MASTER'S THESIS

A COMPARISON OF METHODS FOR EVALUATING AGGREGATE STABILITY OF MOUNTAIN SOILS

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY KASEM CHUNKAO ENTITLED A COMPARISON OF METHODS FOR EVALUATING AGGREGATE STABILITY OF MOUNTAIN SOILS BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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Permission to publish this thesis or any part of it must be obtained from the Dean of the Graduate School.

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CHAPTER I

INTRODUCTION

Almost everywhere in the world man has been slow to recognize soil erosion and to take the necessary preventive action. Many areas have been abandoned because they no longer produced adequate food, clothing, and shelter. A particularly critical need for proper watershed management in many of the developing countries is a workable erosion classification scheme. A similar need exists for the remote or "wild" lands in the more developed nations where use of heretofore neglected lands is growing rapidly.

Soil erosion is a complex process related to both the eroding forces and the soil's resistance to these forces. Among the factors influencing soil erosion are rainfall, topography, vegetation, and soil characteristics. The soil characteristics may be further delineated into such properties as infiltration, percolation, texture, and structure. This study is concerned only with the soil structural stability part of the erosion complex.

Various approaches have been used to study soil structural stability. Middleton (1930) used the dispersion ratio. Many different methods of sieving soils in water have been tried since the time of Middleton. Other workers have tried rainfall applicators with a wide range of designs to simulate drop sizes and intensities. In this study three methods are compared: 1) the dispersion ratio of Middleton, 2) wet-sieving of 1-2 mm aggregates, and 3) water drops on single 2-3 mm aggregates.

Soil samples were selected from 9 sites in the Front Range of the Central Rocky Mountains. The soils were chosen to include a wide variety of great soil groups. Only 3 samples were taken at each site, therefore the samples are not necessarily considered to characterize the specific soil groups as they exist in the area with reference to their erodibility.

Summarily, the objective of this study was to compare three different methods of ranking soil structural stability on a widely varied assortment of mountain soils with the hope that some ideas for a simple and convenient method might result.

CHAPTER II

REVIEW OF LITERATURE

Dispersion Ratio

Middleton (1930) was one of the first to try to obtain an index of soil erodibility based on the physical properties of the soil. He used the dispersion ratio for the erodibility index; the dispersion ratio defined as the percentage of silt and clay that was dispersed by shaking under certain specified conditions to the total percentage of silt and clay by mechanical analysis. Smerdon and Beasley (1959) found that the dispersion ratio measures a physical phenomenon which actually occurs in the erosion of a channel bed, i.e., the dispersing of soil aggregates in water. Anderson (1951) stated that the dispersion ratio of Middleton proved to be a simple and useful expression of erodibility as measured by the erosion produced from watersheds. Andre and Anderson (1961) used dispersion ratio to measure the variation of soil erodibility with geology, geographic zone, elevation, and vegetative type, and Anderson (1962) used dispersion ratio to measure the sediment and erosion in California wildlands.

Free, Browning, and Musgrave (1940) found that dispersion ratio correlated directly to the bulk density and inversely to infiltration, aggregation, silt and clay content, clay content, total porosity, organic matter, moisture equivalent, and pH. Chang and Drengne (1955) treated a Gila clay loam with Na_2CO_3; the treated soils showed the dispersion ratio increased with increase in exchangeable sodium percentage.

Willen (1963) modified Middleton's method to determine dispersion ratio by using 50 grams of equivalent dry soil instead of 10 grams, believing 50 grams to give a better average of the inherent variation of a soil to disperse.

Aggregate Stability

Kemper and Chepil (1965) define an aggregate as a group of two or more primary particles which cohere to each other more strongly than to surrounding particles; the units of the soil mass which maintain their identity as aggregates will be those in which the cohesive forces among particles are greater than the disruptive forces. Bryant, Bendixen, and Slater (1948) felt that initial stabilities were most important in estimating the ability of the soil to resist slumping under field conditions of wetting and drying. Chepil (1958) has shown that mechanical stability of dry aggregates or clods is a good index of the ability of soils to resist wind erosion. Robinson and Page (1950) used the silt and clay fraction being modeled into "spaghetti" of 3, 5, and 10 mm in diameter and found that the initially larger sized aggregates resulted in larger mean weight diameter and greater aggregate stability.

Kroth and Page (1946) report that their findings give strong support to the concept that organic matter promotes aggregation largely through active polar materials produced during its decomposition. These polar organic substances form physio-chemical bonds with the surface-active clays; inorganic oxides, fats, waxes, and resins were also reported to bind soil particles into aggregates; this binding resulting from physical forces alone. They conclude their study by stating that the superiority of polar substances is produced by decay of fresh organic matter. McHenry and Russell (1943) indicated that undecomposed organic matter markedly reduced aggregation.

Mazurak (1950) studied the role of different clay minerals in aggregates. Under most conditions, given quantities of higher surface area clay (bentonites) seem to be more effective in causing aggregation than equal quantities of low surface area clay (kaolinite).

McHenry and Russell (1943) found that aggregation increased with increase in clay content; they also found that monovalent ions gave better aggregation than divalent ions, which in turn were better than trivalent ions.

Myers and McCalla (1941) have shown that maximum aggregation lagged behind maximum microbial activity. Chester, Attoe, and Allen (1957) found microbial gums to be an important aggregating factor. The filamentous soil fungi were also observed to bind soil particles together in stable aggregates. Martin (1946) stated that the bacterial polysaccharides were better aggregating substances than was caesin or lignin. Martin, Waksman, and Selman (1940) found that microorganisms produced a binding and aggregating of the soil; the extent of the binding depending on the organisms and the nature of the organic matter. Martin (1945) found that two soil microbes, a fungus of the *Cladosporium* group and an aerobic bacillus, brought about marked aggregation. Up to 50% of the aggregating effect of the fungus was due to cell materials; the remainder was due to mycelium. The bacillus cells accounted for 20% of the aggregating effect; substances produced by cells 80%. Primary responsibility for the marked aggregating effect was attributed to a hemicellulose-like polysaccharide. However, McCalla (1945) concluded that the increase in structural stability resulting from biological activity is temporary, remaining as long as the stabilizing decomposition products exist. He stressed the importance of quality of organic matter over quantity, and believed that lignin and proteins were probably largely responsible for the stabilizing effects of organic matter.

Acton, Rennie, and Paul (1963) added fine ground wheat straw to samples of the A horizon of a dark brown solodized solonetz and the A horizon of a low humic eluviated gley soil and then incubated the mixtures. They found that the level of aggregation is a function not only of the microbial gum content of the soil but also of the carbohydrate content of the humic acid-humin fraction.

Kolodny and Neal (1941) report that the local weather cycle and dispersion parallel each other. Alderfer (1946), working with a Hagerstown silt loam, found the soil, when analyzed in the air-dry condition, possessed a maximum percentage of water-stable aggregates during the months of July, August, and September and a minimum during the winter and early spring months.

Wet Sieving

Tiulin (1928) and Yoder (1936) were among the early workers to use wet sieving. Kemper (1965) said that the purpose of sieving the samples is to separate the fine slaked material from stable aggregates without undue disruption of the aggregates before sieving since wetting soils under tension is a fairly time-consuming process.

