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A STUDY OF DETACHMENT OF SOIL BY ARTIFICIAL RAINFALL
AND ITS RELATION TO THE DISPERSION RATIO AND
WATER STABLE AGGREGATES FOR NINE UTAH SOILS

by

Pundlik N. Kalbhor

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Soil Science
(Soil Survey and Conservation)

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INTRODUCTION

The study of soil erodibility has become of paramount interest in the last few decades. The effects of soil erosion are serious and extensive and affect nearly all people.

In general, man can do little or nothing about the geologic erosion or natural erosion in which the processes of rock weathering and soil erosion gradually wear down the earth's surface. However, human disturbance of the natural conditions of the land surface often creates accelerated erosion. Fertility of eroded soil is usually reduced measurably and crop yields are lowered considerably as erosion removes seed soil nutrients and cover crops. Loss of fine soil fractions such as silt, clay and organic matter and the loss of various nutrients is tremendous. Such losses are difficult to replenish even in several generations.

In irrigation and drainage engineering the study of soil erosion is essential because the life of reservoirs and distribution systems is shortened by silting. In addition, the erosion factor is an important item to be considered in devising the appropriate irrigation method for an area. The effectiveness of methods for both surface and subsurface drainage depends upon the knowledge of the erosiveness of the soils in question. Erosion control measures on the farm and the development of general agricultural machinery also involve knowledge of the erosive characteristics of the soil.

In watershed management, also, soil erosion is a primary problem. It affects the quality and quantity of water as well as the time of peak flow and duration of flow. In addition to this, good watersheds control floods and exhibit valuable range land.

As a result of these many factors, the study of soil erosion has secured an important place in the various fields of science which depend directly on water, livestock, crops and timber production.

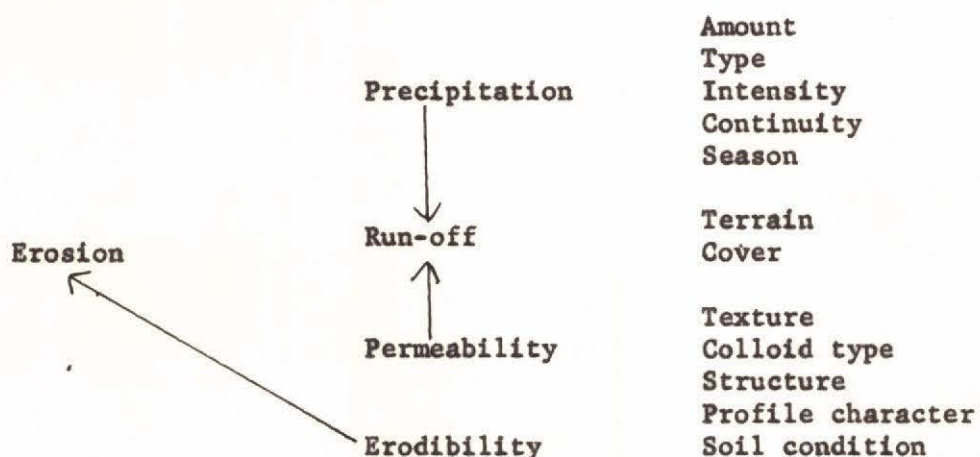
There is general agreement that soil detachment is one of the important influences on erosion of soil. Raindrops are one of the most disruptive agents and artificial rainfall has frequently been used in the study of soil detachment. Very often the erosiveness of soils on equal slopes and with similar climate and cover will be directly related to the detachability of the soil. Attempts to find a simpler measure than rainfall to determine the detachability of soil brought about the use of two measures, aggregate stability and the dispersion ratio. The relationship of these latter methods to soil detachment by rainfall has been both good and poor in various studies.

Consequently, these three methods -- rainfall, dispersion ratio and stability of aggregates -- are used here in an initial study of the detachability of selected Utah soils. An attempt is made to estimate the detachability of these soils and to observe the relation, if there is one, between soil detachment, aggregate stability and dispersion ratio.

REVIEW OF LITERATURE

Factors Influencing Soil Erosion

Soil erosion is the final result of multiple factors which are of variable importance in different soils. Middleton and Slator (1935) gave the following diagrammatic outline of these factors.



Horton (1938) has stated that four factors must be taken into consideration in order to have a complete picture of erosion hazard, viz., pedologic, physiographic, hydrologic and hydraulic. Baver (1956) modified these concepts and added others to those he calls climate, topography, vegetation, soils and the human factor. In a schematic diagram (Figure 1) he shows the relationship of all these factors in erosion except for the human factor.

This thesis is concerned mainly with some aspects of soil erosion such as detachability and influence of soil cements.

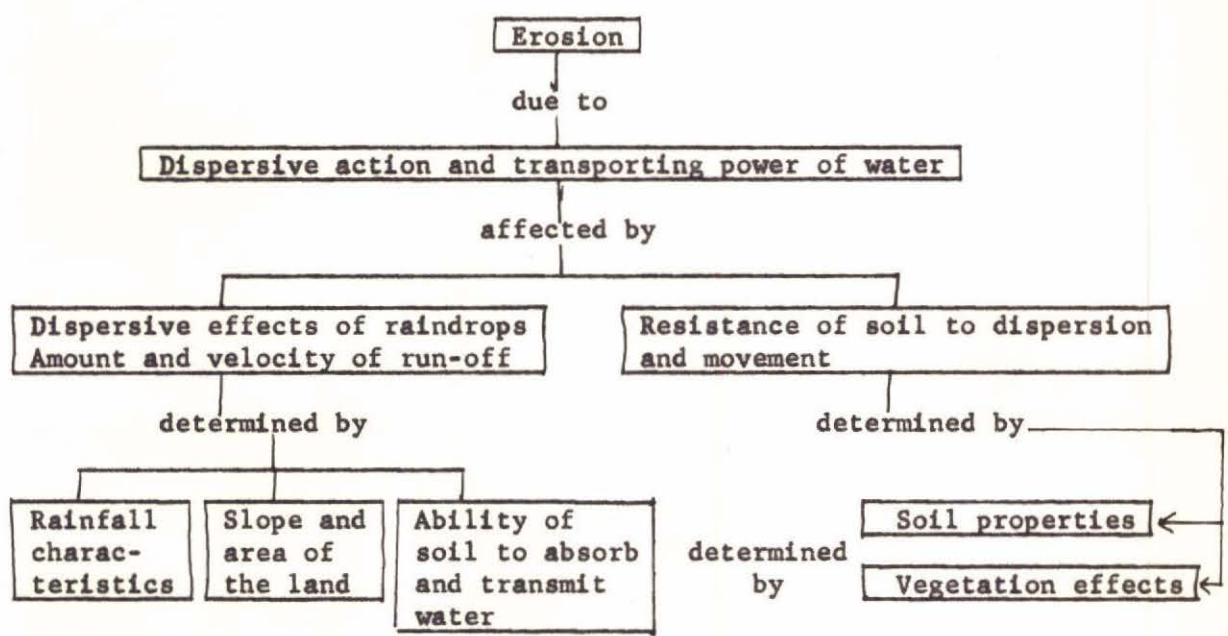


Figure 1. Factors influencing soil erosion (Baver, 1956).

The Process of Soil Erosion

Only in the last few decades has the knowledge of some factors of erosion become well known and been set down in detail. Ellison (1947a) did considerable work in this illuminating period of time. He divided soil erosion into two distinct categories, detachment and transportation. According to him, these two principal sequential events, detachment of soil particles and transportation of the detached soil particles, should be studied independently. The second of these processes, transportation, acts largely independently of soil detachment, although its effect may be increased by soil breakdown. Likewise, detachability of soil can be in large part separate from transportability. Only the factors involved in soil detachment will be reviewed here.

The Detachment of Soil

From studies of Ellison (1944b, 1947a, 1947b), it appears that, in general, the detaching capacity of an erosive agent can be related to the force of energy of the agent. Surface flow detachment is increased slightly by the increased run-off velocity but is increased markedly by an increase in amount of suspended soil particles. The major detaching agent is falling raindrops, and its effect is especially important in areas of high-intensity rainstorms. To a considerable extent, soil detachment is directly proportional to raindrop velocity and size; but it is also associated with soil characteristics that alter the raindrop effect.

Soil changes during rainfall

Ellison (1944b) concluded that there are three distinct effects of raindrop impact. First, soil aggregates are broken down. Second, there is some displacement and minor transportation of soil particles. Third, fine material is suspended into free water standing on or moving over the soil surface. Baver (1956) agreed with this general idea but added that initially the soil must become wetted before splash occurs, that raindrop impact causes the soil to be compacted, and the suspended particles in percolating water seal the immediate soil surface.

Bennett, et al. (1951) gave more detail. They emphasized the disturbance of the immediate soil surface. When raindrops fall on a dry soil, the air below the surface layer becomes trapped and retards downward movement of water. In dry clods and peds, the capillary forces pull water into the clods trapping and compressing air. They believed that the force of compressed air and the weakened aggregating agents (due to being wetted) results in disruption of the aggregates. The clods or peds then slake down to become a pasty mass with reduced permeability as the pores become clogged. The water on the soil surface contains more and more suspended soil, which is more abrasive than the clear water.

Mechanical force of rainfall

The impact of raindrops is related to the number and size of drops, added velocity due to wind (Neal and Baver, 1937) and to other factors. Laws (1940) stated that any given rain is composed of an almost unbelievable mixture of different-sized drops falling at different velocities.

It is largely this velocity of the drop (its kinetic energy) that causes its destructive force.

The kinetic energy of a drop is one-half its mass times its velocity squared. Thus, by knowing the size and velocity of the drops, the energy can be computed. Laws (1940) has developed an E/A (energy of raindrop divided by area) index which is shown to correlate highly with the concentration of soil in the run-off water and with the rate of infiltration. Laws (1941) and Laws and Parsons (1943) further found that the upper limit of drop size for intense rains was about 7 mm. in diameter. The maximum velocity of falling rain was calculated to be 20 miles per hr.

The velocity of artificial raindrops of different diameters falling from different heights has been determined by Laws (1941). For example, a raindrop of a diameter of 5.5 mm. and a fall of 3 meters developed a velocity of 6.86 m./sec. It was further observed that as drop diameter increased from 1 mm. to 5 mm., the infiltration rate decreased by as much as 70 percent and run-off increased about 1200 percent.

Ekern (1953) presented a comprehensive review of literature on the kinetic energy of natural rainfall. He represented the erosive features of impacting force by the following equation:

$$\text{Erosivity} = f \left[\frac{(\text{Precipitation intensity})(\text{time})(\text{drop mass/drop cross section})(\text{drop velocity})^2}{\text{cross section}} \right]$$

According to Ekern, the kinetic energy of falling rain ranges from 1000 to 100,000 times the work capacity of shallow sheets of run-off water because the velocity of falling rain (20 mph) exceeds by 10 and perhaps

by 100 times the velocity of shallow surface run-off (0.2 to 2 mph). Ekern (1954) later reported that the impact energy of rainfall was a nearly identical function of intensity and slope and that the additive energy of shallow flow and drop impact should approximate the 1.5 power of the storm intensity. He concluded that the erosivity of storms should be proportional to the additive kinetic energy from the impact of falling rain and shallow flow of water.

Nichols and Gray (1941) assuming the velocity of rain of 20 mph have calculated that 2 inches of rain on an acre would carry 194,900,000 ft.-poundals or 6,000,000 ft. lb. of kinetic energy. They stated that though this terrific energy is dispersed both from point of time and space, it is still extremely important.

Interrelationships of Detachment and Erosion

Detachment has been given as the first principal sequential event in the two-step soil erosion process. But no statement has yet been given as to whether or not erosion varies directly with the detachment. Actually erosion may or may not be closely related to ease of soil detachability.

Ellison (1945) has done a very convincing study using Keene silt loam. Erosion resulting from rainfall or surface flow, and a combination of the two, was determined with increasing time on a clover meadow plot and an adjacent bare-soil plot. Curves of soil loss against time were similar except that quantities of eroded material from the bare plots were about 40 times as great as those for the young meadow plot. A more unexpected finding was evidence indicating that detachment by raindrops

was a major factor in making soil transportable. After surface flow had removed the loose soil particles existing on the surface, soil protected from rainfall had minor erosion due to surface flow. But when the soil was not protected from rainfall, surface flow carried away large quantities of the soil.

Shreenivas et al. (1948) also agreed that raindrop splash and total erosion were closely related. Using Houston black clay they observed that the curves for soil splash and soil erosion were almost parallel. Only the magnitude was different. The splash curve had the higher values. They summarized that first, there is a high correlation between soil splashed and soil eroded, and second, all soil particles detached may not be transported. Osborn (1950) agreed with this first point stating that the amount of surface flow available to carry the detached and suspended materials is in general proportional to the splash.

In contrast to these ideas, Adam et al. (1958) claim a nonsignificant correlation between detachment and total erosion in Iowa soils.

To bring such disagreement together into a compatible theory it is necessary to go back again to soil properties influencing detachability. Ellison (1948) summarized these properties as follows:

Detachability may vary with (a) cohesive properties of soil, (b) shapes of particles that may affect their interlocking, (c) distribution of particle sizes that affect their interlocking, (d) sizes of particles as they may affect the smoothness of the surface that is exposed, (e) chemical properties of soil, (f) biological conditioning of the soil, and (g) physical condition of the soil.

After reviewing these factors and considering the results of other workers, it seems clear that soil splash or detachment might have a high degree of correlation with soil erosion in a single soil type.

But, since the factors mentioned by Ellison are likely to vary or change considerably from soil to soil, the relationship of detachment to soil erosion may not be good when many soil types are considered together.

Aggregation and Soil Cements

Lutz (1934) stated that soil structure is important in influencing soil erosion. He stated that the "non-erosive" nature of the Davidson clay was largely due to the high aggregation in the B horizon. The high percentage of the aggregates in the Davidson soil was larger than that in the erosive Iredell soil. Erosion difference was also due to a difference in type of aggregates. Elson and Lutz (1940) concluded that the better the aggregation, the less is the soil erosion. In line with this concept, Peele et al. (1945) found in Cecil clay loam and Dunhern sandy loam that as the degree of aggregation for <0.2 mm. size increased, the erosion ratio or susceptibility to erosion decreased.

Rai et al. (1954) have stated that the size of aggregates had the greatest influence on the erosion of soil. They observed that there was a highly significant negative correlation of erosion vs. percent water stable aggregates-2 mm. Ellison (1945, 1947c) has shown that there is a higher percentage of sand and aggregates smaller than 0.105 mm. in splash than in the original soil. He further found that runoff also contained more aggregates smaller than 0.105 mm. than were present in the original soil because the impact of raindrops broke down the larger aggregates in the soil. Yoder (1936) concluded that the erosion losses from strongly aggregated Cecil clay soil occurred primarily in the form of water stable aggregates and that larger aggregates eroded considerably less than the smaller ones.

Erosiveness of a soil is therefore closely associated with soil aggregation. Such aggregation depends upon soil texture, physical environment and the cementing agents that are present. Different soils will have the cementing agents--organic matter, iron, oxides, silica and alumina--in different proportions and of different importance. Each of the cementing agents, the soil texture and soil environment are considered separately.

Organic matter

Soil organic materials are prominent soil-cementing agents. Thus, they are important in erosiveness of soil. Bayer (1956) indicated that organic matter is conducive to the formation of relatively large stable aggregates and that the effect of organic matter is more pronounced in those soils containing the smaller amounts of clay (less than 25 percent). He stated further that organic matter appears to be more effective in causing the finer fractions to aggregate. Knoblauch et al. (1942) observed in Collington sandy loam that additions of organic matter did not increase appreciably the percentage of aggregates present in the eroded material but that these additions reduced the total soil and water loss. The erodibility studies performed by Peele et al. (1945) indicated that the organic aggregates rupture easily but that inorganic aggregates are resistant to rupture.

