EFFECTS OF SOIL TEXTURE ON SOIL CONSISTENCE

by

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INTRODUCTION

Soil consistence is one of several soil physical properties that limit soil productivity. Others are soil texture and structure. Many researchers believe that physical conditions of the soil depress crop yields despite the use of improved crop varieties, supply of adequate nutrients and moisture, and proper disease and pest control. In addition, soil consistence greatly affects the draft and performance of tillage implements.

Soil consistence is used to designate cohesion and adhesion within soils at various moisture contents. At low moisture contents the soil is hard and very coherent because of the cementing effect between dried particles. In soil survey work soil consistence is determined by the ease or difficulty of breaking a moist or air-dry soil crumb between the thumb and fore-finger. The consistence of dry soils is described in the Soil Survey Manual (Soil Survey Staff, 1960) as loose, soft, slightly hard, hard, very hard, and extremely hard. Unfortunately, these terms are widely misused by surveyors who are familiar with them but not with their definitions. It must be admitted, however, that it is very difficult to define these terms by feel only. In this paper soil consistence will be used to express the degree of cohesion of the soil and the resistance opposed to forces tending to deform or rupture the aggregates (Scott Blair, 1932). The consistence of dry soils will be used interchangeably with soil hardness.

A dry pulverized soil is loose. In dry conditions, the soil capillaries and the surfaces of soil particles usually are occupied by air.

This prevents the particles from adhering together. The situation is different if there is water in the soil. Water entering a dry soil displaces the air from the surfaces of soil particles, fills the capillaries, and forms menisci, especially at the contact points between soil particles. The surface tension in the water meniscus binds the soil particles very tightly together, thus producing "apparent" cohesion in the soil. The thickness of this surface film depends on the mineralogical composition of the particles, and the duration and character of weathering. Generally, the smaller the soil particles, the greater the relative thickness of this film.

As the soil desiccates gradually, the free moisture evaporates first and the menisci get smaller and smaller, resulting in a great increase in tension. If the water of the hydrated ions evaporates, the soil particles come closer. At some point the particles get close enough that Van Der Waals' forces (and other chemical bonding) become significant especially in fine-grained clay soils. The smaller the diameter of the ions, the larger the surface area, the closer the particles approach each other, and the greater the forces interacting between them. Particle size is, therefore, highly important if the particles must approach each other very closely during cohesion. The relative surface of sand-to-clay particles is about 1 to 2,000 , hence the attractive forces on sand surfaces are weak. Dolgov (1958) pointed out that coarse particles cannot cohere if their own weight exceeds the forces of cohesion; and cohesion is possible only with particles less than 0.1 mm. in diameter. The consistency of dry soils, therefore, likely depends upon the amount of surface contacts per unit volume of the soil mass and the attractive forces between soil particles.

The problems of soil hardness and very low silt content of tropical soils have concerned some soil scientists (Panabokker, 1959; Smyth and

Montgomery, 1962; Ahn, 1970; and Bidwell, 1973). According to Bidwell (1973), these pose a great threat to maintenance of natural fertility and agricultural productivity in general. The silt fraction contains primary minerals such as apatite, orthoclase, and calcite that weather to release phosphorus, potassium and calcium respectively. Where there is no silt, these minerals do not exist.

The objectives of the present study were:

(1) To estimate quantitative values of tensile strength or modulus of rupture corresponding to the various degrees of consistence.

(2) To discover if low silt content could be one reason why loamy sands and sandy loams of the tropics once they are dried out, become as difficult to till as dried clays or sandy clays.

REVIEW OF LITERATURE

Numerous attempts have been made to standardize consistence measurements. Much less effort has been devoted to studying the effect of texture alone on consistence measurements, as compared to the effects of moisture content.

Measurements of soil consistence dates back to the late 1920's. At Utah Agricultural Experimental Station (Stauffer, 1927) an attempt was made to measure cohesiveness of soils by measuring the force necessary to draw rods and tubes through wet soil. They also tried forcing wet soil through a glass tube held in a vertical position, and determining the mean force necessary to overcome the internal cohesive forces of the soil.