Robinson and Page (1950) indicated that the organic matter associated with the clay fraction and adsorbed on the surfaces of clay particles is the most important factor in aggregate stabilization, its effects consist mainly in reducing the swelling and the destructive forces of entrapped air, decreasing the wetting, and strengthening the aggregates.

Kemper (1965) found that 5 minutes of sieving were adequate to separate the fine slaked material from aggregates in all cases. There was a slight tendency for aggregate stability to decrease when the temperature of water used to wet and sieve the samples was increased from 20 to 30 C. Consequently, it is suggested that the temperature of this water be within the range of 22 to 25 C. He also indicated that appreciable salt in the water can cause changes in the ionic status of the soils themselves. Changes in the ionic status can cause changes in the stability, and therefore it is suggested that the salt content of the water be low.

Raindrop Impact

The mechanics of soil erosion involve three distinct processes recognized by soil scientists as detachment, transportation, and deposition. Rainfall may act as both a detaching and transporting force.

Smith and Wischmeier (1962) stated that study of rainfall momentum and energy in relation to erosion requires knowledge of the determining factors - raindrop mass, size, size distribution, shape, velocity, and direction.

Ellison (1944) has emphasized the role played by raindrop impact in the soil erosion processes. He also gave a broad grouping of the factors affecting raindrop erosion processes including: (1) variables of rainfall, (2) slope of the land, (3) soil characteristics, and (4) protection of the soil against, or exposure to, rainfall impact.

Wischmeier (1959) showed that precipitation amount was poorly correlated with erosion potential; rainfall energy is a better predictor of erosion losses than is rainfall amount.

Laws (1940) found the kinetic energy of a drop to equal one half of its mass times its velocity squared. He calculated the following relation for the distribution of dropsize with the intensity of rainfall:

$$Dm = 2.23I^{0.182}$$

where Dm is the drop diameter in mm which divides the total rainfall into two equal volumes and I is intensity of precipitation in inches per hour. Bentley (1904) determined the average of dropsize by weighing and counting the number of drops in the catcher. Laws (1941) took pictures for determining the average drop size.

Blanchard (1948) made laboratory investigations of the stability of water drops suspended in a vertical column of air. When the air flow was periodically interrupted to simulate turbulent air, all drops larger than 5.4 mm in diameter were broken apart. When the air flow was uninterrupted as in still air, all drops larger than 9.5 mm were broken, and only those smaller than 7.7 mm were stable. He also reported that drop growth by collision seldom formed drops larger than 7.3 mm in diameter, which corresponds very closely to the 7.2 mm maximum diameter observed in natural rain. He further showed that the shape oscillated through a remarkable series of flattened spheroids.

Smith and Wischmeier (1962) stated that the shape of raindrops as they strike the surface of the earth is not spherical owing to differential air pressure created by the falling drop; the resultant shape approximates an ellipsoid flattened on the bottom.

The change in shape of a raindrop has significance from an erosion standpoint in that it affects the velocity as stated by Laws (1941) and the impact force per unit area of soil as stated by Ekern (1951).

Bisal (1960) worked on the effect of raindrop size and impact velocity. His method, the three drop sizes, 4.88, 4.52, 4.13 mm fell from the strings when water was sprayed, the height is 2.44 to 7.01 meters, but not less than 2.44 meters since impact velocity of drops was too low. He used the intensity 3 to 6 inches per hour and impact velocity of 7.4 meters per second. He found that the amount of sand splashed was an index of the effective energy of the raindrops:

$$G = KDV^{1.4}$$

where _G_ is the amount of sand splashed (gm), _K_ is the constant for sand, _D_ is the diameter of drop (mm), _V_ is the velocity of impacting drops (m/sec).

McCalla (1944) used one aggregate (0.15 gm) placed on a 1-mm screen and drops of distilled water 4.7 mm in diameter falling 30 cm from a burette were allowed to strike it. He used the number of drops to indicate the stability of soil.

Smith and Cernuda (1951) suggested that the use of 1-gm of dry soil is better than the use of one aggregate as in McCalla's method.

The intensity of rainfall plays an important role in soil losses; when drop size, drop shape, and velocity were held constant, the amount of sand transportation was directly proportional to the simulated intensity (Ekern 1950). Neal (1938) found rainfall intensity to be the most important factor affecting runoff and erosion from data obtained from the use of artificial rainfall on variable slope plots in a greenhouse. Copley, Forrest, McCalla, and Bell (1944) state that soil losses are not directly proportionate to the total amount or rainfall intensity. Wischmeier (1959) said that, in general, maximum 30-minute intensity is more highly correlated with soil loss than is maximum 5-, 15-, or 60-minute intensity.

Mutch and Moldenhauer (1963) developed an applicator for a laboratory rainfall simulator to measure soil stabilization. They used a drop diameter between 4.84 and 5.00 mm. The intensity can be controlled during each run.

Infiltration Relating to Soil Losses

Bauer (1961) suggested that an understanding of the character of erosion and control methods could be advanced by investigating the interrelationships of the factors which were associated with erosion. Infiltration rate plays an important role in soil loss phenomena; an increasing infiltration rate is associated with decreasing soil loss. Ellison (1945) states that since raindrop impact is responsible for surface sealing, research in problems of infiltration must also start here. The significance of surface sealing caused by drop impact in reducing infiltration has been investigated and discussed by Duley 1939 (~~1954~~). Horton (1940) postulated that surface control of infiltration was the result of raindrop impact effects on surface packing, puddling, structure deterioration, and clogging of macroopenings.

Smith and Wischmeier (1962) indicated that soil properties which influence soil erodibility by water may be grouped into two types: (1) those properties that affect the infiltration rate and permeability; and (2) those properties that resist the dispersion, splashing, abrasion, and transporting forces of the rainfall and runoff.

Grant and Struchtemeyer (1959) used a laboratory infiltrometer and found that removal of aggregates larger than 4.76 mm caused a decrease in infiltration rate. Rai, Raney, and Vandeford (1954) studied size of aggregates and found that as the amount of $< 500\ \mu$ aggregates decreased the erosion was greatly increased.

CHAPTER III

METHODS AND MATERIALS

Selection of Samples

Soil samples were taken from July 23, 1964 to September 26, 1964. All sites were located within the Cache la Poudre watershed in the Front Range of the Colorado Rockies at elevations from 5,000 to 11,000 feet. Three samples of each soil were taken in a triangular pattern approximately 100 feet apart. Only the top of the mineral A and B horizons were sampled. The thickness of the samples ranged from 2½ to 6 inches. The moisture content of the soils at the time of sampling was such that the larger clods could be gently crushed by hand. Soil samples were placed in paper sacks and taken to the laboratory and allowed to air dry at room temperature for approximately 48 hours before testing. A summary description of the soil sampling sites is given in Table 1. The locations of the soil samples are described in the Appendix.

