THE EFFECT OF CERTAIN WETTING AGENTS ON THE WATER INTAKE AND ERODIBILITY OF SOILS

by

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INTRODUCTION

An important correlation which is often overlooked is the one between soil erosion and soil moisture conservation. Just consideration of the causes and effects of soil erosion by runoff water leads to the conclusion that any treatment which reduces erosion tends simultaneously to increase the amount of moisture retained.

The problem of preventing or decreasing erosion has been customarily approached from the viewpoint of controlling runoff and remedies have been based on changing the exposed surface of the soil. This approach has led to the development of such measures as terracing, contouring and the use of cover crops and mulches. Although effective, such measures are not always applicable nor feasible.

The object of this study was to investigate the effect certain changes within the soil would have on erosion. If it is possible to increase the water absorption of soils during periods of rainfall, more water will be available for plant growth and erosion losses will be reduced. In order to increase the normal water intake of soils it is supposed that some physical changes must be made within the soil. Such changes may be introduced by certain chemical reagents and can certainly be brought about by adding organic matter to the soil. A search of the literature did not reveal any previous investigations of the effect of chemical reagents in reducing soil erosion. Reagents which lower the surface tension of water were selected for study.

In testing the hypothesis that the physical characteristics of soils could be changed by treatment with chemical reagents, products known commercially as "wetting agents" were used. These materials are similar to soaps in that they markedly lower the surface tension of water, but they differ from soaps by their greater efficiency in hard water. This is due to the greater solubility of their calcium and magnesium salts. In addition, many wetting agents are neutral salts, functioning equally well in acid or alkaline solutions. Structurally, these reagents are similar to ordinary soaps. They are often prepared from the same fats by reduction to the alcohol followed by conversion to the sulfonic acid and thence to the sodium salt of the sulfonic acid. These compounds possess the necessary structural form for satisfactory detergent action: (1) a long carbon (non-polar) chain and (2) a strongly polar group at the end of the molecule. Theoretically such reagents should increase the wettability of the soil, particularly when it is in a dry powdery condition. They might also be expected to increase the permeability of the soil to water because of lowered surface tension.

The wetting agents used in the course of this study are designated as A-240, A-375, and S-3. (Table 1 - appendix).

In the field investigations of this problem two other types of material were tested. Both of these are chemically inert, but because of their own physical properties they would be expected to alter those of the soil. The first is a finely divided micaceous mineral sold commercially and recommended for its high porosity and water retention. This material is designated as M-1. The second is exploded wood fiber of the type employed to make wall board. This material, designated as M-2, is very porous and when mixed with the soil should act like a sponge, greatly increasing the amount of water retained. (Table 1 - appendix).

LABORATORY INVESTIGATIONS

Preliminary qualitative tests indicated that the wetting agents do speed the wetting of certain soils when in the air-dry condition, particularly those with a high organic matter content. Almost all soil samples were found to sink immediately when placed on a dilute solution of A-240, but many floated for several minutes on a water surface. Several soil samples allowed 10 or 12 drops of water to roll off an inclined surface, but when previously treated with the reagent the first drop entered the soil. In order to obtain quantitative data concerning the action of the wetting agents three experimental procedures were followed. The rate of capillary rise, percolation rate, and moisture retention were measured. In preparation for these tests a definite procedure was followed in treating the soil samples.

Preparation of Soil Samples: The material passing a 2 mm seive was thoroughly mixed and air-dried. Treatment of the soil samples consisted of thoroughly mixing 150 ml of 0.1% solution of the wetting agent with 1000 grams of soil, allowing the water to evaporate, and again passing the soil material through a 2 mm seive. The untreated check soil sample had exactly the same physical treatment using 150 ml of water.

Capillary Rise: This was measured by the time required to wet 25 grams of loose soil packed in a tube of 23 mm inside diameter. The wetting agent increased the rate of capillary rise in only two of the seven soil samples tested, a sand and a sandy loam. The treatment decreased the rise in the other soils. (Table 1).

Percolation Rate: The rate of percolation of water through the soil was determined by placing 50 grams of loose soil in a tube of 23 mm inside diameter. After the soil was saturated, a constant hydraulic head was

Table 1. Laboratory studies of seven prepared soil samples.

Prepared Soil Sample		Rate of Capillary Rise in Minutes (Average of 4)	Rate of Percolation in Milliliters per hour (Average of 2)	Moisture Retention in Per Cent (Average of 2)
1. Sandy (Berrien)	Untreated	4.5	165.0	18.4
	Treated	1.1	127.5	14.2
2. Sandy loam (Hillsdale)	Untreated	10.8	11.8	21.2
	Treated	7.3	29.4	21.9
3. Sandy loam (Fox)	Untreated	5.4	7.9	11.0
	Treated	14.9	3.3	10.7
4. Loam (Acid)	Untreated	24.0	4.8	37.4
	Treated	34.0	3.3	36.9
5. Loam (Napanee)	Untreated	13.0	6.5	25.1
	Treated	30.0	4.4	29.0
6. Silt Loam (Miami)	Untreated	10.8	9.8	22.3
	Treated	15.5	5.2	21.8
7. Clay Loam (Warsaw)	Untreated	7.1	9.8	20.3
	Treated	10.5	24.2	20.6

maintained over each sample and the amount of percolate measured. Wetting agents increased the rate of percolation in two of the seven soils, a sandy loam and a clay loam. In another sandy loam the percolation was markedly decreased by the treatment. The remaining soils also showed a tendency toward slower percolation after treatment. (Table 1).

Moisture retention: Comparable values of moisture retention were measured by the suction method of Bouyoucos (2). The detergents affected this value in only two cases. The power of moisture retention of the sand was decreased by treatment, whereas treatment increased this power in one of the loam soils.

Replicated permeability experiment: The apparatus used in this experiment consists of ten 9 inch glass tubes, 35 mm inside diameter mounted in a single trough to insure a constant hydraulic head. 150 grams of loose air-dry soil was placed in each tube, the soil saturated by capillary action and 22.5 ml of 0.1% A-240 solution added as the treatment. To the check tubes an equal amount of water was added. The tubes were allowed to drain for a period of one hour, then the tubes and trough were filled with distilled water. With this apparatus the percolate from ten tubes was measured simultaneously, consequently the values obtained from each trial run are strictly comparable as to elapsed time as well as treatment. The treatments were randomized and compared for significant difference by the technique of analysis of variance. A number of trials were made on each set of soil samples placed in the tube. The soil samples studied were taken from locations of the field plot experiments.

The permeability of some of these soil samples to water was increased by the addition of the wetting agent. In none of the samples tested did the treatment decrease significantly the permeability. Generally, the treatment was most effective during the first few trials on the

Table 2. Results of replicated permeability experiment.

Soil Samples	Total milliliters* of percolate Untreated	Treated	F calc.**	F 1%
Location I Subsurface Soil 18 Trials	16,508	16,418		
Location I Subsurface Soil First 7 trials of 18	5,736	6,569	129.0	13.7
Location II Surface Soil 13 Trials	4,978	3,875	4.24	9.33
Location II Subsurface Soil 15 Trials	4,565	7,287	98.05	8.86

*This includes the sum of the five replications in each trial.

**The F value was calculated using the average of the five replications of each trial. There is a significant difference between treated and untreated when F calc. is greater than F 1%.

sample and as more water passed through the effectiveness decreased. (Table 2) This decrease in permeability may be attributed to one of two possible causes. The first is the removal of the wetting agent by leaching from the soil. Such an action would result in an increase in the surface tension of the water solution and a decrease in the apparent permeability of the soil. The second possible cause is the dispersion of the soil particles by the reagent. It is conceivable that with the light textured soil samples tested, dispersion of the colloidal material and subsequent clogging of the capillary drainage pores would not be apparent until a considerable amount of water had passed through the soil and rearranged the particles.

Conclusion: The laboratory studies have shown that the treatment of soil samples with wetting agent solution does affect properties of the soil concerned with water relationships. However, the results are not consistent for all classes of soils tested.

Two effects of the treatment with the wetting agents have been demonstrated. In certain instances the rate of water intake has been increased by the lowered surface tension of the water. On the other hand, the permeability of some soil samples has been decreased, particularly after considerable percolation has taken place. Whether this is a result of leaching of the detergent from the soil or of dispersion of the soil particles can only be determined by comparison with the check samples. If the wetting agent should decrease the permeability considerably below that of the check samples, then dispersion of the soil must certainly have occurred.

Because the laboratory results indicated the possibility of increasing the permeability of light textured soils this type was selected for further study. The difficulty in applying laboratory results on soil samples to field soils, made it necessary to establish field experiments to test the effect of the reagents under natural soil conditions.

FIELD INVESTIGATIONS

In order to study this problem in the field three sets of erosion plots were established. The data from two seasons were obtained on two sets and from one season on the other set.

Description of field plot location: The first set of plots (Location I) was located in a steeply sloping area of Hillsdale sandy loam, light phase. This adjoined an area of Berrien loamy sand, which may very likely have contributed coarser particles to the surface by wind action. (7). The slope was greater than that usually cultivated under normal agricultural practices but was selected because it represented extreme conditions. The surface soil plots were carefully laid out on a gradient of 23%, while to get uniform subsoil plots it was necessary to construct them on a 25% gradient because of slope variations.

The second set of plots (Location II) was located in an area of Miami loam (7) which on this slope graded into a sandy loam texture. There was considerable evidence of previous erosion as the area had been cultivated. The gradient was not as steep as Location I, being only about 20%.

The third set of plots (Location III) was located in an area of Hillsdale sandy loam (7) which had been broken for the first time during the fall preceeding the layout of the plots. The land had been protected through the winter by a rye cover crop and showed only slight evidences of erosion. The gradient of the plots was 9.3% and is representative of the type of slope frequently encountered by Michigan farmers.

The mechanical analysis of the soils in the three locations as determined by the hydrometer method (4, 6) is shown in Table 3.

Experimental procedure in establishment of field plots.

