ns	-.2443 *	-.2789 *		
	Youker-Mcguinness							-.1982 *	+.0997 ns	-.0681 ns	-.2118 *	-.2449 *		
	Gardner								+.320 *	+.022 ns	-.114 ns	-.198 ns		
IV 8	Van Bavel								+.2826 *	+.1052 ns	-.0322 ns	-.0668 ns		
	Youker-McGuinness								+.2979 *	+.1301 ns	-.0136 ns	-.0467 ns		
	Gardner									-.298 *	-.434 *	-.518 *		
V 5	Van Bavel									-.1777 *	-.3148 *	-.3494 *		
	Youker-McGuinness									-.1678 *	-.3115 *	-.3446 *		
	Gardner										-.136 ns	-.220 ns?		
V 6	Van Bavel										-.1374 ns	-.1720 *		
	Youker-Mcguinness										-.1437 ns	-.1768 *		
	Gardner											-.084 ns		
V 7	Van Bavel											-.0346 ns		
	Youker-Mcguinness											-.0331 ns		

between the others.

Series II being more stable than IV or V is in agreement with the dry sieving results and is probably due to the tillage difference. Series II was plowed at a moisture content that resulted in large, hard clods. Series IV and V were disced resulting in small, crumbly clods. Series II was plowed in July permitting the surface soil to weather more than the September disced plots on Series IV and V.

There is no apparent reason why plot 7 should be about the least stable on Series II and the most stable on Series IV while on Series V there is essentially no difference between it and the other plots. Altogether, the treatment effects are inconsistant in the surface soil.

The subsurface soil comparisons are given in Table 17. Out of the 66 comparisons Gardner's method finds 24 significant differences, Van Bavel's method finds 29, and the Youker & McGuinness method finds 27. The latter two methods differ in five cases and in two of them the Youker & McGuinness method finds significance while the Van Bavel method is not particularly close, but in the three cases where the Van Bavel method finds significance the machine calculation method is extremely close to significance also.

In all the comparisons made the two methods which calculate the mean weight-diameter found more significant differences than Gardner's geometric mean diameter method. There was very little difference between the first two methods. The machine calculation method will always give a slightly higher value for the mean weight-diameter than the graphical method (if the graphing is dohe accurately) but this tends to cancel itself out when computing differences between samples. A correlation was made between the Van Bavel graphical method and the Youker & McGuinness machine calculation method with a resulting correlation coefficient of 0.983. The following regression formula was computed: Y & M = 1.2149 (V B) - 0.0462. Youker and McGuinness (54) made a similar comparison. They found a correlation coefficient of 0.986 and computed the regression formula: Y & M = 0.876 (V B) - 0.079. They assumed that it would be satisfactory to use this formula in any case but advised checking it if data was available. The difference between these regression formulae shows that neither of them would be accurate for every case. The difference may be caused by the difference in the soils analyzed or by the difference in the way the analysis was made. Apparently Youker and McGuinness used a subsample of the whole soil in contrast to the subsample of only the aggregate fraction between 4.76 and 2.00 mm used in this study.

It is obvious that the Youker and McGuinness method would be of little value if it was necessary to first compute the mean weight-diameter graphically then derive a regression formula. The results of this study are based on mean weight-diameters which have not been corrected by the regression formula. It is important to note that the machine calculation method is just as sensitive as the graphical method even without the correction.

This study was based on 5 aggregate size ranges, i.e. 0.0 - .25, .25 - .50, .50 - 1.00, 1.00 - 2.00, and 2.00 - 4.76 mm. The Youker and McGuinness study was based on the same number of size ranges but with slightly different values. As the number of size ranges is increased the calculated mean weight-diameter approaches the graphical value. Thus it seems advisable for the particular soils used in this study to increase the number of size ranges at least to 8 by adding a 0.100 mm sieve and determining the 0.0 - 0.002 and 0.002 - 0.05 mm sizes by hydrometer. This should give sufficient accuracy to make it unnecessary to correct the calculated values.