Mechanical Analysis

The procedure used to determine the percentage of sand, silt and clay (only the $<$2-mm soil, clay was determined separately from silt and clay) by using a hydrometer was as follows:

1. Add the equivalent of 50 g of $<$2-mm oven dry soil to the electric mixer cup.

2. Add distilled water to fill about 2/3 full.

3. Add to the contents 5 cc of a solution of Calgon (sodium hexametaphosphate $(NaPO_3)_x$.

TABLE 1. Characteristics of sample sites

	Lithosol (1)	Chestnut (cold) (2)	Regosol (chernozemic) (3)
Elevation (ft)	6,800	8,000	8,100
Slope (%)	37	12	9
Aspect	NE	W	SE
Litter layer (in)	¼	½	1
Vegetative cover (%)	70	90-95	95
Parent material	Gneiss Schist	Gneiss Schist	Alluvium
Predominant plant cover	*Pinus ponderosa* *Purshia tridentata* *Cercocarpus montanus* *Stipa* spp. *Juniperus* spp. *Pseudotsuga menziesii*	*Carex* spp. *Poa* spp. *Festuca* spp. *Danthonia* spp.	*Carex* spp.
Sampling thickness from top of A horizon (in)	2½	3	6
Sampling thickness from top of B horizon (in)	4	4	6
% sand of 2 mm soil of A horizon	74.7	67.5	65.1
% silt of 2 mm soil of A horizon	20.2	26.4	29.5
% clay of 2 mm soil of A horizon	5.1	6.1	5.4
% sand of 2 mm soil of B horizon	76.9	66.5	58.9
% silt of 2 mm soil of B horizon	15.5	23.8	29.6
% clay of 2 mm soil of B horizon	7.6	9.7	11.5
Structure	Granular	Granular	Granular
Color of A horizon (dry)	Gray	Brown	Very dark gray
Color of B horizon (dry)	Pale brown	Brown	Brown

TABLE 1. Characteristics of sample sites (continued)

	Gray wooded (4)	Podzol (5)	Chestnut (cold) (6)
Elevation (ft)	9,100	9,550	8,100
Slope (%)	37	38	7
Aspect	SE	SE	N
Litter layer (in)	1	1	1
Vegetative cover (%)	75	80	70-80
Parent material	Glacial morrine (granite)	Granite Gneiss	Gneiss Schist
Predominant plant cover	_Pinus contorta_ _Juniperus communis_ _Picea_ spp. _Arctostaphylos uva-ursi_	_Pinus contorta_ _Vaccinium_ spp. _Picea engelmanni_ _Abies lasiocarpa_	_Pinus ponderosa_ _Purshia tridentata_
Sampling thickness from top of A horizon (in)	4	5	4
Sampling thickness from top of B horizon (in)	4	5	4
% sand of <2 mm soil of A horizon	73.5	63.3	69.6
% silt of <2 mm soil of A horizon	21.0	28.3	26.1
% clay of <2 mm soil of A horizon	5.5	8.4	4.3
% sand of <2 mm soil of B horizon	73.9	69.7	65.2
% silt of <2 mm soil of B horizon	21.1	22.7	25.5
% clay of <2 mm soil of B horizon	5.0	7.6	9.3
Structure	Platy	Platy	Granular
Color of A horizon (dry)	Light brown	Brown	Brown
Color of B horizon (dry)	Light gray	Pinkish gray	Gray brown

TABLE 1. Characteristics of sample sites (continued)

	Tundra (alpine turf) (7)	Brown (8)	Brown (9)
Elevation (ft)	11,000	5,500	5,500
Slope (%)	-	3	14
Aspect	N	NE	N
Litter layer (in)	0-2	0	0
Vegetative cover (%)	70-80	45	60
Parent material	Gneiss Schist	Sandstone	Sandy Shales
Predominant plant cover	*Kobresia bellardi* *Carex* spp.	*Carex* spp. *Eurotia lanata* *Bouteloua* spp. *Rhus trilobata* *Agropyron smithii* *Artemisia frigida*	*Stipa comata* *Eurotia lanata* *Bouteloua* spp. *Rhus trilobata* *Agropyron smithii* *Artemisia frigida*
Sampling thickness from top of A horizon (in)	4	4	5
Sampling thickness from top of B horizon (in)	4	4	4
% sand of <2 mm soil of A horizon	56.7	68.4	38.5
% silt of <2 mm soil of A horizon	39.6	19.5	48.9
% clay of <2 mm soil of A horizon	3.7	12.1	12.6
% sand of <2 mm soil of B horizon	51.9	70.9	34.3
% silt of <2 mm soil of B horizon	41.0	15.0	50.9
% clay of <2 mm soil of B horizon	7.1	14.1	14.8
Structure	Granular	Granular	Granular
Color of A horizon (dry)	Very dark gray	Pale red	Dark red
Color of B horizon (dry)	Brown	Red	Dark red

4. Stir for about 5 minutes with electric stirrer.

5. Transfer soil suspension to sedimentation cylinder and fill with water to lower mark when the Bouyoucos hydrometer is in the cylinder.

6. Remove hydrometer and shake cylinder vigorously by holding palm of hand over the mouth. Turn cylinder upside down and back several times.

7. Place cylinder on table and record the time immediately.

8. Record hydrometer and temperature reading at the end of 40 seconds, and again at the end of 2 hours.

9. Since the hydrometer is calibrated at 68F, add a correction of 0.2 to the hydrometer reading for each degree F above 68F and subtract 0.2 for each degree below that temperature.

10. Divide corrected hydrometer reading by grams of total soil in suspension and multiply by 100 to get the percentage of material still in suspension at the time of reading.

11. Silt and clay are measured at the end of 40 seconds while only the clay is in suspension after 2 hours.

Dispersion Ratio

The following procedure based on the description by Middleton (1930) was used in determining the dispersion ratio:

1. A sample of air-dry soil ($<$2-mm) equivalent to 10 grams of oven-dry soil was placed in a tall cylinder of approximately 1,200 cc capacity.

2. Sufficient distilled water was added to make the volume 1 liter.

3. The cylinder was closed with palm of hand and shaken end over end 20 times.

4. The suspension was then allowed to settle for 100 seconds and then a 25 cc sample was withdrawn from a depth of 25 cm [computed from Tanner and Jackson (1947), temperature of water was 26C].

5. The total weight of silt and clay in the suspension was calculated from the dry weight of the pipetted fraction.

6. The ratio, expressed in percentage, of silt and clay dispersed to the total silt and clay obtained by mechanical analysis is called the dispersion ratio.

7. The dispersion ratio for 2-3 mm soil was determined in the same way as for < 2-mm soil. The time, temperature, and depth for withdrawing the suspension followed the computation of Tanner and Jackson (1947).

Aggregate Stability (Wet Sieving)

The procedure based on Kemper (1965) was as follows:

1. Sieve the sample, saving the aggregates which pass through a 2-mm sieve and are retained on a 1-mm sieve.

2. Transfer soil equivalent to 4 g of 1-2 mm oven-dry soil to 60-mesh sieves 1.5 inches in diameter, and place these sieves on filter paper on a ceramic plate in a vacuum desiccator containing a few cc of water, and having an inlet through which water can be brought to the bottom of the desiccator from the outside.

3. Evacuate the desiccator, allowing the water to boil for 2 or 3 minutes. This tends to sweep out the other gases and leave water vapor as the only remaining gas. Keep a small (6 to 8 cm high)

barometer in the desiccator to make sure the pressure is lowered to the boiling point of water. Leave the samples in the evacuated (except for water vapor) desiccator for at least 10 minutes.

4. Deaerate a supply of water by reducing the pressure over it in a desiccator so that boiling takes place for 10 minutes; the water should be allowed to come to room temperature.