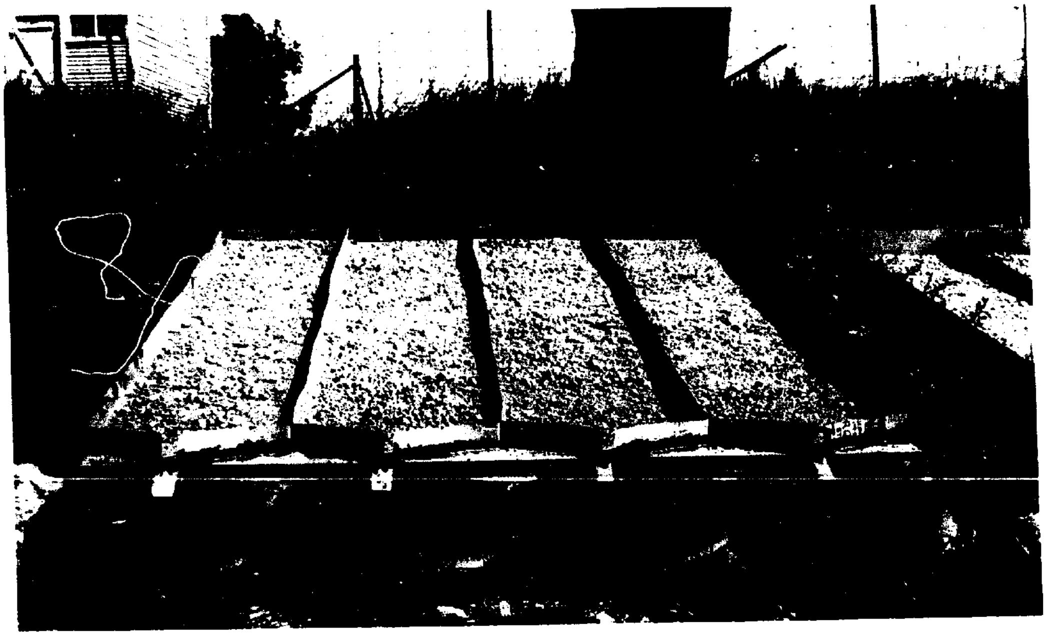
Location I. Four plots were constructed on the existing surface soil, and four on the subsurface soil. The term subsurface soil as employed here indicates that the top four inches of surface soil has been removed. This would be comparable to the condition after heavy erosion losses had occurred. Each individual plot was two feet wide by ten feet long, enclosed on each side and at the top by galvanized iron strips six inches in width, placed edgewise into the soil to a depth of three inches. At the foot of each set of plots a two by six inch plank was placed in the soil flush with the surface above it. Sheet metal strips were driven into the soil on the upper side of the plank to prevent seepage of water underneath. By bending the ends of the side strips towards the center of the plots provision was made to concentrate the runoff water flow as it crossed the plank. Metal troughs fastened to the edge of the plank conveyed the water directly to the catch basins. Fifty gallon oil drums cut in the center furnished 25 gallon open top containers. These were placed in a trench at the foot of each plot with their top edges against the edge of the embedded plank. Sheet metal covers prevented rain from falling directly into the catch basins or conducting troughs. See Plate 1.

Table 3. Mechanical analysis of erosion plot soils.*

		Location I		Location II		Location III	
Texture	Size Limits (millimeters)	Surface Soil	Subsoil	Surface Soil	Subsoil	Surface Soil	Subsoil
Sand	2.00 - 0.05	71.2	78.3	57.1	64.5	56.9	55.2
Coarse Silt	0.05 - 0.02	8.1	5.2	14.0	12.5	9.9	11.5
Silt	0.02 - 0.005	10.0	9.1	12.6	10.8	16.8	16.0
Fine Silt	0.005 - 0.002	6.5	4.3	5.7	4.7	6.2	6.8
Clay	Less than 0.002	4.2	3.1	10.6	7.5	10.2	10.5
Soil Class		Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam

*These analyses were made by the hydrometer method.

Plate 1



Surface Soil Erosion Plots   Location I

Plate 2

Subsurface Soil Erosion Plots   Location II

A rain gauge of the type approved by the U.S. Weather Bureau was placed with each set of plots to measure the amount of total rainfall. The intensity of the rain was not measured since this investigation was not concerned with the effect of intensity on the amount of erosion. For all the plots at a given location the intensity is the same and therefore the results are comparable.

The amount of treatment added was calculated on the basis of the amount of soil in the top three inches. The rate of application was the same as used in the laboratory experiments. With an average volume weight of 1.5 for this sandy loam soil the weight of the top three inches was calculated to be slightly less than 215 kilograms. On the basis of 150 milliliters of solution per kilogram of soil, 32 liters of 0.1% A-240 was applied to two surface soil plots. A like amount of 0.1% A-375 was applied to two subsurface soil plots. The other four plots were left as checks and received 32 liters of water each. The liquid was applied by means of sprinkling cans to the soil which had been cultivated to a depth of three inches. Care was taken to apply it at such a rate that it did not run off the surface of the slope.

The treatment of the plots at this location was completed June 2, 1939. The data collected from the first three rains aggregating almost 2.50 inches were disregarded to allow the soil to reach equilibrium conditions after cultivation and treatment. The first results considered was taken June 30, 1939.

Location II. These plots were identical with those of Location I in size and shape as well as construction. Since this slope had suffered more severe erosion only three inches of the surface soil was removed in the construction of the subsurface soil plots. See Plate 2.

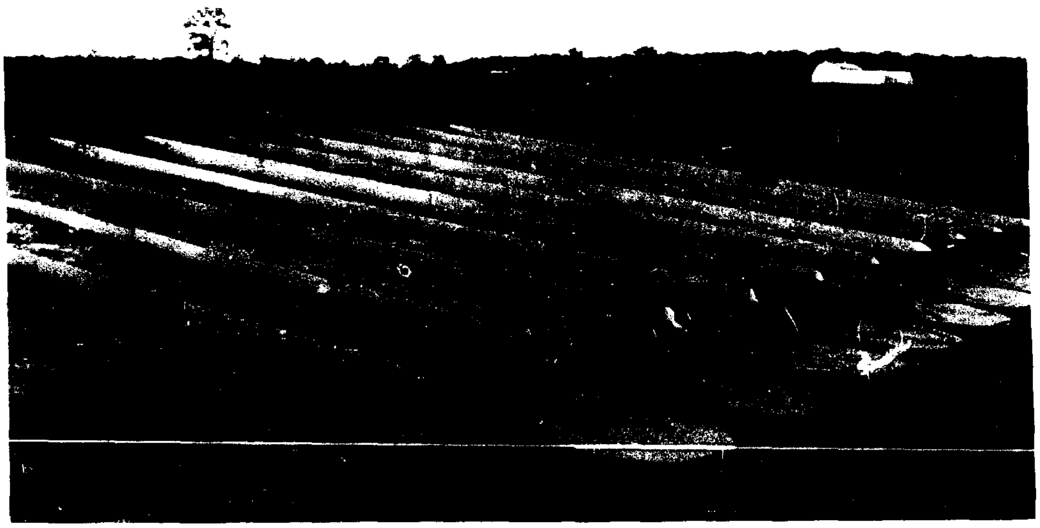
Treatment consisted of the application of 32 liters of 0.1% A-240 to two surface soil and two subsurface soil plots. The remaining four plots were left as checks. Treatment was completed by July 28, 1939, but no results were considered until September 5, 1939. During the time allowed to restore equilibrium in the soil, rainfall amounting to 1.00 inch fell on the plots.

Location III. These plots were constructed in the spring of 1940 to determine whether the wetting agents would be effective on more gentle slopes. Treatments with the materials M-1 and M-2 were also applied to test their efficiency in increasing the intake of precipitation and decreasing runoff. Each treatment was replicated three times and they were randomized within blocks in order that statistical analysis might be applied to the results. See Plate 6.

Construction of the plots was very similar to that of the previous locations with the exception that the plots were two feet wide by fifteen feet long with nine plots in each set. The sheet metal strips surrounding the plots were nine inches wide and buried in the soil to a depth of five inches. The catch basins were made to order with a capacity of 33 gallons. See Plates 3, 4 and 5.

To determine the effect of the various materials on the retention of water the resistance-absorption method was employed (3). Plaster of Paris absorption blocks were buried in each of the plots of Block 2 at depths of 3, 6, 9 and 12 inches. These were placed three feet down from the top of the plots midway between the sides. Continuous moisture curves were obtained by measuring the resistance of the absorption blocks at short intervals of time.

Plate 3

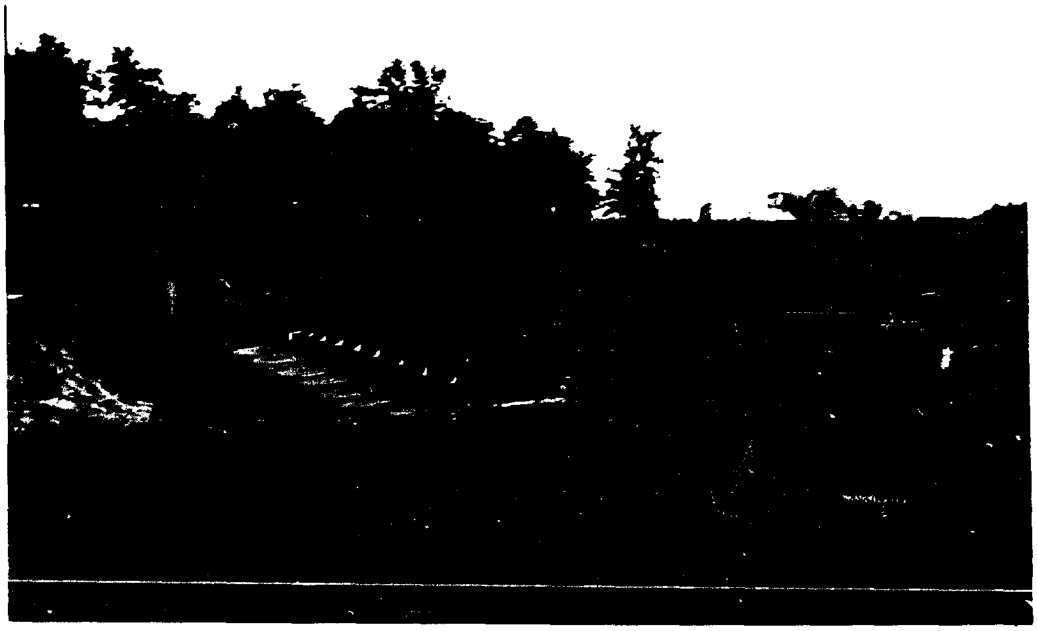


Side View - Block 1   Location III

Plate 4

Front View - Block 1   Location III

Plate 5



Full View Location III

Plate 6

Block Number	Plot Number								
	1	2	3	4	5	6	7	8	9
1	3	1	5	4	9	6	7	2	8
2	6	8	9	3	5	1	7	4	2
3	1	3	6	7	2	5	8	4	9

Treatment Number

Plot Arrangement in the Field Location III

The plots treatments were as follows:

1. Untreated
2. Seven pounds of M-1, micaceous mineral, mixed with the soil to a depth of four inches. This amounts to an application of 0.75%.
3. 48 liters of 0.2% A-240. This is double the application used in Locations I and II.
4. 48 liters of 0.7% A-240. This is seven times the application used in Locations I and II.
5. 100 grams of S-3 dusted over the surface of the soil.
6. 1000 grams of S-3 dusted over the surface of the soil.
7. 28 pounds of M-2. This amounted to a 2% application by weight in the top six inches of soil. To mix this material into the soil it was necessary to first remove the soil to a depth of six inches and then return the soil and wood fiber together to the excavation a small quantity at a time.
8. 42 pounds of M-2. This amounted to a 3% application by weight of the fiber.
9. Four trenches six inches wide by twelve inches deep were excavated across the plot at three foot intervals from center line to center line. Each of these trenches was packed with the fiber, M-2. The average amount used was 7 pounds in a trench.

All the treatments with the exception of No. 2 were completed June 5, 1940. No. 2 was completed June 19, 1940. In the total analysis data was considered from June 18, 1940. Statistical analysis of the runoff from the individual rains was made on all results obtained after June 24, 1940.

