EFFECT OF SOIL CONDITIONERS ON CROP YIELDS AND PHYSICAL PROPERTIES OF TWO OKLAHOMA SOILS

By

J. C. True

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EFFECT OF SOIL CONDITIONERS ON CROP YIELDS AND PHYSICAL PROPERTIES OF TWO OKLAHOMA SOILS

Thesis Approved:

Robert M. Reed
Thesis Adviser

H. F. Murphy

Robert T MacVicar
Dean of the Graduate School

PREFACE

In January of 1953, the writer was assigned to work with Dr. Charles L. Sarthou who had begun research on synthetic soil conditioners during the fall of 1952. When Dr. Sarthou joined other members of the Oklahoma A. and M. staff at the Imperial Ethiopian College of Agricultural and Mechanical Arts in June of 1953, the writer was assigned to work with Dr. Robert M. Reed of the Agronomy Department, Oklahoma Agricultural and Mechanical College.

Krilium developed by the Monsanto Chemical Company, Aerotil developed by the American Cyanamid Company, CMC (carboxymethylcellulose) Gums developed by the Hercules Powder Company, and other synthetic soil conditioners have been placed on our commercial market in recent years. An interest concerning the effectiveness of these synthetic conditioners on improving the physical conditions of some Oklahoma soils, led to the research in this thesis.

The writer wishes to express his appreciation to the staff of the Agronomy Department of Oklahoma Agricultural and Mechanical College for their helpful advice and criticisms and especially to Dr. Charles L. Sarthou and Dr. Robert M. Reed, under whose supervision the experimental work was carried out. Dr. Reed has offered invaluable guidance and constructive criticisms in the writing of this paper.

TABLE OF CONTENTS

LIST OF TABLES

Table | Page

LIST OF ILLUSTRATIONS

I. INTRODUCTION

The addition of organic material to soil for the amelioration of structure is not a new idea. It has been found that the improvement of soil structure is due mainly to the presence of polysaccharides and polyuronides which are closely related chemically and are formed by the decomposition of organic matter.

Most of the soil conditioners which have been placed on the market in recent years are synthetic polymers having similar properties to the natural polyuronides. Since these synthetic polymers do have characteristics similar to the polyuronides which occur in the soil as a result of the decomposition of manures and crop residues, there is reason to believe that these synthetic soil conditioners may improve the physical condition of many of our so-called "problem soils."

Renfrow loam and Kirkland silt loam which are good examples of Oklahoma soils with poor physical condition, especially the latter, were chosen for this study of the effect of soil conditioners on the physical properties of soils and crop yields.

II. REVIEW OF LITERATURE

The prime purpose of synthetic soil conditioners as pointed out in recent magazine articles is to aggregate clays and fine silts. Claims were made in these articles that benefit from increased soil aggregation include increased aeration, increased water-holding capacity, improved workability, hastened seed germination, increased emergence, accelerated early growth, increased root formation, improved drainage, decreased crusting, and ultimately improved crop response.

Quastel (24) reviewed the findings of a number of investigators on the composition of products derived from decomposed organic matter and pointed out the aggregating properties of polyuronides, polysaccharides, alginic acid, and cellulose esters on soil particles.

Hendrick and Mowry (12) presented the results of a program of several years duration in which more than 700 chemicals were evaluated for their effect on aeration and aggregation of soil. It was found that certain water-soluble polymeric electrolytes of high molecular weight and optimum configuration were effective in low concentrations. These polyelectrolytes were given the Monsanto Chemical Company's trademark name of "Krilium" which have been made into various formulations, such as CRD-186, CRD-189, CRD-931, etc.

Hendrick and Mowry reported aggregation of soil particles less than 0.25 mm. in diameter into water-stable aggregates greater than 0.25 mm. increased from seven percent on untreated soil to 96 percent on soil treated at the rate of 0.2 percent CRD-186. The moisture equivalent value ascended from 24.2 percent on untreated soil to 27.6 percent on soil treated at the rate of 0.1 percent CRD-186. Treatments also hastened seed germination and seedling emergence of radishes, carrots, and beans. The soil used in this experiment was Miami silt loam which contained 22.2 percent clay, 46.6 percent silt, and 31.2 percent sand.

Peters et al. (22) gave data which conflicted with that obtained by Hendrick and Mowry. Additions of CRD-186 and CRD-189 were made at rates from 0.02 to 0.40 percent to five different soils ranging from sandy loam to clay. Applications up to 0.2 percent followed by drying and re-wetting caused a slight reduction in moisture equivalent, whereas applications at the rate of 0.4 percent tended to cause a slight increase in moisture equivalent, especially of the coarse-textured soils. Any changes in the moisture equivalent of these soils resulting from conditioner treatments were too small to be of practical importance.

The stabilizing action of polyelectrolytes on clays was studied by Ruehrwein and Ward (27) who employed X-ray diffraction, adsorption measurements, and flocculation measurements of clays treated with different synthetic polymers. X-ray diffraction patterns of montmorillonite clay treated with polyelectrolytes demonstrated that the polycation, but not the polyanion, was absorbed on the faces of the montmorillonite layers. Adsorption of sodium polymethacrylate on kaolinite was found to be a strikingly slow process requiring more than a month to reach equilibrium. Results demonstrated that clay becomes saturated with approximately 2.0 me. of polymer per 100 grams of clay. Polyanions were not flocculating agents since both the clay and the polyanion are negatively charged; however, polyanions do increase the resistance of clay floccules to re-dispersion. Polycations were found to be both effective flocculating and clay-floccule stabilizing agents.

To study the changes in the physical characteristics of the soils and the effect on different crop yields, Martin et al (19) applied Krilium soil conditioners at the rate of 0.02 percent to Miami silt loam, Crosby silt loam, Brookston silty clay loam, and Paulding clay soils. In every case soil aggregation, permeability, and aeration increased and remained significantly higher in the treated plots than in the untreated plots after two cropping seasons. Statistically significant yield increases of corn, oats, and carrots occured as a result of the treatment but other crops, potatoes, sugar beets, turnips, and soybeans showed no significant yield increases as a result of the treatment.