5. Let the deaerated water into the bottom of the desiccator through a tube connecting the desiccator to another desiccator containing the deaerated water, until the aggregates in the first desiccator are covered with water.

6. Place the sieves containing the samples in a sieve holder, and sieve the sample in distilled water for 5 minutes at 42 cycles per minute. In each cycle the sieves should go down and up 0.5 inch. Maintain the water at a level high enough to keep the samples covered when the sieves are at the top of their stroke.

7. At the end of 5 minutes remove the sieves from the holder, and wash the sample into a weighing dish. Pour off excess water, and dry the sample in an oven at 105C.

8. Weigh the dish containing the aggregates and sand.

9. Wash the aggregates and sand back into the sieves, and sieve them for 5 minutes in 30% Calgon solution. At the end of this time only the 60-mesh sand should remain. Break any remaining aggregates with a rubber-tipped rod.

10. When only the sand remains, wash it back into the weighing dish, pour out the excess water and oven dry the sand.

11. Weigh the sand and dish.

12. Calculation and interpretation of results are as follows:

Sample No.	Dish No.	Dish Weight g	Dish + Agg. + Sand g	Dish + Sand g	Sand (5)-(3) g	Aggregate (4)-(5) g	Total Aggregate 4g-(6)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			After sieving 5 minutes in water	After sieving 5 minutes in Calgon solution			

$$\% \text{ Aggregate stability} = \frac{\text{Water stable aggregate (7)}}{\text{Total aggregate (8)}} \times 100$$

Waterdrop Impact

The procedure was adapted from method McCalla (1944) used to determine the effect of microbiological and organic matter treatments on the resistance of soil structural groups or clods to the action of raindrops. The number of waterdrops required to disintegrate the soil aggregate was determined as follows.

Aggregates of 2-3 mm size were selected and placed on a 1-mm screen. Drops of distilled water 4.6 mm in diameter, falling 60 cm from a constant-head burette, were allowed to strike the aggregate. When a soil aggregate was broken down and washed through the screen, it was considered to be destroyed and the number of drops were recorded. The rate of falling drops was 2 drops per second; the temperature of distilled water was 28C. Thirty replicates were run on each soil sample. Counting was stopped at 500 drops.

CHAPTER IV

RESULTS AND DISCUSSION

In the following each method is discussed individually and then a comparison of all methods together is made. Because the emphasis of this study is on comparison of methods rather than soils, only numbers are used to identify soils in the tables. If the reader desires to identify the various soils then he should refer to Table 1 in Chapter III. In the following discussion Appendix tables are lettered and text tables are numbered.

Dispersion Ratio

The mean values (3 samples x 2 determinations on each) for the dispersion ratio for both the <2 mm soil and the 2-3 mm soil are presented in Table 2. The values are listed in order of decreasing stability of the A horizon of the <2 mm soil.

TABLE 2. Dispersion ratios for <2 mm and 2-3 mm soil

Soil No.	Dispersion ratio			
	<2 mm soil		2-3 mm soil	
	A horizon	B horizon	A horizon	B horizon
8	31.1	31.1	20.1	20.4
3	32.6	37.4	9.4	10.1
7	33.9	29.5	20.6	23.7
9	34.7	25.2	16.7	14.5
2	38.7	33.4	12.1	13.8
5	41.9	36.6	13.0	11.6
4	45.5	52.8	29.4	32.7
6	45.7	44.0	12.6	16.0
1	48.8	35.9	38.8	32.4

Statistical analyses (Appendix Tables B-G) indicate that the differences in the dispersion ratios of <2 mm soils are highly significant.[1] Differences in horizons and soil x horizon interaction were not significant at the 5% level. A closer examination of the differences between soils by separate horizons shows that no significant differences exist in the A horizon; highly significant differences are indicated for the B horizon.

If the dispersion ratio for only the 2-3 mm portion of the various soils is considered then highly significant differences are found between soils and no significant differences are found for either horizon or interaction. Both the A and B horizons show differences between soils at the 1% level.

Based on Hartley's sequential tests as described in Snedecor (1962) the 9 soils were grouped in order of decreasing structural stability (Table 3). The groups represent soils that are not different from each other at the 5% confidence level. Tables 4-6 present the sequential comparisons in detail.

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[1] Throughout the discussion the terms "highly significant" and "significant" are used to represent the 1% and 5% confidence levels respectively.

TABLE 3. Comparison of dispersion ratio (5% level of significance)

< 2 mm soil				2-3 mm soil			
A horizon		B horizon		A horizon		B horizon	
Soil	Dispersion ratio	Soil	Dispersion ratio	Soil	Dispersion ratio	Soil	Dispersion ratio
(Most stable)							
8	31.1	9	25.24	3	9.44	3	10.05
3	32.6	7	29.49	2	12.06	5	11.60
7	33.9	8	31.06	6	12.57	2	13.77
9	34.7	2	33.04	5	12.95	9	14.54
2	38.7	1	35.89	9	16.74	6	15.97
5	41.9	5	36.62	8	20.11	8	20.44
4	45.5	3	37.39	7	20.55	7	23.73
6	45.7	6	43.95	4	29.41	1	32.38
1	48.8	4	52.77	1	38.83	4	32.68
(Least stable)							

] = all soils same at 5% level.

Interpreting Table 3 one can see that there are no differences in the A horizon for the < 2 mm soil. In the A horizon of the 2-3 mm soil: soil 4 is less stable than soils 3, 2, 6, and 5; soil 1 is less stable than all other soils except soil 4. In the B horizon, soil 4 differs from all others except soils 1, 5, 3, and 6 for the < 2 mm soil. In the 2-3 mm soil B horizon: soil 8 is less stable than soils 3 and 5; soil 7 differs from soils 3, 5, 2, 9, and 6; soils 1 and 4 are less stable than all others.

TABLE 4. Sequential test (5% level) of dispersion ratio of B horizon, $<$ 2 mm soil

Soil No.	Mean $\overline{X}$	$52.77 - \overline{X}$
9 (Most stable)	25.24	27.53 (21.03)[1]
7	29.49	23.28 (20.48)
8	31.06	21.71 (19.80)
2	33.40	19.37 (19.04)
1	35.89	
5	36.62	
3	37.39	
6	43.95	
4 (Least stable)	52.77	

[1] The value for 5% level of significance.

TABLE 5. Sequential test (5% level) of dispersion ratio of A horizon,2-3 mm soil

Soil No.	Mean $\overline{X}$	$38.83 - \overline{X}$	$29.41 - \overline{X}$
3 (Most stable)	9.44	29.39 (15.82)[1]	19.97 (15.41)
2	12.06	26.77 (15.41)	17.35 (14.90)
6	12.57	26.26 (14.90)	16.84 (14.32)
5	12.95	25.88 (14.32)	16.46 (13.65)
9	16.74	22.09 (13.65)	
8	20.11	18.72 (12.76)	
7	20.55	18.28 (11.52)	
4	29.41		
1 (Least stable)	38.83		

[1] The value for 5% level of significance.