Measurement of Water and Soil Losses: The runoff from the plots was not measured at regular intervals, but instead after the completion of each rain of sufficient intensity to produce a measurable water loss. The suspended soil material in the catch basin was flocculated by the addition of $Al_2(SO_4)_3$ and the water siphoned off into a calibrated container. Water losses from Locations I and II were measured to the nearest 50 ml, those from Location III to the nearest 100 ml. These data were converted to percentage of the total rainfall per plot during a given rain. Knowing the total inches of rainfall as measured by the rain gauge this calculation was carried out as follows:

$$\text{Gallons of rainfall per plot} = \frac{\text{Area of plot in sq. inches x inches of rainfall}}{231}$$

$$\text{Runoff in gallons} = \frac{\text{Runoff in liters}}{3.785}$$

$$\text{Percentage runoff} = \frac{\text{Runoff in gallons}}{\text{Gallons of rainfall}} \times 100$$

The soil loss was not measured after each rain, but was allowed to remain in the catch basin until a considerable mass had accumulated. This procedure was followed in order to eliminate to some extent, the experimental error introduced by the impossibility of completely removing all the soil from the containers. It also reduced the error in weighing the soil. The eroded soil was weighed in a tared container to the nearest 0.10 lb. Representative samples were taken for moisture determination in the laboratory. From these data the pounds of oven dry soil lost from each plot was calculated.

Experimental Results of Erosion Plot Studies

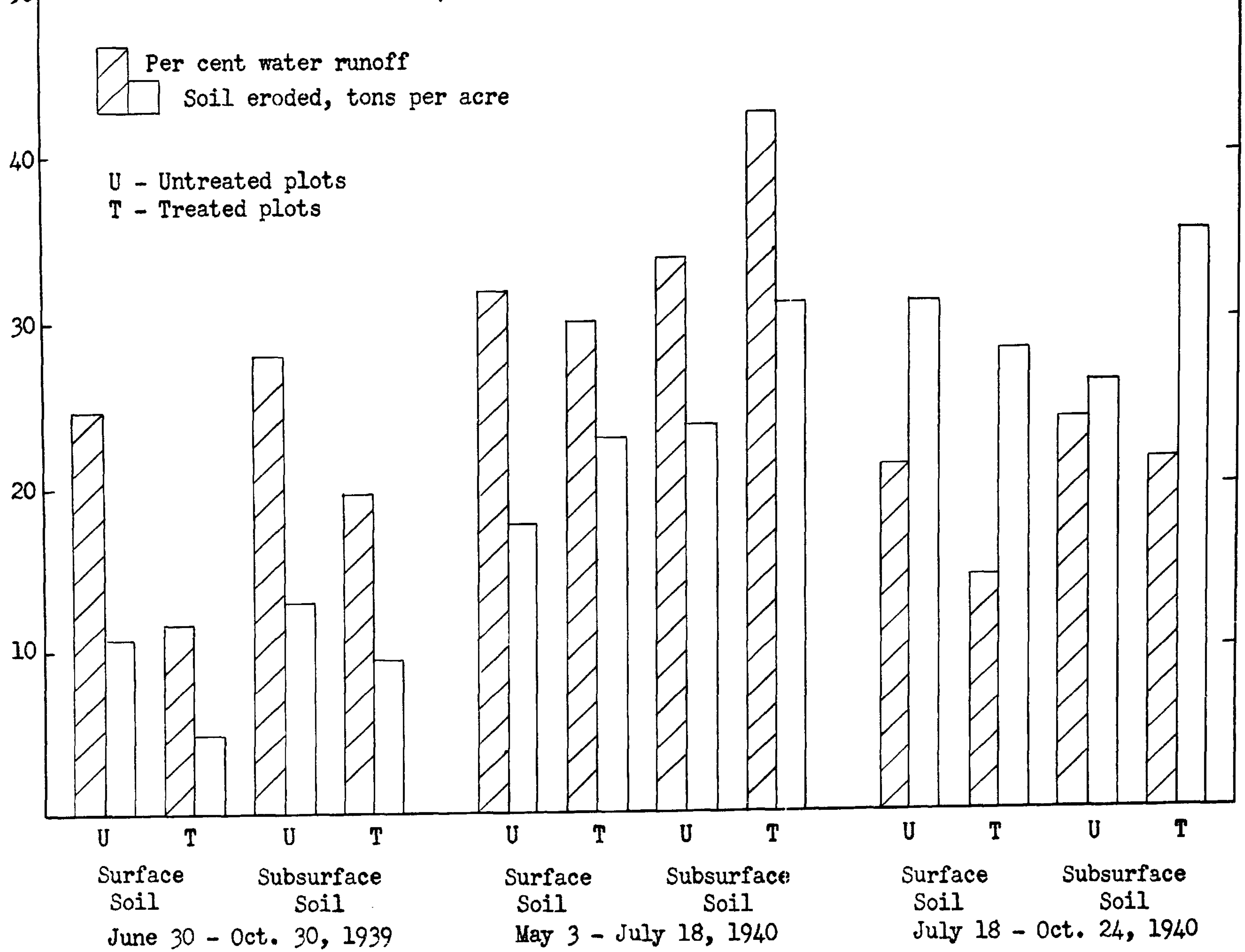
Location I. The results from these plots were grouped according to three time intervals. The first grouping includes the results of the entire 1939 season. The treatment reduced the water runoff 50% on the surface soil and 30% on the subsurface soil. The soil losses were reduced in about the same proportion. See Table 4 and Plate 7. These data indicate that the treatment with A-240 and A-375 is effective in increasing water intake of the soil either by increasing its wettability or permeability, or both. However, the pounds of water necessary to erode one pound of soil are almost equal for the treated and untreated soil. During this season the treatment did not increase the susceptibility of the soil to erosion. Erosion losses are slightly higher for the subsurface soil than for the surface soil. This might indicate that the A-375 treatment is not as effective as the A-240, but it is more likely due to the influence of the 2% greater gradient of the subsurface plots.

The next period includes the first 2½ months of the 1940 season. In preparation for this season the plots were reconditioned and cultivated to a depth of three inches, but no new treatment was applied. During this period the water runoff from the surface soil was not significantly less on the treated soils. The runoff from the treated subsurface soil was in fact 25% greater than from the untreated. The amount of soil lost from the treated plots was approximately 30% greater than that from the untreated on both surface and subsurface soil. As shown by the pounds of water necessary to erode a pound of soil, the plots which had been treated were more susceptible to erosion during this period. It is difficult to explain why these results were so very different from those of the previous season. It seems logical that most of the A-240 and A-375 had been leached

Table 4. Soil and water losses. Location I.

Type of Plot	Gallons Water Runoff	Per Cent Water Runoff	Pounds Soil Eroded per Plot	Tons of Soil Eroded per Acre	Pounds of Water Lost Per Pound Soil Eroded
June 30 to October 30, 1939		Rainfall 93.8 gallons/plot.			
Surface Soil Untreated	22.9	24.4	9.8	10.7	19.5
Surface Soil Treated	10.8	11.5	4.3	4.7	20.9
Subsurface Soil Untreated	25.9	27.6	11.7	12.7	18.5
Subsurface Soil Treated	18.0	19.2	8.4	9.1	18.0
May 3 to July 18, 1940		Rainfall 119.1 gallons/plot.			
Surface Soil Untreated	37.4	31.4	16.0	17.4	19.5
Surface Soil Treated	35.1	29.5	20.5	22.3	14.3
Subsurface Soil Untreated	39.8	33.4	21.3	23.2	15.6
Subsurface Soil Treated	50.2	42.1	28.2	30.7	14.8
July 18 to October 24, 1940		Rainfall 131.8 gallons/plot.			
Surface Soil Untreated	27.3	20.8	28.2	30.7	8.1
Surface Soil Treated	18.4	14.0	25.5	27.8	6.0
Subsurface Soil Untreated	31.2	23.7	23.7	25.8	11.0
Subsurface Soil Treated	27.7	21.0	32.0	34.9	7.2

Plate 7. Soil and water losses. Location I.



from the soil by this time. Yet it is possible that enough of this material remained in the soil to effect dispersion of the soil granules which caused a decrease rather than an increase in the permeability of the soil to water.

On July 18, 1940 the plots were given another treatment. The last period of analysis includes all rains after this date until the end of the 1940 season. During an exceptionally heavy rain on August 26 the catch basins overflowed. The missing data were calculated from the average per cent runoff during this period knowing the total amount of rainfall. This is not strictly accurate for Neal (5) has found that the percentage of runoff varies with the intensity of the rain as well as the time duration; however, for comparing amounts of runoff the percentages remain the same as determined from the other rains. The soil losses are shown as measured.

Retreatment of the soil decreased the water runoff from the surface soil 30%, but the decrease amounted to only 10% on the treated subsurface soil as against the untreated. If the high percentage of runoff from the treated subsurface during the previous period is considered, the decrease is considerable. The new treatment brought the water losses from 25% greater than the check to 10% less. Soil losses from the treated surface soil were about 10% less than from the untreated, but on the subsurface soil the losses were about 35% greater from the treated plots. The number of pounds of water necessary to erode one pound of soil shows that the treated plots were still more susceptible to erosion than were the untreated. These results indicate that treatment with the wetting agents may decrease runoff losses and yet cause dispersion of the soil particles to such an extent that soil losses may be as great or greater.

Location II. During the 1939 season the treatment was effective only in reducing the water runoff from the subsurface plots about 10%. Differences in both water and soil losses from the surface soil and in soil losses from the subsurface soil are easily within the limits of experimental error. See Table 5 and Plate 8. Although the data shows that the treatment with A-240 may have slightly increased the susceptibility of the soil to erosion, the differences are not great enough to be important.

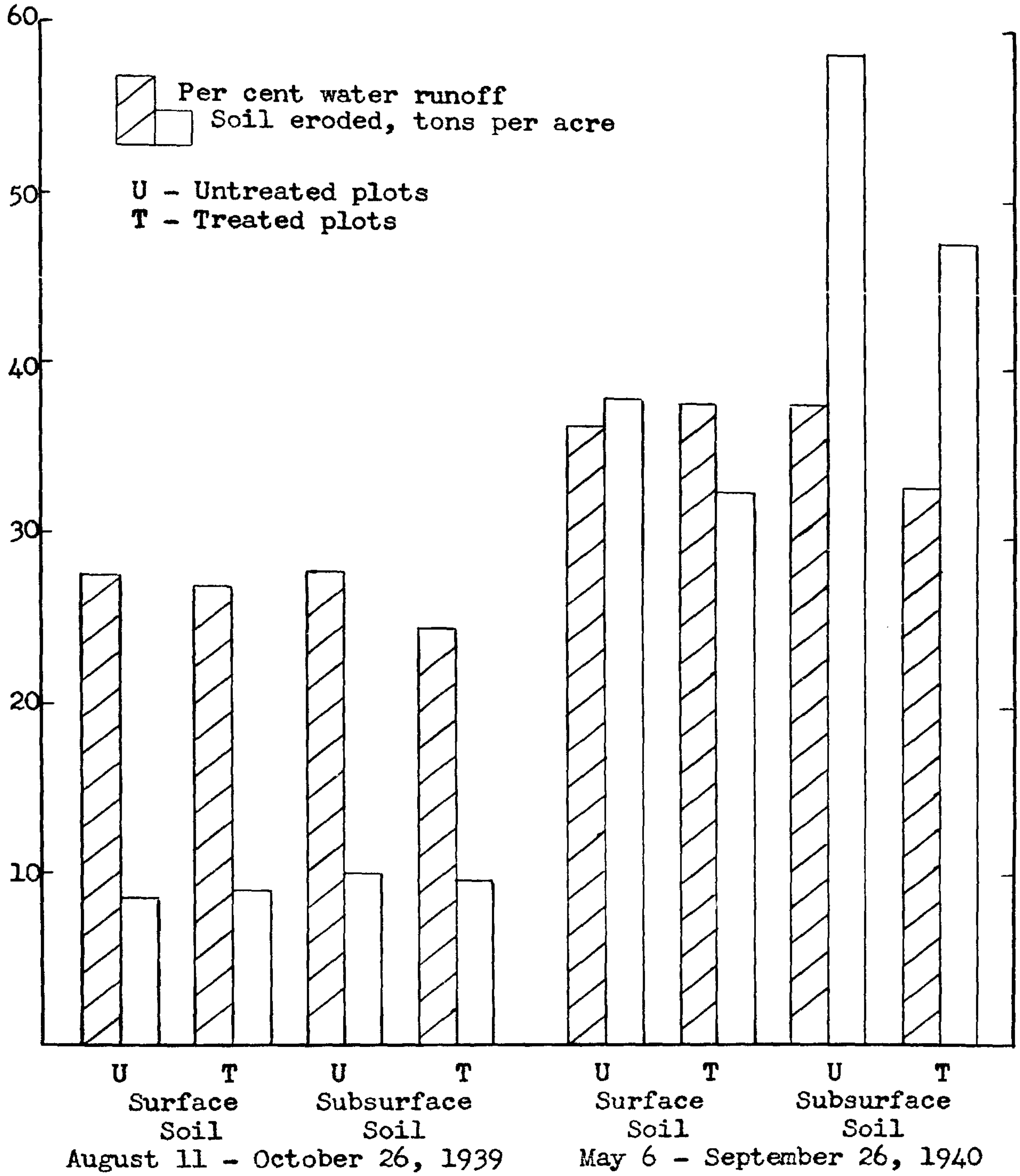
These plots were reconditioned but not retreated for the 1940 season. The results compiled cover the period from May 6 to September 26, 1940 exclusive of the water and soil losses caused by the rain of August 26. Again the differences in runoff losses between the treated and untreated plots were small, but the water losses from the treated subsurface soil continued to be about 10% less than those from the check plots. However, on both the surface and subsurface soils the treated plots showed 15 - 20% less soil eroded than from the respective check plots. Evidently during the second season the treatment was functioning to reduce the susceptibility of this soil to erosion. This would indicate that on the heavier soil the treatment became more effective after some leaching had occurred, while on the lighter soil of Location I the treatment became less effective after leaching.