Rhodes used the plastograph (Bodman, 1927) to estimate the quality of soil material for subgrade use. He measured the resistance which the soil-water mixture presented to the rotating blades in the mill. He concluded that the work-moisture content function was affected to a lesser degree by the 140-200 mesh fraction and least of all by the coarser fractions.

In 1911 Atterberg described the consistency of soils in terms of consistency limits (Lambe, 1951). The liquid, plastic and shrinkage limits are indices of the workability of artificial mixtures of soil and water as affected by the water content in the mixture. These limits have been defined by Casagrande (1932).

Stone and Williams (1939) described a soil hardness gage which could be used to measure surface hardness. The penetrator or hardness gage readings may be used for various agricultural and engineering studies including:

(1) determining the degree of firmness or compactness of the seedbed for various crops,

(2) expressing accurately the hardness factor in classifying soil types in soil survey work,

(3) determining the relation between soil hardness and soil moisture content, and

(4) determining the relation between soil hardness and resistance to plowing.

Reed (1940) reported a device designed to measure the penetration of a tapered rod when dropped from a pre-determined height. Other units have been designed to push a probe into the soil with a fixed force. Grossman and Bartelli (1957) used the Hand-Dynamometer to measure soil consistence in the field. With the penetrometer (Bodman, 1949; Freitag, 1968), the mechanical resistance of the soil to a downward moving probe or the force required to maintain a steady rate of penetration is considered a measure of soil consistency. All of these methods give a composite value to the depth of penetration, but fail to indicate the conditions that might go to make up this result.

However, Swanson and Jacobson (1956) used the penetrometer to measure the hardness or resistance to compaction of the soil surface. They found a negative correlation (-0.770) between average number of strokes per plot (soil hardness) and corn yield. Taylor et al. (1966), using the same instrument, found that root penetration percentage was reduced drastically as soil strength increased to 25 bars. Philips (1959), studying the influence of compaction on corn growth, concluded that mechanical impedance was the only physical property of the soil that correlated with corn yields.

Blair and Cashen (Bodman, 1949) designed an apparatus for measuring the volume change of soils in the field and laboratory. Low compressibility represented a dry powdery soil or a soil consisting of hard, incompressible lumps.

Dry or hard soils are under tension; and the tensile strength of soil is the force required to pull the soil apart (Gill, 1968). Sourisseau (Gill, 1968) designed a method primarily for measuring tensile strength in the fields.

Tension may be placed directly upon columns of soil by pulling at the ends. Hardy, Gill and Willets (Gill, 1968) have used this method. Preparation of the sample essentially precludes measuring tension of undisturbed soil samples.

In the laboratory the most widely used methods to measure the coherence of dry soils are based upon the breaking strength of dried briquets. The dry strength is now referred to as tensile strength, breaking strength, dry strength, or modulus of rupture (Baver, 1972). The modulus of rupture is defined as the maximum force per unit area (expressed in dynes/cm^2) that a material will withstand without breaking.

Modulus of rupture studies on artificial briquets imply that the physical properties of the briquets are similar to those of natural crusts. Allison (1923) used it to express the breaking strength as an index of soil structure and for evaluating the effect of liming. Stauffer (1927) found the relationship between percentage composition and the modulus of rupture to be linear; that is, increase in clay content increased the modulus of rupture. Carnes (1934) also found that the modulus of rupture was proportional to the surface area of the fine particles in contact.

Table 1: Sizes of soil particles and cohesion forces (Joffe and Revut, 1966, p. 207).