TABLE 6. Sequential test (5% level) of dispersion ratio of B horizon, 2-3 mm soil

Soil No.	Mean $\bar{X}$	32.68 - $\bar{X}$	32.38 - $\bar{X}$	23.73 - $\bar{X}$	20.44 - $\bar{X}$
3 (Most stable)	10.05	22.63 (9.03)[1]	22.03 (8.79)	13.68 (8.50)	10.39 (8.17)
5	11.60	21.08 (8.79)	20.48 (8.50)	12.13 (8.17)	8.84 (7.79)
2	13.77	18.91 (8.50)	18.21 (8.17)	9.86 (7.79)	
9	14.54	18.14 (8.17)	17.54 (7.79)	9.19 (7.28)	
6	15.97	16.71 (7.79)	16.11 (7.28)	7.76 (6.57)	
8	20.44	12.24 (7.28)	11.64 (6.57)		
7	23.73	8.95 (6.57)	8.35 (5.41)		
1	32.38				
4 (Least stable)	32.68				

[1] The value for 5% level of significance.

The <2 mm soils of all 9 representatives of the Central Rocky Mountain soils are poorly aggregated; most of the soils are coarse textured (Table 1). All dispersion ratios are above Middleton's 10 which he used to separate unerodible (<10) from erodible (>10) soils. The results of the dispersion ratio tests, particularly the lack of differentiation of soils, would indicate that the dispersion ratio of <2 mm soil is a poor index of structural stability for soils similar to those studied.

When the dispersion ratio of 2-3 mm soil was used, more differences in the soils in both the A and B horizons were detected. More of the material in this size range consists of aggregates in comparison to the amount of aggregates in the <2 mm soil. For this reason the dispersion ratio of the 2-3 mm soil would appear to be a much better test for structural stability in poorly aggregated, coarse textured soils. There appears to be good general agreement between the tests of the two soil fractions, the major difference being the greater sensitivity of the 2-3 mm soil material to the dispersion test.

One possibility of error in using the dispersion ratio in very coarse textured soils is the effect of abrasion caused by the large amount of the coarser textured primary particles. This might tend to give higher dispersion ratios and help explain the relatively high values obtained for the soils used in this study, most of which are generally observed to have very low erodibility under field conditions.

Aggregate Stability - Wet Sieving

The analyses of variance of the wet sieve data are presented in Appendix Tables H-J. These analyses indicate highly significant differences between soils, horizons, and soil x horizon interaction. The soil x horizon interaction reflects the variability in magnitude of the difference between the A and B horizons for the various soils. If the horizons are considered individually then both the A and B horizon reflect the differences between soils.

The mean values (3 samples x 2 determinations on each) for the percentage of aggregate stability of 1-2 mm soil for both the A and B horizons are presented in Table 7. These values are listed in order of decreasing stability of the A horizon.

TABLE 7. Percentage of aggregate stability for 1-2 mm soil

Soil No.	% Aggregate stability		Difference between A and B horizon
	A horizon	B horizon	
9	79.3	89.4	10.1**
8	77.7	84.5	6.8**
1	76.7	89.8	13.1**
5	73.5	92.6	19.1**
3	66.4	89.8	23.4**
4	66.3	94.6	28.3**
6	63.4	78.2	14.8**
2	60.2	73.7	13.5**
7	58.2	80.3	22.1**

** Highly significant L.S.D. = 6.696

The comparison between the A horizon and B horizon by using L.S.D. shows that in 1-2 mm soil, the B horizon is more stable than the A horizon for all 9 soils. All of these differences are significant at the 1% level.

Hartley's sequential tests as described in Snedecor (1962) were used to group 9 soils in order of decreasing structural stability (Table 8). The groups represent soils that are not different from each other at the 5% confidence level. Tables 9 and 10 present the sequential comparisons in detail.

TABLE 8. Comparison of percentage of aggregate stability of 1-2 mm soil (5% level)

A horizon		B horizon	
Soil	% aggregate stability	Soil	% aggregate stability
(Most stable)			
9	79.31	4	94.55
8	77.66	5	92.59
1	76.73	1	89.83
5	73.49	3	89.75
3	66.40	9	89.44
4	66.28	8	84.53
6	63.41	7	80.32
2	60.23	6	78.32
7	58.17	2	73.73
(Least stable)			

] = all soils same at 5% level.

The interpretation of Table 8 would be as follows. In the A horizon: soils 3, 4, 6, and 2 are less stable than soils 9, 8, 1, and 5; soil 7 is less stable than all the other soils except for soils 6 and 2. In the B horizon: soil 8 is less stable than soil 4; soils 7, 6 and 2 are less stable than soils 4, 5, 1, 3, and 9; and soil 2 is less stable than all other soils except soils 7 and 6.

One difficulty observed in making the wet sieve determinations was the resistance of some aggregates to the sieving in Calgon, spraying with a jet of water, or brushing with a rubber-tipped rod. These were not concretions and most could be broken into primary particles with a little extra effort.

TABLE 9. Sequential test (5% level) of percentage of aggregate stability of A horizon, 1-2 mm soil

Soil No.	Mean $\bar{X}$	$\bar{X}$-58.17	$\bar{X}$-60.23	$\bar{X}$-63.41	$\bar{X}$-66.28	$\bar{X}$-66.40
9 (Most stable)	79.31	21.14 (7.74)[1]	19.08 (7.53)	15.90 (7.29)	13.03 (7.00)	12.91 (6.68)
8	77.66	19.49 (7.53)	17.43 (7.29)	14.25 (7.00)	11.38 (6.68)	11.26 (6.24)
1	76.73	18.58 (7.29)	16.52 (7.00)	13.32 (6.68)	10.45 (6.24)	10.33 (5.63)
5	73.49	15.32 (7.00)	13.26 (6.68)	10.08 (6.24)	7.21 (5.63)	7.09 (4.63)
3	66.40	8.23 (6.68)				
4	66.28	8.11 (6.24)				
6	63.41					
2	60.23					
7 (Least stable)	58.17					

[1] The value for 5% level of significance.

TABLE 10. Sequential test (5% level) of percentage of aggregation of B horizon, 1-2 mm soil

Soil No.	Mean $\overline{X}$	$\overline{X}$ - 73.73	$\overline{X}$ - 78.23	$\overline{X}$ - 80.32	$\overline{X}$ - 84.53
4 (Most stable)	94.55	20.82 (10.17)[1]	16.32 (9.90)	14.23 (9.57)	10.02 (9.20)
5	92.59	18.86 (9.90)	14.36 (9.57)	12.27 (9.20)	
1	89.83	16.10 (9.57)	11.60 (9.20)	9.51 (8.77)	
3	89.75	16.02 (9.20)	11.52 (8.77)	9.43 (8.20)	
9	89.44	15.71 (8.77)	11.21 (8.20)	9.12 (7.40)	
8	84.53	10.80 (8.20)			
7	80.32				
6	78.23				
2 (Least stable	73.73				

[1] The value for 5% level of significance.

Waterdrop Impact

The analyses of variance for the waterdrop impact method are in Appendix Tables K-M. These analyses show that there are highly significant differences between soils, horizons, and soil x horizon interaction. If the horizons are considered individually then both the A and B horizon reflect the differences between soils.

Thirty determinations were made on each sample and the average calculated. There was a slight modification in averaging the thirty determinations in that counting was halted at 500 drops. There were 7 aggregates among those from soil 7 that were not broken down after 500 drops. These determinations were counted as 500 in averaging. The mean values of the 30 determinations for the waterdrop impact of 2-3 mm soil for both the A and B horizon are presented in Table 11. The soils are listed in order of decreasing stability of the A horizon.