Iron oxide cementation

The importance of iron oxide in affecting the erosion characteristics of soils has not been evaluated sufficiently to date. Bayer (1956) stated that the irreversibility of colloidal iron hydroxide in lateritic soils

is the important factor in production of stable aggregates. Iron oxides make up a large percentage of these soils. Lutz (1937), however, did find a very close relationship between the amount of free iron oxide and the degree of aggregation for the silt and clay in Cecil, Davidson, Iredell and other soils of North Carolina. Lutz (1934) observed that the Iredell was erosive while the Davidson was relatively non-erosive. This difference was attributed to differences in percent, largeness and type of aggregates. In a later paper Elson and Lutz (1940) explained this. Their data indicated that chemically the Cecil and Davidson are very similar and are more lateritic than the Iredell. The electron microscopic examination of natural Davidson clay by Kroth and Page (1946) revealed that the aggregates are smaller and the crystal edges are shown with less details. Individual crystals of Davidson were found apparently coated with iron and aluminum oxides. Removal of these oxides destroyed the aggregates thus indicating that aggregation in Davidson clay soil is due to physical binding forces of these compounds.

Chesters et al. (1945) found in Kewaunee soil that iron oxide was of prime importance in smaller sized aggregate formation. They further observed that in the soils studied, iron oxide was exceeded in importance in aggregate formation only by the microbial gum fraction. They also found that in high clay soils (30 percent clay) the effect of clay in aggregate formation was exceeded by that of free iron oxide. Bouyoucos (1935) studied lateritic soils for their erodibility and stated that these soils with low clay ratios (high percentage of clay) are less erodible.

From the above discussion, it appears that iron oxides play an important role in forming stable soil aggregates in high clay soils particularly soils of lateritic nature (areas of high effective temperature and with adequate moisture).

Alumina and silica cementation

No data were found regarding the importance of alumina or silica as soil-cementing agents. However, it was felt that alumina or silica might also be an effective soil-cementing agent in some soils.

Soil texture and cementation

Woodburn and Kozachyn (1956) found in a group of Mississippi gully soils that splash erosion increased with increase in sand content of the soil material. This was believed due to decreased aggregate stability with increasing sand content. Ellison (1947a) stated that most sands and clays, in general, are of low erodibility. The clay is of low erodibility because it is difficult to detach. The sand is of low erodibility because it is difficult to transport. When the detachability rates of all samples from the same site were averaged and grouped by textural classes, Osborn (1950) observed that there was a general tendency for the detachability rate to decline from sands to clays to silts. Ekern (1953) concluded that the relative amount of transport increased from 30 percent for coarse sand to 100 percent for fine sand, and it was decreased from 100 percent for fine sand to 21 percent for silt.

Soil condition

Baver (1956) indicated that soil moisture was important in soil erosiveness. He claimed that an intense rain that fell on wet soil would have a pattern entirely different from that of the same type of rain that fell on dry soil. He found in Missouri soils that there was more runoff and erosion in April than in May because most of the rains in April fell on wet soil. King (1952), however, showed that even an extremely thin film of water on the soil surface absorbed the drop impact and greatly reduced the amount of soil loss. Cermuda and Smith (1954) found that with all natural aggregates in those soils of Puerto Rico which they studied the ease of destruction with water drops increased with decreasing initial moisture content, except that some completely saturated samples with no air-water interface were more easily destroyed than were aggregates at initial pF values of 2.3 or 4.2.

Pulverizing a soil greatly increased its detachability compared with the soil in the field condition or that sampled by natural cores (Woodburn, 1948). This was also found by Osborn (1950) who found that there was more variation in the detachability rates of the natural cores than of the pulverized soils. His results further indicate that detachability is more in pulverized soil than in natural cores of the same soil.

Measurement of Detachability

Several methods and modifications of methods for the measurement of soil detachability have been proposed. The two considered most often in erosion studies are first, the loss of soil by raindrop splash and second, the dispersion ratio.

Soil loss by splash

Ellison (1947b) is of the opinion that splashed material represents detached material and that soil splash can be used to represent the detachment caused by the impact of falling raindrops. He stated that while the splash does not represent an exact measure of soil detachment, methods can be used for measuring the splash which will make the difference between this measure and the detachment very small. He presents an equation in which the quantity of soil detached is proportional to the detaching capacity of the falling raindrops and the detachability of the soil. He represented this in the following form:

$$D_1 = D_2 \times D_3$$

where D_1 = the soil detachment hazard
 D_2 = the soil's detachability
 D_3 = the capacity of the erosive agent to detach soil

If the capacity of the erosive agent to detach soil is determined and is kept constant, the detachability of various types of soils can be compared.

According to Ellison (1947b) detachment of soils should be tested on undisturbed soil cores as well as on the screened soil from which all stones and firm clods have been removed.

Dispersion ratio

Puri (1930) first evaluated the dispersion coefficient using the 0.002 mm.-size particles as the point of division. Middleton (1932) evaluated the dispersion ratio similarly to Puri's dispersion coefficient except that he used the 0.05 mm.-size particles instead of 0.002 mm. as the point of division. There is, unfortunately, only a small amount of

work done on the relationship of dispersion ratio and detachment of soil. Middleton et al. (1932) has defined the dispersion ratio, expressed in percentage, as the ratio of total weight of silt and clay in the non-dispersed sample to the total silt and clay in the dispersed sample. They considered the dispersion ratio as the most valuable single criterion and suggested that the soils with a dispersion ratio more than 15 be classed as erosive soils.

The dispersion ratio is a function of the ease of dispersion and of the mechanical composition of the soil and thus it would express the relative erodibility of the soils. In other words, the dispersion ratio is a measure of aggregation. The lower this ratio, the greater is the percentage aggregation of the silt and clay. Thus, dispersion ratio gives the negative measure of the "degree of aggregation" of the finer mechanical separates. However, the relation between dispersion ratio and detachability or splash of soil is not well understood.

Ayres (1936) commented on Middleton's dispersion ratio as related to erodibility as below:

Probably the most significant single quality inherent in a soil is its dispersion ratio or the readiness with which individual particles go into suspension in water. Soils in which silt predominates with a corresponding shortage in clay exhibit this property to a marked degree as there is insufficient clay to serve as a binder. It should not be inferred from this, however, that a high percentage of clay is necessarily indicative of non-erosive soil. On the contrary, if most of the clay particles are of colloid size--0.002 to 0.005 mm. or less in diameter--it is probable that excessive swelling will occur when the soil is wet and excessive shrinkage when dry. Swelling will tend to reduce infiltration and shrinkage will open surface cracks and tend to create fragments which are easy to dislodge.

Kolodny and Joffee (1940) have stated that the dispersion is associated with a number of properties such as stability of small and large aggregates, phenomena of swelling of colloids, translocation of the finely dispersed fractions through the soil profile, etc. They further observed and discussed the relation between dispersion ratio and moisture content, the method of wetting and artificial pretreatment. Adams et al. (1958) have observed that the magnitude of the dispersion ratio was not a definite indication of the degree of susceptibility to erosion in Iowa soils. They found that there was no significant correlation between dispersion ratio and splash erosion or wash erosion in Iowa soils.

Summary of Literature Review

In summary, the detachment by raindrops is considered to be the major factor in making soil transportable. Splash or detachment alone might be related to soil erosion in a single soil type, but there may not be any relation of splash to erosion when different soils are used. Erosiveness of soil is closely related with size and type of aggregates. Splash erosion losses decrease as the percentage of water stable aggregates increases.

Formation of large stable aggregates is believed due to addition of organic matter in soils containing less than about 25 percent of clay. As the percentage clay increases, free iron oxides are believed to be more effective as a binding agent in soils. But no references of value were found concerning the importance of silica and alumina in soil aggregation.

Splash erosion apparently increases with an increase in sand content of soil material, at least of fine sands. The relation between the clay content of soil and splash erosion depends upon the extent and nature of soil aggregation and condition. A thin soil moisture film on the soil surface has been shown to greatly reduce the amount of soil loss. Soil splash is also increased by pulverizing the sample. Splashed material is believed to represent the measure of detachability of soil.

It is suggested that soils having a dispersion ratio (for the <0.02 mm. size) greater than 15 be considered of an erosive type. The correlation between the dispersion ratio and splash erosion has been both good and poor and no clear relationship is obvious.

Objectives

The main objectives of this investigation were:

1. To determine the detachability of different selected soils in the Northern Utah area.
2. To correlate data for the dispersion ratio and the aggregate stability with the splash erosion.
3. To evaluate the potential erodibility of each soil site by taking into consideration the detachability studies in various soil conditions and actual site characteristics.
4. To study the relationship between the effectiveness of the cementing materials and the splash erosion.

EXPERIMENTAL METHODS AND PROCEDURES

Field Methods

Undisturbed soil core samples were taken by means of samplers designed to avoid compacting or disturbing the structure of the soil. The soil sampler was prepared according to measurements and suggestions of Woodburn and Jones (1946). Metal cylinders 3.5 in. in diameter and 2 in. deep were prepared with the lower edge sharpened with an outside bevel. This metal cylinder was driven into the soil by means of a special driving head until the upper edge of the cylinder was flush with the soil surface. Care was taken not to allow the driving head to touch or disturb the soil in the core. The cylinder with the undisturbed soil core in it was then lifted with a shovel and the soil was cut flush with the bottom of the cylinder. The cylinders with the soil cores were kept in air-tight containers until the detachability tests were run. Five such samples were taken at each site. The disturbed soil representing the top 2 in. was collected at the same time at each site for moisture, physical, and chemical determinations.

The description of each site regarding the cover, soil condition, visible soil erosion status, slope, sampling place, and other information was recorded at the time of sampling and is given in the appendix.

Laboratory Investigations

Splash analysis

Rainfall applicator and turntable.--The raindrop applicator was prepared as proposed by Ellison (1944a) and modified by Goodman (1952). It consists of a metal water pipe frame 5' x 5' fitted with four fine spraying nozzles (mist spray system with standard oil-burner type nozzles were used here) each being at the center of one side. A drip screen was made by stretching a 2-in. mesh poultry netting over a strong wooden frame. A single layer of muslin cloth was laid over the screen and punched through the holes in the wire mesh to form pockets of uniform depth. The muslin cloth was then stitched strongly in place at the edges. One end of a 2-in. length of cotton yarn was stitched at the center of each pocket and left hanging. The drop screen was suspended 1 foot below the water pipe frame.

A rotating table was also prepared in order to have a uniform rain on all soil samples (Figure 2). The turntable was made to rotate at the rate of five revolutions per min. The table diameter was 4 ft. with splash samples on a 1.5 ft. radius. Thirteen compartments were prepared on the table in order that the splash of one soil may not go to another splash cup.

Splash cups.--Splash cups were prepared about the same size as that of the cylinders which were used for taking undisturbed soil cores (Figure 3). The splash cups were about 3.5 in. in diameter, large enough for the cylinders to be fitted inside the splash cups. The splash cup had a depth of 1.75 in. and at the bottom had circular metal rings fixed for the purpose of fitting the splash cup in the mouth of



Figure 2. Rotating turntable.



Figure 3. Splash cup and cylinder. 1. Splash cups. 2. Splash cup fitted on jar for testing disturbed soil samples. 3. Cylinder with undisturbed soil core fitted over splash cup.

the bottle. The bottom of the splash cup was perforated. In the center, a slit of 1 in. was made in order to insert a wick. Absorbent cotton was put on the perforated bottom. The quartz sand which was sieved through 30 mesh and washed clean was spread over the cotton for good drainage. The splash cups thus prepared were used for splash of undisturbed soil cores by fitting the cylinders with undisturbed soil into them. For splash of disturbed sieved soil, the sieved soil was put in the space above the sand. For splash of standard sand, the standard sand was placed in the cup over coarse sand.

Preparation of standard sand.--The sand which passed through a 60-mesh sieve but which was retained on 80-mesh sieve was saved. It was washed 3-4 times with tap water, and then washed with strong HCl by soaking it overnight. The supernatant acid was decanted and the fine dirt layer was scraped from the top of the sand. The sand then was washed on 80-mesh sieve with water several times and finally with distilled water. The sand retained on the 80-mesh sieve was oven-dried. The particle size of this sand may range from 0.246 to 0.175 mm. in diameter (Ekern et al., 1948). This standard sand was then used to fill the cup to the rim over coarse sand and was used for splash analysis.

Rainfall application and its characteristics.--The distance from the lower end of cotton yarn of the drip screen to the upper rim of the splash cup was 11 ft., and the average diameter of raindrop was 5.36 mm. Hence, the fall velocity of raindrop was about 7 meters per sec. or approximately 23 ft. per sec. (Laws, 1941).

Rainfall was applied for 30 min. The average rain measured was from 1.03 to 1.39 in. The average of all rains applied was 1.17 in. in 30 min.

The underside of the drip screen and the cotton yarns were moistened thoroughly first, and then the water was allowed to run through the nozzles for fine spray. When there was uniform rain, the oilcloth which covered turntable and samples was pulled out and the time of starting was noted. At the end of 30 minutes, the oilcloth was again put over the turntable, and the rainfall application stopped. The turntable rotated at the rate of five revolutions per minute while rain was falling on soil samples.

Soil splash analysis.--The splash cup with wick, cotton and coarse sand was oven-dried, cooled in desiccator and weighed. The air-dried soil (treated or untreated soil) or the undisturbed soil core on which moisture percentage was determined was placed in the splash cup and weighed. From the determined moisture percentage, the oven-dry weight of the whole system was calculated. This splash cup was then fitted on the quart-size fruit jar keeping the wick dipping in water in the jar. These jars with the splash cups fitted on them were placed at random, one in each compartment on the turntable. Two splash cups with the standard sand were prepared in the same manner and were placed on the turntable with each set of nine soil samples. Two rain gauges were also put on the turntable to measure total rainfall for each splash analysis run. After exactly 30 minutes of rainfall, the water collected in two rain gauges was measured immediately. The splash cups were taken from the bottles, and the outer sides of the cups

were washed to remove splashed soil. These splash cups were oven dried at 110° C. for 45 hours in case of disturbed soil and for 65 hours for undisturbed soil cores. (A preliminary study of drying to constant weight indicated these times were needed.) The splash cups were then weighed after cooling in a desiccator and the loss of soil due to the splash was calculated.

Procedures for removal of binding agents from the soils

Removal of organic matter.--Organic matter was removed from the soil by 30 percent H_2O_2 . In the first set of samples (one sample of each site) lime was not removed by treatment with HCl. For the second and third sets, the lime was removed by HCl previous to organic matter removal by 30 percent H_2O_2 . The procedure (Jackson, 1956) that follows was used.

A 75 gm. sample of soil was placed in a 600-ml. beaker, moistened with water and warmed up to 60° C. after addition of a few ml. of H_2O_2 . Additions of H_2O_2 and warming were repeated till there was no reaction. The supernatant liquid was then filtered, and the soil washed with water. The soil was then air-dried, sieved through a 2-mm. sieve and placed in the previously weighed splash cup and weighed again. At the same time, moisture determinations were made.

Removal of iron oxide.--Free iron oxide was destroyed and removed according to the method of Jackson (1956). Ninety gm. of soil (2 mm.-sieved) was placed in a 600-ml. beaker, and 360 ml. of sodium citrate (0.3M) and 45 ml. of sodium bicarbonate (1M) were added. The mixture in the beaker was then heated slowly over a low flame. When the temperature of the contents was raised to $70-75^{\circ}$ C., 9 gm. of sodium

dithionite ($\text{Na}_2\text{S}_2\text{O}_4$) were added slowly with a measuring spoon. The temperature of the contents was maintained within $75^\circ\text{-}80^\circ\text{ C.}$ by constant manual stirring for 15 minutes. The beaker was then cooled.

The supernatant liquid was filtered, and the soil washed with distilled water five times and filtered. The filtrate was collected and measured. A 500-ml. portion of this filtrate was kept for iron determination, and the remaining solution was discarded.

The iron oxide cleaned soil was air dried and then was gently crushed by hand with a mortar and pestle to pass through a 2 mm. sieve. A small portion of each sample was weighed and put in the oven for moisture determinations. At the same time, previously weighed splash cups were filled with this material and tested for splash.