Two separate tests, water-stable aggregate distribution and aggregate stability, were made by Jamison (14) to conduct screening tests on the effectiveness of various soil conditioners. Lloyd and Hurricane clay soils were used to conduct these tests. In general, these tests showed the cellulose gums to be most effective, CRD-186 ranked second, with CRD-189 and Aerotil third. CRD-189 and Aerotil were found to be more effective than the other acrylic acid derivatives. The total aggregates test was out of line with the degree of stability test in some cases, but it was explained that calcium acrylate does not compare favorably with the acrylate polymers since it is probably more nearly molecular than colloidal in its properties.

Laboratory studies were made by Coleman (10) with the objective of studying the influence of CRD-186, CRD-189, Aerotil 40% dry form, and Aerotil 83% wettable form on 16 North Carolina soils which had been secured from the Piedmont, Mountain, and Coastal Plains regions. Soils were treated at the rates of 0, 0.025, 0.05, 0.10, and 0.20 percent and the water-stable aggregation of the soil fraction less than 0.25 mm. was measured by a wet sieving procedure. The conditioners were approximately equal in aggregate stabilization effectiveness, although CRD-186 was somewhat more effective for soils containing montmorillonite clay and hydrous micas. CRD-186 was also found to be more effective in the water-stable fragment creation for several clay mineral specimens.

A field experiment by Coleman was conducted to determine the effect of CRD-189 on emergence, growth, and yield of soybeans. The conditioner was applied at rates of 0, 16, and 32 pounds per acre in a six-inch band over the row and mixed to a depth of one-half inch. Another treatment consisted of 1000 pounds per acre worked in four inches deep. Growth measurements were not made but throughout the season it was noted that the 1000-pound rate plot contained from 15 to 20 percent larger plants than the other treatments. The yield data had not been statistically analyzed, but it was apparent that yield differences between the treatments were not significant. Aggregate analysis of samples taken from the plots two weeks following the application of the conditioners and after two rains showed 48 percent aggregation in the 1000-pound treated plot soils as compared to 18 percent in the untreated plot soils.

Coleman also performed a field experiment on the emergence of cotton and soybeans as affected by a spray application of CRD-186 at the rates of 0, 0.02, 0.05, and 0.10 percent in a four-inch strip on top of the row. Ten days after planting, the average number of cotton plants per 18 foot row was 34, 37, 41, and 42 for the 0, 0.02, 0.05, and 0.10 percent treatments, respectively. The average number of soybean plants per 18 foot row was 25, 43, and 43 for 0, 0.05, and 0.10 percent treatments, respectively. Aggregation determinations on the 0, 0.02, 0.05, and 0.10 percent treated soils planted to cotton were 18, 43, 52, and 65 percent water-stable aggregates.

Using cotton emergence and growth as indicators, Jamison and Weaver (15) conducted an experiment that started in 1951 and continued through 1952 on the residual effect of CRD-186 applied at rates of 0, 500, and 2000 pounds per acre on soil frames of Lloyd clay. The 1952 results were similar to those of 1951 except the effects were less pronounced. In 1952, the percentage emergence was highest on the frames that had treatments of 500 pounds CRD-186 per acre to a depth of three inches. The highest yield of seed cotton was obtained from the frames treated at the rate of 2000 pounds per acre to a depth of three inches.

Westgate (31) using Leon fine sand found no effect on growth of radishes from treatments of Krilium at rates up to 2000 pounds per acre. Also, tests with Krilium and Aerotil had no effect on celery plants, and Krilium at 1000 pounds per acre did not effect the growth of beans.

Emergence studies of sericea planted on Lloyd clay with surface applications of CRD-186 at the rates of 0, 50, 100, and 200 pounds per acre were made by Wilson and Jamison (32). Results showed a 22.2 percent increase in plants per acre on the 200-pound per acre treated plots over the check. The number of plants per acre on the check, 50, 100, and 200-pound CRD-186 treated plots was 220,000, 386,000, 436,000, and 988,000 plants, respectively.

Both Aerotil wettable and Aerotil dry forms were found by Hervey (13) to be somewhat less effective than 0.1 percent Krilium treatments in increasing trefoil stands on Houston black clay. The 0.1 percent

Krilium treatments at one-half and two inch depths increased trefoil stands as much as 40 percent, but the same rates mixed to five inches were found to be less effective.

To test the effect of CRD-189 on the uptake of phosphorus from radioactive superphosphate, a greenhouse randomized block factorial experiment using Pearman silt loam soil, two rates of Krilium (0 and 2000 pounds per acre), two rates of superphosphate (0 and 20 pounds of P_2O_5 per acre), with three replications, and wheat as a test plant was carried on in the winter of 1951-52 by Murdock and Seay (20). Results showed no significant difference in either yield of wheat or uptake of phosphorus from the fertilizer.

Allison (1) conducted a preliminary laboratory and a field study to determine the effect of CRD-186 and CRD-189 in promoting water-stable aggregation of several Western saline and alkali soils. No significant difference was found in the ability of these two synthetic conditioners to produce water-stable aggregates in eight of the nine soils tested. Treated and untreated plots representing normal, non-saline-alkali, and saline-alkali soil conditions were used to study the effect of CRD-186 on the yield of sweet corn. The treatment did not significantly increase yields on the normal soil, but it did give large increases on all three treated alkali soils. The outstanding result of this experiment was the higher yield of corn on the treated non-saline-alkali soil as compared to the yield of the treated normal soil.

Field and laboratory studies of the effectiveness of CRD-186 and CRD-189 for erosion control have been made by Weeks and Colter (30). The stabilizing effect of these conditioners on the surface of Dayton alluvial soil was demonstrated by photographs of water drops falling upon treated and untreated trays of soil. Field experiments with various treatments of soil on slopes of 34° and 22° were conducted and evaluated under semi-controlled conditions. Surface treatment was found to be at least twice as effective as a "raked in" treatment. Both CRD-186 and CRD-189 gave good control of soil movement when applied at the rate of one-half to one pound per 100 square feet of surface. CRD-189 at these rates was also found to be about as effective in reducing erosion and runoff as a two-ton per acre straw mulch.