TABLE 11. Waterdrop impact for 2-3 mm soil

Soil No.	Number of drops		Difference between A and B horizon
	A horizon	B horizon	
7	249.9	66.0	183.9**
5	73.4	131.9	58.5**
3	50.7	38.1	12.6*
6	48.3	19.1	29.2**
2	47.9	57.7	9.8
4	41.5	21.1	20.4**
1	25.0	25.5	0.5
9	21.1	31.0	9.9
8	13.6	17.1	3.5

** Highly significant L.S.D. = 20.1

* Significant L.S.D. = 11.0

The comparison between the A and B horizon by using L.S.D. shows that there are highly significant differences in soils 7, 5, 6 and 4; significant differences in soil 3; and no significant differences in soils 2, 1, 9 and 8. It is of interest to note that only in soil 5 is the B more stable than the A horizon.

Based on Hartley's sequential tests as described in Snedecor (1962) the 9 soils were grouped in order of decreasing structural stability (Table 12). The groups represent soils that are not different from each other at the 5% confidence level. Tables 13 and 14 present the sequential comparisons in detail.

TABLE 12. Comparison of waterdrop impact of 2-3 mm soil (5% level)

A horizon		B horizon	
Soil	No. of drops	Soil	No. of drops
(Most stable)			
7	249.9	5	131.9
5	73.4	7	66.0
3	50.7	2	57.7
6	48.3	3	38.1
2	47.9	9	31.0
4	41.5	1	25.5
1	25.0	4	21.1
9	21.1	6	19.1
8	13.6	8	17.1
(Least stable)			

] = all soils same at 5% level.

The interpretation of Table 12 would be as follows. In the A horizon: soils 5, 3, 6 and 2 are less stable than soil 7; soils 4 and 1 less than soil 5; soil 9 less than soils 3, 5, and 2; soil 8 is less stable than all others except soils 1 and 9. In the B horizon: soils 7, 2, and 3 are less stable than soil 5; soils 9 and 1 are less than soil 7 but the same as soils 2 and 3; soils 4, 6, and 8 are less stable than all the other soils except for soils 3, 9, and 1.

Several possible sources of error were observed in conducting the waterdrop tests. Bias may occur when selecting the individual aggregate; the test should be repeated on a large number of aggregates. Also, there is the possibility that an aggregate may behave differently as an individual than when in a mass of soil.

TABLE 13. Sequential test of waterdrop impact (5% level) of 2-3 mm soil, A horizon

Soil No.	Mean $\bar{X}$	$\bar{X}$-13.6	$\bar{X}$-21.1	$\bar{X}$-25.0	$\bar{X}$-41.5	$\bar{X}$-47.9	$\bar{X}$-48.3	$\bar{X}$-50.7	$\bar{X}$-73.4
7	249.9	236.3 (32.49)[1]	228.8 (31.64)	224.9 (30.59)	208.4 (29.41)	202.0 (28.03)	201.6 (26.20)	199.2 (23.65)	176.5 (19.45)
5	73.4	59.8 (31.64)	52.3 (30.59)	48.4 (29.41)	31.9 (28.03)				
3	50.7	37.1 (30.59)	29.6 (29.41)						
6	48.3	35.3 (29.41)	27.8 (28.03)						
2	47.9	34.3 (28.03)	26.8 (26.20)						
4	41.5	27.9 (26.20)							
1	25.0								
9	21.1								
8	13.6								

[1] The value for 5% level of significance.

TABLE 14. Sequential test of waterdrop impact (5% level) of 2-3 mm soil of B horizon

Soil No.	Mean $\bar{X}$	$\bar{X}$-17.1	$\bar{X}$-19.1	$\bar{X}$-21.1	$\bar{X}$-25.5	$\bar{X}$-31.0	$\bar{X}$-38.1	$\bar{X}$-57.7	$\bar{X}$-66.0
5	131.9	114.8 (40.87)[1]	112.8 (39.8)	110.8 (38.48)	106.4 (37.00)	100.9 (35.27)	93.8 (32.96)	74.2 (29.75)	65.9 (24.47)
7	66.0	48.9 (39.80)	46.9 (38.48)	44.9 (37.00)	40.5 (35.27)	35.0 (32.96)	27.9 (29.75)		
2	57.7	40.6 (38.48)	38.6 (37.00)	36.6 (35.27)					
3	38.1								
9	31.0								
1	25.5								
4	21.1								
6	19.1								
8	17.1								

[1] The value for 5% level of significance.

Comparison of Methods

Table 15 shows the ranking of aggregate stability by all methods for all soils. The brackets enclose soil groups that are not significantly different from one another at the 5% confidence level. These groupings are based on the sequential tests previously discussed. Figure 1 illustrates graphically the wide variation in methods for each soil and also shows the relation between the A and B horizons.

There are several facts readily observable from both Table 15 and Figure 1. Firstly, there is a great variation in the results from the different methods. This is particularly striking for soils 4, 7, and 8 in which a given horizon is ranked most stable of all soils by one method and least stable by another. This variability is even more emphatic if it is considered that each of the lowest rankings for these three soils is given by a different method as are each of the highest rankings. Thus, there appears to be a very great interaction of soil x method.

A second readily apparent trend in the data is for the A and B horizons to give a similar response to the different methods; although the A and B may differ quantitatively from each other for any given method, the response curves to different methods are in fairly good agreement (Figure 1).

Thirdly, there is a tendency for the B horizons to vary less in stability rankings by the different methods than the A horizons. This tendency can be observed by comparing the range of the ranking and method points of the A and B horizon curves; soils 3, 4, and 5 are exceptions to this statement (Figure 1).

TABLE 15. Ranking of soils for various methods

Rank No.	Soil No. DR, 0-2 mm A	B	DR, 2-3 mm A	B	AS, 1-2 mm A	B	WD, 2-3 mm A	B
1 (Most stable)	8	9	3	3	9	4	7	5
2	3	7	2	5	8	5	5	7
3	7	8	6	2	1	1	3	2
4	9	2	5	9	5	3	6	3
5	2	1	9	6	3	9	2	9
6	5	5	8	8	4	8	4	1
7	4	3	7	7	6	7	1	4
8	6	6	4	1	2	6	9	6
9 (Least stable)	1	4	1	4	7	2	8	8

1 = Lithosol

2 = Chestnut (cold)

3 = Regosol (chernozem)