Removal of colloidal silica.--The method used was similar to the one adopted by Jackson (1956). To 150 gm. of 2 mm. sieved soil in a 600-ml. beaker was added 200 ml. of 2 percent Na_2CO_3 . The contents were stirred gently and warmed to 65° C. on a hot plate for about half an hour. The beaker was then cooled, and the supernatant removed. Another 100 ml. of 1 percent Na_2CO_3 was then added, and the mixture was stirred and warmed up to 65° C. for about half an hour. The mixture was cooled, and the supernatant removed. Finally 20 to 30 ml. of distilled water was added, and the mixture stirred slowly. The contents including the 150 gm. of soil were divided and transferred to four centrifuge tubes. About 10 ml. of saturated solution of NaCl were added to each tube and mixed well by slow stirring. The volume was then made to about 150 ml. volume by adding distilled water. These bottles were centrifuged for about 5 minutes. The supernatant

liquid was discarded, and 20 to 30 ml. of distilled water and 10 ml. of 10 percent magnesium acetate were added and mixed slowly by stirring. The volume was then made up to about 150 ml. by using distilled water and centrifuged for about 5 minutes. The supernatant liquid was discarded. The soil was then washed with water and air dried. The dried soil was carefully crushed by hand with a mortar and pestle to pass through a 2 mm. sieve. The moisture determinations were made on the soil at the time it was placed in splash cups for splash determinations.

Dispersion ratio

The dispersion ratio of the chemically treated and untreated samples, which were crushed by hand in a mortar and passed through a 2 mm. sieve, was determined for 0.1 mm. and 0.02 mm. size fractions. A modified pipette analysis was used for both the chemically dispersed and non-dispersed sample. The method was similar to that adopted by Adams et al. (1958). A sample of air-dry soil equivalent to 10 gm. of oven-dry soil was weighed and placed in a 1000 ml. cylinder. After making to a total volume of 1000 ml. with distilled water, the cylinder was tightly stoppered and shaken. The stop watch was started just when shaking was started. After 30 times of end-over-end shaking in 60 seconds, the cylinder was placed under the fixed pipette. A pipette withdrawal was made at 10 cm. depth at the required time interval for 0.1 mm. and 0.02 mm. size fractions to have settled below 10 cm. Quantitatively the pipetted sample was transferred to a clean, small, previously weighed stainless steel can and oven dried for 24 hours at 105° C. The

oven-dried sample was cooled in a dessicator and weighed on an analytical balance to 0.0001 gm.

A similar procedure was followed for the chemically dispersed analysis. Ten grams of oven-dry sample were placed in a high speed mixer cup, 250 ml. of distilled water was added to the cup, 10 ml. of sodium hexameta phosphate solution (35.7 gm. of sodium metaphosphate and 7.94 gm. sodium carbonate in 1 l. of solution) was added by pipette, and the suspension was mixed for 10 minutes. The sample was transferred quantitatively to the 1000 ml.-cylinder, and the volume made to 1000 ml. with distilled water. The same procedure as used for non-dispersed soil was followed from this step on.

The dispersion ratio was then calculated according to Middleton's method (1930) as:

Dispersion ration =

$$\frac{\text{gm. oven dry material } < 0.1 \text{ (or } 0.02) \text{ mm. chemically non-dispersed}}{\text{gm. oven dry material } < 0.1 \text{ (or } 0.02) \text{ mm. chemically dispersed}} (100)$$

The dispersion ratio was determined for the following soil treatments:

1. Original soil.
2. Soils from which organic matter was removed.
3. Soils from which iron oxides were removed.
4. Soils from which colloidal or amorphous silica was removed.

Percent breakage of aggregates > 0.1 mm. into soil particles < 0.1 mm. of stable aggregates

The method used was exactly the same as that for determination of

the dispersion ratio. The formula for calculation, however, was different and was derived in the following manner:

$$Z = 1000(X - Y)$$

where, Z = percentage of aggregates >0.1 mm. that break into <0.1 mm. size particles.

X = oven-dry material <0.1 mm. chemically dispersed.

Y = oven-dry material <0.1 mm. chemically non-dispersed.

The factor 1000 results from diluting a sample of air-dry soil equivalent to 10 gm. of oven-dry soil in a 1000 ml. cylinder to 1000 ml. by adding distilled water and taking a pipette withdrawal of 10 ml.

The percentage of true water stable aggregates is equal to $100-Z$.

Mechanical analysis

Mechanical analysis was done for sand, silt and clay (International Society of Soil Science classification) by the pipette method. A sample of air-dried soil, equivalent to 10 gm. of oven-dry mineral soil, (organic matter was previously removed by H_2O_2 treatment) was placed in a mixer cup. Ten ml. of sodium hexametaphosphate solution (Calgon, same as that used in the dispersion ratio analyses) was added to the mixer cup and 250 ml. of distilled water added. The sample was mixed by the stirrer for 10 minutes, quantitatively transferred to a 1000 ml. capacity cylinder, and made to 1000 ml. The cylinder was then stoppered and inverted for 30 times in 60 seconds. Withdrawal by the pipette was made at a 10 cm. depth at the required time interval for 0.02 mm. and 0.002 mm. size fractions. Care was taken to keep the cylinders in constant room temperature in order to avoid mixing by convection heat

currents. The percent of sand was calculated by subtracting total percent of silt and clay from the mineral soil weight.

Chemical determinations

Organic matter.--Organic matter contents were determined by using the method described in the U.S.D.A. Agricultural Handbook No. 60 and modified by James P. Thorne, who has supervision of the Soil Conservation Service Co-operative Laboratory in Logan, Utah.

Subsamples of each soil were ground by hand in a mortar and passed through a 40-mesh sieve. A 0.250 to 1.000 gm. sample of the mixed soil was placed in a 400 ml. beaker, and 10 ml. of potassium dichromate was added with an automatic pipette. The beaker was swirled to wet the soil, 20 ml. of concentrated sulphuric acid added by an automatic dispensing burette, and the mixture swirled. The beaker was then placed in a hot sand bath and heated for one minute to 150° C., cooled to room temperature and made approximately to 200 ml. with distilled water. Twenty-five ml. of ferrous ammonium sulfate solutions $[\text{Fe}(\text{NH}_4)_2(\text{SO}_4)_2]$ was added to the beaker by means of an automatic pipette, the beaker placed over a light and standardized KMnO_4 added from a burette until the color just changed from the green to a slight purple-red which persisted. Blanks were run and treated in the same manner.

After subtracting the blank reading, the percent of organic carbon was calculated by the following relation:

$$\% \text{ organic matter} = \frac{(0.003)(\text{ml. KMnO}_4)(\text{normality of KMnO}_4)}{(0.89)(\text{Sample weight, g.})} (100)$$

The organic matter content was determined in the original soil of all

series and in selected samples after removal of organic matter, iron oxides and silica and alumina.

Free iron oxides.--The standard Fe solution was obtained by dissolving 0.05 gm. of pure iron wire in 10 ml. of 0.6N HCl and 1 ml. of conc. HNO₃ and adjusting the volume to 1 l. The solution contains 50 mgm. of Fe per ml.

The method used for iron was adapted by Jackson (1956). In this method, ferrous iron is obtained by reducing free iron oxide coatings by sodium hydrosulphite (Na₂S₂O₄) in a sodium citrate buffer solution. By dropwise addition of hydrogen peroxide the citrate and dithionite ions are then destroyed. The peroxide also oxidizes iron to the ferric state. The concentration of iron is then determined colorimetrically at 490 mμ wavelength in hydrochloric acid solution using 20 percent KSCN. The percentage iron was determined from the standard curve obtained with the standard iron solutions.

RESULTS AND DISCUSSION

Detaching Capacity of Falling Raindrops

Efforts were made to test the soils for their detachability under identical rainfall patterns but this was quite difficult. However, it was possible to obtain a relationship between the detaching capacity of the raindrops during each determination and the splash of the standard sand. This was close to a straight-line relationship as shown by Figure 4. Although some scatter is apparent, the relationship is good and the correlation coefficient is highly significant ($r = 0.825^{**}$).

From Table 1 and Figure 4, it is seen that splash runs No. 1, 2, 6, 7, 8, and 16 deviate more than the others from the regression line. Some observations during each of these splash analysis runs might help explain some of these greater deviations. The rainfall applicator was fixed in a partially open shed. Effort was made not to run the splash when the atmosphere was windy. However, the wind velocity increased after splash run No. 2 was started. The increased wind velocity might have been additive to rainfall intensity which would cause greater splash than that expected.

During splash runs 7 and 8, hot water was passed into the tap end of the long delivery hose pipe so that water entering the rainfall applicator would not be at freezing temperature. However, while falling through the yarn threads, the low temperature in the shed

Table 1. Mean splash of standard sand due to various rainfall intensities

Splash No.	Rain in./0.5 hr.	Splash gm.
1	1.30	41.8
2	1.39	50.4
3	1.28	45.6
4	1.23	45.2
5	1.03	37.9
6	1.09	37.8
7	1.09	42.0
8	1.13	43.5
9	1.12	40.5
10	1.17	42.6
11	1.10	42.0
12	1.24	43.2
13	1.22	41.8
14	1.13	40.1
15	1.17	44.0
16	1.11	37.7
17	1.10	40.0

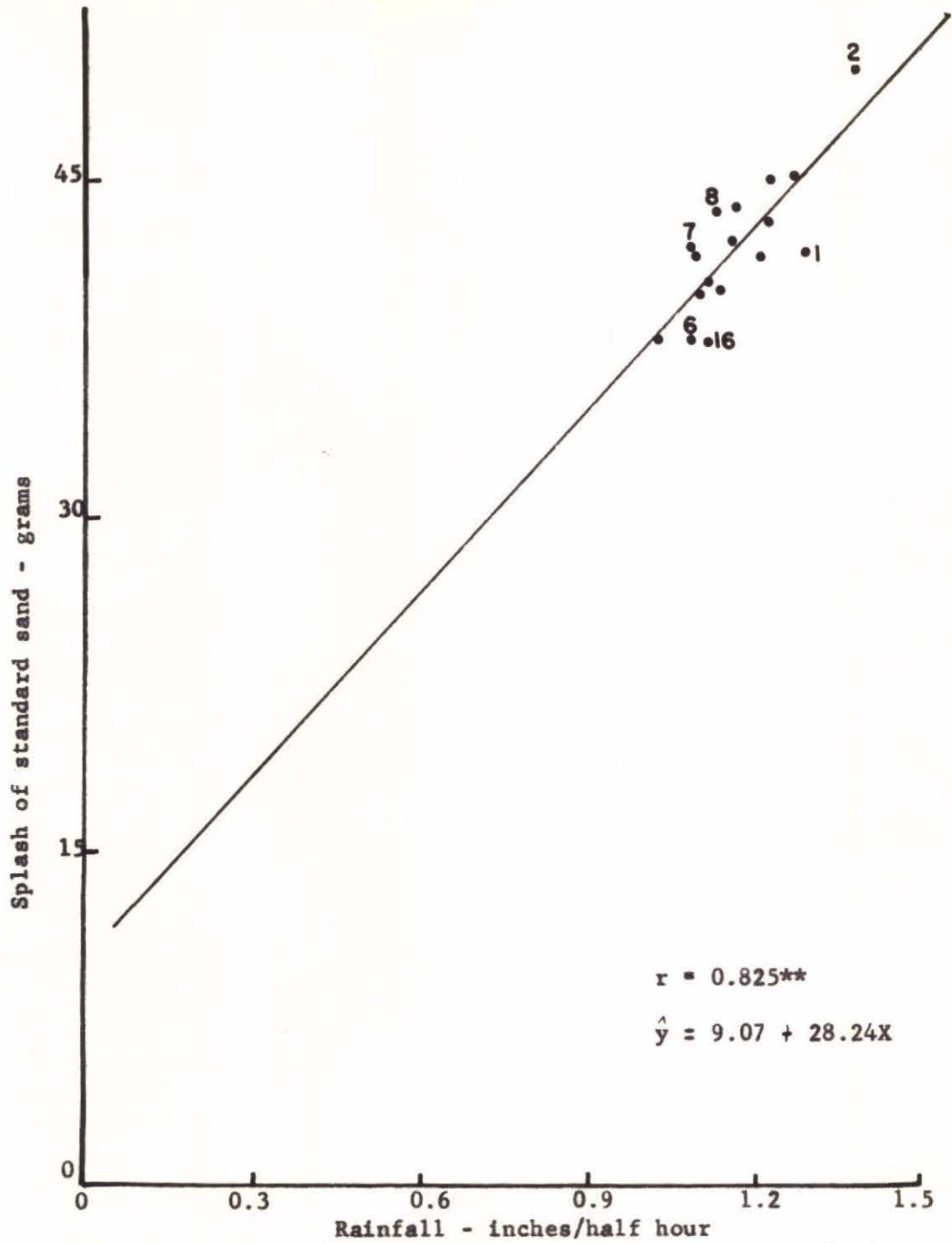


Figure 4. Mean splash of standard sand in grams in relation to the amount of water applied in 30 minutes with a raindrop applicator.

appeared to affect the pattern of raindrops. This possible change in pattern of raindrops might have caused the splash to be different.

In all other cases except splash run No. 16, the difference in the two rain gauges in each run was 0.02 to 0.06 in. For run 16, the difference in the gauges was 0.11 in. Hence, the rainfall appears not to be very well distributed in splash No. 16. The reason for this deviation is not apparent.

In general the standard sand (60-80 mesh) used in this study had splash losses in proportion to the amount of rainfall applied for the one-half hour period. The value of the splash in these cases would be a measure of the detaching capacities of corresponding rain.

However, these values alone would not represent the full amount of detachment because the sides of the cup interfere with the splashing particles when the level of the sand is lowered. Thus, the amount of splash would be higher if corrected by Bisal's formula (1950) which takes into account the depth from the cup's rim to the sand level in calculating the actual splash. Measurements of detaching capacity in these evaluations were not corrected by Bisal's formula as only comparative studies in detachability of different soils were done and the corrections would be relatively small.

Splash Erosion

Detachability of undisturbed soil cores

Table 2 presents the amount of splash obtained after different treatments and corrected to 1.2 in. of rainfall in a one-half hour period. The values in Table 2 are the means of two observations in

Table 2. Means of soil and standard sand splash in grams corrected to 1.20 inches of rainfall within one-half hour

Soil condition	Moisture treatment	Soil									Standard sand
		Sinks	Franklin	Mendon	Manila	Avon	Wheelon	Garr	Mud flat	Trenton	
Undisturbed	Field moisture	8.1	15.7	14.1	1.6	14.8	11.7	14.5	22.7	13.5	41.1
Undisturbed	Saturated	8.2	10.8	10.2	4.0	10.5	7.8	29.5	19.9	15.5	43.6
Disturbed	Air-dried	15.0	14.8	16.2	16.2	13.8	14.4	13.7	16.8	21.3	44.0
Disturbed	Saturated	17.7	16.3	17.4	16.6	15.9	13.8	13.8	18.4	24.9	43.5
Organic matter removed	Saturated	12.8	8.8	11.4	11.1	8.7	14.4	7.5	13.3	25.2	41.5
Iron oxides removed	Saturated	18.3	17.1	13.6	19.0	10.6	19.8	12.0	23.8	14.8	43.9
Silica removed	Saturated	16.9	15.8	24.3	17.0	20.3	20.4	15.6	16.4	36.5	42.2

each treatment. Some cores were tested for splash at field moisture, and some were tested after the cores were saturated.

The soils appear to be divided into three distinct groups: (1) Soils which splashed in equal amounts at both of the initial moisture conditions, viz., Sinks; (2) soils which splashed more when saturated than when at the field moisture content, viz., Manilla, Garr and Trenton; and (3) soils which splashed less at saturation than at field moisture, viz., Franklin, Mendon, Avon, Wheelon and Mud flat area.

The moisture percentage in the Sinks soil (first group) at sampling time was quite high (Table 3) and possibly because of this equal amounts of splash occurred when run in the field condition and when initially saturated in the second group of soils, reduction in infiltration capacities and cohesion due to presaturation might have caused more splash at saturation than that at field moisture. But an explanation for the splash of the third group is not readily apparent. Three of these soils are high in organic matter and well aggregated. The other two soils (Avon and Wheelon) are well aggregated and friable. In general, if both moisture conditions are averaged, the Mud flat and Garr soils had the greatest splash and the Manilla soil splashed least.