III. MATERIALS AND METHODS

Since synthetic soil conditioners are relatively new, many people know these materials only by their trademark name. In order to prevent confusion, a list of the materials used in this research is given in the following table.

Company	Trademark Name	Formulation & Active Ingredients
Monsanto Chemical	Krilium	Krilium-6 or CRD-186, 100% Calcium-Salt of Vinyl Acetate-Maleic Acid
Monsanto Chemical	Krilium	Krilium-9 or CRD-189, 100% Polyacrylonitrile
Monsanto Chemical	Merloam	CRD-631, a 25% CRD-186 Formulation
W.A. Cleary Corp.	Soiloam	16% Polyacrylonitrile
American Cyanamid	Aerotil	Dry Form, 40% Polyacrylonitrile
American Cyanamid	Aerotil	Wettable Form, 83% Polyacrylonitrile
Hercules Powder	Cellulose Gum	CMC-70-H, 100% Carboxy Methyl Cellulose
Soil-Aid Corp.	All-N-One	Fortified coal by-product with a guaranteed analysis of 3-2-3 (total N, available P_2O_5, and available K_2O)

All of these conditioners were furnished by the different companies for research purposes.

Greenhouse Studies

The surface six inches of a Kirkland soil was collected from the Oklahoma A. and M. Agronomy Farm on January 1, 1953. After sieving through one-fourth inch mesh hardware cloth, the soil was brought into the greenhouse and dried.

Wheat Pot Cultures

Equal weights of air-dry soil were placed in 28 one-gallon glazed, earthenware pots. Then the pots received applications of Merloam or CRD-631 at the rates of 0, 100, 200, 400, 800, 1600, and 3200 pounds per acre and one-half of them were fertilized at the rate of 100 pounds of NH_4NO_3 and 150 pounds superphosphate per acre. Both the fertilized and unfertilized series were run in duplicate.

Ponca Red winter wheat was planted in each pot and thinned to four plants per pot after emergence. All pots were watered with tap water regularly or as the soil moisture conditions deemed necessary. Four months and 11 days after planting, the plants were cut at ground level, oven dried for 36 hours at 85° C., and weighed to determine the amount of dry matter produced.

Oat Pot Cultures

Equal weights of air-dry soil were placed in 42 one-half gallon, earthenware pots. Treatments were the same as those used in the wheat pot study except the CRD-631 was applied at rates of 0, 100, 200, 400, 800, 1600, and 3200 pounds per acre of active ingredients. The fertilized and unfertilized series were made in triplicate.

Andrew oats were planted in each pot and thinned to two plants per pot after emergence. The plants were cut at ground level three months and 28 days after planting, oven dried at 85° C. for 36 hours, and the dry matter weight recorded.

Emergence Tests

Ten frames were filled with equal amounts of air-dry soil and different rates of Aerotil dry and Aerotil wettable forms were applied. Treatments consisted of 0, 25, 50, 100, and 200 pounds of Aerotil dry form in one series of frames. Another series of frames were treated with Aerotil wettable form in amounts equivalent to those of the dry form. The Aerotil dry form was applied to the surface of the soil and raked in to a depth of one-half inch. The Aerotil wettable form was mixed with the amount of water that was required to saturate the soils treated with the Aerotil dry form.

Fifty Stoneville 62, acid delinted, Ceresan treated cottonseeds were planted one inch deep in each of the frames prior to the addition of water. Ten days after planting, the number of plants emerged in each frame were counted and recorded.

These emergence experiments were repeated using the same frames of soil without further treatment. Ten days after planting, the number of emerged plants were again noted. Pictures were taken of the frames on the fifth day after planting of the second emergence tests to illustrate the effect of these conditioners in preventing the formation of a surface crust on the soil.

Root Penetration Observations

Simulated "plow pans" were made by placing six inches of soil in glass-sided boxes, wetting to two inches and tamping to form a hard, two-inch thick, impermeable layer. The soil was periodically tamped until air dry. Four inches of loose soil was placed on top of these simulated "plow pans". The boxes were given the following treatments: Aerotil dry form at the rate of 2000 pounds per acre was mixed with the surface four inches of soil; Aerotil wettable form at a rate equivalent to the 2000 pounds of the dry form was mixed with water and applied to the surface four inches of soil; Aerotil dry form at the rate of 1000 pounds per acre was applied directly on top of the two-inch simulated "plow pan" plus an additional 1000 pounds per acre to the surface four inches, and Aerotil wettable form at the equivalent rate of 1000 pounds per acre was applied to the top of the simulated "plow pan" plus an additional 1000 pounds per acre (equivalent rate) to the surface four inches of soil. Two boxes received no conditioners and were used as checks.

Prior to wetting the surface four inches of soil, wheat and cotton were planted for an evaluation of the effect of these materials. Brown wrapping paper was used to cover the glass side of the boxes to prevent root injury from light.

Two months after treatment, the glass sides were removed from the boxes and the soil washed away from the roots to determine the amount of penetration. Photographs were made to show the results obtained by these materials of the amounts of root penetrations through the simulated "plow pans".

Field Studies

Completely randomized field plots, 25 by 25 feet, of ten different treatments with four replications of each were seeded to Pawnee wheat in the fall of 1952. These field plots made up of fairly uniform Renfrow loam soil have an almost level typography and are located on the Oklahoma A. and M. College Agronomy Farm. Three hundred pounds of superphosphate per acre was used as a pre-treatment to equalize previous fertilizer applications.

The ten treatments consisted of: (1) CRD-186, (2) CMC-70-H, and (3) Aerotil dry form, all applied at the rates of 1000 pounds per acre and mixed to a depth of six inches by rototilling, (4) Soiloam-40 gallons per acre, (5) Gypsum-4000 pounds per acre, and (6) All-N-One-2000 pounds per acre mixed to six inches by rototilling, (7) CMC-70-H-200 pounds per acre, (8) CRD-189-200 pounds per acre and (9) Aerotil wettable form-50 pounds per acre were applied to the surface and mixed to a depth of two inches, and (10) check plots receiving no conditioners.

