CONTINUOUS CULTIVATION AS A FACTOR IN AGGREGATE STABILITY AND OTHER PROPERTIES ON A KIRKLAND SILT LOAM SOIL

By

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INTRODUCTION

Since the beginning of the 20th Century, it has been accepted that continuous intensive cultivation causes a substantial loss in organic matter which precedes a deterioration of the structural properties of the soil. It has been suggested that structural deterioration, as well as nutrient depletion, are responsible for yield reduction under continuous cultivation. Today, it is widely accepted that continuous intensive cultivation will result in a structural breakdown, a decrease in organic matter, macro-porosity and infiltration.

With the present trend toward a more mechanized and intensive agriculture, a better understanding of the processes involved in the formation, stability and deterioration of soil structure is of prime importance. The objectives of this study were:

1. To study the effects of 40 years of continuous cotton cultivation on a Kirkland silt loam field as compared to a non-cultivated area of the same soil type.

2. To evaluate the effect of organic matter, nitrogen, per cent sand, silt and clay, exchange capacity and exchangeable calcium, magnesium, potassium and sodium on the stability of the soil aggregates.

3. To examine a new method of evaluating the aggregate stability of a soil.

REVIEW OF LITERATURE

A favorable soil structure has long been recognized as one of the foundations of crop production. The use of barnyard manure, green manure, crop residues and the inclusion of grasses and legumes in a rotation all stem from the farmer's observation that these practices might improve the physical condition of the soil and increase yield.

Soil structure has been defined in many ways. Lyon, Buckman and Brady (28)[1] state "structure is strictly a field term descriptive of the gross over-all aggregation or arrangement of the soil solids." Baver (7) defines soil structure as "the arrangement of the primary and secondary particles into a certain structural pattern." Page (37) states "soil structure is the arrangement of soil particles." It is of importance to mention that in spite of the importance of soil structure, its definition is general and vague.

Yoder (54) describes an ideal soil structure as one which will result in:

1. Minimum resistance to root penetration.
2. Free intake and moderate retention of rain or irrigation water.
3. Optimum soil air and moderate gaseous exchange.
4. Minimum competition between air and water for occupancy of the soil pore space.

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[1] Figures in parenthesis refer to "Literature Cited."

Bradfield (10) argues that an ideal structure is formed under grass vegetation. He maintains that an ideal structure has two systems of soil pore space. Micro-capillary pores within the aggregates and macro-non-capillary pores between the aggregates. A soil aggregate is defined by Page (36,37) as "a cluster of soil particles held together more or less loosely but with sufficient strength so it behaves in the soil as a unit." Bradfield's system will result in rapid water intake approaching that of sand between the aggregates and a high water holding capacity approaching that of clay within the aggregates. The most important characteristic which a good structure imparts to the soil is the extra macro-pores. Page (36,37) discussed the favorable porosity in a well aggregated soil and concluded that aggregation which result in larger soil units will provide better aeration and drainage through improvement of the macro-porosity.

The Formation of Aggregates

Aggregates in the soil are formed by two natural processes: (a) clumping together of the soil primary particles; and (b) fracture of larger masses of soil into aggregates. Yoder (54), Baver (7), Page (36,37) and others agree that the most important processes leading to the formation of soil aggregates are:

The action of plant roots-Bradfield (10) maintains that numerous roots in the soil tend to separate it into clumps which are compressed due to the penetration and growth of the roots. Each root is a center of water removal from the soil and thus causes localized shrinking and compression which further breaks the soil down into aggregates. Decaying roots are claimed to encourage microorganism activity on the surface of the soil aggregate. This activity produces microbial by-products which act as cementing materials to hold the aggregate together as a unit.

Freezing and thawing-Baver (7) and Chepil (16) state that uneven volume and pressure changes caused by the formation of ice tend to break the soil mass down into smaller aggregates. The aggregates formed remain as separate units, because the cohesion forces between the clay particles within the aggregate are stronger than the forces acting between the aggregates. Chepil (16) reports that if the soil is too dry or too wet no breakdown as a result of freezing will occur. He also claims that rapid freezing will form small ice crystals which will cause excessive breakdown of soil aggregates.

Wetting and drying-Shrinking and swelling of the soil will result in cracking and breakdown of the soil mass. Page (36,37) claims that clay swelling, which is caused by the adsorption of water molecules on the clay surfaces, will weaken the cohesive forces between soil particles and aid in the soil breakdown. Yoder (55) observed that a wetting front compressed the air trapped in soil masses and caused miniature localized explosions and a further breakdown of the soil.

Flocculation of the soil colloids-The place of flocculation in the formation of soil aggregates has been much debated. The idea that flocculation is important in aggregate formation was deduced from the observation that some highly aggregated soils had a high calcium content. Since calcium salts will flocculate clay suspensions, it was inferred that flocculation was an important process in aggregation. Baver (4) reported no difference in the physical properties of a hydrogen or calcium saturated soil. Bradfield (11) maintains that flocculation favors aggregation by immobilizing the clay particles. Lutz (30), Baver (4,7) and Robinson and

Page (45) report that hydrogen saturated soils were as well aggregated as calcium saturated soils. Peel (40) added various amounts of calcium salts to a soil and reported no increase or decrease in aggregation. Lutz (30) reported that the clay of a Davidson soil was flocculated irrespective of the cation on the exchange complex. Page (36,37) maintained that in most soils the clay was naturally flocculated by either hydrogen, calcium, or organic substances while aggregation varied quite widely. He believed that flocculation was not important in the formation of soil aggregates. However, it has been noted that in alkali soils the clay is dispersed and a prerequisite to aggregation in such soils is the flocculation of soil colloids (7,36,37). Russell(46) maintained that the analogy drawn between the flocculation of clay suspensions and aggregate formation in the soil was invalid. Flocculation occurred only when the electrokinetic potential of the clay particle was low (low dissociation of cations) while for the formation of the aggregate a high electrokinetic potential and a high dissociation of the cations was needed.

The place of clay in the formation of soil aggregates-The clay fraction of the soil controls to a large degree its physical and chemical properties. A soil of low clay content will usually result in a favorable porosity but a poor nutrient supplying power. A soil high in clay will maintain a high nutrient supplying power, however, the structure and porosity of this soil will depend on the arrangement of the soil particles. Many investigators (7,36,37,46,49) note the importance of clay in the formation of soil aggregates. Baver (5) analyzed 77 different soils and reported a high correlation between clay content and aggregation. Hide and Metzger (20) reported a higher clay content in well aggregated soils as compared to the same soil in a poorly aggregated condition. Garey (18) found a higher clay content in the aggregates than in the whole soil and he postulated that the clay is important in the aggregation process. It has been postulated that clay participates in the formation of aggregates in three ways:

1. The linkage of clay particles by water dipoles or bridging by different cations was originally advanced by Russell(46). He claimed that since the water molecules were polar they would orient themselves between the surface of the clay particle and the cations in the diffuse double layer. The positive end of the water molecule would orient itself to the negative charge on the clay surface, the negative end towards the positive charge of a cation in the diffuse double layer. Russel claimed that some of the cations would share the water molecules which envelop them with two adjacent clay particles, thus forming a linkage system. This linkage system can be roughly described as: clay particle - H_2O molecule - cation - H_2O molecule - clay particle. This mechanism seems to be important under moist conditions. However, it is questionable in accounting for the forces holding the aggregates together in the dry state.
2. Cohesive forces between the clay particles.
3. Linkage of clay particles by long polar organic liquids.

The Stability of Soil Structure

Once the structural units are formed in the soil, they would rapidly disappear if they were not stable. Thus, the stable soil aggregates are those which will stay on a set of sieves after 30 minutes of sieving in water.

Effect of organic matter-The importance of organic matter in the stability of soil structure is generally agreed upon. Robinson and Page (45) removed the organic matter from a Brookston soil and measured aggregate stability. They reported a high reduction in the stability of aggregates when organic matter was removed as compared to the undisturbed soil. Garey (18) collected the stable aggregates attained by wet sieving and compared their properties with that of the whole soil. He reported higher organic matter in the smaller stable aggregates than in the whole soil. Baver (5) reported that organic matter content of 77 soils was highly correlated with the stable aggregates. This was especially true when the clay content was low. Baver and Harper (6) found a close correlation between organic matter and stable aggregates in desert soils from Arizona. A number of mechanisms which are claimed to help stabilize the soil aggregates are reported in the literature:

1. The binding of soil particles by fungi and bacteria is a subject of much interest. Martin and Waksman (33) and Martin (31) report that bacterial cells and fungi mycelia are important materials in the binding of the soil particles. Martin reports that 50% of the aggregation effect of fungi was due to physical effect of the mycelium and the other 50% was due to substances other than the cell wall produced by the fungi. With bacteria, however, the results were different, only 20% of the aggregation effect was due to the bacterial cells, while 80% was a result of other cellular materials produced by the bacteria. Page (37) argues that the importance of the fungi and bacteria themselves as materials capable of stabilizing aggregates has been overemphasized. He points out that claims for the effect of microorganisms on aggregation were achieved in the laboratory with an abundant microbial food supply and without competition from other organisms, and it was questionable that these conditions existed in the field.

2. The cementing or linkage of soil particles by polar long chain organic molecules has been discussed by many workers. The actual manner in which organic materials promote a stable structure is not understood. Myers (35) claims that organic substances are adsorbed on the clay surfaces as a result of the polarity of the humic compounds, thus forming linkages between clay particles. Sideri (49) suggested a similar hypothesis. He maintains that the humic substances are adsorbed on the clay particles through a process of orientation of the organic molecules. Peterson (43) reports that large amounts of polyuronides are found in the soil organic matter and on the outer layers of plant root hairs. He maintains that the polyuronides are important in cementing the clay particles. Peterson suggests a linkage between polar polyuronides, calcium cations, and the clay particles as roughly as: clay - calcium - pectin - calcium - clay. Baver (7) quotes Geoghegai who suggests that the hydroxyl group produces the linkage between the clay and the polyuronides. Martin (32) reports that polysaccharides produced by bacteria are effective in aggregate stability. He claims that this effect is short lived since these mater-

> ials are destroyed by soil microorganisms. Robinson and Page (45) concluded that the organic materials associated with the clay were largely responsible for aggregate stability. Page (36,37) maintains that the importance of these proposed mechanisms was overemphasized.

The cohesive forces between clay particles-Baver (7) maintains that the cohesive forces between the clay particles and the larger fractions are important mechanisms in aggregation. Sideri (49) reports that cohesion between the clay particles is of prime importance in aggregation. Page (36,37) claims that the cohesive forces in the clay are the most important mechanisms in the formation and stability of soil aggregates. The cohesive forces between the clay particles are a result of intercrystalline ionic forces and of the interaction of exchangeable cations between oriented clay plates. Page states that these cohesive forces in some clays can account for all the binding necessary for soil aggregation and stability. When the clay particles are in close contact and the number of points of contact between particles is large, the cohesive forces are at their maximum. This effect is observed in dried puddled clays and the result is a very hard mass which is unfavorable for plant growth. Under field conditions, without excessive cultivation, the clay particles are randomly arranged and the number of points of contact are low, this results in a small cohesive force. Water molecules and organic substances adsorbed on the clay surfaces will further reduce the cohesive force between the clay particles. This is probably due to loss of surface energy of the clay particles. The reduction of the cohesive forces will create a favorable field of force for the formation of stable aggregates. Page claims that the role of the organic polar compounds is twofold:

1. To weaken the potentially strong cohesive forces between clay particles, thus permitting the formation of aggregates.

2. To link clay particles together through mutual adsorption of such compounds by two or more clay particles.

The place of adsorbed cations in the formation and stability of structure-Assuming that the theory advanced by Page (36,37) and discussed in the preceding chapter is the most accurate, adsorbed cations should be important in aggregation. From his theory, it is easy to deduce that the kind of cations adsorbed in the diffuse double layer and their charge will tend to affect, to a considerable degree, the surface energy and the electrokinetic potential of the clay particles. Thus, the cohesive attraction between the clay particles is greatly affected. Baver (5) analyzed 77 different soils but found no correlation between aggregate stability and calcium level. Aldrich (3) reports no effect of magnesium level on aggregate stability. He also reports, depending on the soil, the aggregate stability might or might not be affected by the potassium level. This was observed by Reeve and Bower (44). Aldrich found that increasing the sodium content would reduce aggregate stability and that the same effect was caused by excess lime. McHenry and Russell (34) worked with puddled materials and they reported that sodium additions greatly increased the stability of aggregates. Hide and Metzger (20) reported a higher exchange capacity in stable aggregates, but explained it as a result of higher clay content. Garey (18) separated the stable aggregates and compared their properties with those of the whole soil. He found that the larger aggregates had a lower exchange capacity than the whole soil. Myers (35) reported a higher percentage of stable aggregates in hydrogen saturated soil than in a calcium saturated soil. The results obtained by Robinson and Page (45) agree with those obtained by other workers (3, 30,35). Lutz (29) reported a high correlation between free iron and aggregate stability in lateritic soils. He claimed that the free iron in solution acts as a flocculating agent, while the colloidal iron acts as a cementing agent.

The Disintegration of Soil Structure

Opposing the processes which are assumed to build up the soil structure are natural forces and processes which tend to destroy the soil structure. Alderfer and Merkle (1) list most of the processes responsible for the destruction of soil structure:

1. Impact of beating rain.
2. Shearing and polishing action of cultivation implements.
3. Compaction by machinery, animals and man.
4. Absence of organic residues.
5. Leaching of soluble salts and consequent deflocculation.

Agronomic Practices and Structural Stability

The effect of continuous cultivation on structural stability-Jenny (22) reported that 40 years of continuous cultivation of corn in Missouri caused a 38% decrease in organic matter, a 35% decrease in nitrogen, 33% decrease of exchangeable bases, 28% decrease in sand and 39% decrease in clay as compared to a virgin prairie soil. Laws and Evans (27) reported that a Houston black clay after 50 to 90 years of continuous cultivation showed a marked decrease in organic matter and nitrogen as compared to the virgin soil. They also reported a much higher percentage of large stable aggregates in the virgin soil than in the cultivated one. Browning (13) reported a decrease in organic matter from 3.5% to 2.0% as a result of continuous cultivation. A reduction in organic matter, nitrogen and stable aggregates has also been reported (1,2,14,19,23,25,51,53).

Crop rotation and aggregate stability-Van Bavel and Schaller (52) reported that the stable aggregates were twice as high in a soil cropped to corn in a corn-oats-meadow rotation as compared to the same soil under continuous corn. Aggregate stability dropped rapidly when continuous corn followed sod crops and increased when cropping was changed from continuous corn to a corn rotation. They reported that a corn-oats-meadow rotation showed a slight insignificant decrease in organic matter and that 11 years of alfalfa or bluegrass maintained the most stable structure. Johnston *et al.* (23) reported a decrease in stable aggregates as a result of cropping systems in the order of: bluegrass, clover-oats-corn rotation, and continuous corn. Alderfer and Merkle (2) found a higheraggregate stability in a soil cropped to sod. Gish and Browning (19) listed the order of aggregate stability under cropping systems as Bluegrass, rotation meadow, rotation corn, and continuous corn. Thus, it seems that there is a general agreement among the investigators that continuous cultivation will result in a considerable reduction of the stability of aggregation. Sod crops and crop rotation would increase the aggregate stability or maintain it on a favorable level.

Manure application and aggregate stability-There is general agreement as to the value of manure application in maintaining and improving aggregate stability. It should be mentioned though that most of the work reported has been from the northeast or north central parts of the United States. Several workers (1,2,8,12,17,26,47,53) report a highly significant increase in aggregate stability with manure application. Bertramson and Rhoades (9) reported that in Nebraska manure application had no effect on aggregate stability. It ought to be said that too much attention has been given to the kind of plants grown and not enough on type and numbers of cultivation.

In spite of a voluminous literature, the mechanisms that lead to good soil structure are still unknown. This is partly due to the variability of the manifestation of structure formation and stability on different soils.

METHODS AND MATERIALS

The soil studied was a Kirkland silt loam which belongs to the Red Prairie soil group. A detailed description of the soil profiles near the sites sampled is given in the Appendix.