Clay content of the soils (Table 4) was plotted against the splash of undisturbed cores at saturation (Figure 5). The correlation was found to be insignificant. However, the data indicate that the higher the clay content, the lower the splash erosion if the two groups based on clay content, as indicated in Figure 5, are considered separately. It is interesting to note that the opposite relationship is obtained when organic matter or silica material was previously removed (Figures 6 and 7).

Table 3. Moisture percentage at the time of starting splash analysis

Soil condition	Sinks	Franklin	Mendon	Manila	Avon	Wheelon	Garr	Mud flat	Trenton
Undisturbed cores	23.3	25.9	6.9	9.3	5.3	4.7	3.7	16.1	9.3
Disturbed	2.3	3.4	3.5	2.7	2.8	3.0	2.2	3.9	3.4

Table 4. Mechanical analysis (International system of separate sizes)

Size fraction	Sinks	Franklin	Mendon	Manila	Avon	Wheelon	Garr	Mud flat	Trenton
Sand 2 - 0.02 mm.	42.1	40.3	25.3	47.8	38.1	37.0	37.3	28.2	9.2
Silt 0.02 - 0.002 mm.	30.0	37.0	49.0	23.5	26.8	32.9	32.1	26.6	36.9
Clay Below 0.02 mm.	27.9	22.7	25.7	28.7	35.3	30.1	30.7	45.2	53.9
Textural class	loam	loam	loam	sandy clay loam	clay loam	clay loam	clay loam	clay	clay

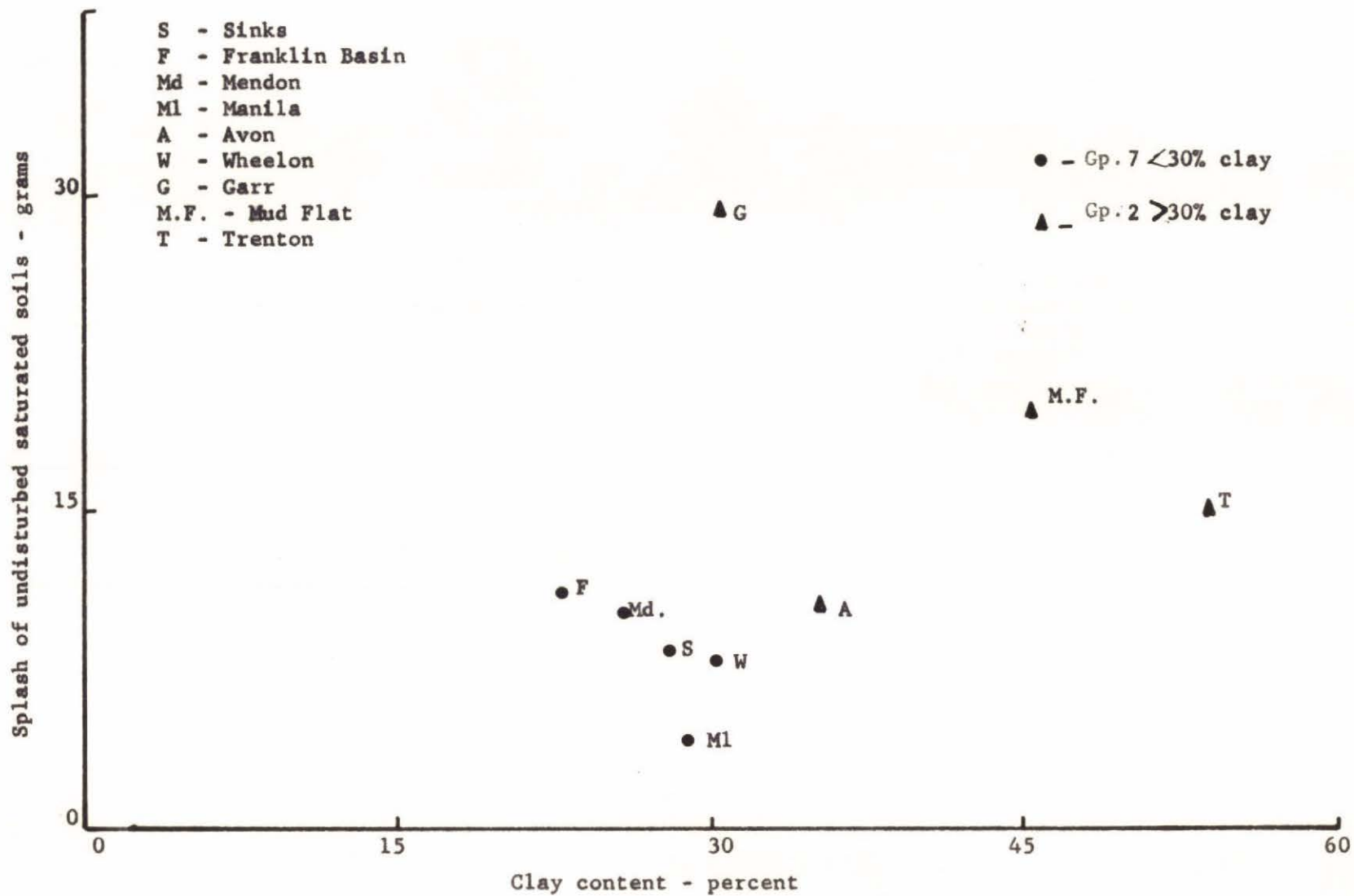


Figure 5. Relation between clay content and splash erosion of undisturbed saturated cores.

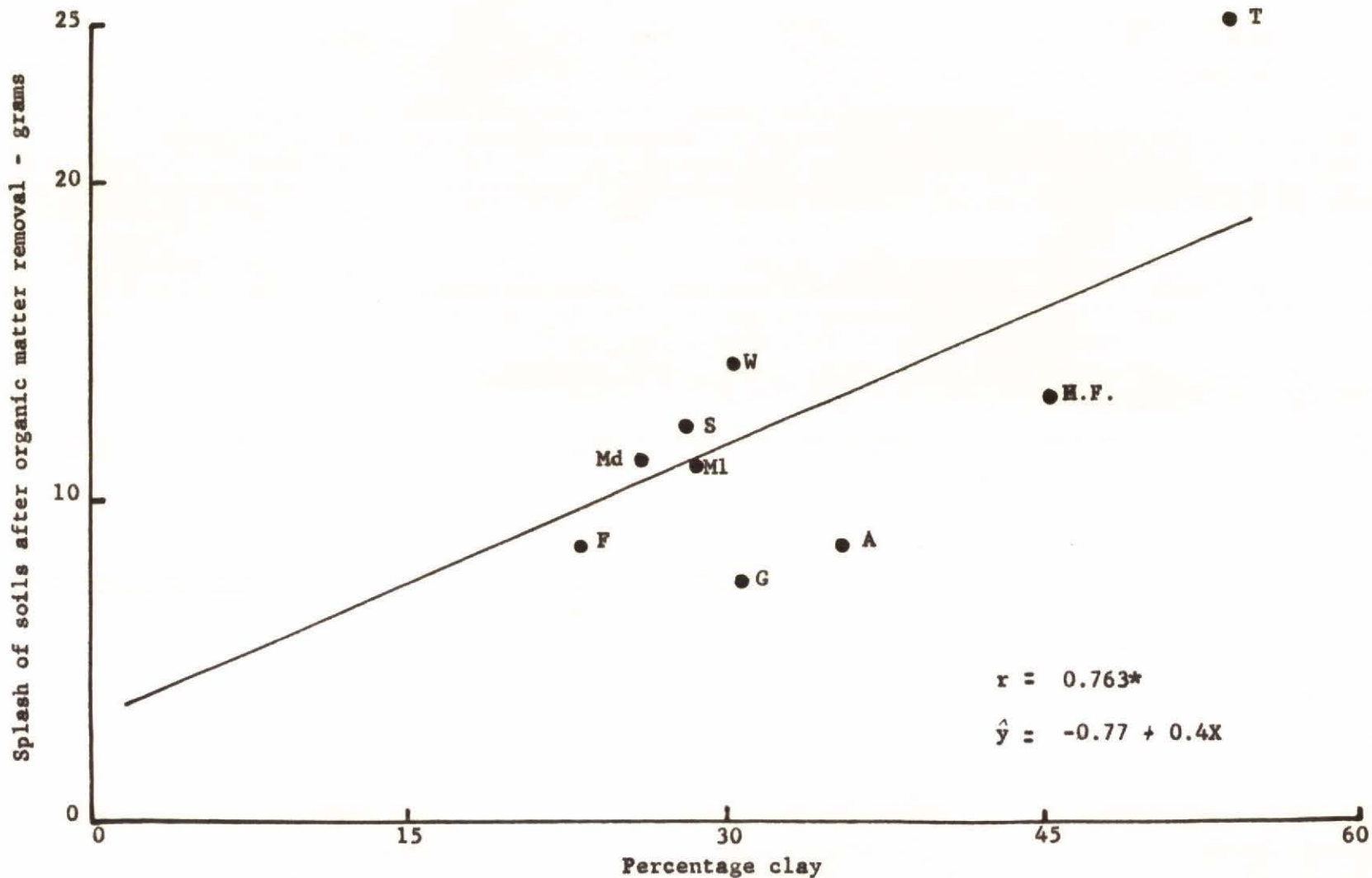


Figure 6. Relation between clay content and splash of soils after organic matter was removed.

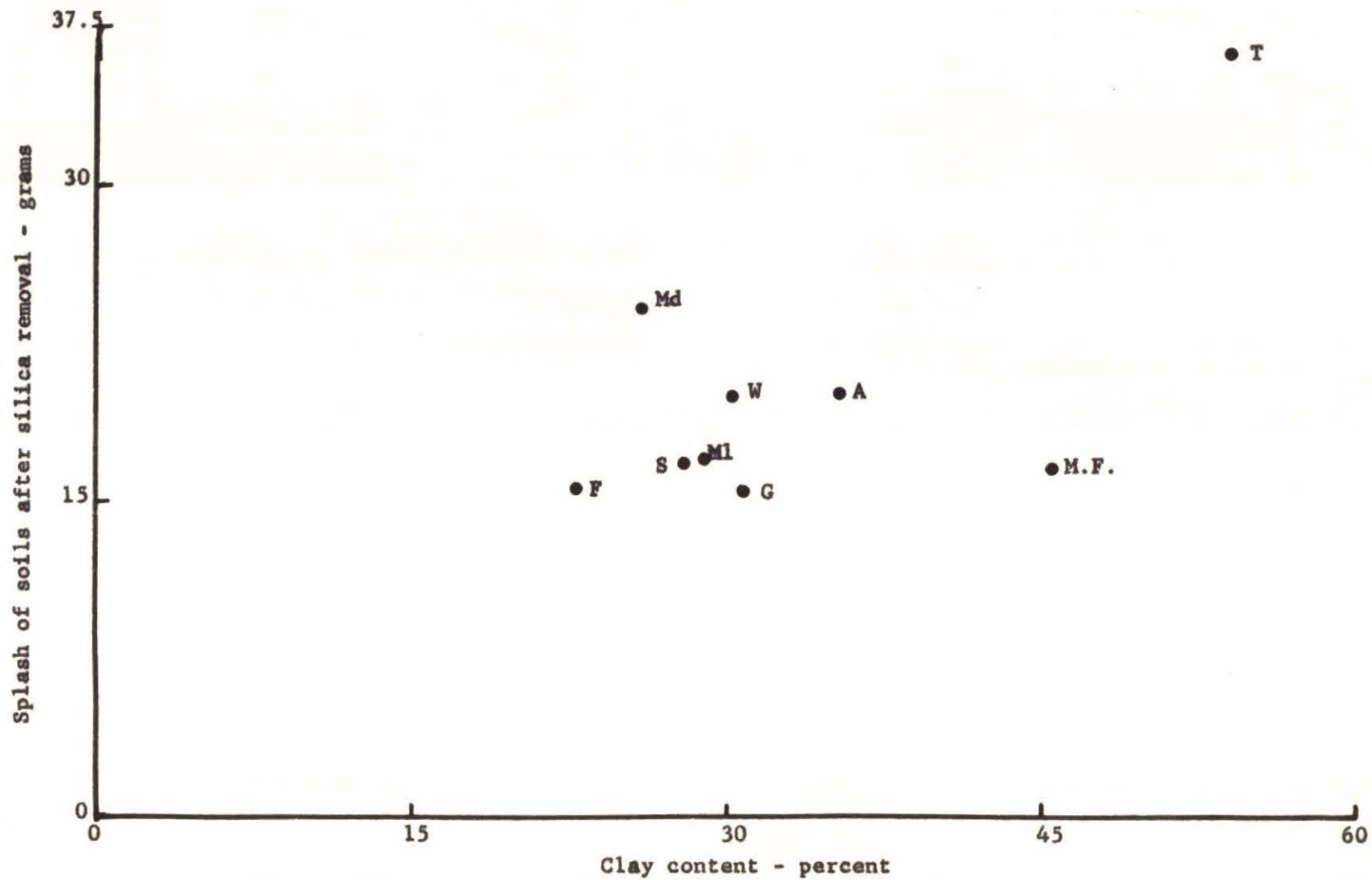


Figure 7. Effect of clay content on splash of soils after silica was removed.

This is explained as being the result of the fact that when the binding agent is taken out, clays would be easier to detach.

Detachability of disturbed soil samples

The splash of disturbed soil samples irrespective of initial moisture condition was found to be more than that in undisturbed cores in all series except in Garr and Mud flat (Table 2). No explanation is offered for these latter two soils except possibly uneven packing of these soils in the cups.

It is interesting to note that for disturbed soil the effect of initial moisture content on the amount of splash was very small. This is in direct contrast to the marked effect of initial moisture on splash of soil from the undisturbed cores. The reason for this is not apparent. It could be suggested that presaturation of the sample loosens binding forces making splash of soil greater. But the loose disturbed samples which were saturated had little or no different splash than the air-dry disturbed samples. Also saturation of many of the soil cores resulted in a decreased splash loss.

Although the average splash loss is generally greater in disturbed soil, the variation between high and low splash losses is much greater in the soil cores. It would be expected that natural cores might have more variable compaction and structure than the disturbed sample. Likewise, the influence of initial moisture would be expected to cause greater influence on splash of natural cores than on disturbed soil if the swelling and disruption due to wetting is important.

Detachability of soils with cementing materials removed

Splash of soils with organic matter removed.--As compared to the splash of disturbed soil in the saturated condition, all soil series except Trenton and Wheelon had less splash loss after organic matter was removed (Table 2). This was unexpected, since disruption of aggregates should result and therefore allow maximum splash of soil. The smaller amount of splash after organic matter was removed might be due to the increased stickiness and reduced permeability of the soil during the rainfall impact. It was observed that the soil particles instead of being detached were sticky and that the raindrop water accumulated in the splash cups on the soil surface. Since the soils used in this study are loams to clays in texture, stickiness and soil impermeability might have been increased due to mechanical agitation during hydrogen peroxide treatment. The inhibiting of soil splash by a thin water layer on the soil surface has been noted by King (1952).

Figure 8 indicates a fair correlation ($r = 0.851^{**}$) between splash of soil before and after organic matter was removed. A look at the data of Table 2 indicates that the highly aggregated and "fluffy" soils (Franklin, Mendon, Manilla, Avon and Garr) had greatest reduction of splash loss after removal of organic matter, the two soils seeming by color and appearance to have been little affected by organic matter (Trenton and Wheelon). The Trenton soil which is a high-clay soil was very sticky in the natural condition and actually has a slight increase in splash after organic matter removal. This would further substantiate the idea that the soil fineness after organic matter removal reduced splash loss by allowing water to puddle on the soil surface during splash.