Location III. The data from these plots covers the 1940 season including all rains of sufficient intensity or duration to cause measurable runoff. The treatments were randomized within blocks and replicated three times. Such an arrangement permitted statistical treatment of the data, which removes the error due to variation between replicated plots and tests only differences due to treatment. Unless otherwise indicated

Table 5. Soil and water losses. Location II.

Type of Plot	Gallons Water Runoff	Per Cent Water Runoff	Pounds Soil Eroded per Plot	Tons of Soil Eroded per Acre	Pounds of Water Lost Per Pound Soil Eroded
August 11 to October 26, 1939. Rainfall 58.7 gallons/plot.					
Surface Soil Untreated	16.3	27.7	8.0	8.7	17.0
Surface Soil Treated	16.0	27.0	8.3	9.1	15.9
Subsurface Soil Untreated	16.5	28.0	9.3	10.2	14.8
Subsurface Soil Treated	14.5	24.7	8.9	9.7	13.6
May 6 to September 26, 1940 Rainfall 164.2 gallons/plot.					
Surface Soil Untreated	60.2	36.6	35.2	38.3	14.3
Surface Soil Treated	62.2	37.9	30.1	32.8	17.3
Subsurface Soil Untreated	62.2	37.9	53.9	58.7	9.6
Subsurface Soil Treated	54.4	33.1	43.6	47.5	10.4

Plate 8. Soil and water losses. Location II.



increases or decreases due to treatment as discussed in this section are statistically significant. Table 8 shows the type of analysis of variance which was carried out on the results. Missing data on three plots, the result of excessive rainfall on several occasions, were calculated from observed data of the individual rains in the recommended manner (1, 8). Table 7 gives the lowest moisture content as measured at each level with the resistance-absorption blocks. Examples of the continuous moisture curves from which these values were obtained are given in the Appendix Plates 2 - 7, together with the laboratory calibration curve for converting the resistance readings to per cent moisture, Appendix Plate 1. The minimum moisture percentages at the four levels were summed to give the cumulative moisture retained for each treatment.

Of the eight treatments, No. 4, the treatment with 0.7% A-240, was the most effective in reducing runoff. The total water losses from Treatment 4 were about 30% less than those from the untreated. Table 9 shows that while this treatment did not increase the water intake during every rain, it was significantly effective during more of them than any other treatment. As would be expected, Treatment 4 was found to have the highest cumulative content of moisture retained.

The continuous moisture curves show that throughout the dryest part of the summer the moisture content of these plots was considerably higher than the check plots at all four depths. It is worthy of note that during the early and late part of the summer when precipitation was plentiful all treatments including the check had very nearly the same moisture content at all levels. At depths below six inches the moisture content of plots having Treatment 4 remained very nearly constant throughout the entire season. This means that the evaporation losses were low from plots receiving the A-240 application.

Table 6. Soil and water losses. Location III.

June 18 to November 17, 1940 Rainfall 251.5 gallons/plot.

Treatment	Gallons Water Runoff	Per Cent Water Runoff	Pounds of Soil Eroded Per Plot	Tons of Soil Eroded Per Acre	Lbs. of Water Lost Per Lb. Soil Eroded
1. Untreated	143.9	57.2	57.5	41.8	20.8
2. 7 lbs. M-1	122.2	48.6	54.3	39.4	18.8
3. 0.2% A-240	119.8	47.6*	47.5	34.5	21.0
4. 0.7% A-240	103.3	41.1**	41.0	29.8	21.0
5. 100 g S-3	116.2	46.2*	47.2	34.3	20.5
6. 1000 g S-3	139.0	55.2	54.8	39.8	21.2
7. 28 lbs. M-2	129.4	51.5	40.0	29.0	27.0
8. 42 lbs. M-2	119.7	47.6*	28.4**	20.6	35.2*
9. M-2 in strips	136.4	54.2	41.0	29.8	27.8

*Significantly different from the untreated plot at the 5% point.

**Significantly different from the untreated plot at the 1% point.

Table 7. Minimum per cent moisture content during 1940 season. Location III.

Depth	Treatment Number								
	1. Untreated	2. 7 lbs. M-1	3. 0.2% A-240	4. 0.7% A-240	5. 100 gr. S-3	6. 1000 gr. S-3	7. 28 lbs. M-2	8. 42 lbs. M-2	9. M-2 In strips
3 inches	7.0	7.5	8.0	10.0	8.0	6.5	5.0	6.0	7.0
6 inches	8.0	8.5	10.0	11.5	10.0	7.5	8.5	9.5	8.0
9 inches	10.0	10.0*	10.0	11.5	10.5	8.5	12.0	10.5	8.5
12 inches	10.0	10.0	10.0	12.0	10.0	8.0	12.5	11.5	10.5
Cumulative moisture retained at the four depths	35.0	36.0	38.0	45.0	38.5	30.5	38.0	37.5	34.0

*Estimated value.

Plate 9. Soil and water losses and cumulative moisture retained. Location III.

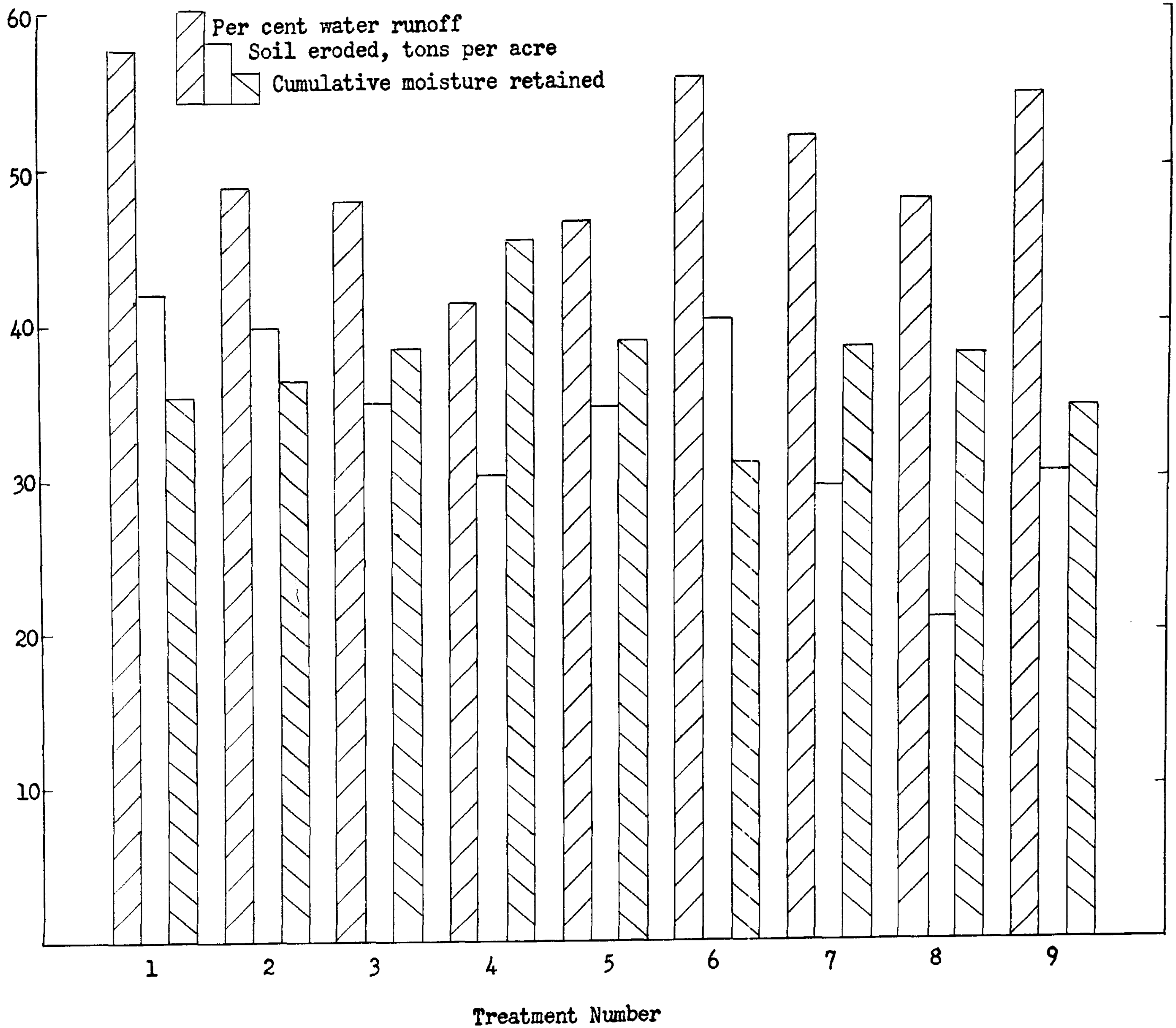


Table 8. Analysis of variance of per cent water runoff. Location III.