Samples were taken from two sites:

Site I - Kirkland silt loam in permanent grass vegetation was located south of the Stillwater Municipal Airport buildings. The site was covered with tall prairie grasses, little bluestem, some big bluestem, switchgrass, and dropseeds. Bulk samples were taken with a spade from two locations about 30 feet apart. The samples were taken at two depths, 0 to 6 inches and 6 to 12 inches. These two locations will be called "Plot A" and "Plot B", respectively.

Site II - The second site was on the Agronomy Research Farm and samples were taken from the western half of series 4100. The western half of series 4100 has been under continuous cotton cultivation since 1916. Two treatments were selected, plots 4 and 7, which were check plots and did not receive any treatment except that the cotton residues were plowed down every year. This treatment will be called from now on "continuous cotton". The second treatment selected was on plots 2 and 8 which had received manure applications of 5 tons per acre every three years. This treatment will be referred to as "continuous cotton plus manure". Two locations were sampled from each plot and at two depths, 0 to 6 inches and 6 to 12 inches. The samples from the two locations and from each depth were mixed into a composite sample to represent the plot at each depth. The samples from each plot were brought to the laboratory and air dried. The air dried samples were crushed with a wooden roller to pass a 4-mesh sieve, mixed and stored in 2½ gallon ice cream cartons. These samples will be referred to as the "stock samples". For chemical analysis, the stock samples were further crushed to pass a 20-mesh sieve as required. Each test was run in duplicate to serve as a check on technique.

A modification of the wet sieving method of aggregate analysis proposed by Yoder (55) was used. The samples were wetted under a vacuum of 20 inches of mercury, preceding the wet sieving. The stable aggregates were removed from each sieve with the aid of a jet of water, oven dried, weighed and stored for further analysis. The sieves used were 5 inches in diameter with the following screen openings:

screen mesh	10	20	40	60	140
mm	2.00	0.84	0.42	0.25	0.10

In addition to wet sieving, the samples were also dry sieved. The size of the sieve opening correspond to those used in the wet sieving, however, 8 inch sieves were used. The sieves were placed on a sieve shaker[1] and were shaken for 6 minutes. Each size fraction of the dry aggregates was weighed and stored in ½ gallon ice cream cartons for further analysis.

Particle size distribution was determined by the pipette method essentially as suggested by Jennings et al. (21) and by Kilmer and Alexander (24), except that organic matter was not removed prior to the test. Corrections for temperature were interpreted from the nomographs

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[1] Cenco-Meizner sieve shaker manufactured by the Central Scientific Company.

published by Tanner and Jackson (50). A constant temperature bath, a 25 milliliter automatic pipette and an automatic depth gauge were used.

Organic matter was determined by the wet combustion method, according to Schollenberger (48).

Total nitrogen was measured by a modified Kjeldal method, suggested by Harper[1].

Exchange capacity was determined by the ammonium acetate method as recommended by Peech _et_ _al_. (39). The ammonium acetate leachates were analyzed for exchangeable calcium, magnesium, potassium and sodium with the Beckman model D. U. flame spectrophotometer with a photomultiplier attachment. The fuel gases were hydrogen and oxygen[2].

Permeability tests were run in the laboratory on bulk samples and on dry-sieved aggregates by the method described below:

Glass cylinders 4.6 cm I.D. (inside diameter) by 30.4 cm in length were stoppered with rubber stoppers fitted with small glass tubes for drains. A 40-mesh wire gauze was then placed in the tube directly above the rubber stopper and a layer of 20-mesh white silica sand was layered over the gauze. Two hundred grams of the soil to be tested were poured into the cylinder and the cylinder was then dropped a distance of one inch ten times. Distilled water was introduced into the cylinder and maintained at a constant head of 16.5 cm. The water that percolated through the sample was collected into a graduated cylinder and the volume of the percolate was determined at 2, 5, and 10 minute intervals.

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[1] H. J. Harper, Methods for the analysis of soil and plant materials, Soils Laboratory, Oklahoma State University, 1948.

[2] Anomymous, Methods for the analysis of soil and plant materials, Soils Laboratory, Oklahoma State University, 1956, (Unpublished).

RESULTS AND DISCUSSION

The Effects of Treatments on the Properties of the Soil as a Whole

The effect of soil treatments on aggregate stability is given in Table I. These results indicate a considerable difference in the per cent of stable aggregates above 0.25 mm. between the grass and the continuous cotton plots. The samples from the grass plots were almost twice as high in water stable aggregates as compared to the samples from the continuous cotton plots. A study of the distribution of stable aggregates (see Appendix,TableXIII)from the grass plots showed that 38% of the aggregates were larger than 0.42 mm. in size, while only 10.5% of the aggregates from the cotton plots were above this size. This demonstrates that the soil under grass cover would have a much more favorable macroporosity than the soil under continuous cotton.

TABLE I

EFFECTS OF TREATMENTS ON AGGREGATE STABILITY

Replications	% Stable aggregate above 0.25 mm. in diameter		
	Grass	Cotton	Cotton + Manure
Rep. I	54.8	28.6	28.0
Rep. II	56.5	28.4	29.2

There was no difference in the per cent of stable aggregates between the continuous cotton plots and the continuous cotton plus manure plots.

This observation is in opposition to many of the published results (1,2, 12,47,53), however, the rate of application of the manure was rather low as compared to other experiments (5 T/A every three years). Under the farming systems practiced in Oklahoma, it is doubtful if farmers could apply higher rates of manure than the one used in this experiment. The hot and relatively wet summers result in a rapid decomposition of the organic matter, thus reducing its effectiveness. The results reported here were obtained on soil samples taken the third year after the last manure application.

Forty years of continuous cultivation of cotton reduced the per cent of stable aggregates above 0.25 mm. by 50% and those above 0.42 mm. by 75%. Manure applications were not effective in checking this reduction.

The effect of the three soil treatments on the organic matter and nitrogen content of the whole soil is given in Table II. The organic matter content of the soil, measured by the wet combustion method, was almost three times higher in the grass plot soils than the continuous

TABLE II

EFFECT OF SOIL TREATMENTS ON ORGANIC MATTER AND NITROGEN

Analysis	Replications	Soil Treatments		
		Grass	Cotton	Cotton + manure
% Organic Matter	Rep. I	3.16	1.16	1.36
	Rep. II	2.99	1.18	1.23
	av.	3.075	1.17	1.295
% Nitrogen	Rep. I	0.139	0.070	0.067
	Rep. II	0.138	0.065	0.068
	av.	0.1385	0.0675	0.0675

cotton and the nitrogen level of the soil was two times higher in the grass plots.

If the assumption is made that the organic matter and nitrogen levels of this soil were originally about the same in all plots, then 40 years of continuous cotton cultivation has reduced the organic matter content by 66% and the nitrogen content by 50%. This is in general agreement with other experiments reported in the literature (13,22,27), although, the magnitude of difference in the experiment reported here is somewhat higher.

The difference in nitrogen and organic matter levels between the continuous cotton plots and continuous cotton plus manure was not significantly different. This observation means that manure applied for 40 years failed to increase the organic matter and nitrogen content and was not successful in checking their decrease.

The effect of three soil treatments on the cation exchange capacity, per cent base saturation, and per cent exchangeable calcium, magnesium, potassium and sodium is given in Table III. The cation exchange capacity of the soil from the continuous cotton plots was 27% lower than the grass plots. Since the clay content of all plots was essentially the same (Table IV), the reduction in cation exchange capacity could be attributed to the loss of soil organic matter. However, since the cation exchange capacity of the subsoils in the continuous cotton plots was found to be lower than the grass plots (Table VIII), the observed reduction in exchange capacity in the topsoil might be a result of localized variations in the subsoils. Reduction in the cation exchange capacity as a result of continuous cultivation was previously reported in the literature (20, 22). Per cent calcium, magnesium, potassium and sodium and the per cent base saturation were quite variable between samples, and significant

TABLE III

EFFECT OF TREATMENTS ON CATION EXCHANGE CAPACITY, PERCENT CALCIUM, MAGNESIUM, POTASSIUM, SODIUM AND PERCENT BASE SATURATION

Soil Treatments	Replications	Analysis					
		Exchange Capacity	% Exchangeable Ca	% Exchangeable Mg	% Exchangeable K	% Exchangeable Na	% Base Saturation
Grass	Rep. I	15.28	37.01	23.82	5.24	0.50	66.57
	Rep. II	15.32	42.98	33.20	3.26	0.58	80.02
	av.	15.30	39.99	28.51	4.25	0.54	73.29
Cotton	Rep. I	11.04	43.45	31.68	4.88	1.04	81.05
	Rep. II	10.90	42.40	29.06	3.85	0.91	76.22
	av.	10.97	42.92	30.37	4.36	0.97	78.63
Cotton + Manure	Rep. I	10.57	43.42	30.06	4.36	0.57	78.41
	Rep. II	11.70	36.95	28.85	4.36	0.93	71.09
	av.	11.13	40.18	29.45	4.36	0.75	74.75

differences could not be found between treatments.

The effect of continuous grass, continuous cotton and continuous cotton plus manure on the particle size distribution is given in Table IV. There were no differences in the clay content of the soils from the various treatments. The grass plots had a higher percentage of stable aggregates with a favorable size distribution, but this cannot be attributed to differences in the total clay content. However, this is in contrast with some of the results reported in the literature (20,22). The plots were on level land where practically no erosion had occurred and, under Oklahoma conditions, soil leaching processes are not intensive.

Total percent of sand was essentially the same under all treatments. However, when percent coarse sand (1.0-0.1 mm.) and fine sand (0.1-0.05 mm) is compared, considerable differences are noted between treatments. The grass plots contained 38% less coarse sand fraction and 18% more of the fine sand fraction as compared to continuous cotton. These differences might be a result of some sheet erosion which might take place on the exposed soil surface of the continuously cultivated plots. There were no observed differences between the various treatments in the total percent of silt or in the percent of coarse silt (0.05-0.02 mm.) or fine silt (0.02-0.002 mm.). No differences were observed in the particle size distribution of the continuous cotton and continuous cotton plus manure plots.

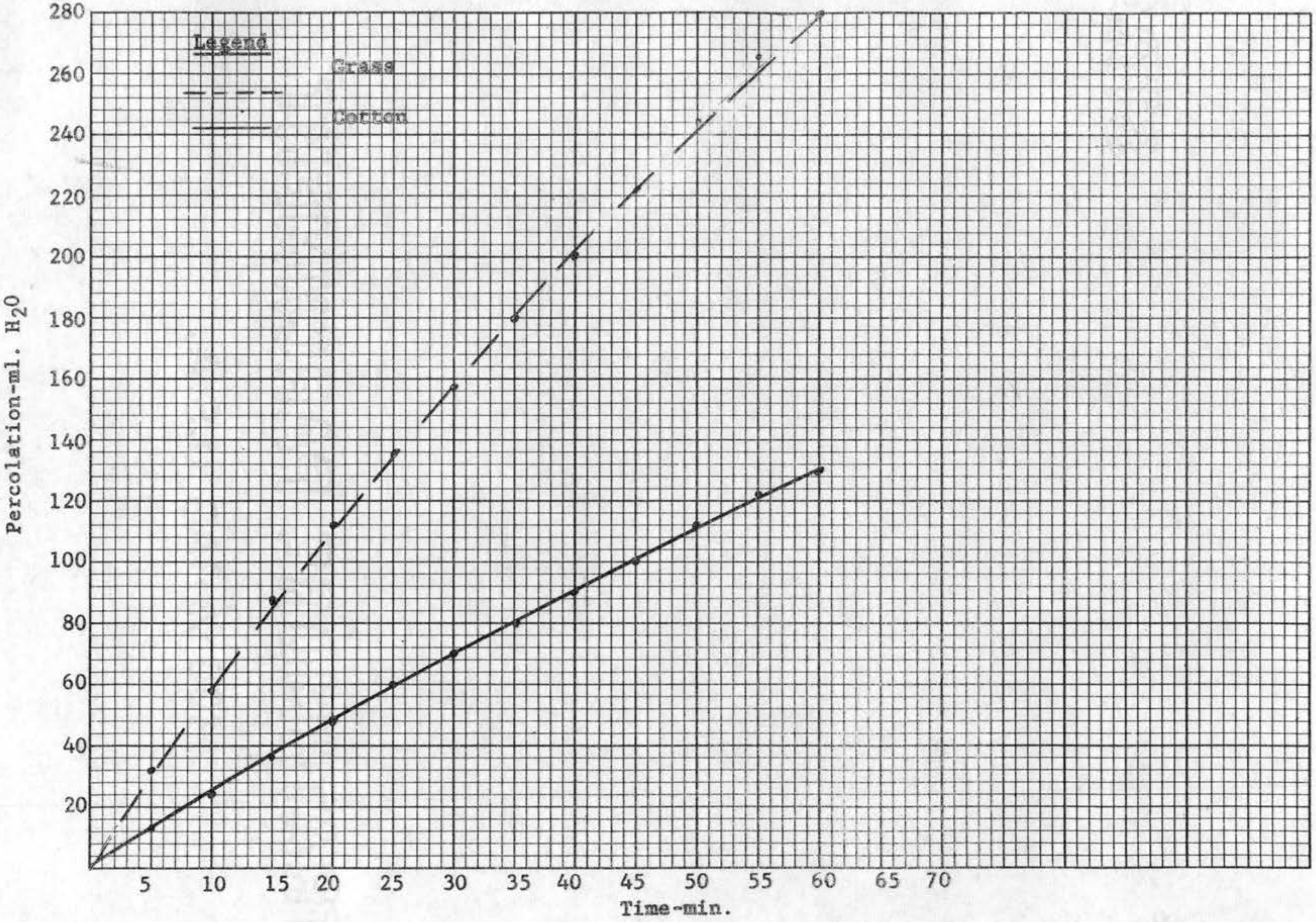
Permeability of the soils from the grass and continuous cotton plots is shown in Figure 1. An appreciable difference in the permeability of the soils from the grass plots as compared to the continuous cotton plots was observed. After 60 minutes, the grass plots had transmitted 280 ml. of water as compared to 130 ml. for the cotton plots. These results agree

TABLE IV

EFFECT OF TREATMENTS ON PARTICLE SIZE DISTRIBUTION

Soil Treatment	Replication	Percent Particle Size Distribution (Diameters in mm.)						
		1.0-0.1	0.1-0.05	Total Sand	0.05-0.02	0.02-0.002	Total Silt	Clay 70.002
Grass	Rep. I	8.83	23.16	31.99	34.21	13.38	47.59	21.04
	Rep. II	7.78	21.90	29.68	29.60	19.42	49.02	21.30
	av.	8.30	22.53	30.83	31.90	16.40	48.30	21.17
Cotton	Rep. I	13.55	18.83	32.38	33.40	13.36	46.76	20.86
	Rep. II	12.16	18.99	31.15	34.15	14.06	48.21	20.46
	av.	12.85	18.91	31.76	33.77	13.71	47.48	20.66
Cotton + Manure	Rep. I	13.98	17.92	31.90	31.84	14.07	45.91	22.18
	Rep. II	10.01	17.95	27.96	35.17	17.87	53.84	21.05
	av.	11.99	17.93	29.93	33.50	15.97	49.47	21.61

Figure 1. Effect of Treatments on the Percolation Rate of the Whole Soils



very well with the observed percent of stable aggregates above 0.25 mm. in the two treatments. The grass plots were twice as high in stable aggregates above 0.25 mm. in size and about three times as high in stable aggregates above 0.42 mm. The macro-non-capillary porosity of the grass plots was much more favorable for downward movement of water. The instability of the aggregates from the continuously cultivated plots, especially the instability of the larger aggregates, caused an excessive slaking of the soil aggregates upon wetting and clogged the larger pores, which caused a sluggish downward water movement.

The Effect of Cropping Treatments on the Subsoil

The same properties which were determined on the topsoil were determined on the subsoil also. This was done because it was felt that too much attention in previous investigations had been directed to the kinds of plants grown and too little to the type and number of cultivations. It was inferred that if the kind of crop grown had a major effect on aggregate stability, differences should be found between soil treatments in the subsoils. This assumption was based on the possible effect of large amounts of grass and cotton roots, found in the subsoils, on the measured properties. Records showed that the subsoils have never been disturbed and the only factor that would change the stability of subsoil aggregates was the cropping systems.