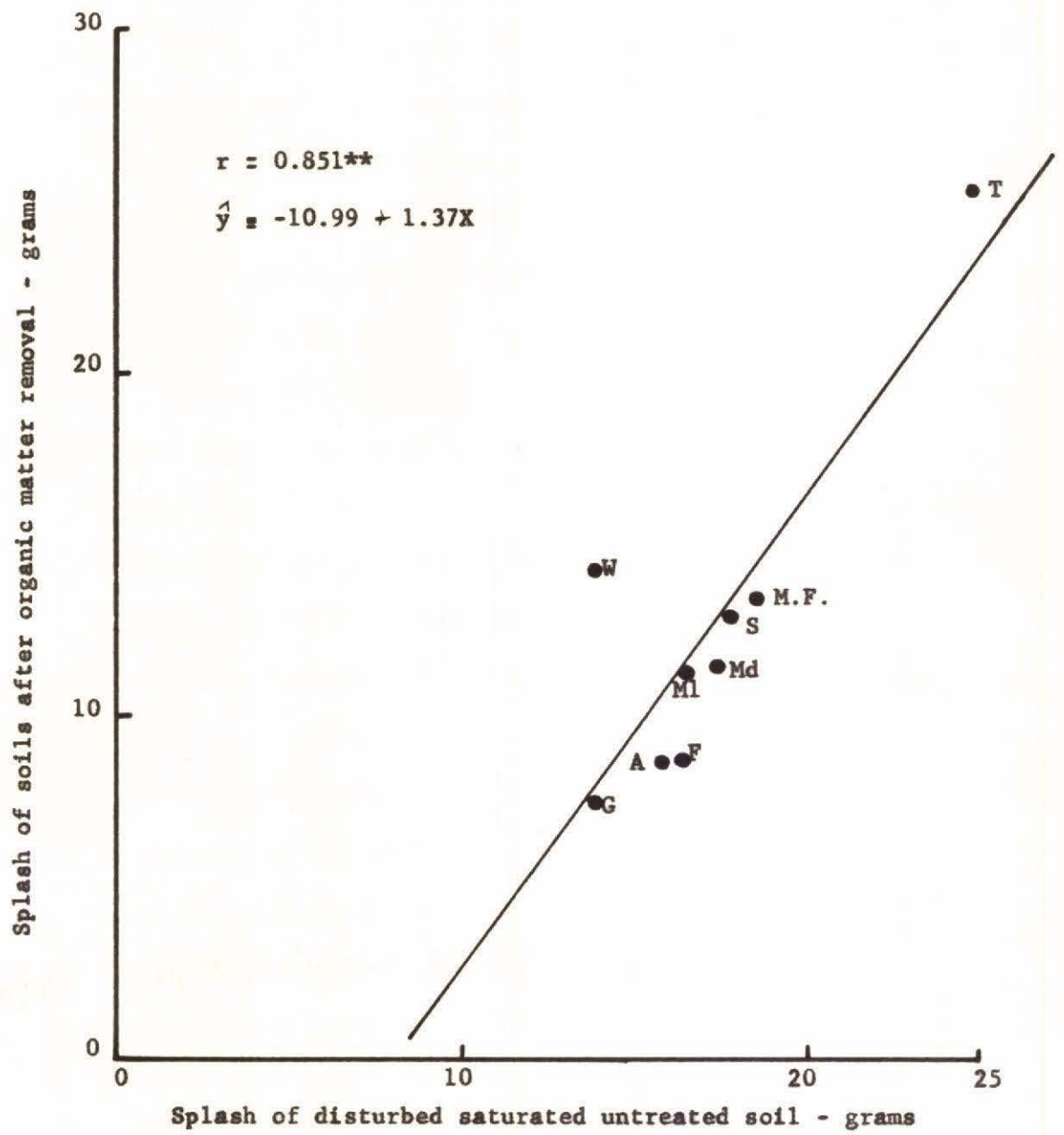


Figure 8. Effect of removal of organic matter on the splash of soils.

It should be remembered that over-all erosion of soil also includes transportation of soil. If such a reduced permeability occurred on a slope, the excess water and loose material would drain by surface flow, and the force of raindrops would not be as likely buffered by the water cushion which occurred here.

It was thought that iron oxides might be the most effective binding agent in many soils after organic matter removal. A plot of splash of soil after organic matter was removed against the iron content of the sample did not support this idea (Figure 9). Excluding the Trenton sample, the regression is significant at the 5 percent level. However, the slope of the regression line is small and soils with a high iron percentage (4 percent) had only slightly less splash than the samples with a low iron content (0.8 percent). The lack of a high increase in splash after organic matter removal, except for the Trenton soil, might suggest that the soil still has aggregation due to other cements or to some of the residual organic matter. But it is not known whether the reduced splash loss is a result of residual aggregates or because of the cushion effect of a surface water film as previously mentioned.

The data for splash of soil with organic matter removed was plotted against the percentage clay for each soil (Figure 6). As much as 3.5 percent and as little as 0.45 percent organic matter remained in the soils even after the hydrogen peroxide treatment (Table 5). In the presence of such a wide range of resistant organic matter, it is difficult to evaluate the effect of clay content alone on the splash of soils. Other factors such as iron oxide and silica content also complicate the situation in this evaluation. However,

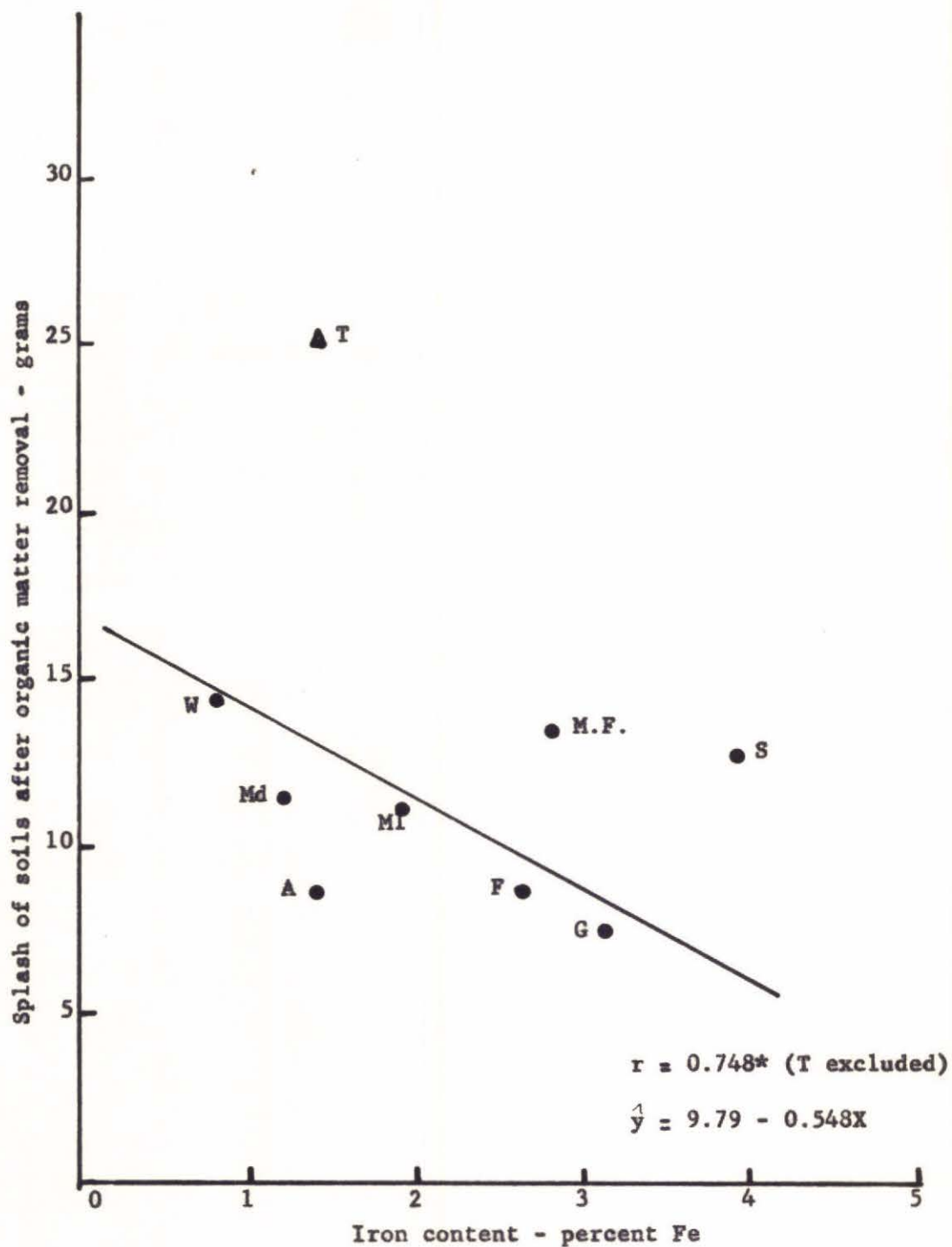


Figure 9. Relation of iron oxide content on the splash erosion of soils with organic matter removed.

Table 5. Organic matter content of soils before and after different treatments

Treatment	Sinks	Franklin	Mendon	Manila	Avon	Wheelon	Garr	Mud flat	Trenton
Original soil samples	6.7	14.5	3.9	6.8	3.0	3.5	3.6	10.5	3.3
Organic matter removed with 30% hydrogen peroxide	-	3.5	-	1.7	0.5	-	-	2.8	-
Free iron oxides removal method	-	13.5	-	6.2	2.3	-	-	8.8	-
Silica and alumina removal method	-	11.3	-	5.2	2.0	-	-	7.0	-

Table 6. Iron content of soils

Soil series	Sinks	Franklin	Mendon	Manila	Avon	Wheelon	Garr	Mud flat	Trenton
Iron content (percent Fe)	4.0	2.6	1.2	1.9	1.4	0.8	3.1	2.8	1.4

it appears from Figure 6 that in general the splash of soils increased as the clay content was increased. The regression coefficient is significant at the 5 percent level ($r = 0.763^*$).

Garr, Avon and Mud flat soils splashed in smaller amounts than would be expected on a percentage clay basis. The causes for this reduced splash would be different in each soil. High iron oxide content (above 3 percent Fe) in Garr might be one of the reasons for small amount of splash, if iron acts to cement the soil into aggregates. In Avon, presumably a high amount of silica with the clay content might have caused greater aggregation and thereby reduced amount of splash, since the highest dispersion ratio was obtained after treatment to remove silica. Both the clay content (45 percent) and the organic matter remaining after H_2O_2 treatment (about 3 percent) were high for the Mud flat soil. It is believed that is responsible for its reduced splash, the splash occurred was less. Baver (1956, p. 139) pointed out that in the comparison of the relative effects of the clay and the organic matter contents, both were found to be equally significant in causing granulation.

Splash of soils with iron oxides removed

In the method used for removing iron oxides, which involves sodium salts, sodium was not removed from the soils after iron removal. Hence, the dispersion of soils was very high. Under such circumstances, it is difficult to evaluate the effect of iron oxide removal. However, it might appear from Table 2 that the splash loss from Mendon, Avon and Trenton soils was not affected due to removal of iron oxides

indicating that iron oxides might not be very important as a binding agent in these samples. Further discussion of these samples seems to be unjustified because of the methods used for sample preparation.

Splash of soils with amorphous silica removed

In Figure 10 the splash of disturbed saturated soils before and after treatment to remove silica is plotted. It appears that the Wheelon, Trenton and Mendon soils splashed comparatively more than the Sinks and Mud flat soils when colloidal silica material was removed from the soil. It should be kept in mind that Na_2CO_3 treatment used should also disperse some clay. Although the regression coefficient is highly significant ($r = 0.797^{**}$), it is in large part directed by one sample (Trenton) with the other samples uniformly scattered. It was interesting to note that the soils which contain more than 5 percent organic matter (Table 5) lie below the sample regression line while those containing less than 5 percent organic matter lie above the line. This is an indication that the organic matter probably was an effective binding agent even after removal of silica. This fact was also indicated by Figure 11 in which splash of silica-removed soils was plotted against the organic matter content remaining in soils after amorphous silica was removed. It was very nearly a straight line relationship indicating that the higher the organic matter content after silica removal, the smaller would be the amount of splash. But the slope of the regression line is very low, and it is expected that a very different picture might be obtained for different samples of similar organic matter content. In the case of

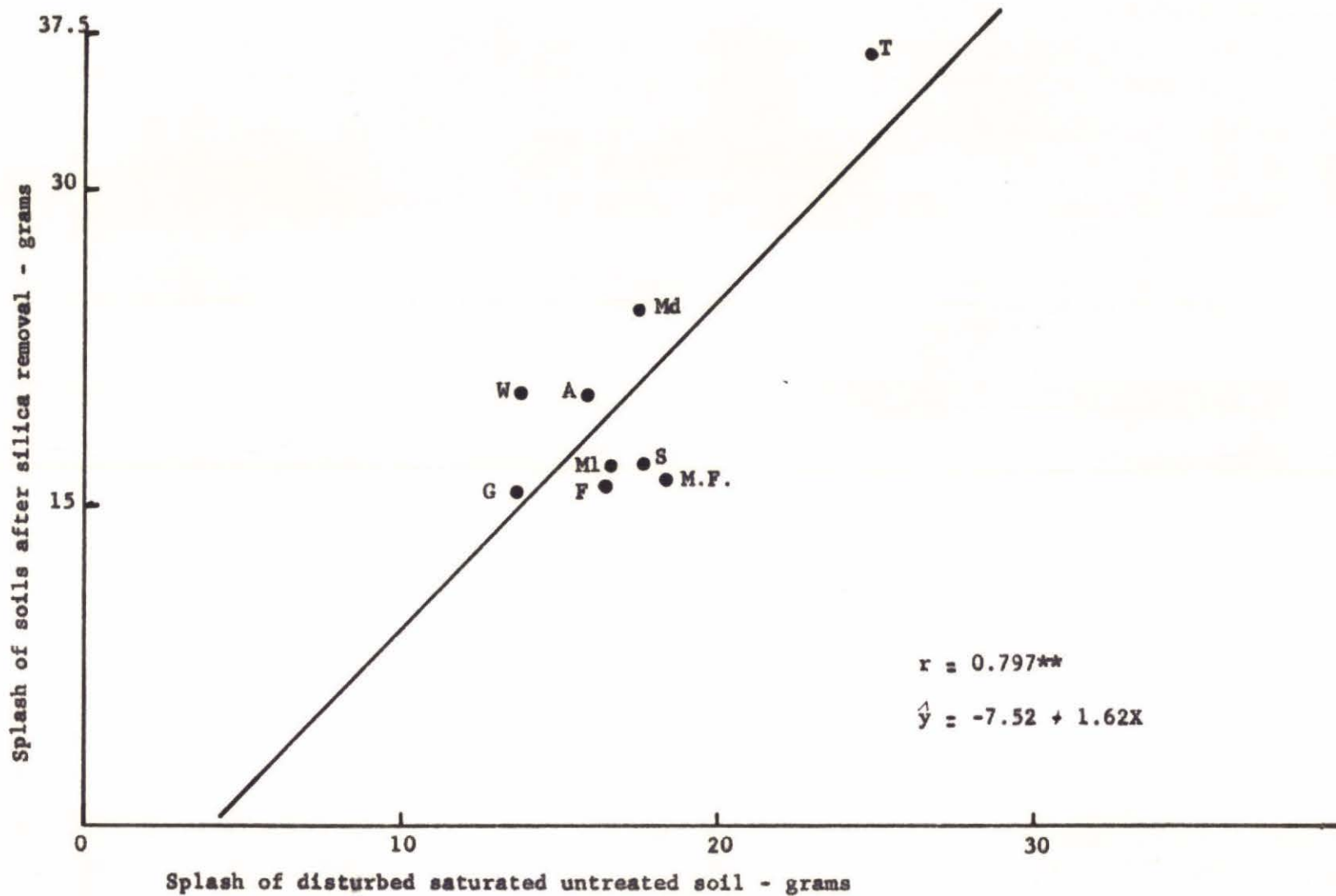


Figure 10. Effect of removal of silica (2% Na₂CO₃ treatment) on the splash of soil.