Block No.	June 18 to November 17, 1940 Treatment Number 1	2	3	4	5	6	7	8	9	Total
1	59.20	52.99	51.61	47.60	43.76	56.16	55.98	38.75	61.62	467.67
2	59.24	45.49	46.87	34.01	46.05	55.79	48.46	52.77	54.71	443.39
3	53.15	47.30	44.42	41.61	48.81	53.78	49.93	51.30	46.31	436.61
Total	171.59	145.78	142.90	123.22	138.62	165.73	154.37	142.82	162.64	1,347.67
Ave.	57.20	48.59	47.63*	41.07**	46.21*	55.24	51.46	47.61*	54.21	

Analysis of Variance

Source	Degrees of Freedom	Sum of Squares	Variance	F calc.	$F_{1\%}$	$F_{5\%}$	Experimental Error
Total	23	1,078.27					
Block	2	59.27	29.64				
Treatment	8	619.42	77.43	3.10	4.30	2.77	
Error	13	399.58	24.97				5.00

$\sigma_{diff.} = 5.00\sqrt{1/3 + 1/3} = 4.08$

$t_{5\%} = 2.16$; $t_{1\%} = 3.01$

Difference required for significance at 5% = 4.08 x 2.16 = 8.81

Difference required for significance at 1% = 4.08 x 3.01 = 12.28

**Indicates significant difference from untreated at 1% point. *Indicates significant difference from untreated at 5% point. Three degrees of freedom subtracted from total to correct for missing data.

Table 9. Significance of water losses from the individual rains. Location III.

Stars indicate losses from treated plots were significantly different from the untreated on that date.

Date	Treatment							
	2. M-1	3. A-240	4. A-240	5. S-3	6. S-3	7. M-2	8. M-2	9. M-2
June 25					***	*	**	**
July 1							*	
July 10								
July 26								
Aug. 6		**	**	**				
Aug. 20	*	**	**	**	**			
Aug. 22	**	**	**	**	**		**	
Sept. 3			*					
Sept. 25		*	**		**			
Oct. 8			**	*				
Oct. 17								
Oct. 23							*	
Nov. 11						*		

***Significantly greater loss than the untreated at 1% point as determined by analysis of variance.

**Significantly smaller loss than the untreated at the 1% point.

*Significantly smaller loss than the untreated at the 5% point.

Although the soil losses were also reduced almost 30% as compared with the untreated plots the statistical treatment did not show this value to be significant, probably due to a large variation between individual plots. Nevertheless, such a difference does indicate that the treatment has not increased the susceptibility of the soil to erosion, but that the treatment by decreasing the amount of water runoff has produced a corresponding decrease in the soil lost.

Treatment 3, 0.2% A-240, reduced the amount of water lost almost 20% as compared with the check plots, while the soil loss was reduced a proportional amount. The cumulative moisture retained was about 9% greater than that of the check plots.

The continuous moisture curves show that this 0.2% application of A-240 did not allow as much evaporation as occurred from the check, but below six inches the differences between the two curves were so small as to be unimportant. The data consequently show that on this soil the more concentrated treatment with A-240 (No. 4) does not increase runoff losses, but produces a 10% greater decrease in these losses than does this weaker treatment.

Treatment 5, consisting of an application of 100 grams of S-3, a different type of wetting agent added in an entirely different manner, produced results very similar to Treatment 3. As compared with the untreated plots the water losses were reduced about 20% and the soil losses were reduced an equivalent amount although the latter value is not statistically significant. The cumulative moisture retained was the second highest of all the treatments, but the moisture curves are little different from those for the check below six inches.

Treatment 6, the application of 1000 grams of S-3, produced a condition in the soil which temporarily increased the runoff losses. During the first rain of the season the losses from these plots were significantly greater than check plot losses. This result, however, is not so surprising if considered in the light of some of the laboratory work which was done. It has been shown that in some soils the reagent decreased the permeability to water by causing dispersion of the particles. This dispersing action is a characteristic of soaps and detergents and makes its influence felt in the presence of a large amount of fine materials or an excess of the dispersing reagent, particularly when accompanied by mechanical agitation. Treatment 6 provided an excess of the dispersing agent which, combined with the impact of the falling rain, puddled the surface layers of the soil decreasing water intake and increasing erosion. It is interesting to note that before the end of the season enough of the reagent had been washed off or leached out so that this detrimental effect of the treatment was no longer evident. During three rains losses from these plots were significantly lower than from the check. Over the whole season soil and water losses from Treatment 6 were slightly smaller than from the untreated soil, cumulative moisture retained was, however, more than 10% less for this treatment. This is the result of lack of penetration of water into the soil during the forepart of the season previous to the dryest part of the summer. The moisture curves show that at all levels the moisture content of this plot was nearly equal to the check or else below it.

Treatment 2, which consisted of mixing the absorbent mineral M-1 with the top 4 inches of soil, reduced the total amount of runoff water almost 15% as compared to the runoff from the untreated plots, but this did not constitute a significant difference. The values of cumulative moisture retained and soil eroded are so close to those of the check plot that the effect of treatment with M-1 at this rate of application is readily seen to be negligible in reducing erosion losses.

Treatment 7, 28 pounds of M-2 incorporated into the soil, reduced the amount of water runoff only about 10%, while the soil loss was decreased almost 30%. This result is contrary to those which have been already discussed, but the explanation is quite simple. In this treatment a bulky foreign substance was mixed with the soil, a substance which occupied about 30% of the volume though it amounted to only 2% of the weight of the soil. This material being fibrous, remained as a mat on the surface of the ground when the soil particles were washed off. Consequently, as the soil was removed from the plots, more of the wood fiber was exposed until a mulch was formed which almost completely prevented soil losses although runoff was relatively high. With water losses relatively high the value of cumulative moisture retained was still found to be about 9% above the untreated. Again this is due to the nature of the material employed in the treatment. In the top three inches excessive drying occurred, but this dry, poorly conducting mulch on the surface prevented capillary rise and evaporation from the lower layers. Coincidentally, the fiber, because of its own absorptive power, increased the water holding capacity of the soil.

Treatment 8, the 42 pound application of M-2, reduced water losses about 15%, and soil losses 50%. This shows that large amounts of the fiber will significantly increase the water intake of the soils. By volume this application amounts to almost 40% so that large reductions in soil loss would be expected. Cumulative moisture retained was not any greater than for Treatment 7, and excessive drying of the top three inches also took place, probably due to the increased internal surface presented by the soil-fiber mulch.

The amount of water runoff and the cumulative moisture retained were almost the same for Treatment 9 as for the untreated plots. The amount of soil lost, however, was reduced 30%. Although the wood fiber was not incorporated within the soil the strips of the material retarded the speed of the runoff water, thus effectively reducing the load of soil it was capable of carrying. Near the end of the season these strips became covered with soil from above and the plot tended to react more like a soil surface.

It is evident from the last column in Table 6 that the variation in erodibility between the first six treatments is negligible. The values obtained are very nearly equal to those obtained during the 1939 season from the plots of Location I. This definitely indicates that these treatments do not increase the susceptibility or resistance of the soil to erosion. It is only through their function of increasing the rate of water intake that the erosion losses are reduced. For the reasons already pointed out, Treatments 7, 8, and 9 apparently required 25 to 35% more water to erode one pound of soil. These treatments do not necessarily increase the water intake of the soil, but like a mulch or furrow, prevent erosion mechanically.

DISCUSSION

Treatment of certain sandy loam soils with a dilute solution of commercial wetting agent was found to lower the runoff from experimental plots as much as 50% over a summer season. Application of a moderate amount of detergent in the powder form had a similar effect. This increase in water intake is postulated as being the result of two actions of the reagent (1) an increase in the rate of wetting of the topsoil particularly when in a very dry state and (2) a lowering of the surface tension of water in contact with the soil, permitting more rapid percolation.

In no case did the treatment increase the amount of total runoff during the season in which it was applied. One heavy application of the reagent S-3 increased the amount of water loss during the forepart of the 1940 season, but when the excess detergent was removed, the runoff was decreased. The surface layers of the soil were dispersed and puddled by this heavy treatment, retarding the water intake. The runoff from the surface soil plots of Location II was not changed during either the 1939 or 1940 season by treatment with the wetting agents. The fact that the drainage is controlled on the Miami type by the heavier subsoil horizon might account for the ineffectiveness of surface treatments.

The results from the light sandy loam plots of Location I indicate that the treatment lost its effectiveness in a period of one year. This may be due either to the leaching of the reagent from the soil or to the clogging of the capillaries by dispersed soil colloids. This theory correlates with the results of the laboratory permeability experiments which showed a decrease in the permeability of the treated soil as more water passed through. Retreatment of the soils, however, again increased the water intake and reduced runoff from the field plots. Apparently dispersion was not an important factor on this light sandy loam soil. As only the plots in Location I received treatment for the second season and the experiments were not carried on for a third season, it is impossible to state whether there is a cumulative effect due to the treatment or whether a new application would be necessary every year to produce results.

Incorporation of the micaceous material, M-1, into the soil in the amount used here was not effective in significantly decreasing the amount of runoff, however larger applications might have a greater influence.

The addition of a relatively large amount of the wood fiber, M-2, was found to be effective in reducing erosion losses. This is due to an increased porosity of the soil and to the formation of a fiber mulch which retards the flow of water off the surface. The practicability of the use of this material in cultivated fields is to be doubted because of the difficulty of uniformly working the material into the soil. However, it might be suitable for holding the soil on road cuts and similar steep gradients until permanent cover could be established.

In general, soil losses from the untreated plots and from the plots treated with the detergents were proportional to the amount of water runoff; the proportionality constant being very nearly the same on all locations; but varying somewhat with the length of plots, gradient and differences in soil type. The data show this direct proportionality to exist in all three locations during the first season the treatment was applied. Such results definitely indicate that during the season of application, treatment with wetting agents does not influence the erodibility of these sandy loam soils.

During the second year of the plots in Location I, the data indicate that the treated soils were more susceptible to erosion than the untreated, both before and after retreatment. This change in reaction from the first season is very difficult to explain, but serves to reveal that the possible effects of the detergent treatment cannot be determined on the basis of one season's results. Several factors will influence the action of the wetting agent, the amount of fine material present and the amount of detergent present being the most important. Since soil erosion is constantly changing the surface soil material, and leaching action is reducing the concentration of the reagent, the creation of a soil condition of increasing or decreasing erodibility is very possible. A stage of decreasing erodibility of the treated soil was reached during the second year of the Location II medium sandy loam plots.

The action of the wood fiber in forming a protective mulch after the surface soil had been eroded has already been explained and in the light of this information the marked decrease in erodibility of the plots treated with this material is easily understood.

Continuous moisture measurements show that in addition to increasing the water intake of the soil the detergent treatment helps maintain throughout the season a higher moisture content in the upper layers of the soil. Since the plots were bare of vegetation, moisture losses occurred only by evaporation. After the surface layer has dried water moves upward by capillary action. It is suggested that the lowering of surface tension decreases the capillary attraction between the soil and water, materially reducing the height of the column of capillary water which can be maintained. Therefore, movement of water to the surface is restricted, and evaporation losses will be smaller from plots which have the wetting agent applied. It is also possible that the hydrophilic groups of the wetting agent adsorb the water and counteract the effect of gravity in emptying the pore spaces. This action would be more economically important with these lighter soils than with soils containing more colloidal material.

Since the wetting agent decreases the water losses, it must increase the water intake of the soil. Preliminary studies have showed that the reagent may increase the rate of percolation through the soil. Both of these actions can be explained on the basis of the lowering of surface tension. Neal (5) has found that soil losses reach a maximum during the first 20 to 40 minutes of the rainfall and then decrease. He postulates that this is due to slaking of the dry soil, putting it in suspension, and carrying off this suspended material. When precipitation begins on light soils treated with small amounts of the reagent, the surface is readily wetted. Because of the small amount of fine material present, the dispersion effect is not great. Furthermore, if the soil particles are already coated with a film of water due to adsorption by the reagent, there will be no tendency for the particles to adsorb more water and swell. This together with lowered surface tension of the water could keep channels open to the surface of the soil and maintain a high rate of percolation. The results of Treatment 6, Location III show the danger of using too large an application of the detergents. On these plots the water intake was decreased and during the dry spells the moisture content fell below that of the check plots. In large quantities, on heavier soils the wetting agent will produce dispersion of the soil particles, decreasing the percolation of water into the soil and increasing the water runoff.