The results, however, do not show any significant differences between the subsoils of the various treatments in organic matter, total nitrogen or aggregate stability as shown in Tables V, VI, VII. This could be interpreted to mean that the kind of plant grown, cotton or prairie grasses, did not play an important role in the stability of the aggregates in the undisturbed subsoils. In the topsoil, large differences in the properties mentioned above were found between the plots continuously cultivated to cotton and the undisturbed plots covered with grasses. It could be hypothesized that a major factor in the deterioration of aggregate stability, under continuous cultivation, is cultivation itself. In other words, the stirring and shearing action of the cultivation implements, the type of implements and the frequency of their use has much to do with the deterioration of aggregate stability. However, it should be noted that this study provides little evidence to prove or disprove this hypothesis and more specific investigations are required to test this hypothesis.

TABLE V

THE EFFECT OF TREATMENTS ON AGGREGATE STABILITY OF THE SUB-SURFACE SOIL (6-12 INCHES)

	Treatment		
Replication	Grass	Cotton	Cotton + Manure
Rep. I	65.2	58.6	64.8
Rep. II	70.0	64.2	57.5
av.	67.60	61.40	61.15

ANALYSIS OF VARIANCE

Source	D.F.	S.S.	M.S.	F
Total	5	45.56	9.11	
Replications	1	0.81	0.81	
Treatment	2	6.10	3.05	0.158 NS[1]
Error	2	38.65	19.32	

[1] NS - Not significant at the 5% level.

TABLE VI

THE EFFECT OF TREATMENTS ON THE ORGANIC MATTER CONTENT OF THE SUB-SURFACE SOIL (6-12 INCHES)

	Treatments		
Replication	Grass	Cotton	Cotton + Manure
Rep. I	1.65	1.48	1.58
Rep. II	1.65	1.19	1.15
av.	1.65	1.38	1.36

ANALYSIS OF VARIANCE

Source	D.F.	S.S.	M.S.	F
Total	5	0.2554	0.0511	
Replications	1	0.0864	0.0864	
Treatments	2	0.1209	0.0605	2.52 NS[1]
Error	2	0.0481	0.0240	

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[1] NS - Not significant on 5% level.

TABLE VII

THE EFFECT OF TREATMENTS ON NITROGEN CONTENT OF THE SUB-SURFACE SOIL (6-12 INCHES)

Replication	Treatments		
	Grass	Cotton	Cotton ≁ Manure
Rep. I	0.069	0.087	0.075
Rep. II	0.080	0.087	0.062
av.	0.074	0.087	0.068

ANALYSIS OF VARIANCE

Source	D.F.	S.S.	M.S.	F
Total	5	0.00051	0.00010	
Replications	1	0	0	
Treatments	2	0.00036	0.00018	2.57 NS[1]
Error	2	0.00015	0.00007	

[1] NS - Not significant on 5% level.

Results on the exchange capacity and particle size distribution of the subsoils under grass, continuous cotton and continuous cotton plus manure are presented in Tables VIII and IX.

TABLE VIII

THE EFFECT OF TREATMENTS ON EXCHANGE CAPACITY OF THE SUB-SURFACE SOIL (6-12 INCHES DEPTH)

	Milliequivalents per 100 gm. of Soil		
Replications	Grass	Cotton	Cotton / Manure
Rep. I	26.03	17.45	17.81
Rep. II	25.97	20.96	21.48
av.	26.00	19.21	18.64

TABLE IX

EFFECT OF TREATMENTS ON THE PARTICLE SIZE DISTRIBUTION OF THE SUB-SURFACE SOIL (6-12 INCHES)

		Percent of each fraction		
Treatments	Replications	Sand	Silt	Clay
Grass	Rep. I	20.90	41.38	37.72
	Rep. II	21.32	45.76	33.00
	av.	21.06	43.57	35.36
Cotton	Rep. I	19.69	51.07	29.24
	Rep. II	16.80	47.76	35.44
	av.	18.29	49.41	32.34
Cotton / Manure	Rep. I	20.87	48.64	30.43
	Rep. II	16.44	46.50	37.16
	av.	18.65	47.57	33.79

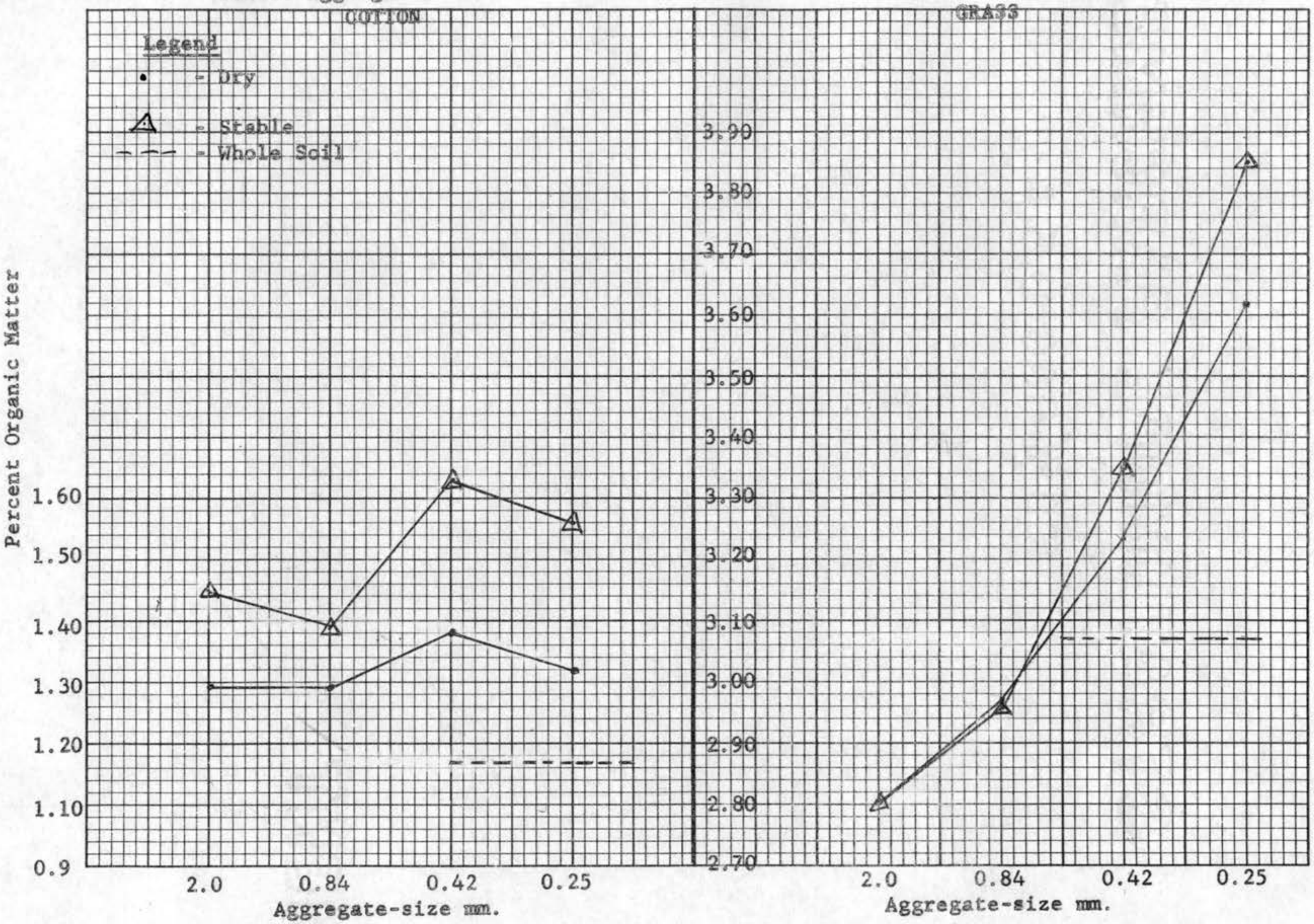
Effect of Cropping Treatments on Properties of Soil Aggregates

Since the differences in the properties tested between the continuous cotton plots and the grass plots were found to be large, it was decided to study two of the treatments in more detail. The continuous cotton plus manure treatment was eliminated from this study since no differences were obtained between it and the continuous cotton plots.

The scheme of this study was to compare the properties of the whole samples versus those of the dry aggregates collected by dry sieving and stable aggregates collected by wet sieving. The assumption was that the magnitude of each of the properties investigated on the whole soil as compared to the dry sieved and stable aggregates would yield valuable information as to the importance of these properties in the formation and stability of the aggregates. Thus, if the level of any of the properties would tend to increase from the whole soil to the dry sieved stable aggregates, it could be inferred that this property was important in the aggregation process. This study also attempted to investigate the effect of the size of the aggregates on the levels of the properties measured.

The effect of cropping treatments and aggregate size on the organic matter content of dry and stable aggregates was investigated by plotting the data as shown in Figure 2. The organic matter content of the dry and stable aggregates from the cotton plots was above that of the whole soil. The dry and stable aggregates from the cotton plots reached a maximum of the 0.42 mm. size aggregates and then declined. In the grass plots, the general trend was somewhat different. The organic matter content of the dry and stable aggregates (2.00 and 0.84 mm.) was below that of the whole soil and the (0.42 and 0.25 mm.) aggregates were con-

Figure 2. The Effect of Treatments and Aggregate Size on the Organic Matter Content of Dry and Stable Aggregates



siderably higher in organic matter than the whole soil, and a maximum was reached in the 0.25 mm. aggregates. The increase in the organic matter content of the stable aggregates above that of the whole soil and that of the dry sieved aggregate was higher in the stable aggregates from cotton than in the stable aggregates from grass as shown in Table X.[1] The differences in the organic matter content reported between the grass and the continuous cotton plots were evident between the dry and stable aggregates, also. The increased organic matter content of the stable aggregates of the cotton plots and the smaller stable aggregates from the grass plots suggests that organic matter plays an important part in the stability of these aggregates. However, the differences in organic matter content of the stable aggregates of the cotton and grass treatments were considerable. The increase in organic matter content of the stable aggregates from the

TABLE X

EFFECT OF TREATMENTS AND SIZE OF AGGREGATES ON THE INCREASE IN ORGANIC MATTER CONTENT OF STABLE AGGREGATES

	Aggregate	Percent increase in each size (size in mm.)			
Treatment	Stability	5.00-2.00	2.00-0.84	0.84-0.42	0.42-0.25
Grass	Above soil	-	-	9	25
	Above dry Aggregate	-	-	4	6
Cotton	Above soil	24	19	39	33
	Above dry Aggregate	11	7	18	18

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[1] For data, see Appendix, Table XIV.

cotton plots might suggest the possibility that organic matter is more important in the stability of aggregates from the cotton than those from the grass. However, the percent of stable aggregates was twice as high in the grass plots, and it could be inferred that the stable aggregates contributed to an increase in the organic matter content of the whole soil, thus the increase in the organic matter content of the stable aggregates of the grass plots above that of the whole soil would be expected to be somewhat lower. There was a tendency for the organic matter content of the dry and stable aggregates to increase, with decrease in size of the aggregates. This might suggest the increasing importance of the organic matter content of the aggregates with decrease in size of the aggregates. A higher percentage of organic matter in the smaller stable aggregates than in the whole soil and a tendency to increase with decrease in aggregate size was reported by Garey (18).

The effect of cropping treatments and aggregate size on the nitrogen level of the dry and stable aggregates was investigated and the results are shown in Figure 3 and Table XI.[1] The nitrogen content of the dry aggregates from the cotton plots was essentially the same as that of the whole soil. However, the stable aggregates from the cotton plots had a higher nitrogen content than the whole soil and reached a maximum in the 0.42 and 0.25 mm. size aggregates. The nitrogen content of the aggregates from grass paralleled the organic matter content. The nitrogen content of 2.00 and 0.84 mm. size aggregates was below that of the whole soil, while that of the smaller aggregates was above the whole soil. The nitrogen content of the aggregates from the grass plots reached a maximum

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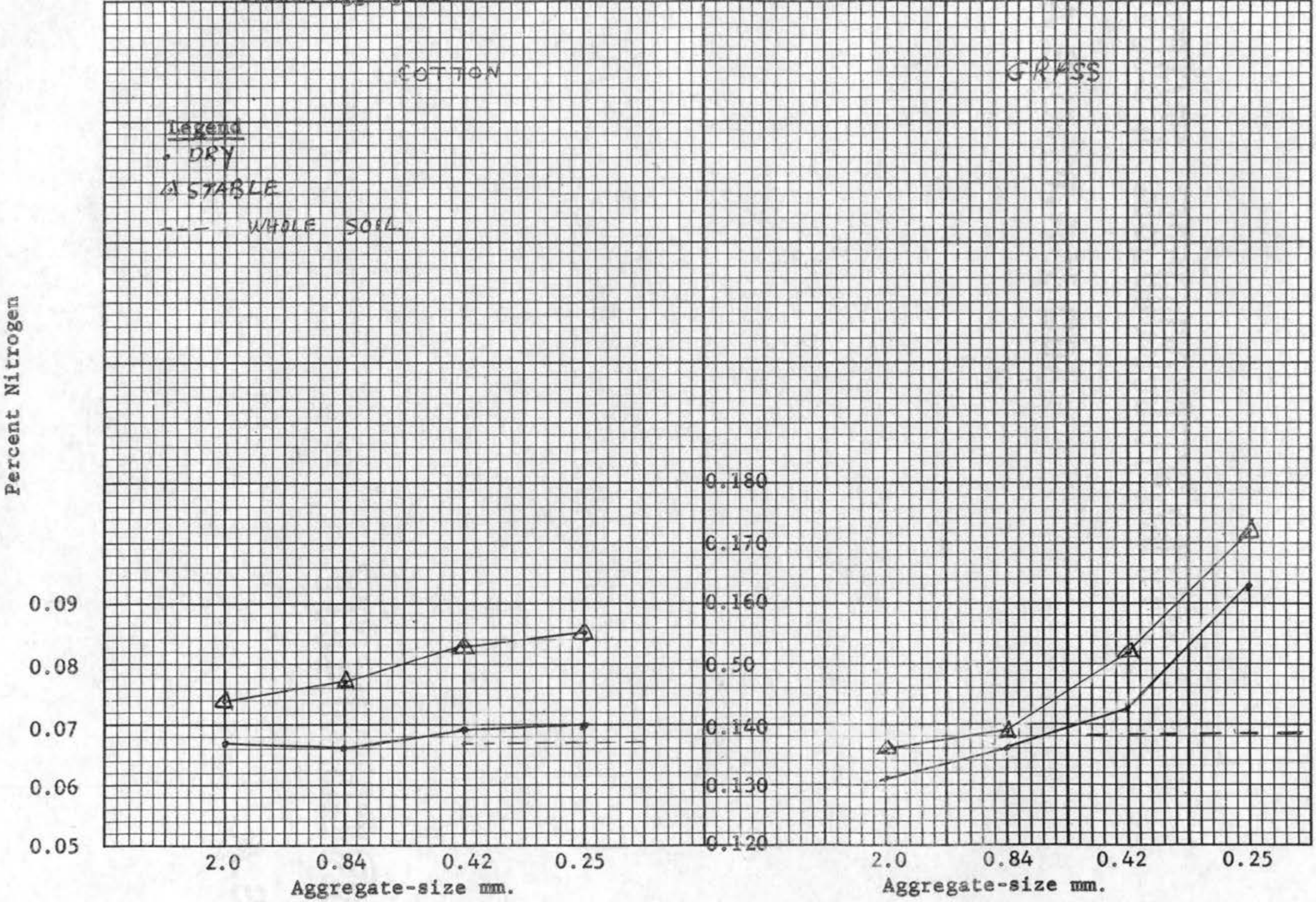
[1] For data, see Appendix, Table XV.

Figure 3. The Effect of Treatments and Aggregate Size on the Nitrogen Content of Dry and Stable Aggregates



in the 0.25 mm. size aggregates. The increase in the nitrogen content of the stable aggregates from the cotton plots, above that of the whole soil and the dry aggregates, was higher than the increase in nitrogen content of the stable aggregates from the grass plots as shown in Table XI.

TABLE XI

EFFECT OF TREATMENTS AND SIZE OF AGGREGATES ON THE INCREASE IN NITROGEN CONTENT OF STABLE AGGREGATES

	Aggregate	Percent increase in each size (size in mm.)			
Treatment	Stability	5.00-2.00	2.00-0.84	0.84-0.42	0.42-0.25
Grass	Above soil	-	-	10	25
	Above dry Aggregate	4	2	6	5
Cotton	Above soil	12	16	24	27
	Above dry Aggregate	12	18	20	21

In general, the change in nitrogen and organic matter levels were similar as follows:

1. An increase in the organic matter and nitrogen levels of the dry sieved and stable aggregates, with a decrease in size of these aggregates.