At maturity the wheat was cut, bound, and shocked on the respective plots. After standing in the shock for ten days, the grain was threshed with a nursery thresher and the yields recorded.

Laboratory Analyses

Samples of Kirkland soil were treated with CRD-186 at the rates of 0, 100, 200, 400, 800, 1200, 1600, 2000, 2400, 2800, and 3200 pounds per acre. These mixtures were made by mixing air-dry soil and the conditioner (one pound portions) in an end over end mechanical mixer for 15 minutes. Seventy-five ml. of distilled water were then added and the samples were mixed for an additional 15 minutes. After the mixtures were air-dried, they were sieved through a one-fourth inch mesh sieve.

Soil samples were removed from the greenhouse oat pot cultures after the oats had been harvested. These soils were also sieved through a one-fourth inch mesh sieve after becoming air-dry. Soil samples from the surface six inches of the field plots were collected, air-dried, and sieved through a one-fourth inch mesh sieve.

Physical Determinations

In order to make calculations on an oven-dry basis, moisture percentages were determined as outlined by Baver (2) for all laboratory soil samples.

Sand, silt, and clay fractions of both the Kirkland and Renfrow soils were determined by the Bouyoucos Hydrometer method (6).

Hendrick and Mowry (12) found the moisture equivalent of Miami silt loam which contained 22.2 percent clay, 46.6 percent silt and 31.2 percent sand to be increased from 24.2 percent on the untreated samples to 27.6 percent on samples treated with CRD-186 at the rate of 0.1 percent. The moisture equivalent measurements were made to evaluate the effect of synthetic conditioners on the field capacity of the two soils used throughout this research. The determinations were made by the centrifuge method described by Briggs and McLane (8).

Duplicate 50 gram samples of the soils were used to determine the aggregate-size distribution. The Yoder technique (34) was used for the determination of the aggregates in the synthetic mixture of Kirkland soil and CRD-186. A modification of the Yoder technique was made in the aggregate analysis of the greenhouse pot soils and the soils from the field studies. Since Tiulin (28) suggests that only those aggregates larger than 0.25 mm. are responsible for stable soil structure, the 0.10 mm. screen was omitted in the aggregate analysis of the greenhouse oat pot and field plot soils.

A core sampler similar to the one described by Baver (2) was used to obtain core samples from twenty of the field plots. The cores were oven-dried for 60 hours, cooled to room temperature, weighed, and the volume weight calculated by the following formula:

$$\text{Volume Weight} \quad \frac{\text{Weight of Soil Core (grams)}}{\text{Volume of Core (c.c.)*}}$$

*Volume of Cores 347.32 c.c.

Quadruplicate determinations of the specific gravity or density of the untreated field plot soils were performed by means of the pycnometer method presented by Baver (2).

Total pore space, capillary pore space, and non-capillary pore space of the field plot soils were calculated, using the information obtained from the volume weight, specific gravity, and moisture equivalent determinations as outlined by Baver (2). The following formulas were used in making these calculations:

1. $\text{Total Pore Space} = \left(1 - \frac{\text{Volume Weight}}{\text{Specific Gravity}}\right) \times 100$

2. Capillary Pore Space = Moisture Equivalent X Volume Weight

3. Non-Capillary Pore Space = Total Pore Space - Capillary Pore Space

IV. RESULTS AND DISCUSSION

Greenhouse Studies

Wheat and Oat Pot Cultures

The objectives of these studies were to determine the effect of different rates of CRD-631 on the dry matter yields of wheat and oats grown on fertilized and unfertilized Kirkland soil pots.

Data from the wheat pot tests, presented in Table 1, indicate little or no increase in yields of dry matter due to the CRD-631 treatment. These results support those obtained by Murdock and Seay (20) in their greenhouse pot study.

The higher yields from the fertilized pots were attributed to the applied fertilizer. The outstanding yield of 31.88 grams of dry matter in one fertilized pot receiving no CRD-631 is completely out of line with the yields of the other fertilized pots. It was noticed throughout the growing period that the wheat in this pot tended to stool to a greater extent than that of any of the other pots in the experiment.

The oat pots were treated with CRD-631 at higher rates of active ingredients than the wheat pots. The results of this study, which are given in Table 2, show there may be an increase in yield of dry matter due to the conditioner. Indications are that CRD-631 at the rate of 400 pounds of active ingredients on the unfertilized soil is equivalent in the production of dry matter to the fertilized soil which did not receive any CRD-631. Both unfertilized and fertilized pots gave fairly uniform increases in yields when treated with CRD-631 up to rates of 400

Table 1. Dry matter yields (grams per pot) of wheat from CRD-631 treated, unfertilized and fertilized soil pots.

Repl. No.	Unfertilized							Fertilized *						
	CRD-631 in Lbs. Per Acre							CRD-631 in Lbs. Per Acre						
	0	100	200	400	800	1600	3200	0	100	200	400	800	1600	3200
1	17.40	17.01	17.50	18.66	15.20	16.19	19.20	31.88	19.60	21.98	20.20	20.02	19.00	20.19
2	16.91	18.01	20.22	18.76	18.53	19.94	17.83	16.49	19.34	18.92	19.29	17.26	20.09	23.16
Average	17.22	17.51	18.86	18.71	16.87	18.07	18.52	24.18	19.47	20.45	19.75	18.64	19.55	21.68

* Fertilized at the rate of 100 lbs. NH_4NO_3 and 150 lbs. superphosphate per acre.

Table 2. Dry matter yields (grams per pot) of oats from CRD-631 treated, unfertilized and fertilized soil pots.