The plots into which was incorporated 42 pounds of wood fiber had a higher rate of moisture intake than the untreated, but during dry spells the top 3 inches of the soil so treated dried excessively. Evaporation from the surface was increased by the greater amount of pore space. Below the three inch level the soil was protected from evaporation losses by the soil-fiber mulch. The presence of the organic material served to increase the water holding capacity of the soil, and the moisture content remained above that of the check plots throughout the season.

SUMMARY

The effect of certain wetting agents on water intake of soils has been discussed. Laboratory and field studies showed that these reagents were responsible for three actions; (1) increased rate of wetting of air-dry soil particles, (2) lowered surface tension of water in contact with the soil and, (3) dispersion of the soil particles.

More rapid wetting of the surface soil prevents immediate runoff when precipitation starts since the water is able to displace the air film surrounding the soil particles.

The lowered surface tension of the water allows it to percolate through the soil more rapidly thus increasing the rate of water intake. It is through these two detergent actions that water runoff and consequently soil losses are decreased. The small attraction between the soil and water results in not only an increase in the amount of water passing into the soil, but also reduced evaporation losses. Thus, the wetting agents increase the percentage of water retained by the soil since they decrease capillary attraction.

The dispersion of the soil particles is an action of the wetting agent which is constantly tending to counteract the other two effects. When the fine material of the soil is dispersed, the water pulls it into the capillary openings, thus impeding drainage and increasing surface runoff. Since only light textured soils were tested in these field studies, dispersion was not an important factor and in no case did the treatment with wetting agents increase the surface runoff during the season which it was applied. Nevertheless, such a treatment should not be applied to heavier soils without first testing its action with field erosion studies.

The effect that the detergent will have on any given soil will depend upon which action is predominant. If initial wetting or increased water intake due to lowered surface tension is the important factor then the reagent will decrease erosion water and soil losses. However, if the soil contains a sufficient quantity of disperable material then erosion losses may be increased. In other soils the three effects may be balanced one against the other so that the treatment will not significantly alter the erosion losses as compared to the untreated soil.

The erosion plot studies established in three different locations on sandy loam soils showed that the treatment of the surface soil with these detergents decreased the amount of runoff water lost and soil eroded, and increased the percentage moisture retained in the soil. Treated plots in existence for two years had to be retreated during the second summer to replace reagent lost by leaching, in order to show optimum differences from the check plots.

During the season of application, moderate treatments did not influence the erodibility of the soil, except as they decreased the water runoff. Two seasons' results were not sufficient to predict the cumulative effects of the treatment.

Incorporation with the surface soil of 2 to 3 per cent wood fiber was found to decrease both water and soil losses. The erodibility of the soil was also reduced, chiefly by the formation of a protective mulch, after the surface layer of soil was eroded.

Heavy applications of the detergent significantly increased the runoff losses until the excess material was removed by washing or leaching. Thus, the dispersing action of the wetting agent became predominant. This phase of detergent action must be more fully studied before these reagents can be prescribed for practical use.

Dilute solutions of the reagent did not in a single case significantly increase the water losses from sandy loam plots during the season of treatment. On two sets of plots the wetting agents decreased the water losses, and consequently increased the water intake. On the basis of the present investigation it is impossible to predict the practical significance of this information, in view of its limited amount.

LITERATURE CITED

(1) Baten, W. D. Formulas for Finding Estimates for Two and Three Missing Plots in Randomized Black Layouts; Mich. Ag. Exp. Sta. Tech. Bul. 165, (1939).

(2) Bouyoucos, G. J. A New, Simple, and Rapid Method for Determining the Moisture Equivalent of Soils, and the Role of Soil Colloids on This Moisture Equivalent; Soil Science 27, pp. 233-241, (1939).

(3) ______________ and Mick, A. H. An Electrical Resistance Method for the Continuous Measurement of Soil Moisture Under Field Conditions; Mich. Ag. Exp. Sta., Tech. Bul. 172, (1940).

(4) ______________ Directions for Making Mechanical Analysis of Soils by the Hydrometer Method; Soil Science 42, pp. 225-299, (1936).

(5) Neal, J. H. The Effect of the Degree of Slope and Rainfall Characteristics on Runoff and Soil Erosion; Mo. Ag. Exp. Sta., Res. Bul. 280 (1938).

(6) Thoreen, R. C. Comments on the Hydrometer Method of Mechanical Analysis; Public Roads 14, pp. 93-105, (1933).

(7) Veatch, J. O. Soil Survey of Ingham County, Michigan, unpublished data.

(8) Yates, F. The Ahalysis of Replicated Experiments When the Field Results are Incomplete; Emp. Jour. of Exp. Ag., pp. 129-142, (1933).

APPENDIX

Table 1. Commercial Products Investigated.

A - 240	Aresket 240, 40% solution of mono-butyl mono-sodium sulfonate of diphenyl. Monsanto Chemical Co.
A - 375	Aresklene 375, paste containing 75% dibutyl phenyl phenol sodium disulfonate. Monsanto Chemical Co.
S - 3	Santomerse No. 3, hygroscopic powder of alkylated aryl sulfonate. Monsanto Chemical Co.
M - 1	Vermiculite, plaster size exploded mineral. Vermiculite Co.
M - 2	Masonite exploded wood fiber, untreated, Masonite Corp.

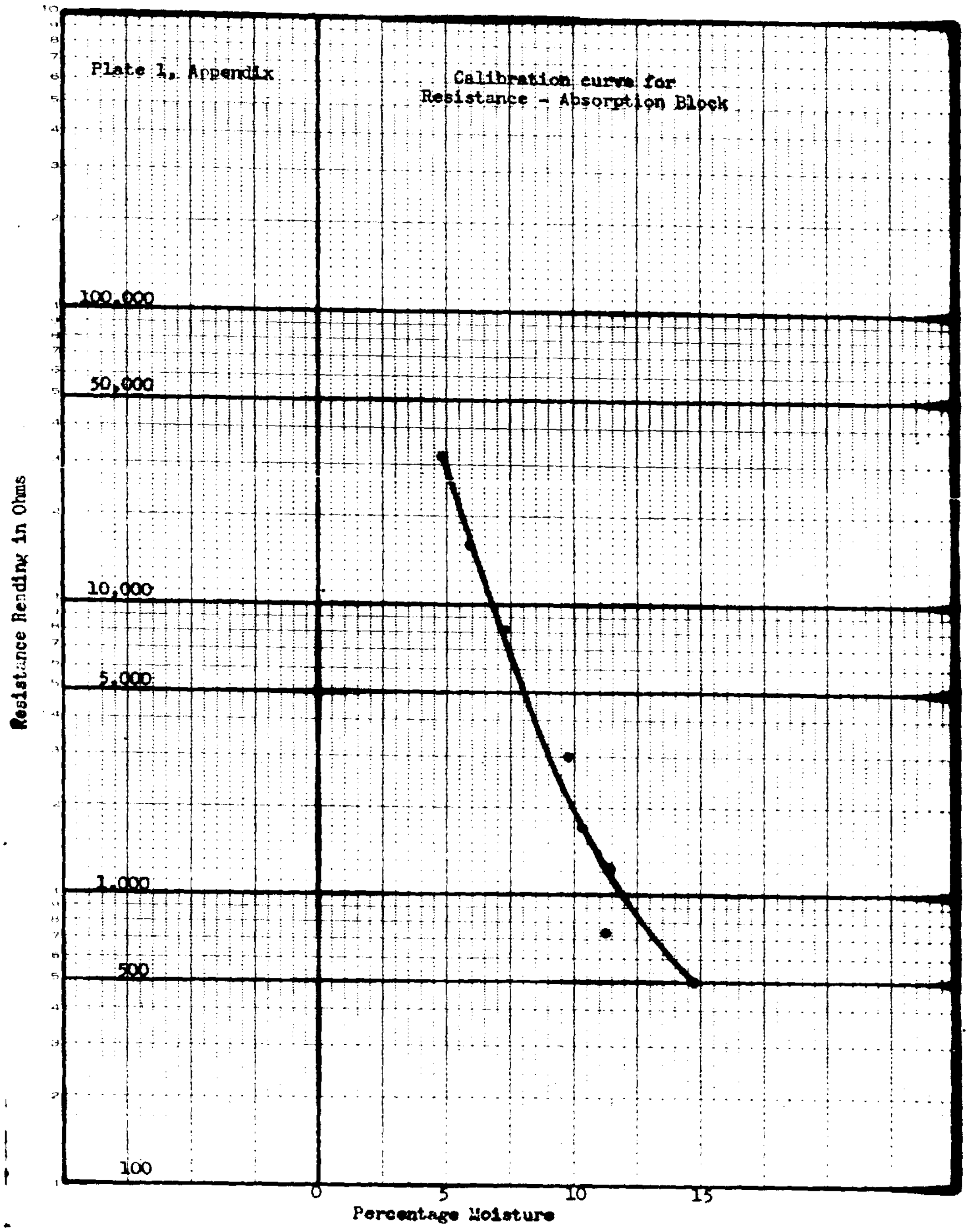


Plate 1, Appendix
Calibration curve for
Resistance - Absorption Block
Resistance Reading in Ohms
100,000
50,000
10,000
5,000
1,000
500
100
0
5
10
15
Percentage Moisture