2. A larger increase in the nitrogen and organic matter content of aggregates from the cotton plots than from the grass plots.

3. The difference between the nitrogen and organic matter levels of the stable aggregates from the grass and cotton treatments was considerable.

It could be inferred that the importance of total nitrogen in the stability of soil aggregates is comparable to that of the organic matter.

The effect of cropping treatments and aggregate size on the exchange capacity of the dry and stable aggregates was investigated and is reported in Figure 4.[1] There was a considerable increase in the exchange capacity of the dry and stable aggregates from the cotton plots as compared to the whole soil. As observed with the organic matter content, a maximum in exchange capacity was reached in both the dry sieved and stable aggregates in the 0.42 mm. size aggregates. The dry sieved and stable aggregates from the grass plots showed only a slight increase in exchange capacity above that of the whole soil. However, the exchange capacity increased somewhat with decrease in size of the aggregates from the grass treatment. There was virtually no difference in exchange capacity between the dry and stable aggregates from the grass plots. The increase in exchange capacity of the stable aggregates from the cotton plots was spectacular and surprising. The whole soil under the cotton treatment was almost 30% lower (4.5 milli equivalents) than that of the grass soil. The exchange capacity of the stable aggregates from the cotton plots was almost the same as that of the stable aggregates from the grass plots. This was an average increase above the exchange capacity of the whole soil of 50%. This was surprising, since the increase in organic matter, about 0.4%, could not account for this increase in exchange capacity of the stable aggregates from the cotton treatment, especially when the increase in organic matter content of the stable aggregates from the grass plots was comparable.

The stable aggregates from the continuous cotton plots were 5% higher in clay and the stable aggregates from the grass plots were approx-

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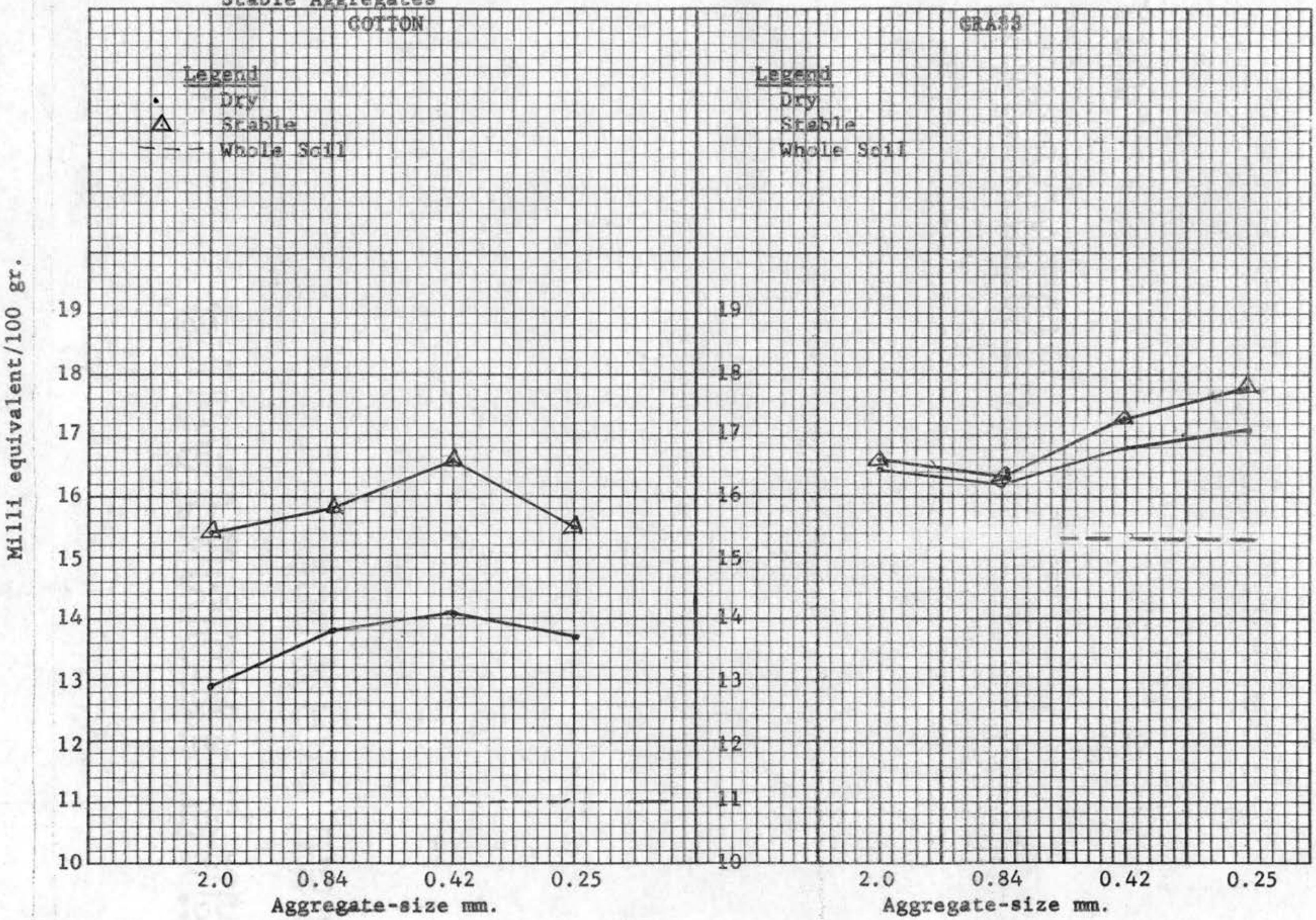
[1] For data, see Appendix, Table XVI.

Figure 4. The Effect of Treatments and Aggregate Size on the Exchange Capacity of Dry and Stable Aggregates



imately 3% higher in clay than the whole soils, as shown in Figure 5. These differences in clay content between stable aggregates from the cotton plots and the whole soil cannot account for the increase of 6 milliequivalents in exchange capacity.

The exchange capacity is a relative measure of the total soil surface and the surface activity of the clay particles. It could be inferred that the clay in the cotton stable aggregates has a higher surface area and activity than that of the whole soil. However, this study does not offer enough evidence to discuss any theory concerning the changes that might take place in the distribution of clay particles. Garey (18) reported an increase in the exchange capacity of the smaller stable aggregates as compared to that of the whole soil.

The effect of cropping treatments and aggregate size on the clay content of the dry sieved and stable aggregates is shown in Figure 5.[1] The clay content of the stable aggregates from the cotton plots increased considerably above that of the whole soil. The clay content of the aggregates from the cotton plots increased with a decrease in size and reached a maximum with the 0.42 mm. size aggregates. There was a smaller increase in the clay content of the grass aggregates above that of the whole soil as compared to the cotton aggregates. No sizable changes in clay content with change in size of the aggregates were observed in the aggregates from the grass plots. The clay content of the aggregates from both the cotton and grass plots as well as that of the whole soils was similar. The aggregate stability of the whole soil and that of the separate dry aggregates (Figures 9 and 10) from the grass plots was consid-

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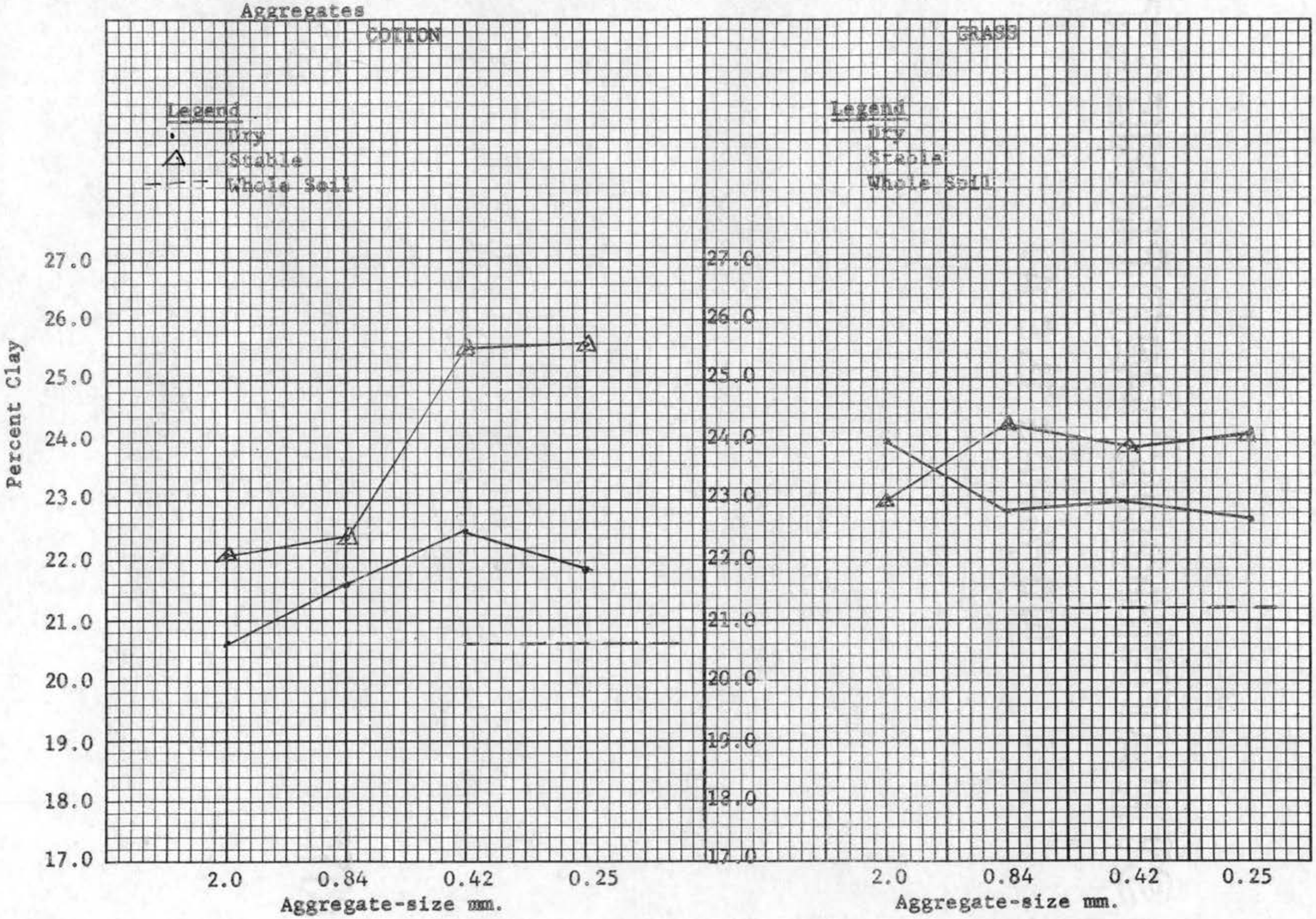
[1] For data, see Appendix, Table XVII.

Figure 5. The Effect of Treatments and Aggregate Size on the Clay Content of Dry and Stable Aggregates



erably higher than that from the cotton plots. The data obtained in this study do not support the reports in the literature which state that the total percent clay is highly correlated with aggregate stability (5,7,18, 36,37).

The effect of cropping treatments and aggregate size on the silt content of the dry and wet aggregates is shown in Figure 6.[1] The silt content of stable aggregates from the grass and cotton plots did not vary appreciably. The aggregates from the cotton plots were slightly higher in silt content than the aggregates from the grass plots and the content increased with decrease in size of the aggregates and reached a maximum (0.42 mm.) in both the dry and stable aggregates. The difference in silt content between the grass and cotton treatments and within each treatment does not seem to be appreciable. It could be concluded that the silt fraction in the Kirkland silt loam soil is not an important factor in the formation and stability of aggregates.

The effects of continuous grass versus continuous cotton and aggregates size on the sand content of the dry and stable aggregates is given in Figure 7.[2] The sand content of the aggregates from the cotton and grass plots was lower than the sand content of the whole soils. The sand content of both the dry and stable aggregates from the cotton plots decreased with decrease in size of the aggregates. A minimum sand content was observed in the 0.42 mm. in size of the dry and stable cotton aggregates with a slight increase in the 0.25 mm. aggregates. The trend of the sand content in the aggregates from the grass plots decreased somewhat with decrease in size of the aggregates, but no appreciable differ-

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[1] For data, see Appendix, Table XVIII.

[2] For data, see Appendix, Table XIX.

Figure 6 The Effect of Treatments and Aggregate Size on the Silt Content of Dry and Stable Aggregates.