4 = Gray wooded

5 = Podsol

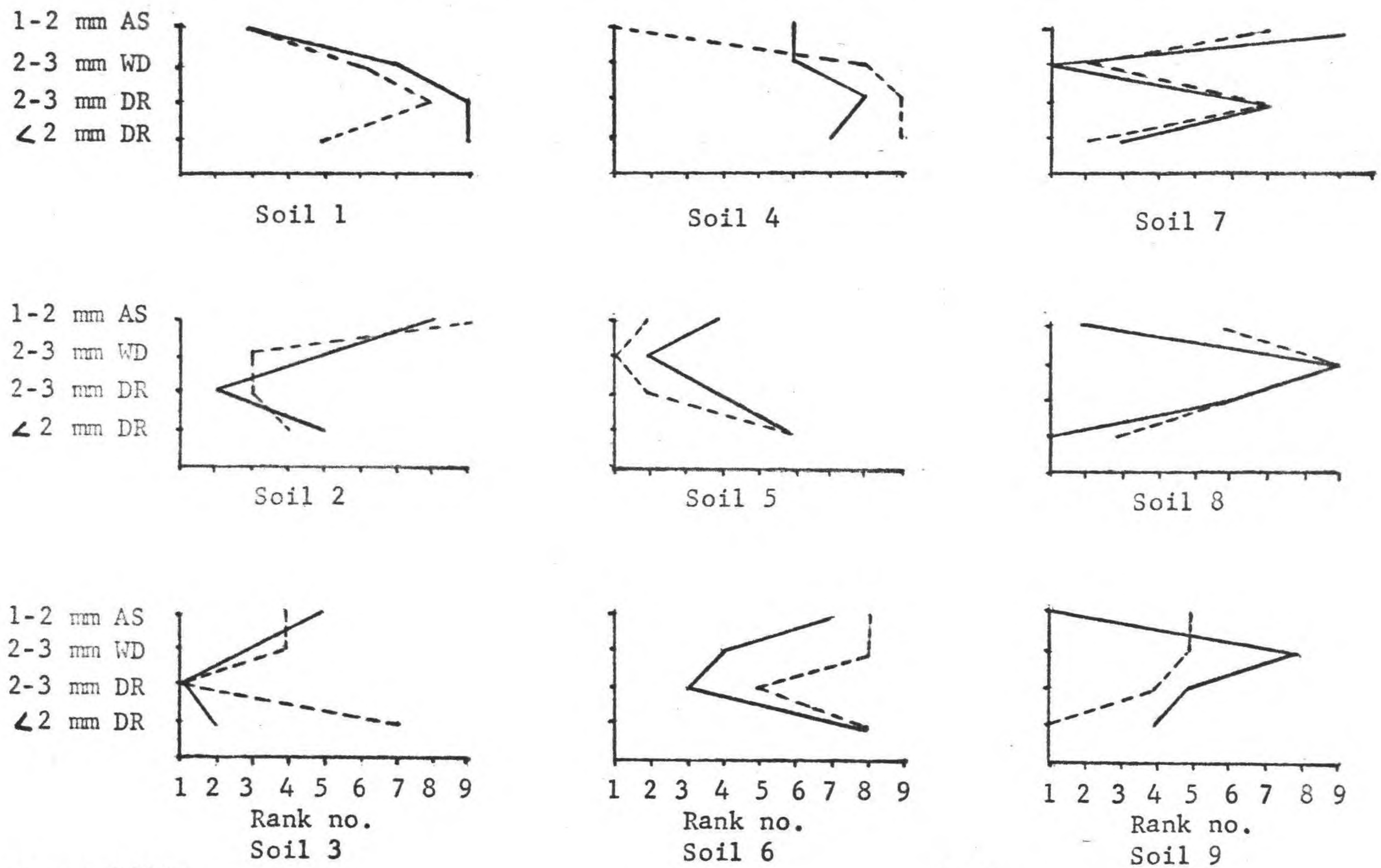
6 = Chestnut (cold)

7 = Tundra (alpine turf)

8 = Brown

9 = Brown

] = all soils same at 5% level.



AS = aggregate stability
WD = waterdrop impact
DR = dispersion ratio

______ A horizon
------ B horizon

Ranking:
1 = most stable
9 = least stable

FIGURE 1. Ranking of aggregate stability by various methods

The differences between the A and B horizons for the different methods are also quite variable. The dispersion ratios are not significantly different between A and B horizons for either the <2 mm or 2-3 mm soils. If the effect of coarse primary particles was accounted for by comparing the dispersion ratio of aggregates separated from primary particles and aggregates and primary particles together, then the dispersion ratio of aggregates may indicate the differences between soils and horizons. The A horizon is more unstable than the B horizon for all mean values of the percentage of aggregate stability of 1-2 mm soil. For the waterdrop impact method: soils 1, 2, 8, and 9 are not significantly different between A and B horizons; in soils 3, 4, 6, and 7, the A horizon is more stable than the B horizon; only in soil 5 is the B horizon more stable than the A horizon. If only highly unstable soils are being compared then the use of a screen size smaller than 1 mm is recommended in the waterdrop impact method.

Although it was not the objective of this study to relate the aggregate stability indices to actual field erosion, a few general comments can be made. Visual observation of erosion at the sampling sites agrees most closely with the waterdrop method. This is particularly true for the relative positions of soils 7 and 9. Based on the high organic matter content of soils 7 and 3, the waterdrop method again appears to give the most reasonable rating.

CHAPTER V

SUMMARY AND CONCLUSIONS

The objective of this study was to compare three methods of determining the aggregate stability of coarse textured mountain soils. The first method involved determining the ratio of the percentage of silt and clay dispersed by shaking under specified conditions to the total percentage of silt and clay in the soil; this is the Middleton (1930) dispersion ratio. A second method involved wet-sieving and calculation of the percentage aggregate stability according to Kemper (1965). The third method employed waterdrop impact and was adapted from the procedure of McCalla (1944).

Nine sites were sampled in the Colorado Front Range of the Rocky Mountains. These sites were selected to include a wide variety of great soil groups and apparent erodibility. Three separate samples of both the A and B horizon were taken at each site. Laboratory determinations of dispersion ratio and percentage of aggregate stability were run in duplicate. Thirty determinations were run on each sample for the waterdrop method.

The results of these studies were as follows:

1. There was a great variation in stability rankings by the different methods.

2. The A and B horizons, although quite different from each other, gave similar responses to the different methods in terms of stability ranking for each horizon separately.

3. There was a distinct tendency for the stability rankings of the B horizons to vary less with the different methods than the A horizons.

4. Differences between A and B horizons were highly variable with the different methods.

5. The B horizon was more stable than the A horizon for all soils with the wet sieve test whereas with the waterdrop impact method only one soil had the B horizon more stable than the A horizon. The dispersion ratio test did not detect any significant (5% level) differences between the A and B horizons.

6. The dispersion ratio was the least powerful test in terms of defining differences between soils. The use of 2-3 mm soil instead of $<$ 2 mm soil increased the distinguishing power somewhat.

7. The waterdrop impact method was the most powerful test in terms of defining differences between soils. The wet sieve method was intermediate between the dispersion ratio and waterdrop impact method.

The results presented above would indicate that none of the three methods tested is the "best" or "ideal" for characterizing the aggregate stability of soils similar to those used in this study. These soils are poorly developed, coarse textured, and have very low aggregation. The wide variability, indeed even complete reversals, in the stability rankings and in the A versus B horizon comparisons by the different methods attests to the dangers of using these tests indiscriminately in evaluating aggregate stability.

This study did not attempt to relate aggregate stability to either field erosion or soil characteristics. However, visual observation of erosion at the various sampling sites and organic matter content of the soils would suggest some form of the waterdrop impact method may have the greatest potential for soils such as those used in this study. This conclusion is further strengthened by the fact that the waterdrop impact method was the most powerful in defining differences in the soils tested.