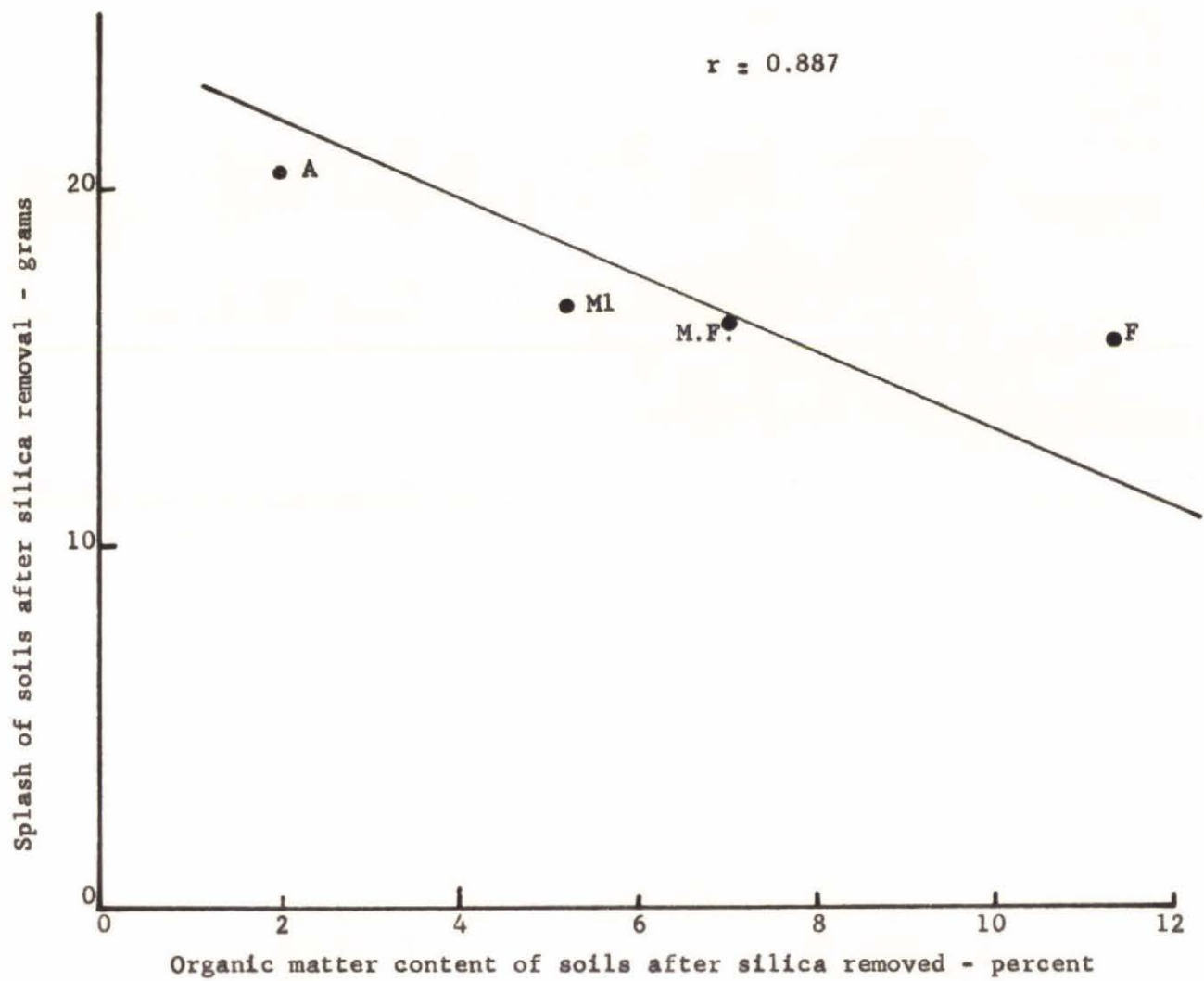


Figure 11. Relation between organic matter content and splash of soils after silica was removed.

several soils of low organic matter content, factors other than organic matter are expected to have dominating influences.

Iron content was plotted against splash of soils after silica removal (Figure 12) and the correlation coefficient was found to be very near to significance at the 5 percent level but with a low and negative slope. The data indicate that iron might also be an effective binding material in minimizing the splash of soils from which amorphous silica was removed, but the relationship is not well shown.

It was observed that there was not significant correlation between the clay content and the splash after silica removal as was found in case of soils with organic matter removed (Figures 6 and 7).

Dispersion Ratio

Dispersion ratio due to different treatments

Table 7 shows the dispersion ratios of soils for the <0.02 mm. and <0.1 mm. size fraction. The Mud flat, Franklin, Manilla, Avon and Trenton soils showed dispersion ratios smaller than 15, the figure which was considered by Middleton (1930) to be the dividing point between non-erosive and erosive soils. The Sinks, Mendon, Wheelon and Garr soils show dispersion ratios higher than 15 in untreated original samples, thus indicating erosive characteristics. It was interesting to observe that by removing any binding material such as organic matter, iron oxides or amorphous silica the dispersion ratio was increased considerably in all soil series. This was not unexpected since the soils underwent some mechanical disturbance in these treatments.

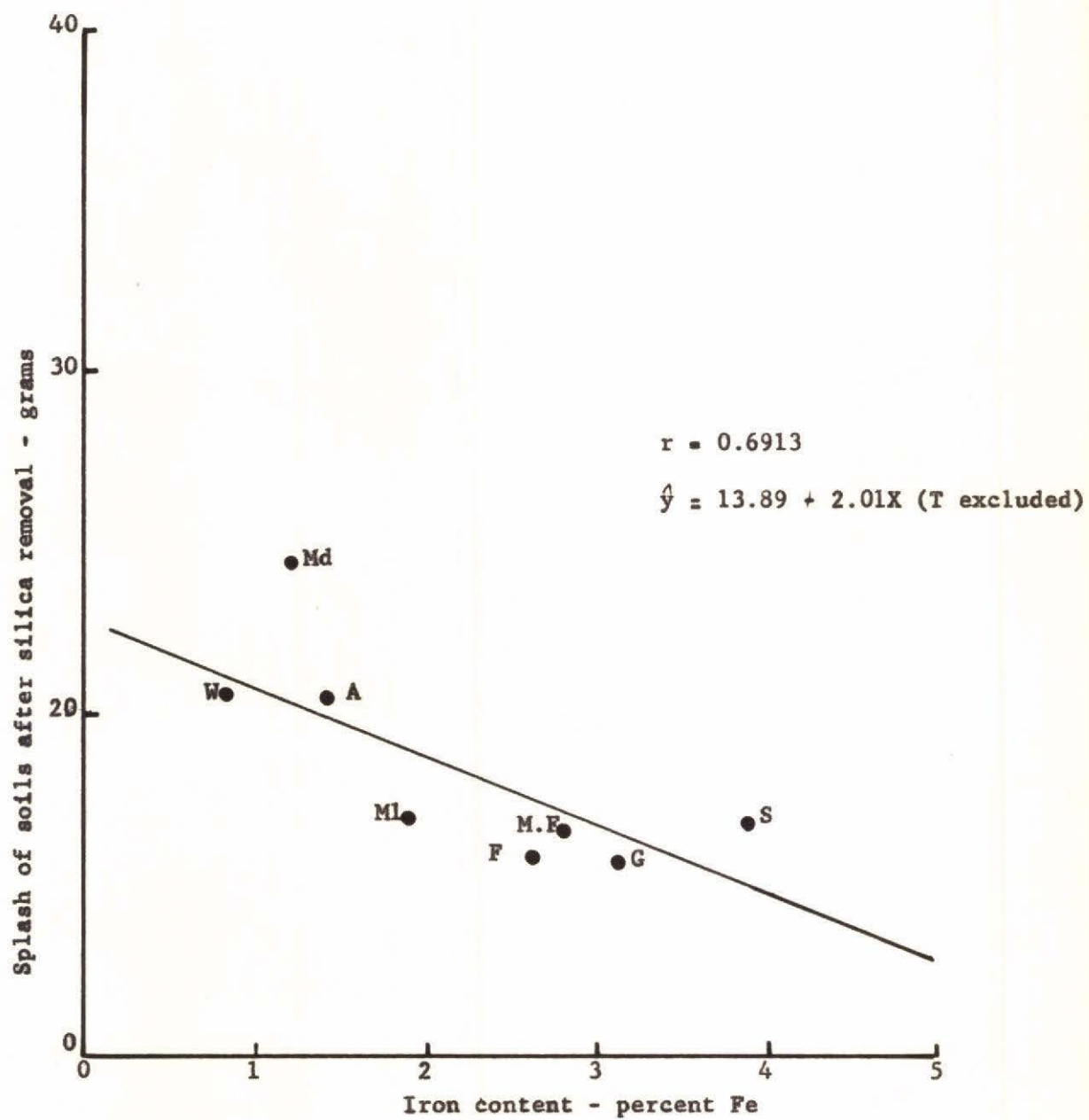


Figure 12. Effect of iron oxide content on splash of soils after silica removed.

Table 7. Means of dispersion ratio of soils due to various treatments

Treatment	Sinks	Franklin	Mendon	Manila	Avon	Wheelon	Garr	Mud flat	Trenton
The <0.02 mm. size fraction									
No treatment	15.8	14.2	20.0	9.9	14.6	18.5	20.6	7.2	12.6
Organic matter removed	30.9	22.3	20.1	28.0	35.0	45.2	36.4	21.2	26.7
Iron oxides removed	52.0	45.2	90.3	70.4	93.6	42.9	92.3	75.9	92.3
Silica removed	18.3	21.1	62.3	31.5	89.5	50.3	74.8	41.7	80.9
The <0.1 mm. size fraction									
No treatment	29.7	28.1	28.7	19.3	26.7	31.7	34.5	17.1	17.3
Organic matter removed	45.8	32.9	29.4	40.6	58.4	69.4	58.8	35.1	41.3
Iron oxides removed	59.0	50.6	91.8	73.0	96.0	51.1	94.6	79.9	94.5
Silica removed	26.1	28.2	74.5	42.0	92.4	55.6	86.1	52.0	84.9

In Figure 13 dispersion ratios for the <0.02 mm. size fraction for all soils are given. The treatment giving highest ratios, iron oxide removal, shows the effect of leaving exchangeable Na on the colloid. The other treatment involving Na, the removal of silica, also shows the effect of breakdown of aggregates.

When organic matter was minimized to about 25 percent of its original content (after removal with H_2O_2), Wheelon appeared to have the highest dispersion ratio. Manilla and Avon soils had high increases in the dispersion ratios when compared with the dispersion ratios of the respective original soils. The soil least affected in its dispersion ratio was the Franklin. This might be due to the fact that comparatively more organic matter (3.5 percent) still remained in the Franklin soil after hydrogen peroxide treatment than remained in the other soils.

Sodium was not removed after removal of iron oxides from the soils and hence the dispersion ratios were very high for soils cleaned of iron oxides. It was therefore difficult to evaluate the effect of removal of iron oxides alone on dispersion ratios. However, after removal of iron oxides and in the presence of exchangeable sodium ions, Mendon, Avon, Garr and Trenton soils have given very high ratios. This would tend to discount the effect of organic matter as an important aggregating agent in these soils. The dispersion ratio of Wheelon was least after iron oxide removal, probably because Wheelon contains about 30 percent $CaCO_3$ in the surface layer which might hinder complete dispersion of the soil.

By removing silica, the dispersion ratio was increased the most over the ratio for the original soil in the Mendon, Avon, Garr and

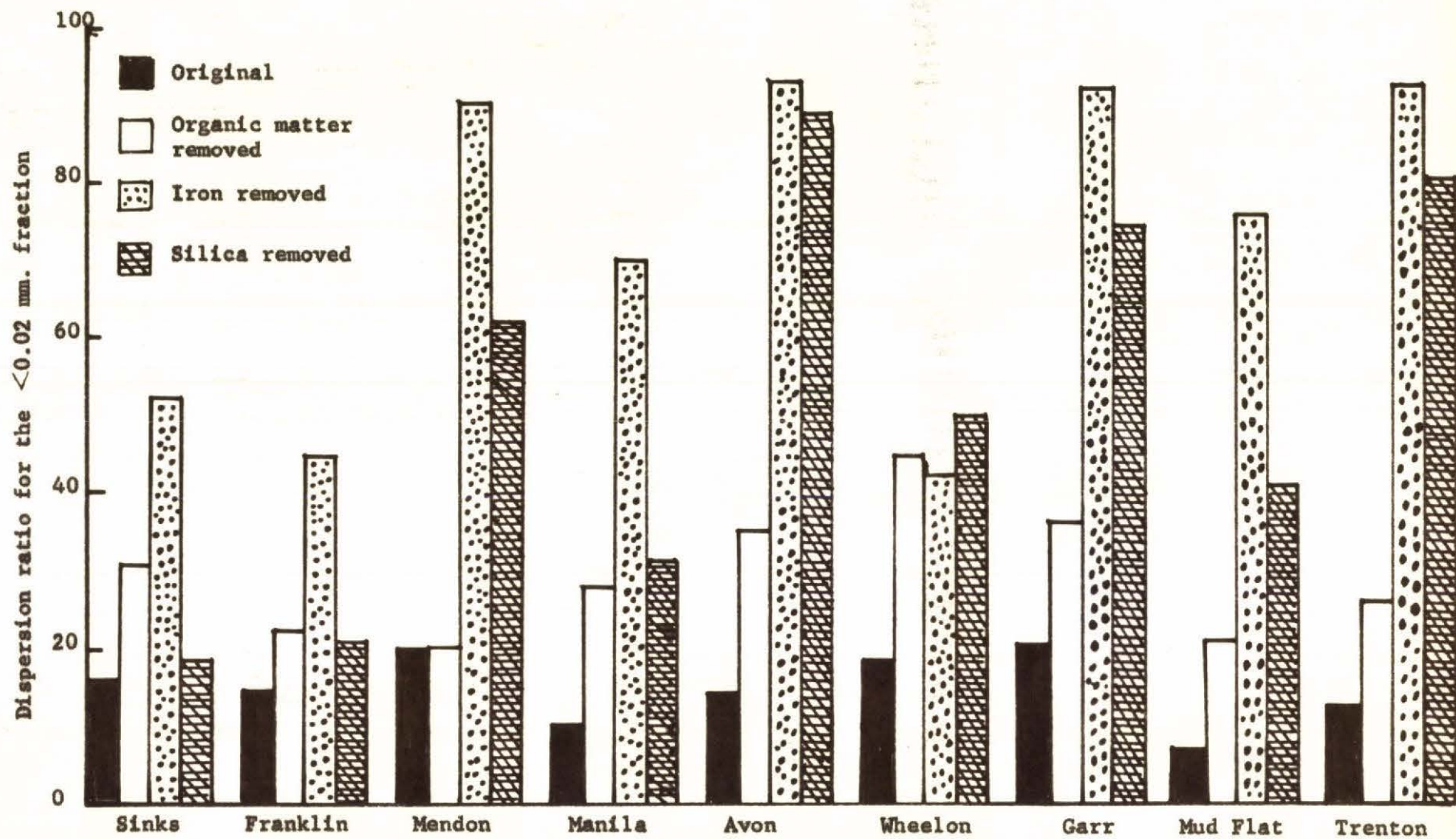


Figure 13. Dispersion ratios for the <0.02 mm. fractions of soils series due to different treatments.

Trenton samples. The Sinks and Franklin soils have the lowest dispersion ratios. This is probably due to the high organic matter content of these soils.

The dispersion ratios for the <0.1 mm. size fractions were higher than those for the <0.02 mm. fractions in the respective treated soils (Table 7). The increase in dispersion ratios in the larger fractions appeared to be proportional to those for the <0.02 mm. size fraction in respective soils (Figure 15).