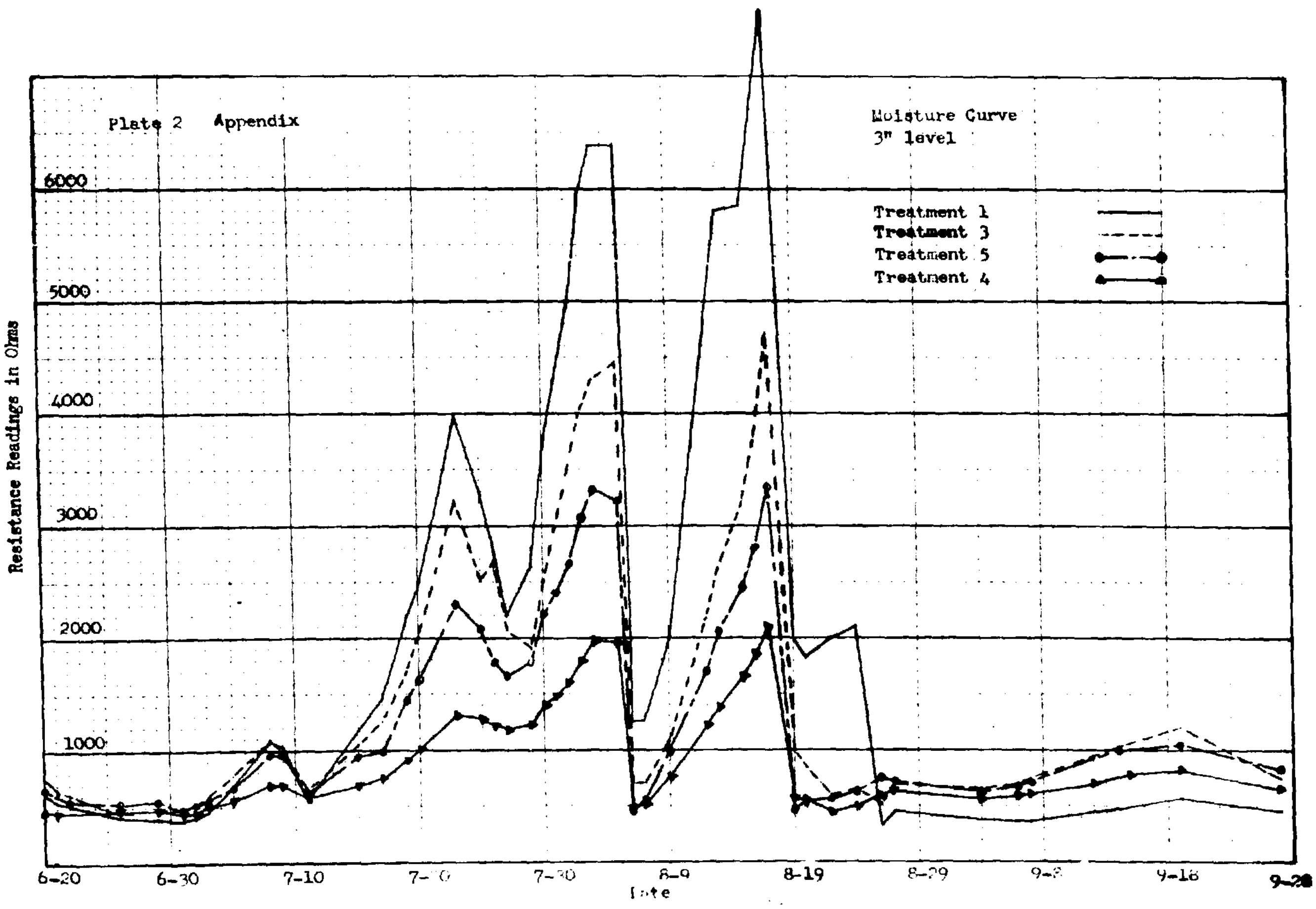


Plate 2 Appendix
Moisture Curve
3" level
Treatment 1
Treatment 3
Treatment 5
Treatment 4
6000
5000
4000
3000
2000
1000
Resistance Readings in Ohms
6-20
6-30
7-10
7-30
8-19
9-18
9-28

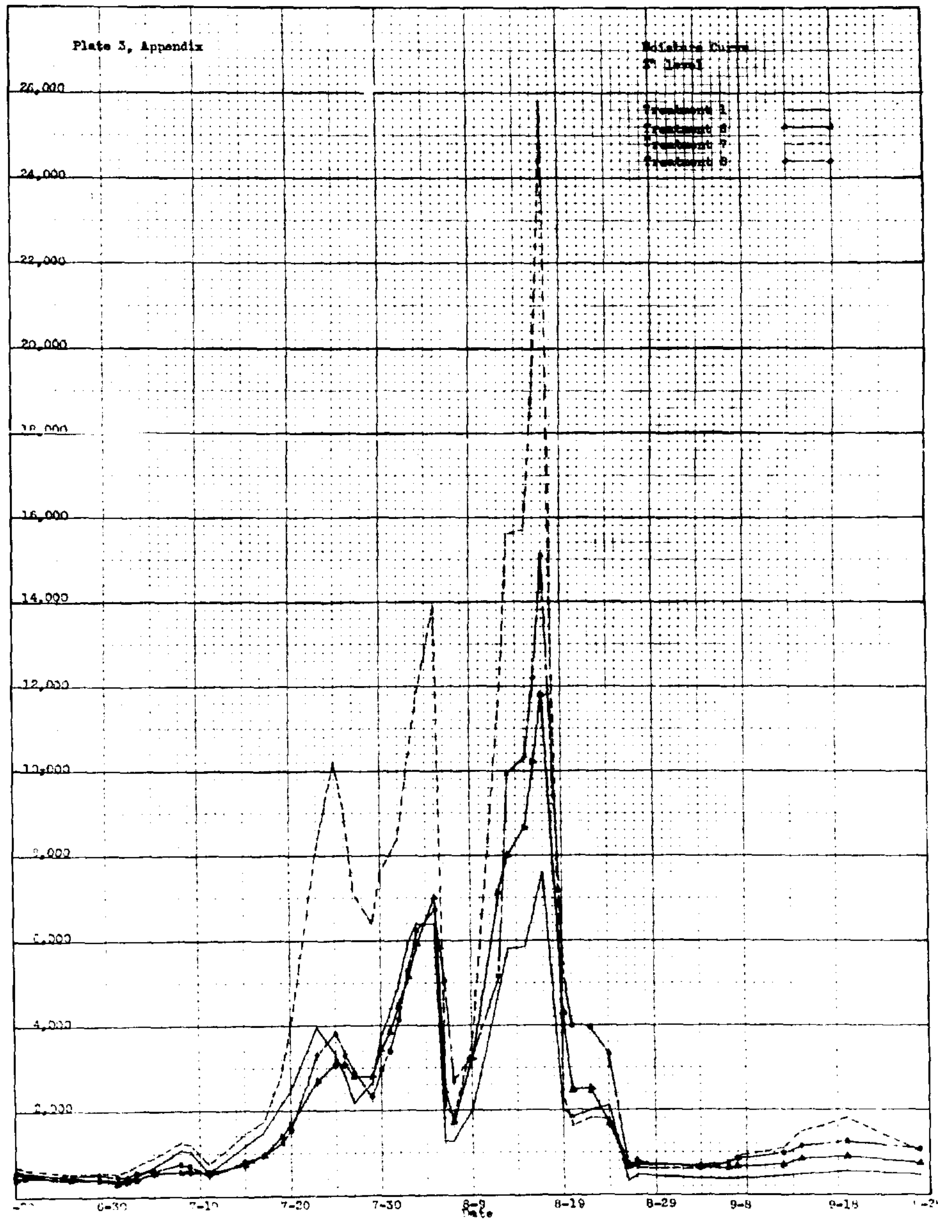


Plate 3, Appendix
26,000
24,000
22,000
20,000
16,000
14,000
10,000
4,000
6-30
7-20
7-30
8-9
8-19
8-29
9-8
9-18
Date

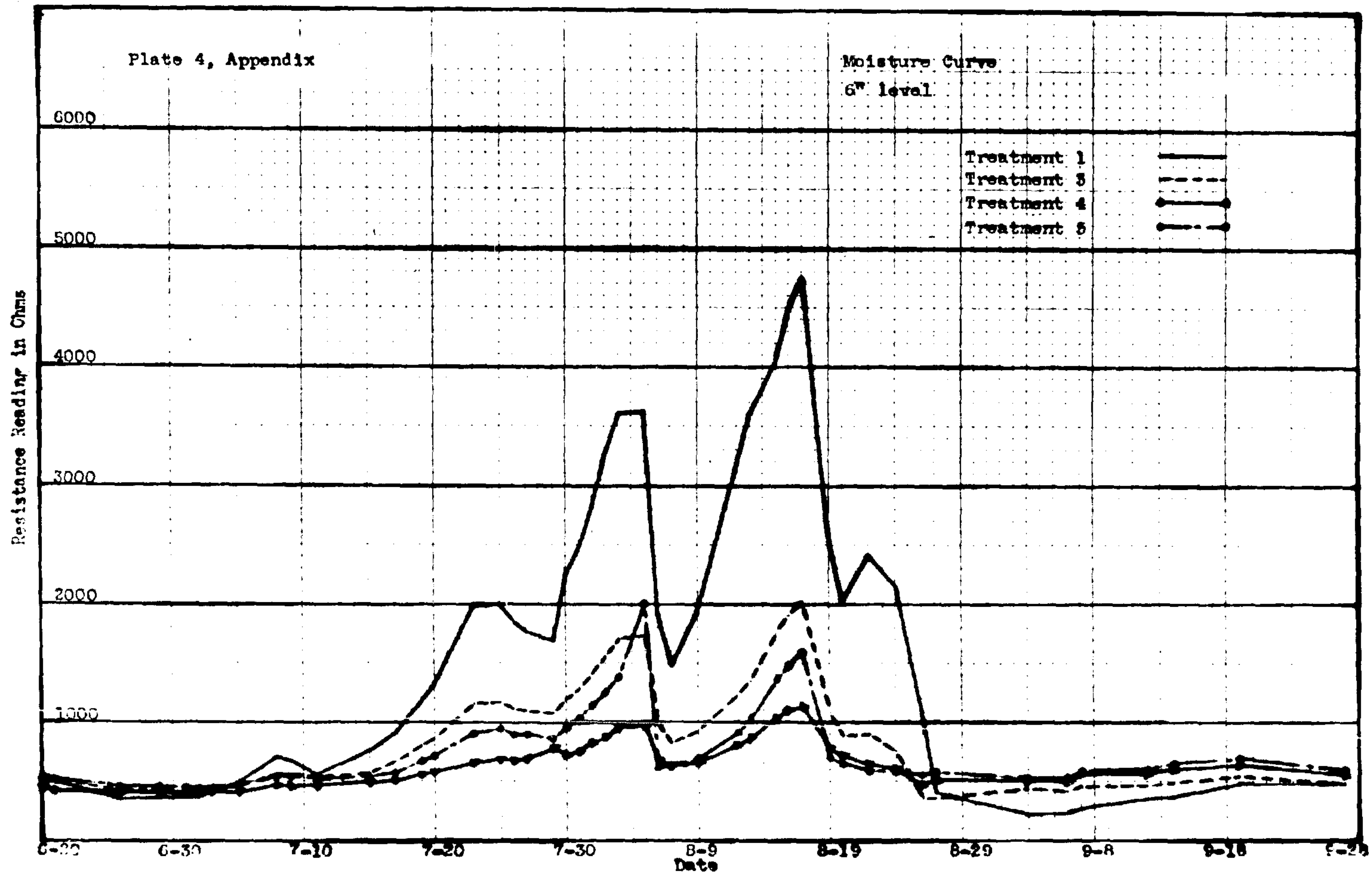


Plate 4, Appendix
Moisture Curve
6" level
Treatment 1
Treatment 3
Treatment 4
Treatment 5
Resistance Reading in Ohms
6000
5000
4000
3000
2000
1000
6-30
7-10
7-20
7-30
8-9
8-19
8-29
9-8
9-18
Date