Considering the comments in the preceding paragraph together with the coarse texture of soils studied, it would appear that a method of studying soil erodibility of these and similar soils that would incorporate both the textural and structural response to water droplets would hold considerable promise for future study. Testing of such a method would require: (1) studies relating soil characteristics (clay content, organic matter, etc.) to erodibility as determined by the method, and (2) field investigation of the relationship between the erodibility index and erosion.

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APPENDIX

TABLE A. Location of soil sampling sites

Soil No.	Name	Location
1	Lithosol	T8N, R72W, approximately on boundary line between NW¼ and SW¼ of Section 5 on south side of road just above cattle guard about 500 feet up Pingree Road from Eggers Bridge.
2	Chestnut (cold)	T8N, R73W, NE¼ of Section 25 at the Quigley Weather Station.
3	Regosol (chernozemic)	T8N, R73W, near ¼ corner of Section 26 on southwest side of gully wall approximately 100 feet below rock treated gully headcut.
4	Gray wooded	T7N, R73W, southeast ¼ of Section 17 on northwest side of Fall Creek Road
5	Podzol	T7N, R74W, northwest ¼ of Section 13 on northwest side of trail up Hourglass Watershed approximately 2000 feet up from lower Hourglass Weir.
6	Chestnut (cold)	T8N, R73W, northeast ¼ of Section 25 approximately 1000 feet east of Quigley Weather Station on south side of road to Little South Poudre River.
7	Tundra (alpine turf)	T7N, R74W, northwest ¼ of Section 22 southeast of Hourglass Pack Trail and north of Hourglass Snowfield.
8	Brown	T9N, R69W, northeast ¼ of Section 6 on south side of road at saddle approximately 2 miles from Highway 287 (at Owl Canyon).
9	Brown	T8N, R69W, northeast ¼ of Section 6 on southeast side of county road approximately 1.6 miles from Highway 287 (at Owl Canyon).

TABLE B. Analysis of variance of dispersion ratio,
$<$ 2 mm soil, A and B horizon

Source	DF	SS	MS	F-ratio
Total	107	11226.40		
Soils	8	4261.00	532.63	4.25**
Horizons	1	244.68	244.68	1.95
S x H	8	991.09	123.89	0.99
Within SH	36	4513.31	125.37	
Determinations	54	1216.32		

TABLE C. Analysis of variance of dispersion ratio,
$<$ 2 mm soil, A horizon

Source	DF	SS	MS	F-ratio
Total	53	5169.53		
Soils	8	2037.83	254.73	1.78
Reps. within Soils	18	2569.43	142.75	
Determinations	27	562.27		

TABLE D. Analysis of variance of dispersion ratio,
$<$ 2 mm soil, B horizon

Source	DF	SS	MS	F-ratio
Total	53	5812.18		
Soils	8	3214.25	401.78	3.77*
Reps. within Soils	18	1938.88	107.72	
Determinations	27	659.05		

** Highly significant (1% level)

* Significant (5% level)

TABLE E. Analysis of variance of dispersion ratio, 2-3 mm soil, A and B horizon

Source	DF	SS	MS	F-ratio
Total	107	11036.43		
Soils	8	7593.63	949.20	21.62**
Horizons	1	2.11	2.11	0.05
S x H	8	249.04	31.13	9.71
Within SH	36	1580.86	43.91	
Determinations	54	1610.79		

TABLE F. Analysis of variance of dispersion ratio, 2-3 mm soil, A horizon

Source	DF	SS	MS	F-ratio
Total	53	6584.12		
Soils	8	4363.48	545.44	8.13**
Reps. within Soils	18	1208.29	67.13	
Determinations	27	1012.35		

TABLE G. Analysis of variance of dispersion ratio, 2-3 mm soil, B horizon

Source	DF	SS	MS	F-ratio
Total	53	4450.21		
Soils	8	3479.70	434.96	21.04**
Reps. within Soils	18	372.06	20.67	
Determinations	27	598.45		

** Highly significant (1% level)

TABLE H. Analysis of variance of percentage of aggregate stability, 1-2 mm soil, A and B horizon

Source	DF	SS	MS	F-ratio
Total	107	14746.07		
Soils	8	4279.43	534.93	27.29**
Horizons	1	7629.22	7629.22	389.25**
S x H	8	1138.66	142.33	7.26**
Within SH	36	705.43	19.60	
Determinations	54	993.35		

TABLE I. Analysis of variance of percentage of aggregate stability, 1-2 mm soil, A horizon

Source	DF	SS	MS	F-ratio
Total	53	3772.40		
Soils	8	3003.55	375.44	25.82**
Reps. within Soils	18	261.63	14.54	
Determinations	27	507.22		

TABLE J. Analysis of variance of percentage of aggregate stability, 1-2 mm soil, B horizon

Source	DF	SS	MS	F-ratio
Total	53	3344.47		
Soils	8	2414.55	301.82	12.24**
Reps. within Soils	18	443.78	24.65	
Determinations	27	486.14		

** Highly significant (1% level)

TABLE K. Analysis of variance of waterdrop impact, 2-3 mm soil, A and B horizon

Source	DF	SS	MS	F-ratio
Total	153	168412.00		
Soils	8	103736.65	12967.08	73.97**
Horizons	1	4475.38	4475.38	25.53**
S x H	8	53888.70	6736.09	38.42
Within SH	36		175.31	

TABLE L. Analysis of variance of waterdrop impact, 2-3 mm soil, A horizon

Source	DF	SS	MS	F-ratio
Total	26	127551.35		
Soils	8	125237.08	15654.64	121.76**
Reps. within Soils	18	2314.27	128.57	

TABLE M. Analysis of variance of waterdrop impact, 2-3 mm soil, B horizon

Source	DF	SS	MS	F-ratio
Total	26	36385.27		
Soils	8	32721.60	4090.20	20.10**
Reps. within Soils	18	3663.67	203.54	

** Highly significant

FIGURE 2. Field characteristics of soil 1

FIGURE 3. Field characteristics of soil 2

FIGURE 4. Field characteristics of soil 3

FIGURE 5. Field characteristics of soil 4

FIGURE 6. Field characteristics of soil 8

FIGURE 7. Field characteristics of soil 9

ABSTRACT

A comparison of three methods - Middleton dispersion ratio, wet sieving, and waterdrop impact - of testing aggregate stability was made. Soil samples were selected from 9 sites representing a wide variety of great soil groups in the Colorado Front Range of the Rocky Mountains at elevations ranging from 5,000 to 11,000 feet. Samples of the top of the A and B horizons were taken.

A great variation in stability ranking was found by the different methods. The A and B horizons, although quite different from each other, gave similar responses to the different methods. There was a distinct tendency for the stability rankings of the B horizons to vary less than A horizons, with the different methods. The B horizon was more stable than the A horizon for all soils with the wet sieve test whereas with the waterdrop impact method only one soil had the B horizon more stable than the A horizon; the dispersion ratio test did not detect any significant (5% level) differences between the A and B horizons. The dispersion ratio was the least powerful test in terms of defining differences between soils; the use of 2-3 mm soil instead of $<$2 mm soil increased the distinguishing power somewhat. The waterdrop impact method was the most powerful test in terms of defining differences between soils. The wet sieve method was intermediate between the dispersion ratio and waterdrop impact methods.

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