	Unfertilized							Fertilized *						
	CRD-631 in Lbs. Per Acre of Active Ingredients							CRD-631 in Lbs. of Active Ingredients						
Repl. No.	0	100	200	400	800	1600	3200	0	100	200	400	800	1600	3200
1	4.19	3.42	3.39	4.81	5.20	2.01	5.21	5.51	7.02	6.79	8.49	4.69	4.05	6.30
2	3.06	3.70	3.74	5.92	3.72	5.15	4.27	7.83	5.66	5.89	8.03	8.10	6.74	3.71
3	3.47	4.76	6.01	5.71	3.24	6.65	3.80	3.15	5.44	6.38	4.47	6.19	4.84	5.50
Average	3.57	3.96	4.38	5.48	4.05	4.60	4.43	5.50	6.04	6.35	7.00	6.33	5.21	5.17

* Fertilized at the rate of 100 Lbs. $NH_4 NO_3$ and 150 Lbs. superphosphate per acre.

pounds of active ingredients per acre and decreased yields as the rates of conditioner were increased above 400 pounds of active ingredients per acre.

Emergence Tests

Rains soon after planting tend to form a surface crust on many soils which prevents emergence of some plants and often causes many crops to be unprofitable due to the added expense of re-planting. Since Kirkland soil tends to crust, it was used to determine the effect of Aerotil dry and wettable forms in preventing surface crusts.

The data obtained from the greenhouse emergence tests of cotton are shown in Table 3. The number of plants which emerged in frame 10 of the first series was 29 as compared to the average of 37 in the checks. This would represent a difference of 16 percent since 50 cottonseeds were planted per frame. Due to this low percentage of emergence in frame 10, which was treated with Aerotil wettable form at a rate equivalent to 200 pounds of Aerotil dry form, the emergence tests were repeated using the same frames of soil without further treatment. Similar results were obtained in the second series except there was increase in emergence and the reduction in the number of plants found in frame 10 as compared to the average of the two check frames was less pronounced. Still this difference amounted to seven percent.

This decrease in emergence indicates that Aerotil wettable form used at the equivalent rate of 200 pounds per acre may hinder germination of certain seeds. The conditioner may form an impermeable coat on the seed, thereby excluding oxygen which is necessary for seed germination. If this is true, the increased emergence in frame 10 of the second series

Table 3. The effect of Aerotil dry form and Aerotil wettable form on the emergence of cotton.

	Number of cotton plants emerged (10 days after planting)									
	Aerotil dry form *					Aerotil wettable form **				
Lbs. Per Acre	Frame No.	1st Series	Frame No.	2nd Series	Ave.	Frame No.	1st Series	Frame No.	2nd Series	Ave.
0	1	36	1	41	38.5	6	38	6	38	38.0
25	2	37	2	41	39.0	7	40	7	48	44.0
50	3	35	3	39	37.0	8	40	8	42	41.0
100	4	34	4	43	38.5	9	36	9	39	37.5
200	5	39	5	41	40.0	10	29	10	36	32.5

* Aerotil dry form applied at rates of the 40% material.

** 83% Aerotil wettable form applied at rates equivalent to Aerotil dry form.

could have been due to the conditioner combining with the soil particles to a greater extent than in the first series.

Although 200 pounds per acre (equivalent rate) of Aerotil wettable form may have an undesirable effect on germination, it appeared to be the most effective in preventing surface crusts. The effectiveness of this treatment is clearly demonstrated in Figure 1. Aerotil dry form applied at the rate of 200 pounds per acre, shown in Figure 2, appears to be approximately equal to 100 pounds per acre (equivalent rate) of Aerotil wettable form depicted in Figure 3. Little difference between other rates of Aerotil wettable and dry forms could be detected. Figure 4 illustrates that Aerotil dry form at the rate of 100 pounds per acre had comparatively little effect on preventing surface crust on the Kirkland silt loam soil.

Root Penetration Observations

"Plow pans" have developed in many of the wheatland soils of western Oklahoma where the "one-way" has been used year after year as the main tillage implement for seedbed preparations. Root penetration of cotton and wheat plants were used to determine the effect of Aerotil dry and wettable forms on simulated "plow pans".

The only treatment in this study which seemed to give any marked results in root penetrations of these simulated "plow pans" was Aerotil wettable form applied at the rate equivalent to 1000 pounds per acre of Aerotil dry form to the surface four inches of soil plus an additional 1000 pounds being applied directly on top of the "pan". This treatment allowed the penetration of both the tap roots of cotton and the fibrous

Fig.1. Cotton emergence tests using soil treated with Aerotil wettable form (80 lbs./A. active ingredients).

Fig. 2. Cotton emergence tests using soil treated with Aerotil dry form (80 lbs./A. active ingredients).

Fig. 3. Cotton emergence tests using soil treated with Aerotil wettable form (40 lbs./A. active ingredients).

Fig. 4. Cotton emergence tests using soils treated with Aerotil dry form (40 lbs./A. active ingredients).

roots of wheat. In Figure 5, the roots in the untreated box extend laterally along the upper surface of the pan, whereas in the Aerotil (wettable form) treated box, shown in Figure 6, the roots grew vertically directly beneath the pan. In some instances, a large number of roots were found below the pan, but in every case, except for the treatment mentioned above, it was found that these roots penetrated the pan at points where it had cracked due to drying or along the sides of the box.

Field Studies

Yields of wheat from the field plots are presented in Table 4. The weights in pounds per plot were converted to bushels per acre and recorded.

Statistical analysis of these yields shows there is a significant difference in the yields of the various treatments. Plots treated with All-N-One produced yields that are higher than the yields of the other plots. The least significant difference indicates that this treatment will give higher yields than any of the other treatments. The average yield of 24.55 bushels per acre for the plots receiving this treatment is outstanding when compared to the average yields of all other plots. Since All-N-One has a 3-2-3 guaranteed fertilizer analysis, it is believed that the increased yields of wheat on plots receiving this treatment was due to the effect of the nitrogen supplied by this material rather than to any physical changes in the soil.

Plots treated with CRD-186 gave approximately the same yields as the plots treated with Aerotil dry form. These plots gave the lowest

Fig. 5. Untreated simulated "plow pan".

Fig. 6. Simulated "plow pan" treated with Aerotil wettable form.

Table 4. The effect of soil conditioners on grain yields (bushels per acre) from the field plots.