Radius of particle (cm.)	No. of particles in 1 cm.^{2}	Force of aggregation of two particles (dynes)
5×10^{-2}	1.3×10^{2}	1.5×10^{3}
1×10^{-2}	3.0×10^{3}	7.0×10^{3}
5×10^{-3}	1.3×10^{4}	1.5×10^{4}
1×10^{-3}	3.0×10^{5}	7.0×10^{4}
1×10^{-4}	3.0×10^{7}	7.0×10^{5}
1×10^{-5}	3.0×10^{9}	7.0×10^{6}
1×10^{-6}	3.0×10^{11}	7.0×10^{7}
1×10^{-7}	3.0×10^{13}	7.0×10^{8}

Richards (1953) used millibars as a unit for expressing the modulus of rupture. He showed than an increase in hardness of the surface crust from 108 to 273 millibars was sufficient to decrease the emergence of bean seedlings from 100 to 0 percent. Chepil (1955) showed that the modulus of rupture varied inversely with the diameter of the mechanical separates from which the briquets were formed. Jamison (1954) found that soils rich in montmorillonite gave higher modulus of rupture values than those rich in kaolinite. This follows since montmorillonite grains are 5000 A^o and kaolinite 20,000 A^o in average size. In addition, the three-layer structure (SiO_2-Al_2O_3-SiO_2) of montmorillonites promote formation of stronger particle-to-particle bonds.

Lemos and Lutz (1957) found that the modulus of rupture was increased by longer periods of drying at 105°C, by slow drying, by compacting the soil in the briquet molds, and by puddling the soil before putting it in the molds. They obtained high modulus of rupture values with soils containing large amounts of silt or total material less than 0.10 mm., and 2:1 type clays.

Kirkham, et al. (1959) used the modulus of rupture method to test the strength of cylindrical undisturbed core samples of field soil. Although they found a high coefficient of variation for the modulus of rupture, it correlated well with yields and the number of blows to drive the soil sampling cans to depth.

Quantitative measures of the strength of cohesive soils can also be determined using the unconfined compression test. The load per unit area at which unconfined cylindrical samples of the soil fail in a simple compression test is known as the unconfined compressive strength of the soil. The strength of air-dry specimens ranges from about 2 to more than 200 kg.

per sq. cm. (Terzaghi and Peck, 1962). This test is most suited to measuring the strength of foundation soils (Black, et al., 1969).

Apart from texture and moisture, drying is one of the most important factors contributing to strength increases of soils. The increases in strength are due to the effect of ultraviolet rays and other components of sunlight on soil (Gill, 1959).

The nature of the cations present in the soil influences its hardness. Allison and Moore (1956) pointed out that sodium is important in determining the crusting behavior of different soils. Reeve, et al. (1954) found the relationship of exchangeable sodium to the modulus of rupture to be positive and linear, but exchangeable potassium had no effect.

MATERIALS AND METHODS

Source materials for sand, silt and clay were collected from two locations in Kansas. Following are descriptions of the Pratt soil and the Terra Cotta shales from the Saline County Soil Survey report (Cline, et al., 1959).

Pratt Loamy Fine Sand:

Samples were taken from the Sandyland Experiment Station (SE $\frac{1}{4}$ Sec 16 T24 R13) in Stafford County. Site of sampling was 13.3 meters west of U.S. Highway 281 and 7.6 meters south of the half-section line. These soils are undulating to rolling and well to excessively drained. The surface soil (25 cm. deep) has a dark brown (10 YR 3/3, moist) color. The soils are formed from deep, sandy parent materials picked up by the wind in sandy alluvial areas. The parent materials usually overlie alluvial deposits or, on the uplands, buried soils that were developed before the windborne materials were deposited. The surface soil is 80 to 90 percent sand.

Terra Cotta Clay Shales:

The location is in Saline County (SW $\frac{1}{4}$ Sec 33 T133 R5W). Samples were taken on an exposed hill $\frac{1}{2}$ mile west of Exit 238 (Brookville Road) on Interstate 70. The clays are very conspicuous 3 to 9 meters below the crest of the hills.