Correlation between dispersion ratio and splash of undisturbed soil

Dispersion ratios of original soil for the 0.02 mm. size fractions were plotted against the splash of undisturbed saturated soils (Figure 14). There did not appear to be good relation between the splash erosion of undisturbed saturated soils and the dispersion ratio ($r = 0.161$, non-significant). Graphing the splash of undisturbed soil cores at field moisture against the dispersion ratios also gave poor correlations (Figure 15). However, Bayer (1956, p. 135, 139) pointed out that the correlation between organic matter and aggregation is less significant in soils containing more than 35 percent clay. Also he stated that at the higher percentages of organic matter, the effect of clay at a medium percentage in secondary particle formation becomes insignificant. Since the dispersion ratio is a negative measure of "degree of aggregation" of the finer soil separates, it was thought that there might be good reason to see what the elimination of some of the soils of high clay or high organic matter content would do to the relationship. Neglecting the high-clay soils (Avon, Trenton and Mud flat--all over 35 percent clay) and the Franklin soil (14.5 percent

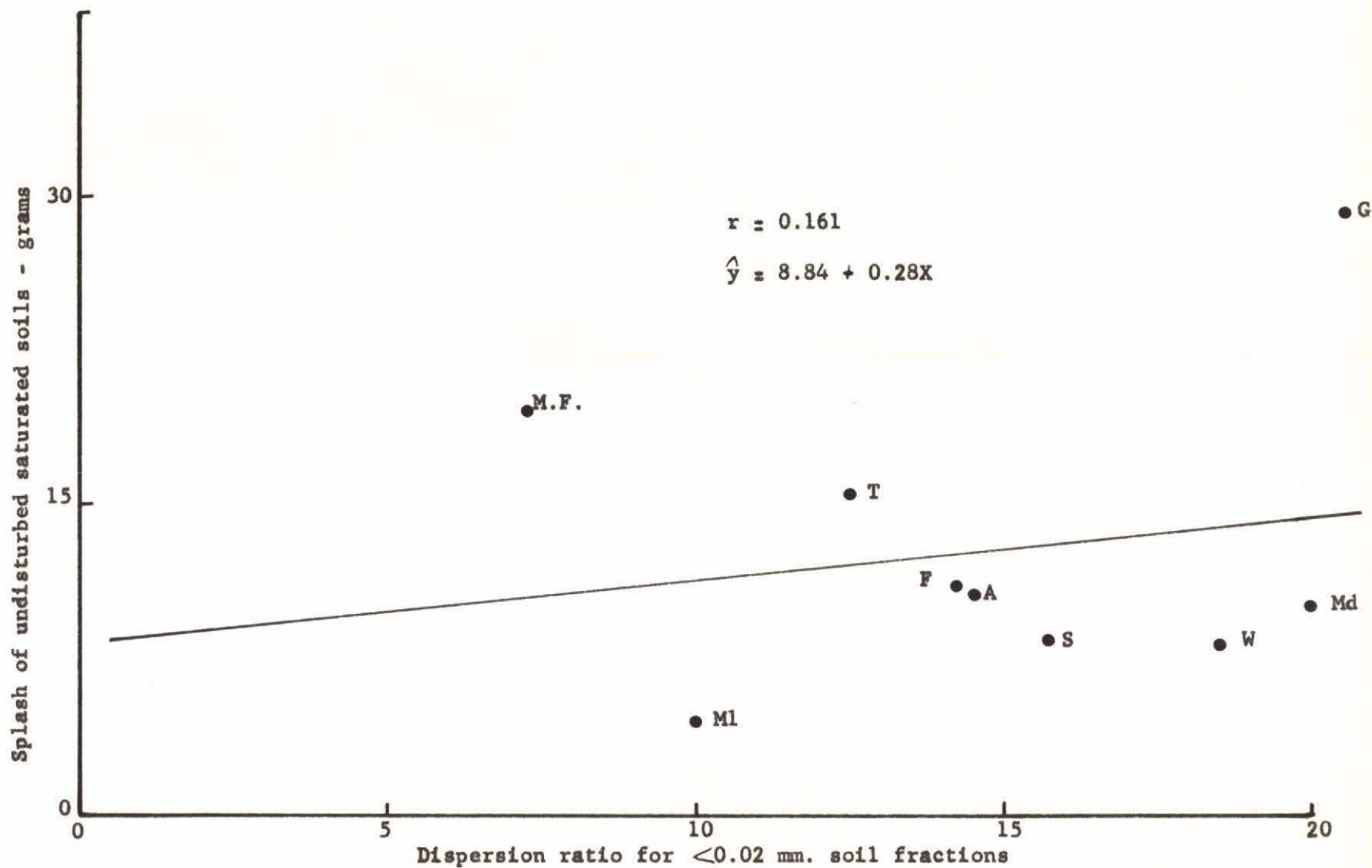


Figure 14. Relation between the dispersion ratio for the <0.02 mm. fractions and splash of undisturbed saturated soils.

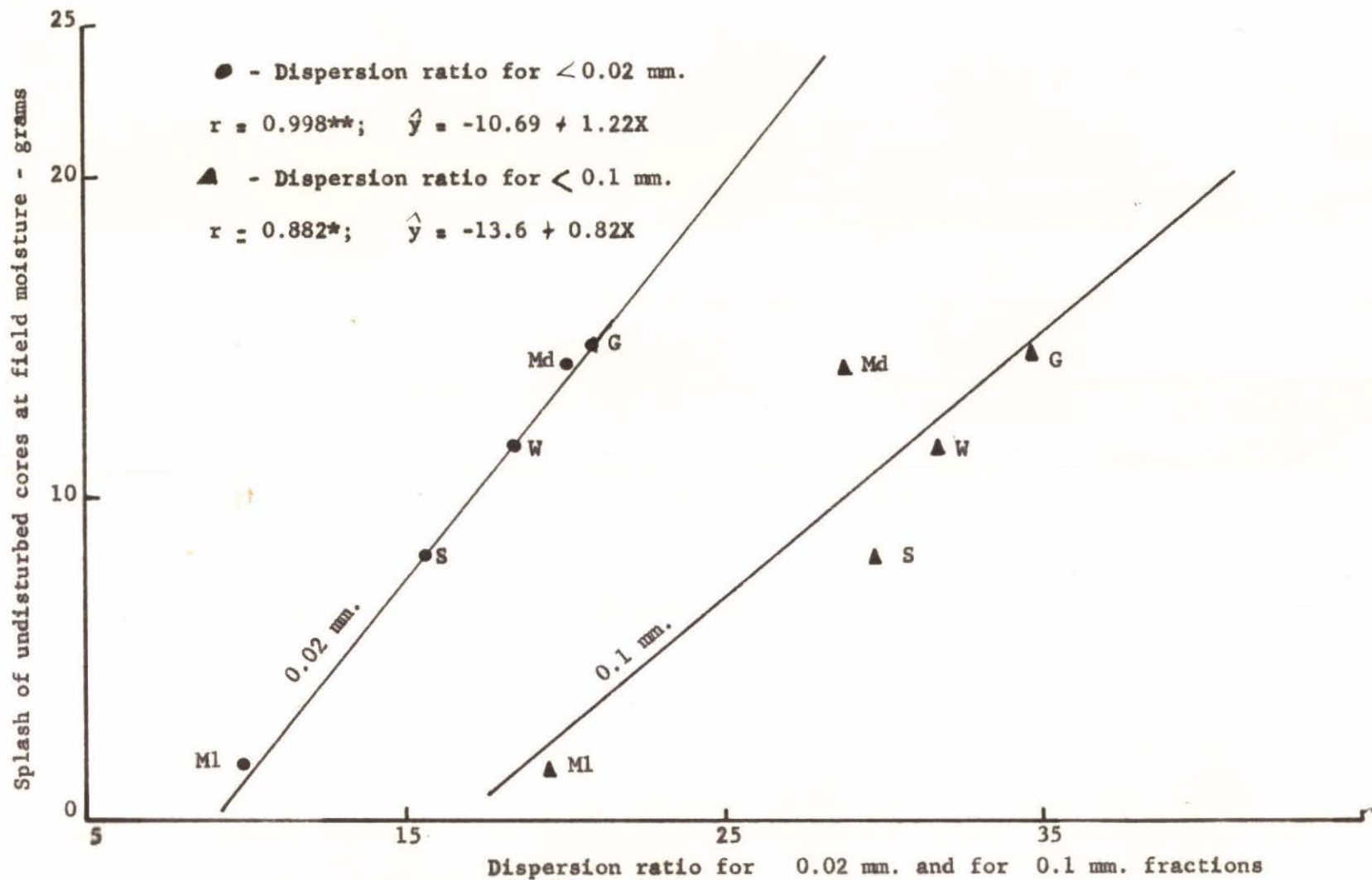


Figure 15. Relation between dispersion ratio for 0.02 mm. and for 0.1 mm. fractions and splash of undisturbed soil at field moisture.
 (Excluding Franklin, Avon, Mud Flat, Trenton.)

organic matter), the correlations in Figure 15 were significant. The dispersion ratio for the <0.02 mm. size fraction was more closely correlated with splash ($r = 0.998^{**}$) than that for the <0.1 mm. fraction ($r = 0.882^*$). On the basis of these few samples, it would seem that the dispersion ratio and splash loss correlate well if the samples used are not overly high in percentage clay or organic matter.

Correlation between aggregate stability and splash of disturbed soil samples

Ellison (1944b) concluded that the first distinct effect due to raindrop impact is the breakage of soil aggregates. In order to confirm Ellison's idea, the percent of aggregates greater than 0.1 mm. which were broken into soil particles smaller than 0.1 mm. were calculated from data from the dispersion ratio analysis (Table 8) and were plotted against the splash of disturbed saturated soil samples (Figure 16). Correlation of the splash loss and the percentage of aggregates larger than 0.1 mm. that broke into smaller than 0.1 mm. soil particles was highly significant ($r = 0.870^{**}$). However, if the soils were divided into two groups according to their organic matter content and taking 5 percent organic matter as the point of division, correlation for soils containing more than 5 percent organic matter was not significant even though it was high (0.905). The correlation for soils containing less than 5 percent organic matter was highly significant ($r = 0.996^{**}$). Thus, it appeared that in soils of low organic matter content the splash erosion increased directly with the breakage of aggregates or, in other words, a significant correlation existed between the splash

Table 8. Percent breakage of aggregates >0.1 mm. and percent true water stable aggregates >0.1 mm.

Soil series	Oven-dry material <0.1 mm. chemically dispersed (= X) gm.	Oven-dry material <0.1 mm. chemically nondispersed (= Y) gm.	Breakage of aggregates >0.1 mm. [= 1000 (X - Y) = Z] %	True water stable aggregates >0.1 mm. (= 100 - Z) %
Sinks	0.06995	0.02075	49.20	50.80
Franklin	0.06215	0.01745	44.70	55.30
Mendon	0.08180	0.02345	58.35	41.65
Manila	0.0586	0.0113	47.3	52.70
Avon	0.07250	0.01935	53.15	46.85
Wheelon	0.07120	0.02255	48.65	51.35
Garr	0.07715	0.02660	50.55	49.45
Mud flat	0.07370	0.01260	61.10	38.90
Trenton	0.09440	0.01630	78.1	21.9

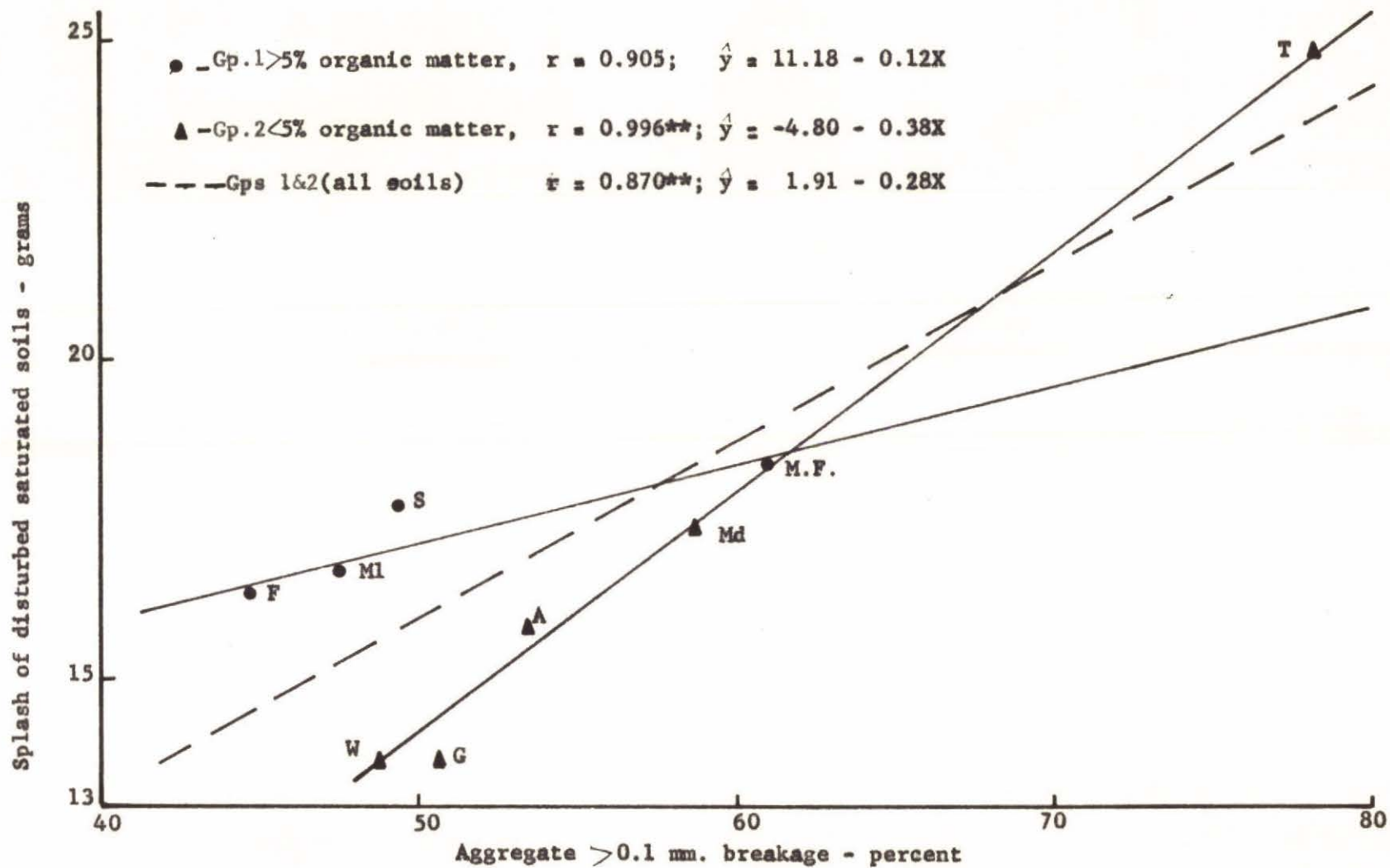


Figure 16. Relation between percent breakage of aggregates >0.1 mm. and splash of disturbed saturated soils.

and the percentage of water stable aggregates. The formulae, which is developed in this thesis (see Table 8 and method on page 28), would automatically exclude most of the primary particles >0.1 mm. from the calculation and only water stable aggregates >0.1 mm. size would be obtained.

Correlations

Table 9 presents the summarization of the statistical correlations determined for various relations. For a discussion of individual relationships, see the respective section in the Results and Discussion.

Detachability and Potential Erodibility of Soils

Splash erosion (detachability) and aggregate stability are taken as the soil detachment measures in evaluating the potential erodibility of the different soils studied. Field observations (see appendix), such as slope of the area and the cover present, are also taken into consideration for evaluating potential erosion. Because Middleton (1935) stated that the soils having dispersion ratios greater than 15 should be considered as erosive soils, the dispersion ratio for <0.02 mm. is therefore also considered only when it is in contrast to the percentage of water stable aggregates or splash erosion.

The soils are discussed in order of increasing splash erosion (detachment) of soil cores (mean splash of undisturbed cores at both field moisture and at saturation).