Repl. No.	Conditioners, Methods of application, and Rates *									
	Rototilled 6-Inches Deep						Surface Application			
	O	K-6	C	A.D.	A.N.O.	G	S	A.W.	C-2	K-9
1	19.81	19.23	17.77	18.65	22.14	18.36	24.78	18.65	21.85	24.18
2	16.61	17.48	18.65	17.19	24.48	19.52	20.99	18.94	22.44	18.07
3	19.23	15.43	19.52	17.48	26.22	23.31	19.52	19.81	18.07	16.32
4	17.77	18.65	16.90	18.07	25.35	22.14	18.07	16.32	18.36	18.36
Ave.	18.35	17.70	18.21	17.85	24.55	20.83	20.84	18.43	20.18	19.23

* Conditioners and rates per acre.

O Untreated
K-6 CRD-186, 1000 lbs.
C CMC-70-H, 1000 lbs.
A.D. Aerotil-dry form, 1000 lbs.
A.N.O. All-N-One, 2000 lbs.
G Gypsum, 4000 lbs.
S Soiloam, 40 gallons
A.W. Aerotil-wettable form, 50 lbs.
C-2 CMC-70-H, 200 lbs.
K-9 CRD-189, 200 lbs.

Analysis of Variance

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	
Total	39	285.26	......	
Treatments	9	158.18	17.576	
Error	30	127.08	4.236	F = 4.149

LSD (.05) = 2.97

average yields in the experiment. The yields were about the same on the check plots, those plots with surface application of conditioners, CMC-70-H at 1000 pounds per acre and gypsum at the rate of 4000 pounds per acre. The difference in the average yields of these plots was from 18.21 to 20.84 bushels per acre, a range of only 2.63 bushels.

Laboratory Analyses

The percentage of moisture in all soil samples used in the laboratory studies was determined by oven drying the soil at 105° C. for 16 hours. These moisture values were used to calculate the weight of soil on the oven-dry basis where applicable throughout the laboratory determinations.

Organic matter content and pH of the Kirkland and Renfrow soils differed only slightly. The Kirkland soil contained 1.84 percent organic matter and had a pH value of 5.7, whereas the Renfrow soil had a pH value of 5.5 and contained 1.82 percent organic matter.

Physical Determinations

Mechanical Analysis

Mechanical analyses by the Bouyoucos Hydrometer method (6) were made of both soils. The Kirkland soil contained 24.25 percent sand, 52.25 percent silt, and 23.50 percent clay which made this soil a silt loam in texture. The Renfrow soil was a loam with 34.25 percent sand, 43.75 percent silt and 22.00 percent clay. Since there was only 10.00 percent difference between the total of the silt and clay fractions of these two soils, they were expected to show similar responses to soil conditioners.

Aggregation Studies

Synthetic Mixture

Size distribution of water-stable aggregates resulting from the treating of Kirkland silt loam soil with varying rates of CRD-186 are shown in Table 5. All percentages of water-stable aggregates were determined from duplicate 50 gram air-dry samples calculated on an oven-dry basis.

From these results it appears that most of the silt and clay particles have become clustered into aggregates 0.10 mm. or larger when CRD-186 is applied at rates ranging between 1200 and 1600 pounds per acre. The percentage of aggregates of 0.10 to 0.25 mm. size increased steadily upward as the rate of conditioner increased to 1600 pounds per acre; above this point the amount of aggregates of this size decreased.

The greatest increase in total aggregates occured between the treatments of 800 and 1200 pounds of CRD-186 per acre. The 800 pounds per acre application produced aggregates of sizes that increased from the larger to the smaller sizes in a step-wise manner. The 1200 pounds per acre treatment caused an increase in the percentage of the larger size aggregates, but only increased the amount of smaller aggregates slightly. Since aggregates of the 1600 pounds per acre rate follow the same trends as the 1200-pound rate, indications are that CRD-186 applied on Kirkland silt loam at rates ranging between 800 and 1200 pounds per acre would probably give the most satisfactory improvement in aggregation.

Table 5. Size distribution of water-stable aggregates found in synthetic mixtures of CRD-186 and Kirkland silt loam.

Rates of CRD-186 in Lbs. Per Acre	Percent Water-Stable Aggregates *						
	> 2.0 mm.	2.0-1.0 mm.	1.0-0.5 mm.	0.5-0.25 mm.	0.25-0.10 mm.	Total >0.10 mm.	Increase over untreated
0	0.07	0.96	3.21	5.30	10.69	20.23	----
100	0.07	1.12	3.33	6.16	11.48	22.16	1.93
200	0.13	2.76	3.97	6.92	11.68	27.39	7.16
400	0.68	3.56	4.56	7.18	11.88	27.86	7.63
800	0.76	4.31	7.88	9.17	11.92	34.04	13.81
1200	1.39	8.68	14.15	10.87	12.63	47.72	27.49
1600	1.56	8.43	19.20	10.25	13.86	53.30	33.07
2000	1.83	7.90	16.96	12.44	12.02	51.15	30.92
2400	3.12	8.28	15.16	13.41	10.82	48.79	30.56
2800	4.41	11.36	17.47	14.90	7.24	55.38	35.15
3200	8.78	15.57	18.58	11.26	5.82	60.01	39.78

* Percent water-stable aggregates are averages of closely agreeing duplicates.

Oat Pot Soil

After the plants had been harvested, representative samples of the greenhouse oat pot soils were made by combining smaller samples from each of the six replications receiving the same CRD-631 treatment. Size distribution of water-stable aggregates were determined on these samples by a slight modification of the method used for the synthetic mixtures. Since it has been stated that only those aggregates greater than 0.25 mm. contribute to the improvement of the physical condition of the soil, the 0.10 mm. size sieve was omitted in these determinations.

Distribution of water-stable aggregate sizes found in the CRD-631 treated oat pot cultures is shown in Table 6. Although the percentages of water-stable aggregates are much higher in this study than those found in the synthetic mixtures, the size distribution of water-stable aggregates tend to follow much the same pattern. The higher percentages of water-stable aggregates in the oat pot soil are believed to be due to wetting and drying which occured during the growing period of the oats, and gave a greater degree of aggregation as well as a more complete reaction between the conditioner and the soil. At first the higher percentage of water-stable aggregates was thought to be due to an increase in organic matter, but organic matter determinations showed no appreciable difference in the amounts in the oat pot soils and in the synthetically mixed soil.