The subsurface soil analysis as indicated by the difference between the means in Table 17 shows that Series II is more stable than IV or V on plot 5, essentially the same as IV and V on plot 6, the same as IV but less stable than V on plot 7, and less stable than IV or V on plot 8. More study is necessary to explain this interaction. On Series II, check plot 5 is more stable than the other three which are essentially the same. In contrast, on Series V, check plot 5 is less stable than the other three with the other check plot 8 being the most stable. And on Series IV, plot 5 was not found significantly different from any other plot although plot 8 was more stable than 7. None of the differences among the subsurface samples seem to correlate with any other known factor. It is possible that these differences are inherent or due to the position of the plots. This cannot be evaluated at this time because no earlier tests were made to make a comparison possible.

A complete set of samples was taken in the spring of 1957 and analyzed as above but the results were destroyed by the fire in Waters Hall in August, 1957. No quantitative data can be presented for the spring analysis, however, the results did show that the season had a considerable effect on the water stability of the aggregates.

This aggregate analysis by wet sieving study does not validate the assumption that the rotations and fertility treatments in the long time Soil Fertility Project did result in consistant and significant changes in the soil structure. The apparent difference in aggregate stability between Series II and Series IV and V is attributed to tillage rather than to the rotation or fertility treatments. Series II and IV had the same rotation and Series IV and V had practically the same tillage.

The fact that this study did detect differences in soil structure indicates that this aggregate analysis by the wet sieving method needs to be studied further under conditions where the factors believed to affect soil structure are controlled. Such factors should at least include season, type of tillage, soil moisture content at the time of tillage, soil moisture content at the time of sampling, cropping treatment, fertility treatment, and soil compaction.

The aggregate stability results did not correlate with any of the other methods evaluated, nor with the average wheat yields.

DISCUSSION AND CONCLUSIONS

Of the five methods studied the only method of evaluating soil physical condition that found consistant significant differences between the fertility treatments was dry aggregate distribution determined by the rotary sieve. This method of analysis indicated that the plots receiving superphosphate each year plus manure just before corn formed larger dry aggregates in the surface 3 inches. All three of the methods based on the analysis of dry aggregates found significant differences between Series which reflected rotation and/or tillage effects. The second sieving method of evaluating dry aggregate coherence showed differences between all three Series but the clod crushing strength method did not, although the results of the two methods proved to have significant correlation. The second sieving was preferred because it was much faster and less subject to errors introduced by the operator.

Neither the porosity method nor the wet aggregate stability determination found consistant, significant differences between series or treatments. The porosity determination is subject to some rather serious errors which vary with the soil and are difficult to avoid. It is difficult to run a large number of samples at one time. The aggregate stability determination by the wet sieving method is fraught with problems. No standard procedure of this method has been developed thus usually invalidating a comparison of results by different investigators. Some have investigated the stability of different aggregate sizes while others studied the size distribution of water stable aggregates in the whole soil. Season and soil moisture content at the time of sampling affect the wet sieving results. Where the analysis of variance was run on the results, the method of determining the statistic for each sample had considerable effect. The results of this study indicate that the calculated mean weight-diameter proposed by Youker and McGuinness (54) is preferable to Van Bavel's (51) graphical mean weight-diameter or Gardner's (18) geometric mean diameter.

The results of this study may have been biased by using the analysis of variance on samples from a systematic design. The study of rotation effects was confounded to a certain extent by the tillage effects and the lack of quantitative information on the soil moisture content at the time of tillage.

None of the soil physical condition differences that were measured correlated with the average wheat yields. Apparently the soil physical condition was of minor importance to wheat production on this soil. However, it was not possible to correlate the measured soil differences with those wheat yields which were not seriously affected by lack of moisture. Additional study will be necessary to determine whether the soil physical condition affects wheat yields during the years of favorable climate.

SUMMARY

Five methods for measuring soil physical condition were studied to evaluate their effectiveness in determining the influence of a long term rotation and fertility experiment on the soil.