Manilla soil

Splash erosion of the Manilla soil (3 gm.) was found to be the lowest of all soils studied. The percentage of water stable aggregates

Table 9. Summary of statistical analysis of various comparisons of soil splash, dispersion ratios, and soil constituents

Comparison	Degrees of freedom	Correlation coefficients	Regression equation $Y = a + bx$
<u>Rate of rainfall vs.</u>			
Splash of standard sand	15	0.825**	$9.07 + 28.24X$
<u>Splash of disturbed, saturated, untreated soil vs.</u>			
Splash of soils with organic matter removed	7	0.851**	$-10.99 + 1.37X$
Splash of soils with silica colloids removed	7	0.797*	$- 7.52 + 1.62X$
<u>Organic matter percent vs.</u>			
Splash of soils with silica colloids removed	6	0.546	$15.68 + 0.54X$
<u>Iron content percent vs.</u>			
Splash of soils with organic matter removed	6	0.748*	$9.789 - 0.548X$
Splash of soils with silica colloids removed	6	0.691	$13.89 + 2.01X$
<u>Clay content percent vs.</u>			
Splash of soils with organic matter removed	7	0.763*	$- 0.77 + 0.4X$
Splash of soil containing <30% clay with silica colloids removed	3	0.155	$14.03 + 0.18X$
Splash of soil containing >30% clay with silica colloids removed	2	0.788	$- 8.35 + 0.74X$
Splash of undisturbed, saturated cores containing <30% clay	3	0.723	$- 9.93 + 0.67X$
Splash of undisturbed, saturated cores containing >30% clay	2	0.402	$6.05 - 0.31X$

Table 9. (continued)

Comparison	Degrees of freedom	Correlation coefficients	Regression equation $Y = a + bx$
<u>Dispersion ratio for</u> <u><0.02 mm. vs.</u>			
Splash of undisturbed soils at saturation	7	0.161	$8.84 + 0.276X$
Splash of undisturbed soils at field moisture	3	0.998**	$-10.69 + 1.22X$
<u>Dispersion ratio for</u> <u><0.1 mm. vs.</u>			
Splash of undisturbed soil at field moisture	3	0.882*	$-13.60 + 0.82X$
<u>Percent breakage of aggregates</u> <u>>0.1 mm. of original soil vs.</u>			
Splash of disturbed soils containing >5% organic matter and at saturation	2	0.905	$11.18 + 0.12X$
Splash of disturbed soils containing <5% organic matter and at saturation	3	0.996**	$-4.80 + 0.38X$
Splash of all soils disturbed at saturation	7	0.870**	$1.91 + 0.28X$

* Denotes statistical significance at 5 percent level

** Denotes statistical significance at 1 percent level

was comparatively high (53 percent, Table 8). The soil at the site occurs on slopes of as high as 30 percent with predominately big sage cover. Some soil erosion was observed on numerous horizontal cattle trails. High amount of splash occurred when the soil samples were tested in a disturbed condition. Thus, disturbance of compaction of this soil may cause considerable erosion, but if adequately managed, erosion should be low.

Sinks soil

The Sinks soil splashed comparatively little (8 gm.) when it was in the undisturbed condition. The percent of water stable aggregates (50.8 percent) was fairly high. However, the soil is loose and moderate erosion occurs. This soil is commonly found on slopes as steep as 12-15 percent. The cover which consists of big sage brush and some grasses is only about 50-60 percent coverage. Under such field conditions, the soils would be better protected from erosion if the percent cover, especially the grasses, is increased.

Wheelon soil

In the virgin condition, a relatively small amount (9.7 gm.) of splash occurred. Fairly high percentage of water stable aggregates (51.4) was found. Both measures would indicate low detachability. The soil occurs on knolls with slopes up to 35 percent with finer-textured and dark-colored soil in the depressions. The cover, consisting of scattered sagebrush with some grasses, would amount to only about 30 percent average. Local inhabitants say the knolls have been heavily eroded since being put into cultivation.

In a preliminary test, which is not recorded in this thesis, Wheelon splashed very heavily (30 gm.) when organic matter was removed but lime was not removed. From the laboratory analysis (1958) it was found that these soils contain a high amount of CaCO_3 (30 percent). Peele et al (1938) observed in Cecil clay that the addition of lime increased the erodibility of the soils, if none or only a small amount of organic matter was present. The same situation might be valid for Wheelon.

Thus, from the splash studies and the slope at the site, it appears that these soils would be erosive and with inadequate cover. The present erosion hazard is believed to be mainly due to the depletion or lowering of organic matter. A high dispersion ratio (18.5) indicated that this soil is easily detached which is in contrast to the indication obtained from aggregate stability and splash analysis.

Mendon soil

Splash of this soil from the soil cores was moderate (12 gm.) indicating considerable ease of detachment. The percentage of water stable aggregates was comparatively low (41.6 percent). The slope of this area is 2-3 percent and the cover at the sampling site consisted of wheat stubble. No visible evidence of soil erosion was observed at the actual site. Perhaps partly due to a high percentage of silt (49 percent) and the low percent of water stable aggregates, the dispersion ratio (20.0) was very high. If the level of organic matter content is kept high, in order to bind the high amount of silt and to strengthen the aggregates, then this soil on such level slopes should be safe from erosion losses.

Avon soil

Soil loss due to splash was moderate (12 gm.) and was almost identical with the value for Mendon. The percentage of water stable aggregates was also low to moderate (47 percent). The slope of the area is 3-5 percent and the cover consisted of alfalfa stubble.

Often the Avon soil is associated with Manilla soil but occurs on the lower and less steep slopes. They are normally considered to be quite similar soils. The splash in Avon was more than that in Manilla. This would not be entirely unexpected since Avon may have as a surface soil layer the deposition of the eroded portions of the Manilla soil higher up.

Under such field conditions of slight slope, this soil should not be erosive, if high level of organic matter content is maintained.

Franklin soil

The splash erosion was moderate (13.2 gm.) and the percentage of water stable aggregates (55 percent) in this soil was the highest found. The slope of the area is about 5 percent and the cover consists mostly of tall (40-45 feet) aspen. The understory is nigger head and some grasses. This cover is very useful in interception of rainfall. Actual visible observation also showed very weak evidence of erosion and erosion control should be easy for this soil.

Trenton soil

Comparatively moderate (14.5 gm.) splash occurred in the undisturbed condition even though the splash was highest (23 gm.) in the disturbed condition. Table 8 reveals that the aggregates are extremely

weak and that the percent of water stable aggregates (22 percent) was the lowest of all soils studied.

The slope of the area is not steep (1-2 percent) and the cover was of alfalfa stubble. There was no indication of erosion. As this soil is very high in percentage clay (54 percent), it would have high splash erosion if the soil is disturbed very often or the organic matter is depleted.

Mud flat soil

A very high amount of splash occurred (21 gm.) when the soil cores were tested. The percentage of water stable aggregates was low (39 percent).

The slope of the area is considerable (about 10 percent) and the cover, consisting of big sage and some small grasses, is only 40-50 percent coverage, which is inadequate for the protection of this soil. The high splash value and observed rill erosion, even with the high clay and organic matter percentage, indicate that erosion control on this soil is probably one largely of keeping maximum vegetative cover on the soil.

It is interesting to note that the dispersion ratio (7.2) was the lowest one, which would suggest that it is non-erosive.

Garr soil

The splash erosion was highest (22 gm.) among all soils when the soil cores were tested. The splash of cores tested at field moisture was moderate (14 gm.) but when the cores were initially saturated, the splash increased two-fold (30 gm.). The percent of water stable

aggregates was moderate (49.5 percent). Baver (1956, p. 168) stated that the hydration effect of excess water, when soils are saturated and the impact of falling raindrops, destroys aggregates very easily if the aggregates are not stabilized with humus or iron compounds. It appears that the aggregates in Garr when thoroughly wetted are not sufficiently stable to withstand the impact of falling raindrops.

The slope of this area is also very steep (20-25 percent). The present cover is wheat stubble and is inadequate for control of erosion. Efforts in maximum control measures to reduce splash erosion is believed a necessary practice in erosion control of the soil.

SUMMARY AND CONCLUSIONS

The surface two inches of six soils of range and dryland areas and three soils of mixed forest and range cover in Cache County in northern Utah were collected in undisturbed cores and also as disturbed samples and were tested for splash erosion under the impact of artificial rainfall. The diameter of raindrops was 5.36 mm., and the fall velocity was approximately 23 feet per second at impact. On an average, 1.17 inches of rain was applied within a one-half hour period. Because it was found that the standard sand used (60-80 mesh) splashed proportionately with the amount of rainfall applied, the splash of soils in all treatments was corrected to 1.2 inches of rainfall. The soils, before and after removal of the cementing agents (organic matter, iron oxides and colloidal silica), were analyzed for splash erosion and dispersion ratio and some chemical determinations were made. A method of calculation for estimation of only water stable micro-aggregates exclusive of primary-sized particles was developed and used in this thesis.

Conclusions reached during this study are given in the following statements.

1. When tested in an undisturbed condition, a considerable amount of splash occurred in soils at Mud flat area and Garr soil series while a very small amount of soil was splashed in Manilla. Other soil series had splash loss between these extremes. Disturbed

soils splashed more than the disturbed soils except in the Mud flat and Garr soils, which splashed less than that in undisturbed condition.

2. Trenton exhibited a comparatively high splash when organic matter was removed from the soil. This is assumed to indicate the excessive loss of aggregation with removal of organic matter. For all soils, excluding Trenton, splash after organic matter removal usually decreased.

3. There was a significant positive correlation between the splash erosion and clay content when the soil organic matter was largely removed. The soils containing 30-45 percent clay splashed less than the soils containing 20-30 percent clay.

4. There was no significant correlation found between the splash of soils from which silica colloids were removed and the organic matter content, iron oxide content, or the clay content.

5. The Mud flat, Franklin, Manilla, Avon and Trenton soils had dispersion ratios smaller than 15, whereas the Sinks, Mendon, Wheelon and Garr soils had dispersion ratios larger than 15. By removing any of the cementing materials studied, the dispersion ratio was increased for all samples. The dispersion ratios for <0.1 mm. size fractions were higher than those for <0.02 mm. size fractions in respective soil series.

6. There was no significant correlation between the dispersion ratio and the soil splash of saturated soil cores. The splash of soils, containing 25-35 percent clay and 3.5-7 percent organic matter, and at field moisture and in the undisturbed condition, was highly correlated with the dispersion ratio. The dispersion ratio for <0.02 mm. size fraction

was more closely correlated with splash than was the dispersion ratio for the <0.1 mm. size fraction.

7. The correlation between the percentage breakage of true water stable aggregates and the splash of disturbed saturated soils was found to be highly significant and positive. Thus, the splash erosion increased with an increase in the percentage of aggregates >0.1 mm. that would break down into smaller sizes.

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APPENDIX

Description of Soils (Surface 2 inches) Studied

The soils studied in this thesis were collected from Cache County, Utah. Soils at Sinks Road, Franklin Basin, Mud Flat area and Garr series were from mountain valley soil series. Avon and Trenton were collected from the valley bottom. The soil samples of Wheelon, Mendon and Manilla soil series were taken from the upland ridge.

Elevation, precipitation and temperature data for each area are taken from the nearest possible recording station as given by Southard (1958) and U.S.D.A. (1941, 1954).

Soils at Sinks Road

Location.--T14N, R4E, SE $\frac{1}{4}$ of the SE $\frac{1}{4}$ of Section 28; southwest slope 400 feet from road.

Elevation.--7800 feet.

Precipitation.-- 30 inches.

Temperature.-- 24-73° F. (Logan).

These soils are pale brown (dry) to very dark brown (moist). The pH ranges from 6.2 to 6.4. The slope of the area is about 12-15 percent and the length of the slope is about 600 feet. The surface structure of the soils is friable, loose and weak granular to single grain. There is a mixture of big sage brush and grasses which cover about 50-60 percent of the surface. Some sheet erosion is evident on the area.

Franklin Basin

Location.--T14N, R3E, SW $\frac{1}{4}$ of the SE $\frac{1}{4}$ of Section 23; 3/4 mile from Highway 89.

Elevation.--7400 feet

Precipitation.-- 30 inches.

Temperature.-- 24-73° F. (Logan).

The soils are dark grey (dry) to very dark grey (moist). The pH of the soils is 6.6 to 6.8. The slope of the area is about 5 percent and the length of slope is about 300 feet to a change in direction. Moderate to strong granular structure and friable soil was observed. Quaking Aspen 60-70 years old and of a height of 40-45 feet, on an average, are generally present and understory is occupied by nigger head and some few grasses. There is very weak evidence of erosion and only slight mounding around the trunks is found.

Mendon series

Location.--T12N, R1W, NE $\frac{1}{4}$ of the SW $\frac{1}{4}$ of Section 32.

Elevation.--4400 feet.

Precipitation.--16-18 inches.

Temperature.--48° F. average annual.

These soils are grey brown (dry) to very dark grey (moist). The pH is about 7.2 to 7.4. Land is gently sloping, having 1-2 percent slope at the sample site. The structure is granular but the surface 2 inches crumbles very easily to moderate fine and medium granules. The land is cultivated and the present cover is wheat stubble. No erosion is evident on the sample site.

Manilla series

Location.-- T10N, R1E, SW $\frac{1}{4}$ of the NW $\frac{1}{4}$ of Section 19.

Elevation.--4800 feet

Precipitation.--16-18 inches average.

Temperature.--48° F. average annual.

The soils are dark grey (dry) to very dark grey (moist). The pH ranges from 6.2 to 6.4. Slope in general is steep rolling to smooth and is 8-30 percent. The slope of land at sample site is about 20-25 percent. The structure of soil is moderate to strong fine granular with moderate fine platy below the surface. The present cover is big sage with considerable understory grass. Erosion on horizontal cattle trails is evident but the site has no marked erosion.

Avon series

Location.--T10N, R1E, NW $\frac{1}{4}$ of the NW $\frac{1}{4}$ of Section 19.

Elevation.--4600 feet.

Precipitation.--16-18 inches.

Temperature.--48° F. annual average.

The color of surface soil ranges from dark grey (dry) to very dark grey (moist). The pH is 6.4-6.6. In general, the slope is 5-15 percent and slope at site is 5 percent. The structure of the surface soil is moderate to strong fine granular. The present cover is alfalfa stubble. Erosion is not evident except nearby ridges show the white color of the substratum.

Wheelon series

Location.--T10N, R1E, SE $\frac{1}{4}$ of the SE $\frac{1}{4}$ of Section 13.

Elevation.--4600 feet.

Precipitation.--16-18 inches.

Temperature.--48° F. average annual.

Surface soil at sample site is light brown grey (dry) to dark grey (moist). The pH of soil is 8.2 to 8.4. The slope at site (ridge top) is 3-5 percent, but the general area is composed of many rolling hills with slopes as great as 35 percent. The structure of the surface soil is loose, nearly single grain, but with some weak fine granular. The cover at present consists of scattered sage brush and largely grass cover on uncultivated areas and wheat on cultivated parts. Sheet erosion is evident. The tops of the hills are white and the depressions are deep dark-colored soil.

Garr series

Location.--T14N, R2E, NW $\frac{1}{4}$ of the NE $\frac{1}{4}$ of Section 28.

Elevation.--6500 feet (approximately).

Precipitation.--18-20 inches.

Temperature.--46°F.

The soils are grey brown (dry) to very dark grey (moist). The pH ranges from 6.6 to 6.8. The slope at site is 20-25 percent and the length of slope is about 400 feet. Many rolling hills are present at the sample site. The structure of the surface soil is weak fine platy and crumbles easily to moderate medium to fine granular. The cover at present is wheat stubble. The surface seems to be slightly eroded. On the ridges and hills around the sample site, there are some rills 3-5 inches deep and 5-6 inches wide near the top.

Soils at Mud Flat area

Location.--T12N, R3E, SE $\frac{1}{4}$ of the NW $\frac{1}{4}$ of Section 11; 200 feet west of guard station.

Elevation.--7400 feet.

Precipitation.--25-30 inches.

Temperature.--24-73° F. (Logan).

The soils are dark grey (dry) to very dark grey (moist). The pH of these soils ranges from 6.4 to 6.6. The slope of the sample site is 10 percent and the length of slope is about 150 feet. The surface soil structure of these soils is moderate to weak fine granular. The cover at present consists of big sage and some short grasses. Sheet erosion is evident on higher parts of the slope. Soil mounds occur under the individual sage or brush. Slight to moderate erosion is also observed at the actual sample site.

Trenton series

Location.--T12N, R1W, SE $\frac{1}{4}$ of the NE $\frac{1}{4}$ of Section 26.

Elevation.--4400 feet.

Precipitation.--14-16 inches.

Temperature.--24-73° F. (Logan).

The soils are light brown grey (dry) to very dark grey brown (moist). The pH ranges from 8.0 to 8.2. In general, the slope of the area is 1-3 percent and slope at sample site is about 2 percent. The land is gently undulating. The structure of soil is moderate fine to very fine granular and crumbles easily. The present cover consists of alfalfa stubble. No rills are present and there is no indication of erosion at the sample site.