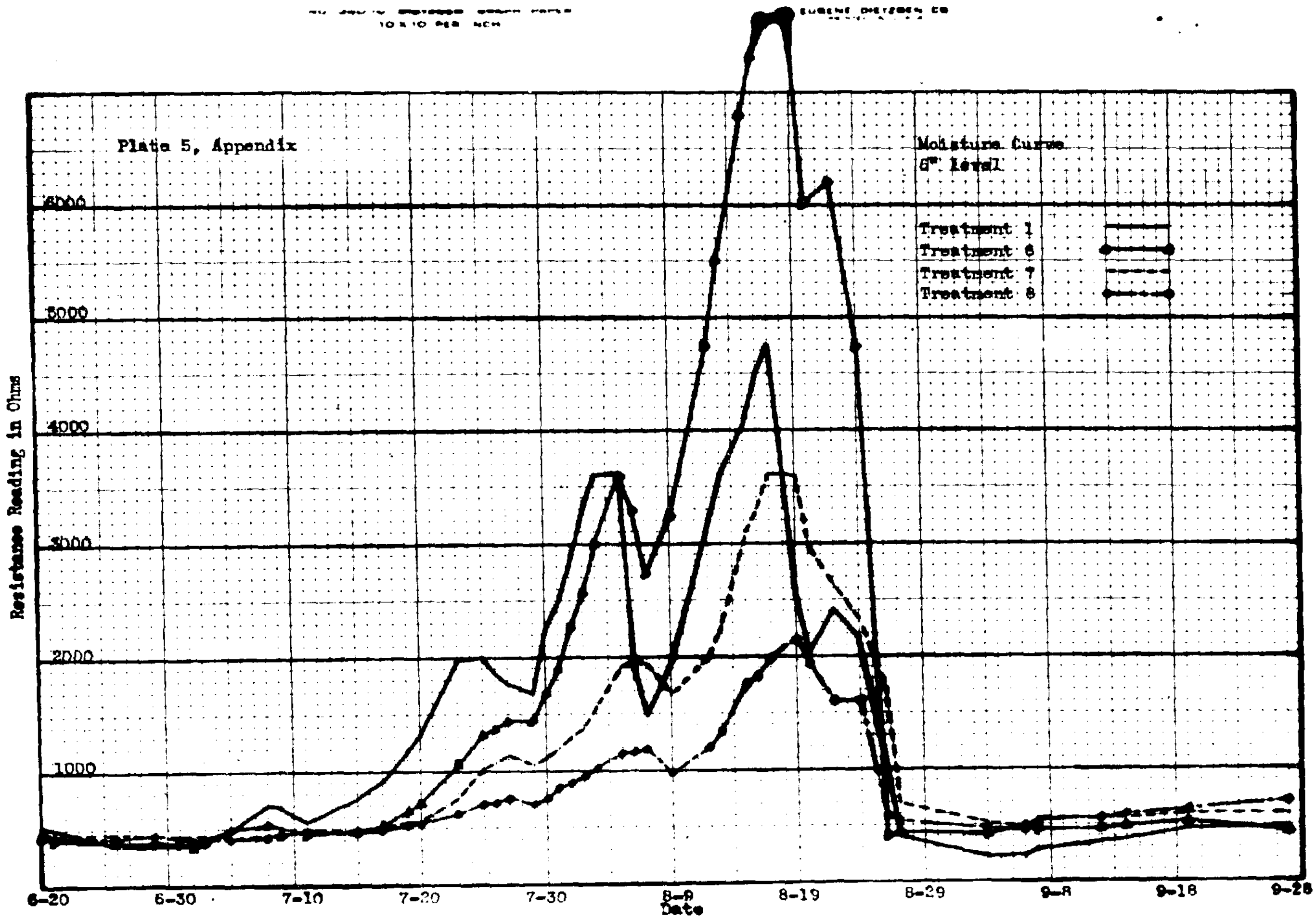


Plate 5, Appendix
Moisture Curve
6" level
Treatment 1
Treatment 6
Treatment 7
Treatment 8
Resistance Reading in Ohms
6000
5000
4000
3000
2000
1000
6-20
6-30
7-10
7-20
7-30
8-9
8-19
8-29
9-8
9-18
9-28
Date

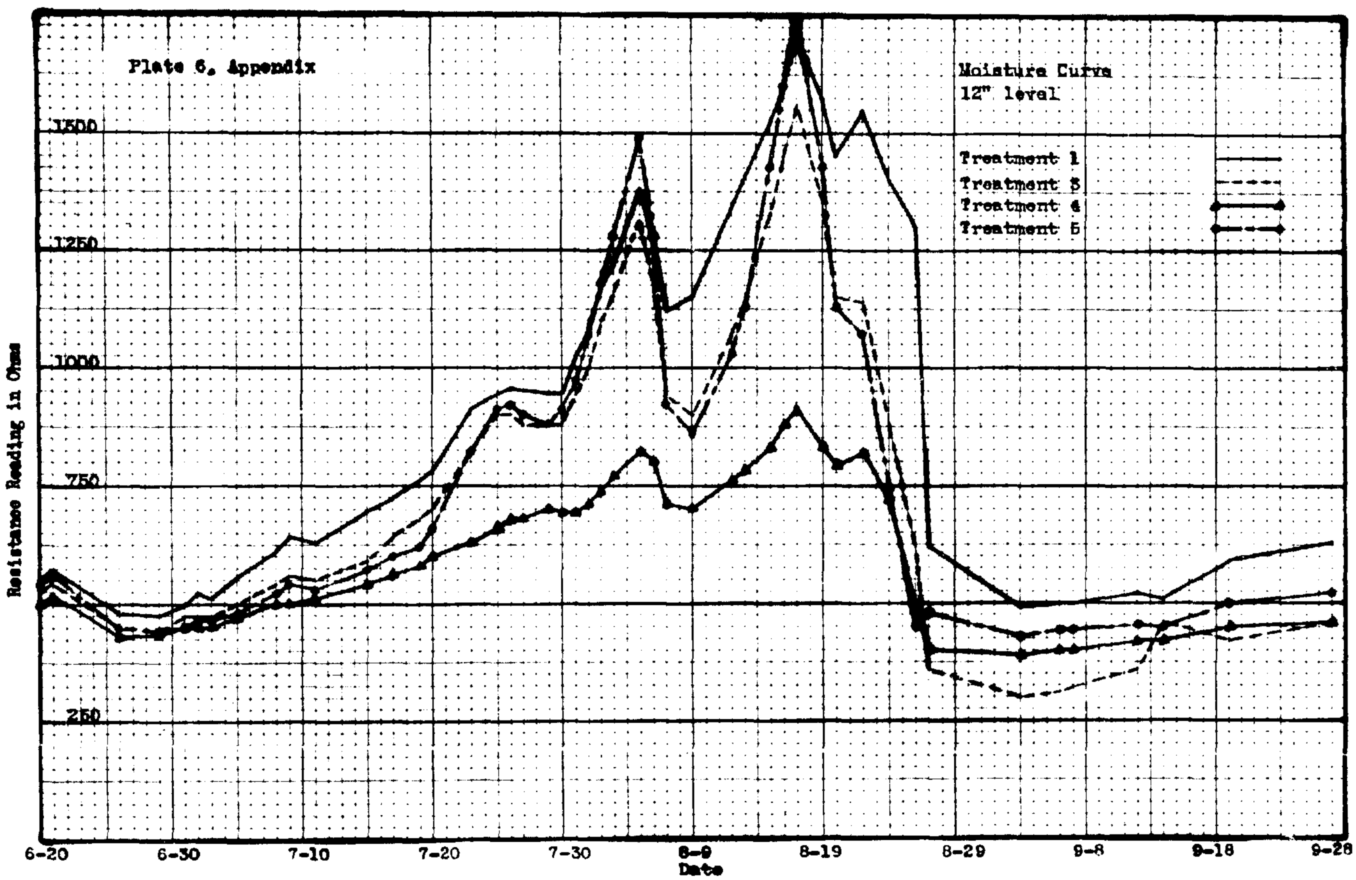


Plate 6, Appendix
Moisture Curve
12" level
Treatment 1
Treatment 3
Treatment 4
Treatment 5
1500
1250
1000
750
250
Resistance Reading in Ohms
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6-30
7-10
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9-18
9-28
Date

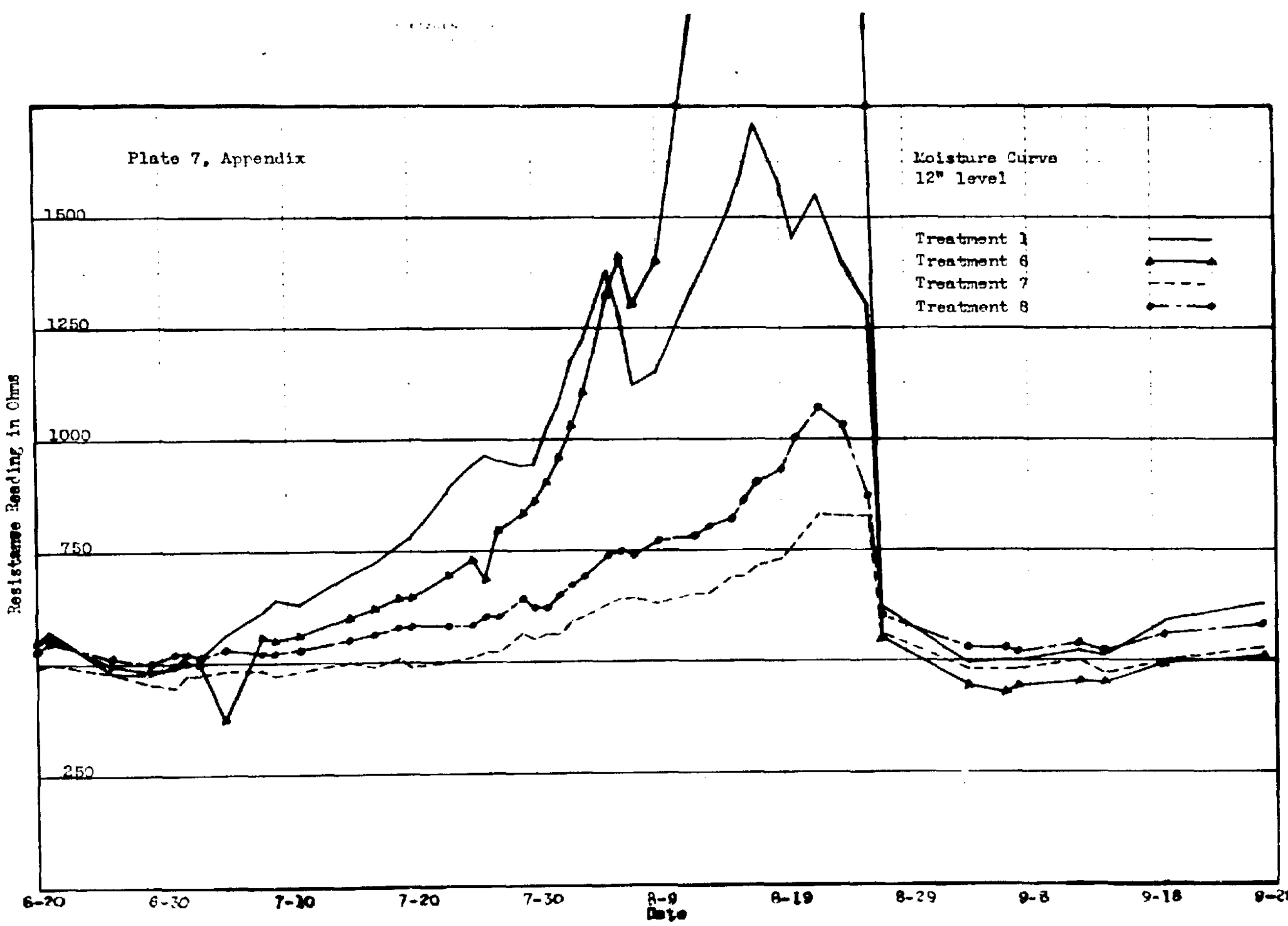
Plate 7, Appendix
Moisture Curve
12" level
Treatment 1
Treatment 6
Treatment 7
Treatment 8
1500
1250
1000
750
250
Resistance Reading in Ohms
6-20
6-30
7-10
7-20
7-30
8-9
8-19
8-29
9-8
9-18
9-28
Date