The Terra Cotta shales are Cretaceous in age and underlie shallow, brown soils of the Lanham series. The weathered material is slightly alkaline in reaction and uniformly clay or silty clay in texture. Many pellets and concretions of ironstones are present. The dominant clay mineral is kaolinite.

Separation of Bulk Samples: Sand, Silt and Clay

Sand (2 to 0.05mm.) was extracted from the Pratt loamy fine sand. The soil was air-dried and sieved with a 2.0 mm. sieve. Larger grains were discarded. Bulk samples were digested with Hydrogen Peroxide and dispersed with Calgon (Sodium Hexametaphosphate) at the rate of 12.5 gm. dissolved in 250 ml. per 100 gm. of soil. Soil was allowed to slake for 10 minutes, and stirred with a paint mixer for 5 minutes. The silt and clay fractions were discarded by wet sieving on a 0.047 mm. sieve. The sand fraction retained on the sieve was dried at 105°C and stored in a plastic bag until needed. This process was repeated several times until sufficient quantity of sand was collected.

To extract clay, 4-gallon straight-sided containers were used in preparing aqueous suspension of soil. The Terra Cotta clay material was dispersed with Calgon (250 ml. per 100 g. of soil) and the soil allowed to slake for about 15 minutes. An electric-powered paint mixer was used to stir the suspension for 10 minutes. According to Day (Black, et al. 1959), at 24°C a soil particle of 0.002 mm. in diameter will settle through water for a depth of 10 cm. in 7 hours 17 minutes. Hence the clay particles were removed by siphoning into another container from a depth of 10 cm. after 7 hours 30 minutes, proceeding slowly to reduce disturbance. The process of mixing, settling, siphoning and subsequent dilution was repeated several times until the clay recovered became negligible. The clay suspension was evaporated to a thick paste and centrifuged 4 or 5 times in ethyl alcohol (95 percent) to displace the sodium added from Calgon. The clay was later dried in the oven and stored for use. An x-ray identification of the clay minerals revealed that kaolinite was the dominant clay mineral with lesser amounts of illite. X-ray diffraction patterns were obtained using Philips x-ray diffactometer with nickel filtered copper K α radiation with a pulse height analyzer.

To obtain the silt fractions, the sedimentation process was repeated (on same samples used for clay extraction) five to seven times to wash off the remaining clay particles from the suspension. Silt was separated from the sand fraction by wet sieving on a 0.047 mm. sieve (number 300). Sand particles retained on the sieve were discarded. The suspension containing the silt fraction was allowed to settle and the supernatant liquid siphoned off. The sediment was oven-dried and stored for subsequent use. The fractionation of clay and silt particles was done many times in order to collect sufficient quantities of clay and silt.