Samples were taken from plots 5, 6, 7, and 8 on Series II, IV, and V of the 46-year old Soil Fertility Project on the Manhattan Agronomy Farm. This project of systematic design on the soil formerly called Geary silt loam included different fertility treatments such as NPK on plot 6, superphosphate each year plus manure just before corn on plot 7, and check on plots 5 and 8, on each of several cropping systems. Series II and IV were in a 16-year rotation: Alfalfa (4 years), corn, wheat, wheat, (12 years). Series II was in wheat after wheat, 11 years after alfalfa, and had been plowed in July. Series IV was in wheat after corn, 7 years after alfalfa, and had been disced in September. Series V was in wheat after soybean hay of the 3-year rotation: corn, soybean hay, wheat. It was disced in September and harrowed in October.

Soil porosity was evaluated by the percent macropores in 3 X 3 inch cores determined by equilibrium with 60 cm water tension applied through tension plates similar to those described by Tanner et al (46).

Dry aggregate size distribution and aggregate coherence were evaluated by Chepil's rotary sieve method (11). Dry clod crushing strength was determined by the Martinson and Olmstead method (30). Wet aggregate stability was determined by a modification of Yoder's wet sieving technique (53).

Five samples for each analytical method were taken at equidistant intervals down the middle of each plot. Both sides of the plots were reserved for wheat yield samples. Porosity and wet aggregate stability samples were taken from presoaked sites of the surface soil, one to four inches, and the subsurface soil, 8 to 11 inches. Samples for these determinations were taken in both fall and spring, however, the results of the spring wet aggregate stability analysis were destroyed by fire.

A single sample of 4 to 10 kilograms of the 0 to 3-inch depth was taken in the dry condition from each site for all three dry aggregate analyses. No spring sample was taken for these determinations because of the continuously wet conditions. The single large sample was oven dried at 80°C then divided for the dry sieving analyses and the clod crushing strength determination.

The porosity results were reported as percent macropores. Differences between surface and subsurface soils were readily apparent. Seasonal effects were inconsistant. The analysis of variance indicated an interaction between Series and Treatments. No consistant differences were found when the interaction was investigated with the LSD. Three important sources of error in the method were pointed out in compaction of the core during sampling, failure to have the sampling site wetted to field capacity at the time of sampling, and failure to achieve complete saturation of the core in the laboratory.

Dry aggregate distribution results were reported as geometric mean diameter determined by Gardner's method (18). The analysis of variance and LSD indicated that Series II had larger aggregates than IV or V and that Series IV and V were essentially the same. This difference was attributed to tillage effects. Plot 7 had larger aggregates than 5, 6, or 8.

Dry aggregate coherence results were reported as percent of aggregates larger than 0.84 mm lost by a second sieving. This is a measure of the mechanical stability of the aggregates. According to this method Series II had more stable aggregates than Series V which in turn was more stable than Series IV. The stability of Series II was attributed to plowing when moist. The stability difference between Series V and IV which were both disced was attributed to the effects of the close-drilled soybeans.

The clod crushing strength results were reported as ounces of crushing force per gram of clod weight. The average of 40 clods was used for each sample. Again Series II was more stable than IV or V and the latter two were essentially the same. This difference was attributed to tillage.

A comparison was made of three methods of reporting wet aggregate stability data. The calculated mean weight-diameter proposed by Youker and McGuinness (54) was found preferable to Van Bavel's (51) graphical determination of mean weight-diameter and Gardner's (18) geometric mean diameter. The analysis of variance revealed interactions between Series and Treatments. The only consistant difference found by the LSD indicated that Series II surface soil aggregates were more stable than those of Series IV or V. This agrees with the dry sieving results.

There was a significant correlation between clod crushing strength and percent macropores, however, more study will be necessary to determine what factors cause them to be related. Second dry sieving results correlated highly with clod crushing strength as was expected since both measure aggregate coherence. The second sieving method was preferred over the crushing strength method since it was faster, simpler, and less subject to operator bias.

None of the soil differences measured correlated with average wheat yields. Apparently soil physical condition is of minor importance to wheat production on this soil.

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A STUDY OF METHODS FOR MEASURING SOIL PHYSICAL CONDITIONS

by

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