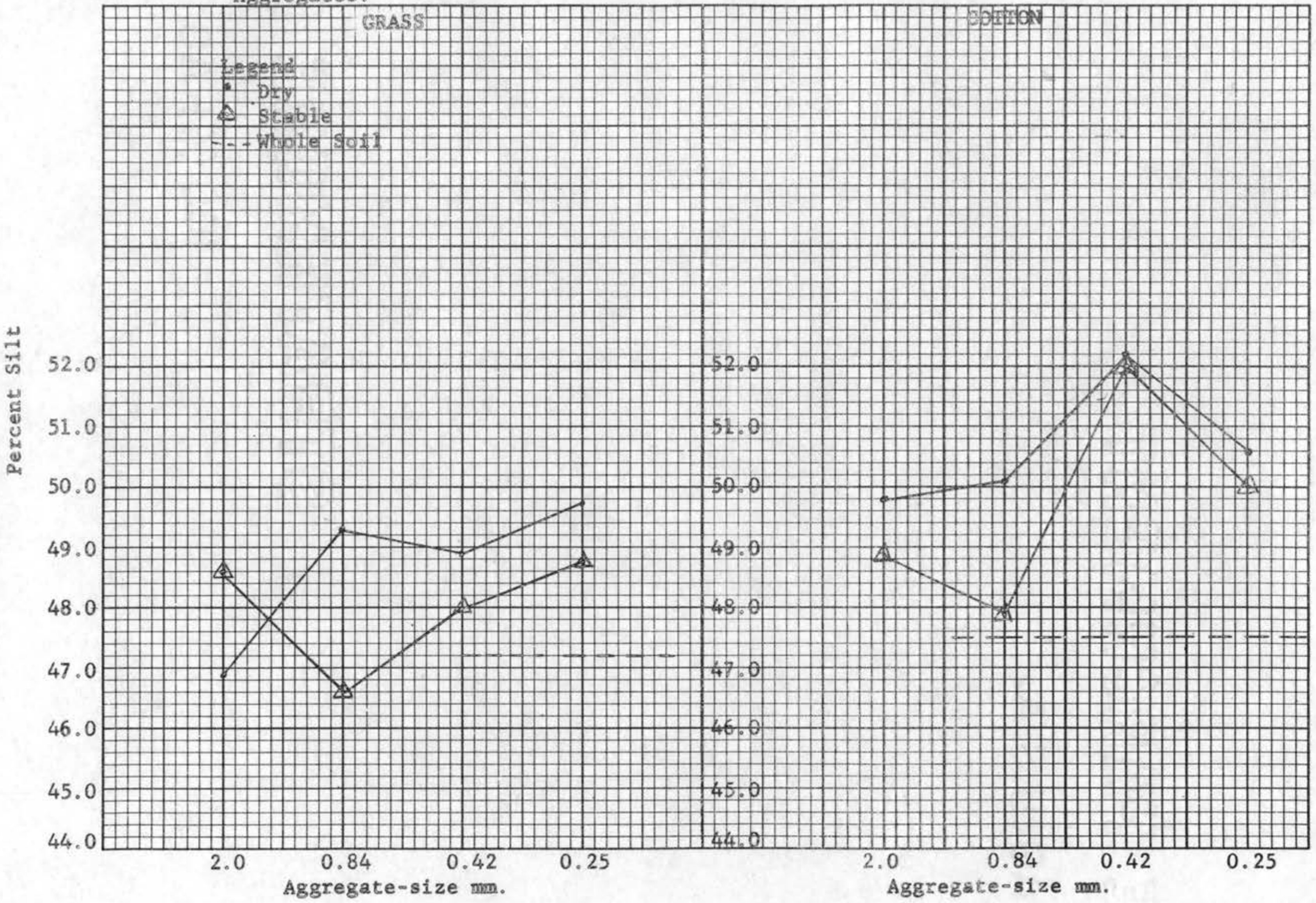
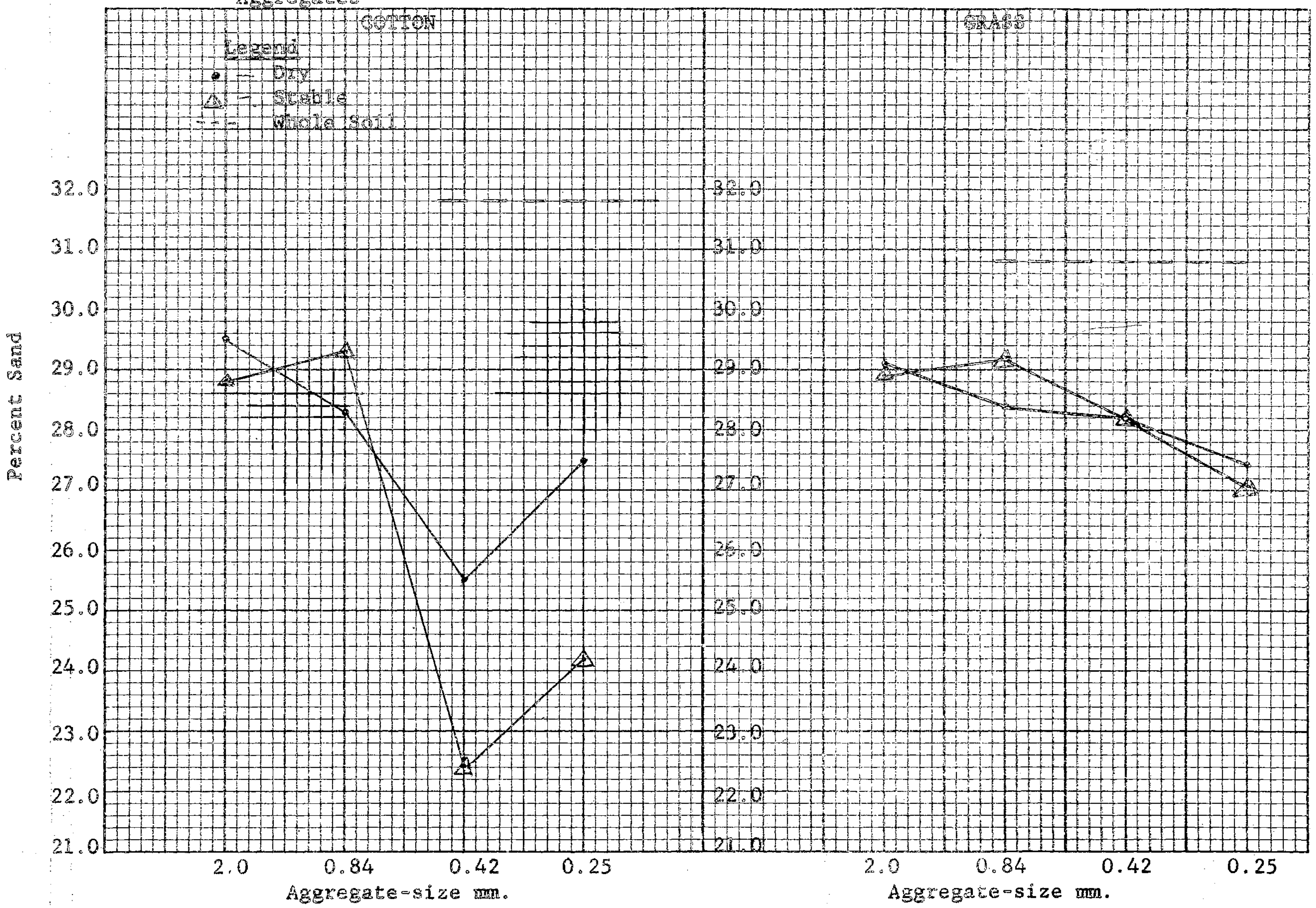


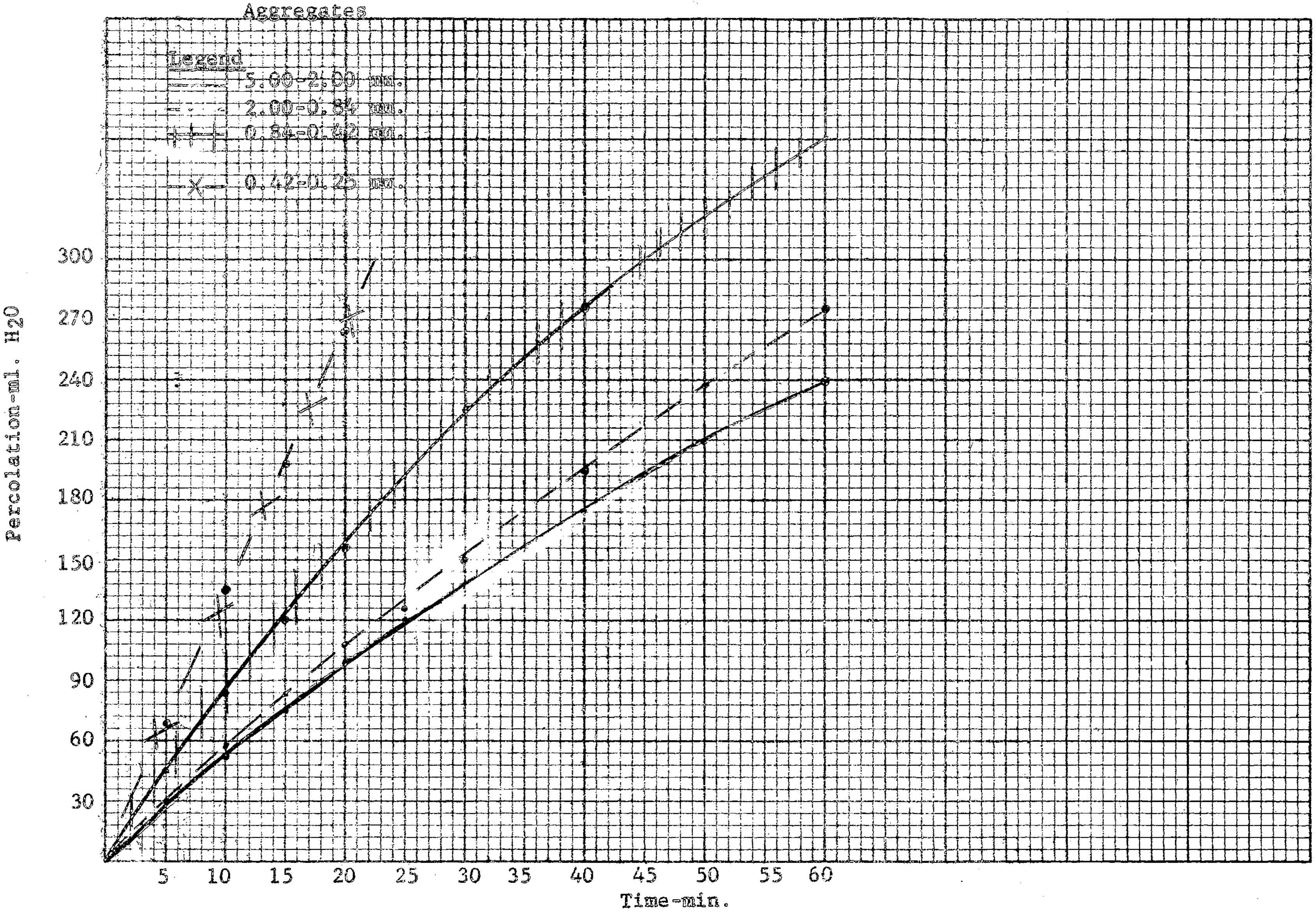
Figure 7. The Effect of Treatments and Aggregate Size on the Sand Content of Dry and Stable Aggregates



ences were found in the sand content of the dry and stable aggregates. The smaller (0.42 and 0.25 mm.) stable aggregates from the cotton plots had a lower sand content than the corresponding stable aggregates from the grass plots. This was somewhat puzzling and suggests the possibility that because of a lower organic matter content in the stable aggregates from the cotton plots less sand could be cemented in the stable aggregates. The observed results suggest that sand content is not an important factor in the stability of the aggregates from the grass and cotton plots.

The effect of cropping treatments and aggregate size on the percolation rate of the dry sieved aggregates is shown in Figure 8. It was observed that the percolation rate was a good indication of the stability of aggregates and the porosity of the whole soil. Thus, it was decided to test the percolation rates of the dry-sieved aggregates from both treatments. It was impossible to keep a constant head and measure the percolation rates of the dry-sieved aggregates from the grass plots. The dry-sieved aggregates from the grass plots of all sizes were very stable (Figures 9 and 10) and the macro-porosity high upon wetting, and water moved through the columns rapidly. The results were different, however, in the dry-sieved aggregates from the cotton plots. The dry-sieved aggregate samples from the cotton plots consisted of particles of one size range, and it was expected that the macro-porosity and the percolation rate would be the highest in the samples consisting of the larger sizes of the dry-sieved aggregates and would decrease with decrease in size of the aggregates. However, the results observed were exactly the opposite. As shown in Figure 8, the dry-sieved aggregates (5.00-2.00 mm.) showed the lowest percolation rate and as the size of the dry-sieved aggregates decreased, percolation rate increased. This was probably due to the

Figure 8. The Effect of Continuous Cotton and Aggregate Size on the Permeability of the Dry Aggregates



excessive slaking and concomitant breakdown of the dry aggregates, which decreased with size. The porosity of the samples was reduced to a low level and the percolation rate of the sample was lowered. It should be pointed out that, except for the 0.22 mm. dry-sieved aggregates, the trend in percolation rate follows similar trends of the organic matter content, cation exchange capacity and clay content. All of these properties tend to increase with a decrease in size of the dry-sieved aggregates.

Aggregate Stability Index

The disintegration of soil aggregates upon wetting will result in a reduction of macro-porosity, aeration and drainage. The stability of soil aggregates is of prime importance in the structure-porosity relationship of a soil.

The conventional method for measuring the stability of soil aggregates is the wet-sieving method, according to Yoder (55). This method measures the size distribution of the stable aggregates of a soil as a result of wetting. However, little real information can be acquired by this method concerning the changes that take place in the distribution of aggregates and the macro-porosity of many soils during the process of wetting. Since information relative to changes in the stability and disintegration of each size of the soil aggregates is of great value, this is a major drawback of this method. In soils where the aggregates are stable and exist as discrete units which do not disintegrate upon wetting, the wet-sieving method is a good index to the conditions which exist in the soil. However, in a soil where the aggregates are not stable, unexpected changes in the size distribution of the aggregates and macro-porosity might take place upon wetting. With these soils, the wet-sieving method as used is of little value for characterizing the porosity.

It was decided to investigate other methods for characterizing aggregate stability and porosity. The first logical step was to establish a reference point in soil aggregation with which the results of the wet-sieving technique could be compared. As a reference point, the size distribution of aggregates in the air dried soil was selected. The objective was to compare the data obtained by dry-sieving the soil with that acquired by wet-sieving. The ratio between the percent of each aggregate size as obtained by the dry-sieving and wet-sieving techniques was to be used as an index of the stability of the soil aggregates.

The reliability of the results acquired by dry-sieving a soil was questioned on the grounds that the results were variable and would depend upon the preparation of the soil in the laboratory. It was decided to make a statistical study of the effect of crushing the soil on the results obtained by dry and wet-sieving methods. For this study, a bulk soil sample was divided into four parts, each part was crushed with a wooden roller to pass a 4-mesh sieve, mixed and stored separately. On each part, dry and wet-sieving analyses were performed four times. Analysis of variance was calculated for each size of aggregates from the results obtained in the four crushings. The results of the statistical test are presented in Table XII. With the dry-sieving method, the effect of crushing caused significant differences in aggregate size distribution except in the 0.42-0.25 mm. group. No significant differences in the size distribution of aggregates as a result of crushing were observed in the wet-sieving method. In view of the significant crushing effect on the size distribution of dry aggregates, differences might be expected in the size distribution of the wet-sieved aggregates also. However, it will be seen later that dry aggregates from the crushed soil tended to break down into a similar size distribution upon wetting, regardless of the original dry-sieved aggregate size. As a result of the statistical study, the possibility of using the size distribution of the dry-sieved aggregates as a reference point was discarded.

TABLE XII

THE EFFECT OF CRUSHING ON THE SIZE DISTRIBUTION OF SOIL AGGREGATES AS MEASURED BY WET AND DRY SIEVING[1]

	Calculated "F" values	
Size in mm.	wet-sieving	dry-sieving
5.00-2.00	0.97	13.25**
2.00-0.84	0.64	3.87*
0.84-0.42	1.61	2.32
0.42-0.25	0.23	4.19*

* Significant at the 5% level.

** Significant at the 1% level.

[1] For Analysis of Variance tables, see Appendix Table XX and XXI.

However, it was believed that a measure of the dry-sieved aggregates of a soil as a reference point would yield valuable information. It was decided to use each size of the dry-sieved aggregates by itself as a reference point. In this manner the uncertainity in the distribution of the dry-sieved aggregates would be eliminated. It was also assumed that an air dried soil contained a certain amount of each size of the dry aggregates. How each size of these aggregates behaved upon wetting, its stability and pattern of breakdown might determine, to a large degree, the porosity changes that might take place upon wetting. The larger dry aggregates in a soil, if unstable, would disintegrate into smaller units upon wetting. This would result in a reduction in macro-porosity which would be extensive.

As a consequence of the assumptions discussed above, the bulk samples from each treatment were dry sieved and the dry aggregates which stayed on each sieve were collected and stored separately. Aggregate stability was determined on each size of the dry-sieved aggregates by the wet-sieving method. The information collected was interpreted according to the following criteria:

1. The size distribution of the stable aggregates which resulted from wet-sieving each size of the dry-sieved aggregates.
2. The percent of each size of the dry-sieved aggregates which retained their size upon wetting.
3. The total percent of the stable aggregates above 0.25 mm. in size from each size of the dry-sieved aggregates.

This information can be used as an effective research tool in evaluating the effect of treatments on the stability and breakdown of each size of the dry aggregates and in the study of the processes and forces involved in aggregate formation and stability. In order to illustrate the value of the procedure discussed above, the information obtained by using this procedure on samples from the grass and continuous cotton are compared to the conventional method of wet-sieving.

The distribution of stable aggregates of each size of the dry-sieved aggregates from the grass and continuous cotton plots is presented in Figures 9 and 10.[1] The percent of each of the four sizes (5.00-2.00, 2.00-

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[1] For additional data, see Appendix Table XXII.