The greatest increase in total aggregates occured between the 100 pounds per acre application of CRD-631 and the untreated soil. The next greatest increase occured between the 100 and 200 pounds per acre treatments, which amounted to 10.34 percent. The difference in total aggre-

Table 6. Distribution of water-stable aggregate sizes in CRD-631 treated oat pot cultures.

Rates in Lbs. Per Acre *	Percent Water-Stable Aggregates**					
	>2.0 mm.	2.0-1.0 mm.	1.0-0.5 mm.	0.5-0.25 mm.	Total>0.25 mm.	Increase over untreated
0	2.50	3.71	6.14	6.53	18.88	----
100	5.32	6.45	9.86	8.48	30.11	11.23
200	7.68	9.02	11.64	12.11	40.45	21.57
400	8.72	10.93	15.31	12.86	47.82	28.94
800	10.93	11.44	15.54	13.25	51.15	32.27
1600	13.83	13.93	19.41	10.91	58.08	39.20
3200	12.67	15.39	19.91	10.82	58.79	39.91

* CRD-631 rates were in lbs. per acre of active ingredients.
** Percent water-stable aggregates are averages of closely agreeing duplicates.

gates between the 200 and 400-pound applications was a further increase of 7.37 percent. Since the 400-pound treatment produced the largest yield of oats, it would probably give the most beneficial results on Kirkland silt loam soil in the field and certainly would be the most practical.

Field Plot Soil

Determinations of the percentage distribution of water-stable aggregates were made on the field plot soil by the same procedure used on the oat pot soil. Results of these analyses are found in Table 7.

The 1000 pounds per acre CRD-186 and the 200 pounds CRD-189 treatments were much more effective in aggregating the Renfrow loam soil than any of the other materials used. Both of these treatments gave a fairly uniform percentage distribution of aggregates from 0.25 mm. to above 2.0 mm. in size. Since the lowest yields of wheat were obtained from the CRD-6 treated plots and these plots stand out above all other treatments in the total percent of aggregates greater than 0.25 mm., indications are that there may be some negative correlation between the two. Aerotil dry form ranked third in effectiveness of aggregating the Renfrow soil. CMC-70-H at the rate of 1000 pounds per acre was fourth followed by All-N-One. Gypsum, Soiloam, Aerotil wettable form, and CMC-70-H at 200 pounds per acre gave about the same results, with Soiloam giving the smallest total percentage of aggregates greater than 0.25 mm. for the treated plots. The untreated soil had an exceptionally low percentage of total

Table 7. Size distribution of water-stable aggregates in the field plots treated with different soil conditioners.

Conditioner	Rate-lbs. Per Acre	Method of Application	Percent Water-Stable Aggregates *					
			>2.0 mm.	2.0-1.0 mm.	1.0-0.05 mm.	0.5-0.25 mm.	Total>0.25 mm.	Increase over untreated
Untreated	----	----------	0.19	1.21	1.25	2.07	2.65	-----
CRD-186	1000	Rototilled 6-inches	7.52	5.71	7.34	6.15	26.72	24.07
CMC-70-H	1000	"	1.11	1.55	2.36	4.09	9.11	6.46
Aerotil-dry form	1000	"	2.12	1.86	2.62	2.99	9.59	6.94
All-N-One	2000	"	1.79	1.89	1.55	2.40	7.63	4.98
Gypsum	4000	Surface	1.46	1.13	1.89	2.55	7.03	4.38
Soiloam	40**	"	0.55	1.58	1.34	2.14	5.61	2.96
Aerotil wettable form	50	"	0.49	1.53	1.50	2.22	5.74	3.09
CMC-70-H	200	"	0.26	1.31	1.72	2.44	5.73	3.08
CRD-189	200	"	4.28	3.47	5.19	5.58	18.52	15.87

* Percent water-stable aggregates are averages of closely agreeing duplicates.
** Rate in case of Soiloam is in gallons of 16% active ingredients per acre.

aggregates greater than 0.25 mm. (2.65 percent). The range in total percentage of aggregates greater than 0.25 mm. found in the untreated soil and the best treatment, CRD-186, was 24.07.

Moisture Equivalent

Since there are conflicting results reported in the literature concerning the effect of soil conditioners on the moisture equivalent percentages of soils, these determinations were made on these two soils with their various treatments. The average moisture equivalent values of CRD-186 and CRD-631 treated Kirkland soils are presented in Table 8. The moisture equivalent measurements of the Renfrow loam field plots treated with various conditioners are given in Table 9.

These data confirm the results obtained by Peters, et al. (22). None of the soil conditioners used in this research appreciably increased the moisture equivalent percentage of either Kirkland silt loam or Renfrow loam soils. There seems to be a tendency for CRD-631 at rates between 1600 and 3200 pounds per acre to decrease the moisture equivalent value of Kirkland silt loam. CRD-186 at the rate of 1000 pounds per acre also decreased the moisture equivalent of Renfrow loam. These results are not in complete accord with those secured from the synthetic mixtures which showed a slight increase of the moisture equivalent value when CRD-186 was applied at higher rates. It is probable that the procedure of mixing, wetting, and drying of these synthetic mixtures did not provide conditions favorable for complete aggregation of the soil particles. This assumption is supported by the lower total percentage of water-stable aggregates obtained in the determinations previously discussed.

Table 8. The effect of CRD-631 on the moisture equivalent values of Kirkland silt loam.

Rate in Lbs. Per Acre	Percentage Moisture Equivalent	
	CRD-186 Synthetic Soil Mixture	CRD-631 * Greenhouse Oat Pot Soil
0	19.22	17.63
100	18.70	17.58
200	18.48	17.50
400	18.78	18.19
800	18.89	17.74
1200	18.95	-----
1600	19.21	17.20
2000	19.24	-----
2400	19.28	-----
2800	19.29	-----
3200	19.44	16.99

* CRD-631 treatments applied at rates of active ingredients.