Figure 9. The Effect of Treatments on the Stable Aggregates Distribution of the 5.00-2.00 and 2.00-0.84 mm. Size Dry Sieved Aggregates

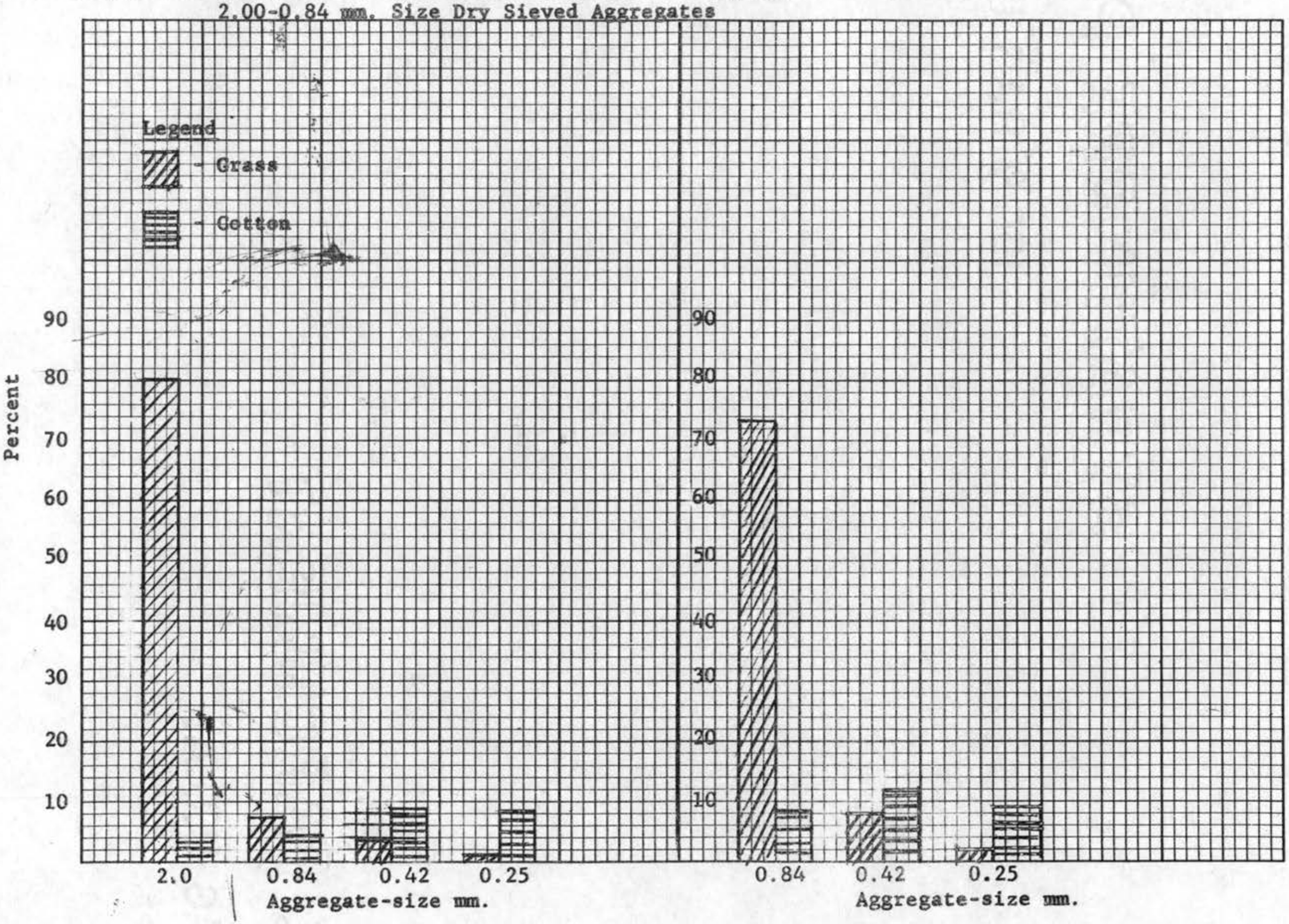
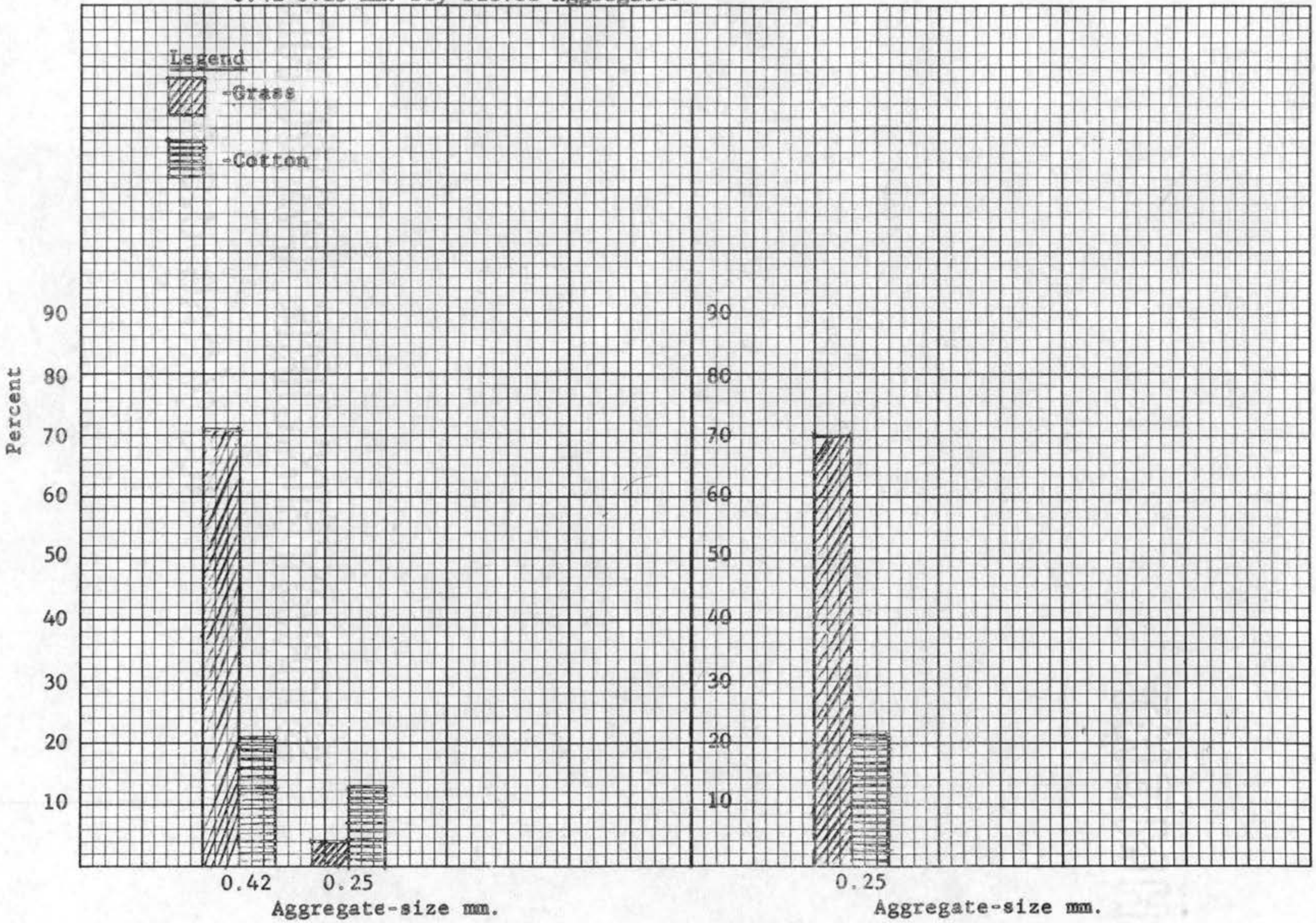


Figure 10. The Effect of Treatments on the Stable Aggregates Distribution of the 0.84-0.42 and 0.42-0.25 mm. Dry Sieved Aggregates



0.84, 0.84-0.42, 0.42-0.25 mm.) of the dry-sieved aggregates from the grass treatment that did not disintegrate upon wetting was high, that is, over 70%, and decreased somewhat with size. It could be inferred that these dry-sieved aggregates had a high stability and did not disintegrate appreciably upon wetting. In the case of the dry-sieved aggregates from the continuous cotton treatment, the results were quite different. The percent of each size of the dry-sieved aggregates which retained their size upon wetting was very low. Only 3% of the dry-sieved aggregates (5.00-2.00 mm.) did not disintegrate upon wetting. The percent of aggregates which did not disintegrate upon wetting increased with decrease in size of the dry-sieved aggregates and reached a maximum of 21% in the 0.84-0.42 mm. and 0.42-0.25 mm. aggregates. These results were interesting and appear to be of significance. If it is assumed that before this land was first cultivated, the stability of the dry-sieved aggregates was similar in all plots, it is obvious that 40 years of cultivation has resulted in a loss of stability of the dry-sieved aggregates. It is notable that the highest reduction in stability was in the 5.00-2.00 mm. size dry-sieved aggregates. The stability of the aggregates from the grass plots showed that 81% of the 5.00-2.00 mm. size dry-sieved aggregates did not disintegrate upon wetting while only 3% of the dry-sieved aggregates from the cotton plots did not disintegrate.

The pattern of breakdown of the dry-sieved aggregates into smaller but stable aggregates further reveals the effect of 40 years of continuous cultivation on this Kirkland silt loam soil. The dry-sieved aggregates from the grass plots showed little, if any, breakdown. However, the size distribution of these aggregates reveals that the percent of stable, though disintegrated, aggregates (0.42-0.25 mm.) was rather low.

From the above observations, it can be postulated that the dry-sieved aggregates from the grass plots existed as discrete and stable units. There was no evidence to suggest that these units were temporary conglomerates of smaller secondary units. As mentioned previously, the disintegration of the dry-sieved aggregates from the cotton plots was relatively large. The size distribution of the disintegrated aggregates showed a tendency for the smaller aggregates to be concentrated in the 0.84-0.42 and 0.42-0.25 mm. sizes. Thus, it could be hypothesized that 40 years of cultivation which was accompanied by a marked decrease in organic matter created an unfavorable environment for the existence of large stable aggregates. The larger dry-sieved aggregates were conglomerates of smaller, stable aggregates loosely held together. The permeability data clearly illustrated this hypothesis (Figure 8). The dry-sieved aggregates from the grass plots, which showed high stability and a low tendency to break down upon wetting, allowed a fast downward water movement as shown by the permeability data. The dry-sieved aggregates from the cotton plots showed a strong tendency to disintegrate, which decreased with the size of the dry aggregates. This was reflected in the percolation data where there was an increase in percolation rate with a decrease in size of the dry aggregates.

The size distribution of the stable aggregates in the whole soil from the two treatments is shown in Figure 11.[1] These results indicate a high concentration of the larger stable aggregates under the grass treatment with an opposite trend in the stable aggregates from the continuous cotton plots. However, the mechanisms responsible for these differences and the source of the stable aggregates can only be approximated from this type of data. For example, wet sieving the whole cotton soil

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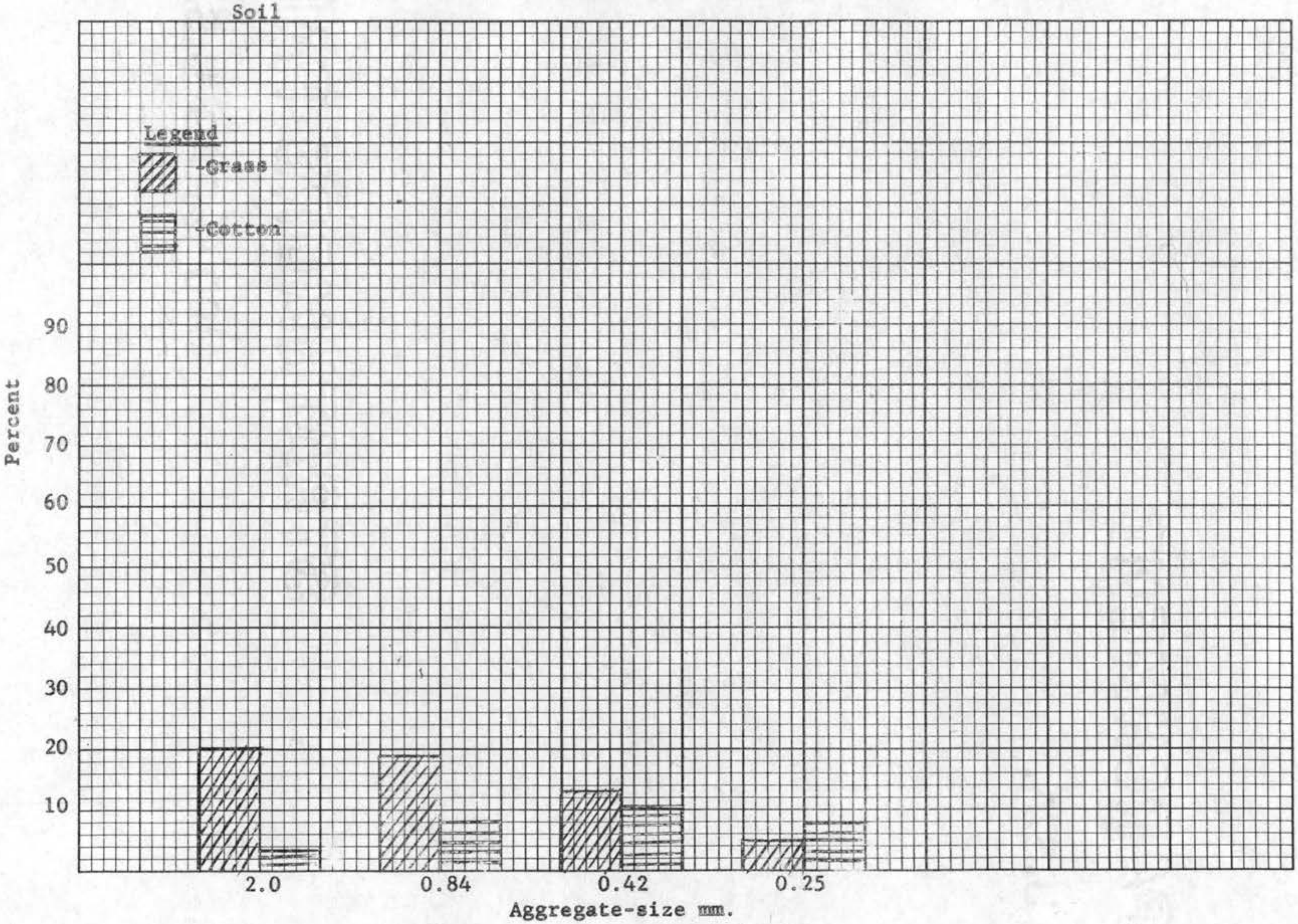
[1] For data, See Appendix Table XIII.

Figure 11. The Effect of Treatments on the Stable Aggregates Size Distribution of the Whole Soil

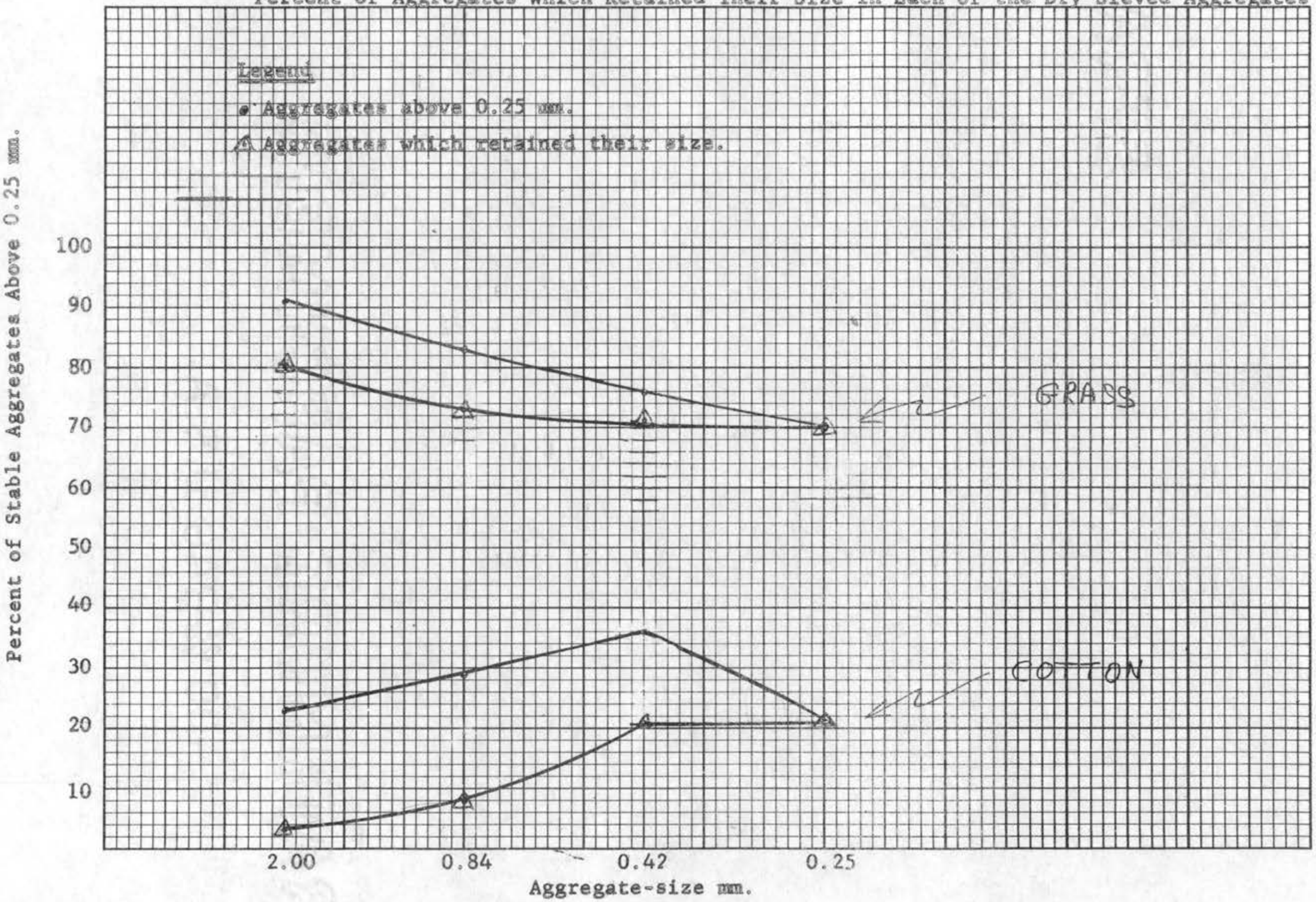


indicates a higher percent of the smaller stable aggregates than the larger ones. However, there is nothing to indicate the origin of these stable aggregates. It is not known whether these were discrete units which existed in the soil before wetting or if they were disintegration products of larger aggregates, and this applies to the stable aggregates from the grass plots as well. It was felt that these questions were important, because if the stable aggregates existed as discrete units in the soil before wet-sieving, then there should not be noticeable changes in the macro-porosity of the soil upon wetting. This was evident in the soil from the grass plots as shown by the percolation data. However, the stable aggregates from the cotton plots existed in the soil previous to wetting as larger units and it could be assumed that the macro-porosity was favorable. Upon wetting, a considerable disintegration of the larger aggregates from the cotton plots took place, followed by a considerable reduction in the macro-porosity of the soil and a low percolation rate.

The conventional method of determining aggregate stability~~y~~ offers little hope for finding an explanation for these data. It should be stressed, however, that the wet-sieving method is a good laboratory method. It is believed that extending the wet-sieving method to the dry-sieved aggregates of a soil will yield additional important information.

A summation of the results from each size of the dry-sieved aggregates is presented in Figure 12. These curves further reveal the observations discussed above. The dry-sieved aggregates from the grass plots show that the percent of stable aggregates above 0.25 mm. in size tends to decrease with a decrease in size of the dry aggregates. The same trend was observed with the percent of the dry-sieved aggregates which did not disintegrate upon wetting. From the previous discussion, it can

Figure 12. The Effect of Treatments on the Percent Stable Aggregates Above 0.25 mm. and the Percent of Aggregates Which Retained Their Size in Each of the Dry Sieved Aggregates



be inferred that this tendency represents favorable structural stability, that is, a high stability of the larger dry-sieved aggregates which decreases slowly as the size of the dry aggregates decreases. It is of importance to note that the organic matter, total nitrogen, and exchange capacity levels of the dry-sieved aggregates from the grass plots, as shown in Figures 2, 3 and 4, tend to increase with decrease in size of the aggregates. The percent of stable aggregates above 0.25 mm. in size of the dry-sieved aggregates from the cotton plots was considerably lower than that of the dry-sieved aggregates from the grass plots. The dry-sieved aggregates from the cotton treatment show that the percent of stable aggregates above 0.25 mm. tended to increase with decrease in size of the dry aggregates and reached a maximum in the 0.42 mm. size dry aggregates. The percent of dry-sieved aggregates which were not disintegrated upon wetting followed the same trend as the percent of the stable aggregates above 0.25 mm. but at a lower level. This observation illustrate the aggregate disintegration which takes place upon wetting. The trend of the percent stable aggregates above 0.25 mm. was very similar to the trends observed previously with organic matter, total nitrogen, exchange capacity and clay levels of the dry sieved aggregates (Figures 2, 3, 4, and 5). These data illustrates the importance of these properties in the stability of the aggregates.

SUMMARY AND CONCLUSIONS

With the present trend toward a more intensive, highly mechanized agriculture, a better understanding of the factors which contribute to the stability of soil structure is of great importance.

The objectives of this study were:

1. To study the effect of 40 years of continuous cultivation of a Kirkland silt loam as compared to the same soil type under continuous grass.
2. To evaluate the effect of organic matter content; nitrogen content; and exchangeable calcium, magnesium, potassium and sodium on the stability of the aggregates of a Kirkland silt loam.
3. To investigate a new index for the stability of soil aggregates.

A considerable reduction in aggregate stability - 50%, organic matter - 66%, nitrogen - 50%, exchange capacity - 27% and percolation rate - 50% as a result of 40 years of continuous cotton cultivation was observed. Results from the subsoils under the treatments suggest that cultivation itself was a major factor in the disintegration of the soil structure. A comparable reduction in the properties mentioned above was observed in the dry sieved and stable aggregates from the continuous cotton plots as compared to those from the grass plots. The properties of the dry-sieved and stable aggregates from the cotton plots showed a tendency to increase in magnitude with a decrease in size of the aggregates and reached a maximum in the 0.42 mm. aggregates. The dry-sieved and stable aggregates from the grass plots showed a similar tendency, but a maximum was reached in the smallest aggregates (0.25 mm.). The stability of the dry-sieved aggregates and their percolation rates followed similar trends. It was concluded that organic matter, total nitrogen, cation exchange capacity and clay content were important in the stability of soil aggregates. The pattern of breakdown of the dry sieved aggregates from the cotton plots suggested the possibility of the existence of larger dry aggregates as conglomerations of smaller stable aggregates loosely held together. It was concluded from this study that 40 years of continuous cotton cultivation caused a considerable reduction in the stability of the soil aggregates, this reduction was especially high in the larger aggregates (5.00-2.00 and 2.00-0.84 mm. in size).

An extension of the conventional wet sieving method of the dry-sieved aggregates of a soil was suggested as a more effective index of aggregate stability.

LITERATURE CITED

1. Alderfer, R. B. and F. G. Merkle. Structural stability and permeability of soils. Soil Sci. 51: 201-211, 1941.

2. ______________ and _____________. Structural stability and permeability of native forest soils compared with cultivated areas of the same soil type. Proc. Soil Science Soc. Amer. 6: 98-103, 1941.

3. Aldrich, D. G. A chemical-microbiological study of the effects of exchangeable cations on soil aggregation. Proc. Soil Science Soc. Amer. 18: 276-281, 1954.

4. Baver, L. D. The relation of exchangeable cations to the physical properties of soils. Jour. Amer. Soc. Agron. 20: 921-941, 1928.

5. ___________. Factors contributing to the genesis of soil microstructure on 77 different soils. Amer. Soil Survey Assn. Bull. XVI: 55-56, 1935.

6. ___________ and W. G. Harper. The aggregation of desert soils. Amer. Soil Survey Assn. Bull. XVI: 54, 1936.

7. ___________. Soil Physics. Third edition, John Wiley & Son, Inc. New York, N. Y. 1956.

8. ___________ and H. F. Rhoades. Aggregate analysis as an aid in the study of soil structure relationship. Jour. Amer. Soc. Agron. 24: 920-930, 1927.

9. Bertramson, B. R. and H. F. Rhoades. The effect of cropping and manure applications on some physical properties of a heavy soil in East Nebraska. Proc. Soil Science Soc. Amer. 3: 32-36, 1938.

10. Bradfield, R. Soil conservation and soil physics. Jour. Amer. Soc. Agron. 11: 85-86, 1937.

11. ___________. The value and limitation of calcium in soil structure. Proc. Amer. Soc. Survey Assn. Bull. 17: 31-32, 1936.

12. Browning, G. M. and F. M. Milam. Rate of application of organic matter in relation to soil aggregation. Proc. Soil Science Soc. Amer. 6: 96-97, 1937.

13. ______________. Changes in the erodibility of soils brought about by the application of organic matter. Proc. Soil Science Soc. Amer. 2: 85-95, 1937.

14. Bryant, J. C., T. W. Bendixen and C. S. Slater. Measurement of the water stability of soils. Soil Sci. 65: 341-345, 1948.

15. Chepil, W. S. Factors that influence clod structure and erodibility of soil by wind: III Calcium carbonate and decomposed organic matter. Soil Sci. 77: 473-480, 1954.

16. ____________. Seasonal fluctuations of soil structure and erodibility of soil by wind. Proc. Soil Science Soc. Amer. 18: 13-16, 1954.

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

18. Garey, C. L. Properties of soil aggregates: I. relation of size, water stability and mechanical composition. Proc. Soil Science Soc. Amer. 18: 16-18, 1954.

19. Gish, R. E. and G. M. Browning. Factors affecting the stability of soil aggregates. Proc. Soil Science Soc. Amer. 13: 51-55, 1948.

20. Hide, J. C. and W. H. Metzger. Soil aggregation as affected by certain crops and organic materials and some chemical properties associated with aggregation. Proc. Soil Science Soc. Amer. 4: 19-22, 1939.

21. Jennings, D. S., M. D. Thomas and W. Gardner. A new method of mechanical analysis. Soil Sci. 14: 485-499, 1922.

22. Jenny, H. Soil fertility losses under Missouri conditions. Missouri Agr. Exp. Sta. Bull. 324: 3-10, 1933.

23. 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 a Marshall silt loam. Proc. Soil Science Soc. Amer. 7: 105-107, 1942.

24. Kilmer, V. J. and L. T. Alexander. Methods of making mechanical analysis of soils. Soil Sci. 68: 15-24, 1948.

25. Klingebiel, A. A. and A. M. O'neal. Structure and its influence on ilth of soils. Proc. Soil Science Soc. Amer. 16: 77-80, 1952.

26. Klute, A. and W. E. Jacob. Physical properties of Sassafras silt loam as affected by long time organic matter additions. Proc. Soil Science Soc. Amer. 14: 24-28, 1949.

27. Laws, D. W. and D. D. Evans. The effect of long time cultivation on some physical and chemical properties of two Rendzina soils. Proc. Soil Science Soc. Amer. 14: 15-19, 1949.

28. Lyon, T. L., H. O. Buckman and N. C. Brady. The Nature and Properties of Soils. Fifth edition, The Macmillan Company. New York, N. Y. 1950.

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

30. ___________. The physico-chemical properties of soil affecting soil erosion. Missouri Agr. Exp. Sta. Res. Bull. 212, 1934

31. Martin, J. P. Microorganisms and soil aggregation: I. Origin and nature of some of the aggregating substances. Soil Sci. 59: 163-173, 1945.

32. ____________. Microorganisms and soil aggregation: II. Influence of bacterial polysaccharides on soil structure. Soil Sci. 61: 157-166, 1946.

33. ____________ and S. A. Waksman. Influence of microorganisms on soil aggregation and erosion. Soil Sci. 50: 29-47, 1936.

34. McHenry, J. R. and M. B. Russel. Elementary mechanics of aggregation of puddled materials. Proc. Soil Science Soc. Amer. 8: 71-78, 1944.

35. Myers, H. E. Physicochemical relations of colloids. Soil Sci. 44: 331-359, 1930.

36. Page, J. B. Principles of soil aggregation. Mimeo. Rpt. Soil Microbiology Conf., Purdue Memorial Union. June 21-24, 1954.

37. __________. Role of physical properties of clay in soil science clays and clay technology, proc. of the first National Conference on clays and clay technology. California Dept. of Natural Resources Bull. 169: 167-176, July, 1955.

38. Parker, E. R. and H. Jenny. Water infiltration and related soil properties as affected by cultivation and organic fertilization. Soil Sci. 60: 353-376, 1945.

39. Peech, M., L. T. Alexander, L. A. Dean and J. F. Reed. Methods of soil analysis for soil fertility investigation. U.S.D.A. Cir. 757, 1947.

40. Peel, T. C. The effect of calcium on the erodibility of soils. Proc. Soil Science Soc. Amer. 1: 47-51, 1936.

41. __________. The effect of lime and O.M. on erodibility of Cecil clay. Proc. Soil Science Soc. Amer. 2: 79-83, 1937.

42. Peterson, J. B. Formation of water stable structure in puddled soils. Soil Sci. 55: 289-300, 1943.

43. ______________. Calcium linkage-a mechanism in soil granulation. Proc. Soil Science Soc. Amer. 12: 29-34, 1947.

44. Reeve, R. C. and C. A. Bower. A comparison of the effects of exchangeable sodium and potassium upon the physical properties of soils. Proc. Soil Science Soc. Amer. 18: 130-134, 1954.

45. Robinson, D. O. and J. B. Page. Soil aggregate stability. Proc. Soil Science Soc. Amer. 15: 25-28, 1950.

46. Russell, E. W. The interaction of clay with water and organic liquids as measured by specific valume changes and its relation to the phenomena of crumb formation of soils. Phil. Tranc. Royal Soc. of London. Series A Vol. 233: 361-390, 1934.

47. Russel, M. B. and A. Klute. Further studies on the effect of long time organic matter additions on the physical properties of Sassafras silt loam. Proc. Soil Science Soc. Amer. 16: 156-159, 1952.

48. Schollenberger, C. J. Determination of soil organic matter. Soil Sci. 31: 483-486, 1931.

49. Sideri, D. I. 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: 461-481, 1928.

50. Tanner, C. B. and M. L. Jackson. Nomographs of sedimentation times for soil particles under gravity or centrifugal acceleration. Proc. Soil Science Soc. Amer. 12: 60-65, 1947.

51. Van Doren, C. A. and A. A. Klingebiel. Effect of management on soil permeability. Proc. Soil Science Soc. Amer. 16: 66-69, 1952.

52. Van Bavel, C.H.M. and F. W. Schaller. Soil aggregation, organic matter and yields. Proc. Soil Science Soc. Amer. 15: 399-404, 1950.

53. Woodruff, C. M. Variation in the state and stability of aggregates as a result of different methods of cropping. Proc. Soil Science Soc. Amer. 4: 13-18, 1939.

54. Yoder, R. E. The significance of soil structure in relation to the tilth problem. Proc. Soil Science Soc. Amer. 2: 21-33, 1937.

55. __________. A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. Jour. Amer. Soc. Agron. 28: 337-351, 1936.

APPENDIX

A DESCRIPTION OF THE PROFILE OF 6 A-1 KIRKLAND SILT LOAM[1]

Site I:

Samples of Virgin Kirkland silt loam were collected just east of the Stillwater Airport building in a large meadow south of the main airport road. No definite evidence of former cultivation was found. This area had a weak convex surface; gradient about 1% to south and east. The profile is described as follows:

Profile*

A_1 0- 10" Dark-grayish-brown (10 YR 4/2; 2.5/2, m) heavy silt loam; weak prismatic; moderate medium granular; porous and permeable; pH 5.8; many worm holes, some of which continue to the surface; roots well distributed; rests with a 1 inch silty clay loam transition on the layer below.

B_{2-1} 10-22" Very dark-grayish-brown (10 YR 3.5/2; 2/2, m) clay compound moderate coarse prismatic and moderate medium blocky; very firm; very slowly permeable; pH 6.0; strong clay films on peds which are shiny when moist; occasional fine black concretions; fine roots penetrate largely in spaces between peds; grades through a 4 inch transition to the layer below.

B_{2-2} 22-42" Brown (7.5 YR 5/2; 4/2, m) clay; moderate medium blocky and weak coarse prismatic; very firm and compact; very slowly permeable; pH 6.5; a few fine black concretions and ferrutinous films; roots run largely in cracks between peds; very compact and sides of peds are darker than interiors being dark-brown (7.5 YR 4/2); grades to the layer below. Many larger roots are greatly appressed.

B_3 C42-52"+ Reddish-brown (5 YR 5/4) clay finely and faintly mottled with yellowish-red (5 YR 5/6); a few light-gray pockets or lenses in the lower part that seem to be of more sandy material; weak medium blocky; less compact than layer above; pH 7.0; fine roots fairly well distributed in cracks.

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* Color notations following color names are based on the standard Munsell system of color designation and refer to the dry soil unless stated otherwise.

[1] Profile description was provided by Harry Galloway, Soil Scientist, (Coop. U.S.D.A. and S.C.S.)

Profile Description (Continued)

C_3 64-84"+ Red (2.5 YR 4/6; 3/6, when moist) silty clay with occasional light-gray steaks and splotches; weak medium blocky; firm but not compact; pH 7.5 +; many fine pores; changes little to greatest depth sampled.