Table 9. The effect of different conditioners on the moisture equivalent, volume weight, total pore space, capillary pore space and non-capillary pore space in the field plots.

Conditioner	Rate in Lbs. per Acre	Method of Application	Moisture * Equivalent	Volume * Weight	Total ** Pore Space	Capillary ** Pore Space	Non-Capillary ** Pore Space
Untreated	——	——	14.67	1.45	42.23	21.28	20.95
CRD-186	1000	Rototilled 6-inches	13.29	1.33	47.01	17.68	29.33
CMC-70-H	1000	"	15.24	1.38	45.02	20.03	24.99
Aerotil dry form	1000	"	14.46	1.36	45.82	19.66	26.16
All-N-One	2000	"	14.02	1.38	45.02	19.36	25.66
Gypsum	4000	"	14.96	1.42	43.42	21.25	22.17
Soiloam	40 ***	Surface	14.69	1.42	43.42	20.87	22.55
Aerotil wettable form	50	"	14.77	1.40	44.23	20.68	23.55
CMC-70-H	200	"	14.95	1.39	44.62	20.78	23.84
CRD-189	200	"	14.34	1.36	45.82	19.50	26.32

* All moisture equivalent and volume weight determinations are averages of closely agreeing duplicates.

** Calculates values.

*** Rate in case of Soiloam is in gallons of 16% active ingredients per acre.

Volume Weight, Specific Gravity, and Porosity

Volume weight determinations of Renfrow loam soil receiving different conditioner treatments were made from cores taken from twenty of the wheat field plots. This gave duplicate determinations of each treatment.

Specific gravity determinations were made in quadruplicate using soil taken from the untreated field plots. These determinations were 2.51, 2.52, 2.51, and 2.50 grams per c.c. which gave an average of 2.51 grams per c.c.

Table 9 presents the condensed data of the moisture equivalent, volume weight, and the calculated porosity values of the field plots. All conditioners lowered the volume weight, increased the total pore space, and reduced the capillary pore space of the Renfrow soil. CRD-186 at 1000 pounds per acre produced the greatest changes in these values, followed by the surface application of CRD-189 at the rate of 200 pounds per acre, Aerotil dry form at 1000 pounds per acre, All-N-One at 2000 pounds per acre and CMC-70-H at 1000 pounds per acre. Small differences of these values were found in the treatments of Soiloam, Aerotil wettable form, CMC-70-H at 200 pounds per acre, and the 4000-pound application of gypsum.

From the results of these measurements of the physical properties of the soil and the yields of wheat, indications are that the untreated Renfrow loam soil is in fairly good physical condition and crops should respond more to fertilization of this soil than to any changes in the physical condition imposed by synthetic soil conditioners.

V. SUMMARY AND CONCLUSIONS

The effect of soil conditioners on the yields and physical properties of Kirkland silt loam and Renfrow loam soils was studied. These experiments were carried on in the greenhouse and in the field. Conditioners were applied at rates varying from 100 to 3200 pounds per acre.

Dry matter yields from the greenhouse pots and grain yields from the field plots were obtained. Root penetration observations and emergence tests were also conducted in the greenhouse. Aggregate analyses, moisture equivalent, and volume weight measurements were used to evaluate the physical condition of the soils.

From the results obtained in the foregoing investigations, the following conclusions seem justifiable:

1. CRD-631 treatments up to 400 pounds of active ingredients per acre increased dry matter yields of oats grown on Kirkland soil pots.

2. Aerotil wettable form used at the rate of 80 pounds of active ingredients per acre reduced seedling emergence, but was the most effective treatment in preventing surface crusts on Kirkland soil.

3. Aerotil wettable form applied directly on top of a simulated "plow pan" at the rate equivalent to 1000 pounds of Aerotil dry form per acre plus additional 1000 pounds per acre mixed with the surface four inches permitted the greatest amount of root penetration through a simulated "plow pan".

4. A single wetting and drying cycle of a synthetic mixture of CRD-186 amd Kirkland silt loam produced less water-stable aggregates than the greenhouse oat pot soil treated with equivalent rates of

CRD-631.

5. Only CRD-186 applied at the rate of 1000 pounds per acre (rototilled to a depth of six inches) and a surface application of 200 pounds per acre of CRD-189 gave any appreciable increase in percentage of water-stable aggregates greater than 0.25 mm. on the Renfrow loam field plots.

6. Moisture equivalent values of the soils showed no appreciable effect from the different soil conditioners.

7. All the conditioners lowered the volume weight, increased the total pore space, and increased the non-capillary pore space of the Renfrow loam soil.

8. These studies seem to indicate that the Renfrow loam soil is in fairly good physical condition and that the physical nature of the Kirkland silt loam may be improved through the use of soil conditioners.

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VITA

J. C. True
candidate for the degree of
Master of Science

Thesis: EFFECT OF SOIL CONDITIONERS ON CROP YIELDS AND PHYSICAL PROPERTIES OF TWO OKLAHOMA SOILS

Major: Soils

Biographical and Other Items:

Born: November 19, 1918 at Rives, Tennessee

Undergraduate Study: Sunflower Jr. College, Moorhead, Mississippi, 1938-1939; University of Tennessee, Martin Branch, Martin, Tennessee, 1950-1951; Oklahoma A. and M. College, Stillwater, Oklahoma, 1951-1953

Graduate Study: Oklahoma A. and M. College, 1953

Experiences: Farm reared; U.S. Army Air Corps, 1942-1945; Asst. Voc. Agri. Teacher, Obion County Board of Education, Union City, Tennessee, 1947-1950.

Member of Agronomy Club, Masonic Club, and The Order of the Red Red Rose.

Date of Final Examination: July, 1953

THESIS TITLE: EFFECT OF SOIL CONDITIONERS ON CROP YIELDS AND PHYSICAL PROPERTIES OF TWO OKLAHOMA SOILS

AUTHOR: J. C. True

THESIS ADVISER: Dr. Robert M. Reed

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TYPIST: Mary Lillian True