No pebble line is found here nor is there definite evidence of lower layers being in old alluvium as under the Bethany silt loam samples some 600 feet southeast of here. It is likely, though, that this substratum is in old alluvium, but of material nearly like the normal "red beds" strata found in this vicinity.

A DESCRIPTION OF THE PROFILE OF 6 A-1 KIRKLAND SILT LOAM[1]

Site II:

A typical profile of the soil was studied in Plot 6100 from a point about 50 feet east of the center of this plot. This area occurs on a plane slope with a gradient of about 3/4%. It was in sorghum during 1953. The profile is described as follows:

Profile*

A_{1p}	0- 8"	Grayish-brown (10 YR 4.5/2; 3.5/2, when moist) heavy silt loam; weak medium granular; friable; permeable; pH 6.5; a few fine pores; rests abruptly on the layer below.
B_{2-1}	8-22"	Dark-grayish-brown (9YR 4/2; 3/2, when moist) clay; moderate fine blocky; very firm; sticky and plastic when wet; very slowly permeable; pH 7.0; sides of peds are varnished and have strong clay films; occasional fine black concretions; grades through a 4" transition to the layer below.
B_{2-2}	22-32"	Dark-grayish-brown (10 YR 4/2; 3/2, when moist) clay; weak angular blocky; very firm and compact; very slowly permeable; pH 7.5; occasional fine black pellets; a few strong-brown specks about the tiny root holes; many fine $CaCO_3$ concretions below 24 or 26 inches; peds have a weak shine when moist; grades through a 3 inch transition to the layer below.
B_3	32-42"	Brown (7.5 YR 5/4; 4/3, when moist) light clay; weak medium blocky; firm or very firm; very hard when dry; pH 7.5; occasional black pellets and $CaCO_3$ concretions; sides of peds have weak coatings of dark-brown (7.5 YR 4/2, when moist); grades to the layer below.
C_1	42-52"	Reddish-brown (5 YR 5/4; 4/4, when moist) heavy silty clay loam or light silty clay much like the layer above; pH 7.5 +; occasional large $CaCO_3$ concretions and black ferruginous films; grades to the layer below.
C_2	52-64"	Reddish-brown (3.5 YR 5/4; 4/4, when moist) silty clay loam splotched with 10% of red (2.5 YR 4/6) has occasional light-gray streaks; weak irregular blocky; firm; slowly permeable; pH 7.5; occasional fine black pellets and fine concretions of $CaCO_3$; grades to the layer below.

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* Color notations following color names are based on the standard Munsell system of color designation and refer to the dry soil unless stated otherwise.

[1] Profile description was provided by Harry Galloway, Soil Scientist, (Coop. U.S.D.A. and S.C.S.)

TABLE XIII

THE EFFECT OF TREATMENTS ON THE STABLE AGGREGATE SIZE DISTRIBUTION OF THE WHOLE SOILS

		Percent of each size (size in mm.)				
Treatment	Replication	5.00-2.00	2.00-0.84	0.84-0.42	0.42-0.25	Total
Grass	Rep. I	21.6	17.9	11.4	3.9	54.8
	Rep. II	17.5	18.9	14.5	5.6	56.5
	av.	19.55	18.40	12.95	4.75	55.65
Cotton	Rep. I	3.0	7.8	10.2	7.6	28.6
	Rep. II	3.2	7.0	11.2	7.0	28.4
	av.	3.10	7.40	10.70	7.30	28.5

TABLE XIV

THE EFFECT OF TREATMENTS AND AGGREGATE SIZE ON THE ORGANIC MATTER CONTENT OF DRY AND STABLE AGGREGATES

		Percent organic matter of each aggregate size (mm.)							
Treatment	Replication	5.00- 2.00		2.00- 0.84		0.84- 0.42		0.42- 0.25	
		Dry	Stable	Dry	Stable	Dry	Stable	Dry	Stable
Grass	Rep. I	2.90	2.91	3.15	3.03	3.26	3.39	3.60	3.90
	Rep. II	2.70	2.70	2.79	2.79	3.20	3.30	3.58	3.80
	av.	2.80	2.80	2.97	2.91	3.23	3.34	3.59	3.85
Cotton	Rep. I	1.34	1.62	1.36	1.43	1.45	1.64	1.32	1.60
	Rep. II	1.22	1.28	1.22	1.35	1.30	1.62	1.32	1.52
	av.	1.28	1.45	1.28	1.39	1.37	1.63	1.32	1.56

TABLE XV

EFFECT OF TREATMENTS AND AGGREGATE SIZE ON NITROGEN CONTENT OF DRY AND STABLE AGGREGATES

Treatment	Replication	Percent nitrogen of each aggregate size (size in mm.)							
		5.00-2.00		2.00-0.84		0.84-0.42		0.42-0.25	
		Dry	Stable	Dry	Stable	Dry	Stable	Dry	Stable
Grass	Rep. I	0.126	0.136	0.140	0.138	0.147	0.149	0.165	0.170
	Rep. II	0.136	0.136	0.132	0.137	0.140	0.155	0.161	0.175
	av.	0.131	0.136	0.136	0.138	0.143	0.152	0.163	0.173
Cotton	Rep. I	0.065	0.076	0.064	0.081	0.067	0.087	0.070	0.086
	Rep. II	0.069	0.073	0.068	0.074	0.071	0.079	0.071	0.084
	av.	0.067	0.074	0.066	0.078	0.069	0.083	0.070	0.085

TABLE XVI

THE EFFECT OF TREATMENT AND AGGREGATE SIZE ON THE EXCHANGE CAPACITY OF DRY AND STABLE AGGREGATES

Treatment	Replication	Milli equivalents in each size (size in mm.)							
		5.00-2.00		2.00-0.84		0.84-0.42		0.42-0.25	
		Dry	Stable	Dry	Stable	Dry	Stable	Dry	Stable
Grass	Rep. I	16.30	16.70	16.68	16.41	16.86	17.16	17.35	17.69
	Rep. II	16.66	16.37	15.66	16.16	16.69	17.34	16.93	18.02
	av.	16.48	16.53	16.17	16.29	16.78	17.25	17.14	17.85
Cotton	Rep. I	12.68	15.15	13.65	15.81	14.07	16.33	13.68	15.50
	Rep. II	13.16	15.74	13.90	16.09	14.14	16.82	13.75	15.50
	av.	12.92	15.45	13.78	15.95	14.10	16.58	13.71	15.50

TABLE XVII

THE EFFECT OF TREATMENTS AND AGGREGATE SIZE ON THE CLAY CONTENT OF DRY AND STABLE AGGREGATES

Treatment	Replications	Percent clay of each size (size in mm.)							
		5.00-2.00		2.00-0.84		0.84-0.42		0.42-0.25	
		Dry	Stable	Dry	Stable	Dry	Stable	Dry	Stable
Grass	Rep. I	23.34	23.08	22.28	24.40	22.60	24.26	22.60	24.28
	Rep. II	25.10	21.86	23.26	24.28	23.34	23.60	22.94	24.02
	av.	24.22	22.47	22.77	24.34	22.97	23.93	22.77	24.15
Cotton	Rep. I	20.62	21.36	20.76	22.32	22.30	25.36	21.08	25.20
	Rep. II	20.62	22.90	22.40	22.64	22.50	25.70	22.76	25.98
	av.	20.62	22.13	21.58	22.48	22.40	25.53	21.92	25.59

TABLE XVIII

THE EFFECT OF TREATMENTS AND AGGREGATE SIZE ON THE SILT CONTENT OF DRY AND STABLE AGGREGATES

Treatment	Replication	Percent silt of each size (size in mm.)							
		5.00-2.00		2.00-0.84		0.84-0.42		0.42-0.25	
		Dry	Stable	Dry	Stable	Dry	Stable	Dry	Stable
Grass	Rep. I	47.77	47.66	49.90	47.08	48.87	47.03	49.82	48.62
	Rep. II	46.02	49.46	48.78	46.05	49.00	48.92	49.70	48.88
	av.	46.90	48.56	49.34	46.56	48.94	47.97	49.76	48.75
Cotton	Rep. I	48.96	50.30	49.31	46.77	51.34	51.57	49.94	48.78
	Rep. II	50.75	47.57	50.97	49.02	52.92	52.53	51.19	51.17
	av.	49.85	48.94	50.14	48.90	52.13	52.05	50.56	49.98

TABLE XIX

THE EFFECT OF TREATMENTS AND AGGREGATE SIZE ON THE SAND CONTENT OF DRY AND STABLE AGGREGATES

Treatment	Replication	Percent sand of each size (size in mm.)							
		5.00-2.00		2.00-0.84		0.84-0.42		0.42-0.25	
		Dry	Stable	Dry	Stable	Dry	Stable	Dry	Stable
Grass	Rep. I	29.20	29.26	27.82	28.51	28.53	28.71	27.58	27.10
	Rep. II	28.88	28.68	28.96	29.68	27.66	27.48	27.35	27.10
	av.	29.04	28.97	28.39	29.10	28.09	28.09	27.46	27.10
Cotton	Rep. I	30.41	28.34	29.93	30.41	26.36	23.07	28.98	26.02
	Rep. II	28.63	29.53	26.63	28.34	24.58	21.76	26.05	22.35
	av.	29.52	28.94	28.28	29.38	25.47	22.42	27.51	24.19

TABLE XX

ANALYSIS OF VARIANCE ON THE EFFECT OF CRUSHING ON THE SIZE DISTRIBUTION OF THE COTTON DRY-SIEVED AGGREGATES

1. Aggregates 5.00-2.00 mm. in size.

Replication	Percent			
	Crushing I	Crushing II	Crushing III	Crushing IV
Rep. I	5.8	12.8	10.0	7.8
Rep. II	7.4	11.8	13.0	8.8
Rep. III	7.8	15.2	14.4	10.0
Rep. IV	9.2	12.6	11.6	9.0
Total	30.2	52.4	49.0	35.6

Analysis of Variance				
Source	D.F.	S.S.	M.S.	F
Total	15	109.72		
Crushing	3	84.30	28.10	
Error	12	25.42	2.12	13.25**

2. Aggregates 2.00-0.84 mm. in size.

Replication	Percent			
	Crushing I	Crushing II	Crushing III	Crushing IV
Rep. I	18.0	21.6	20.0	18.8
Rep. II	18.4	20.0	21.2	21.0
Rep. III	19.2	22.2	22.2	21.4
Rep. IV	20.6	21.2	21.8	21.2
Total	76.2	85.0	85.2	82.4

Analysis of Variance				
Source	D.F.	S.S.	M.S.	F
Total	15	26.92		
Crushing	3	13.22	4.41	
Error	12	13.70	1.14	3.87*

* Significant on the 5% level.

** Significant on the 1% level.

TABLE XX (Continued)

3. Aggregates 0.84-0.42 mm. in size.

Replication	Percent			
	Crushing I	Crushing II	Crushing III	Crushing IV
Rep. I	17.6	17.0	17.2	17.4
Rep. II	17.4	17.8	16.4	16.8
Rep. III	17.0	16.2	15.8	18.0
Rep. IV	17.4	17.4	16.8	17.6
Total	69.4	68.4	66.2	69.8

Analysis of Variance				
Source	D.F.	S.S.	M.S.	F
Total	15	5.36		
Crushing	2	1.95	0.65	
Error	13	3.41	0.28	2.32 NS[1]

4. Aggregates 0.42-0.25 mm. in size.

Replication	Percent			
	Crushing I	Crushing II	Crushing III	Crushing IV
Rep. I	11.0	10.0	10.4	11.2
Rep. II	10.8	10.4	9.4	10.6
Rep. III	10.2	9.2	8.8	10.6
Rep. IV	9.8	10.0	9.4	10.4
Total	41.8	39.6	38.0	42.8

Analysis of Variance				
Source	D.F.	S.S.	M.S.	F
Total	15	6.86		
Crushing	3	3.51	1.17	
Error	12	3.35	0.279	4.19*

* Significant on the 5% level.

[1] NS - Not significant on the 5% level.

TABLE XXI

ANALYSIS OF VARIANCE ON THE EFFECT OF CRUSHING ON THE SIZE DISTRIBUTION OF THE COTTON WET-SIEVED AGGREGATES

1. Aggregates 5.00-2.00 mm. in size.

Replication	Percent			
	Crushing I	Crushing II	Crushing III	Crushing IV
Rep. I	1.8	1.8	1.6	5.6
Rep. II	1.0	1.2	1.2	1.2
Rep. III	0.8	0.6	0.4	0.8
Rep. IV	1.0	1.6	0.8	1.6
Total	4.6	5.2	4.0	9.2

Analysis of Variance				
Source	D.F.	S.S.	M.S.	F
Total	15	21.22		
Crushing	3	4.15	1.38	
Error	12	17.07	1.42	0.97 NS[1]

2. Aggregates 2.00-0.84 mm. in size.

Replication	Percent			
	Crushing I	Crushing II	Crushing III	Crushing IV
Rep. I	8.0	8.0	10.8	8.4
Rep. II	5.4	7.4	4.0	6.0
Rep. III	6.8	4.6	3.2	6.4
Rep. IV	7.6	11.6	4.2	5.6
Total	27.8	31.6	22.2	26.4

Analysis of Variance				
Source	D.F.	S.S.	M.S.	F
Total	15	82.04		
Crushing	3	11.30	3.77	
Error	12	70.74	5.90	0.64 NS[1]

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[1] NS-Not significant on the 5% level.

TABLE XXI (Continued)

3. Aggregates 0.84-0.42 mm. in size.

Replication	Percent			
	Crushing I	Crushing II	Crushing III	Crushing IV
Rep. I	10.6	12.0	10.6	10.8
Rep. II	11.2	12.0	12.0	12.4
Rep. III	14.6	15.2	9.2	12.0
Rep. IV	18.8	13.4	12.4	7.6
Total	55.2	52.6	44.2	47.8

Analysis of Variance				
Source	D.F.	S.S.	M.S.	F
Total	15	98.23		
Crushing	3	28.13	9.38	
Error	12	70.10	5.84	1.61 NS[1]

4. Aggregates 0.42-0.25 mm. in size.

Replication	Percent			
	Crushing I	Crushing II	Crushing III	Crushing IV
Rep. I	6.2	7.4	4.4	4.8
Rep. II	7.6	7.8	9.6	12.8
Rep. III	11.4	7.2	12.4	8.0
Rep. IV	8.2	7.2	9.2	8.0
Total	33.4	29.6	35.6	33.6

Analysis of Variance				
Source	D.F.	S.S.	M.S.	F
Total	15	85.18		
Crushing	3	4.71	1.57	
Error	12	80.47	6.71	0.23 NS[1]

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[1] NS-Not significant on the 5% level.

TABLE XXII

THE EFFECT OF TREATMENTS ON THE STABLE AGGREGATE DISTRIBUTION OF THE DRY-SIEVED AGGREGATES

Treatment	Size of Dry-Sieved Aggregate	Replication	Percent of Sample				
			5.00-2.00	2.00-0.84	0.84-0.42	0.42-0.25	Total
Grass	5.00-2.00	Rep. I	84.5	6.7	2.5	2.0	95.7
		Rep. II	75.5	8.7	4.2	1.8	90.2
		av.	80.0	7.7	3.4	1.9	92.9
	2.00-0.84	Rep. I		79.0	7.0	2.0	88.0
		Rep. II		67.0	9.2	2.3	78.5
		av.		73.0	8.1	2.2	83.2
	0.84-0.42	Rep. I			79.5	2.8	82.3
		Rep. II			63.7	6.0	69.7
		av.			71.6	4.4	76.0
	0.42-0.25	Rep. I				70.0	70.0
		Rep. II				70.0	70.0
		av.				70.0	70.0
Cotton	5.00-2.00	Rep. I	4.5	5.0	8.7	9.0	27.2
		Rep. II	1.5	2.3	8.0	7.5	19.3
		av.	3.0	3.7	8.3	8.3	23.2
	2.00-0.84	Rep. I		9.3	11.7	8.0	29.0
		Rep. II		7.5	12.2	9.5	29.2
		av.		8.4	11.9	8.8	29.1
	0.84-0.42	Rep. I			21.3	13.2	34.5
		Rep. II			21.3	13.2	34.5
		av.			21.3	13.2	34.5
	0.42-0.25	Rep. I				20.7	20.7
		Rep. II				20.7	20.7
		av.				20.7	20.7

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