Preparation of the Soil Briquets

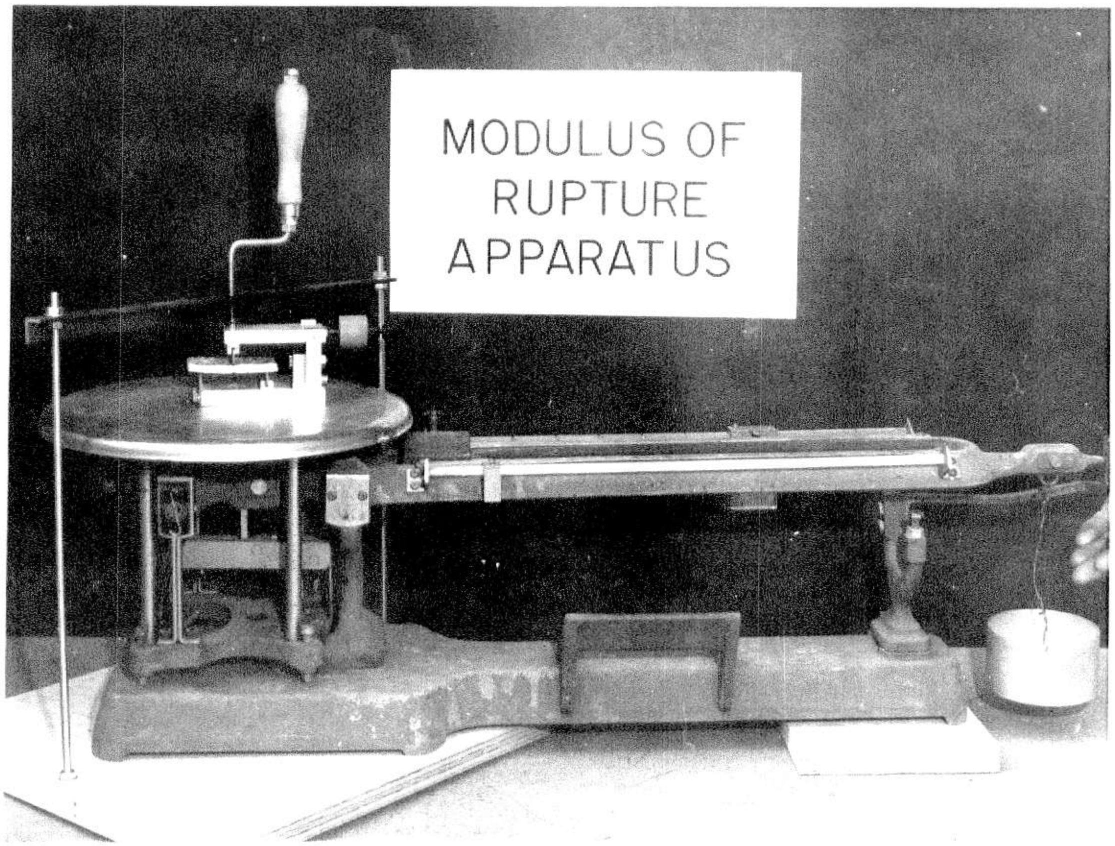
The briquet molds were precision made from brass strips with inside dimensions of 7 cm. by 3.5 cm. by 0.95 cm. high. A rectangular white photographic blotting paper (5 cm. by 8.5 cm.) served as the bottom for each briquet mold (Reeve, 1965).

The dried sand, silt and clay fractions were mixed thoroughly in ratios of 1 : 3 : 5 resulting in seven possible combinations. Thus a 100 gm. of the synthesized sample A contained 11.1 gm. of sand, 33.3 gm. of silt and 55.6 gm. of clay. Each of the sample combinations was mixed to 300 gm. at a time and stored in polythene bags. Another series of seven samples was mixed in various proportions of sand, silt and clay; starting from as high as 90 percent sand, and as low as 5 percent silt and clay. Table 2 shows the various mixtures of sand, silt and clay.

Table 2: Particle Size Composition for Briquet Samples

Sample	% Sand	% Silt	% Clay	Textural Class
A	11.1	33.3	55.6	Clay
B	11.1	55.6	33.3	Silty clay loam
C	33.3	55.6	11.1	Silt loam
D	33.3	11.1	55.6	Clay
E	55.6	33.3	11.1	Sandy loam
F	55.6	11.1	33.3	Sandy clay loam
G	33.33	33.33	33.33	Clay loam
H	90	5	5	Sand
I	80	15	5	Loamy sand
J	80	5	15	Sandy loam
K	65	30	5	Sandy loam
L	65	5	30	Sandy clay loam
M	50	10	40	Sandy clay
N	50	40	10	Loam

Fig. 1: The complete modulus of rupture apparatus. Lead shots were added slowly until the briquet broke.


MODULUS OF
RUPTURE
APPARATUS

The inside of the molds was coated with a thin layer of vaseline so that the soil would not stick to the mold. A metal tray 75 by 60 by 10 cm. served as a soaking tank. A screen-bottomed tray was placed in the soaking tank and the blotting paper placed on the screen. Each mold was placed on the piece of blotting paper and soil samples were poured into each mold. Excess soil was removed with a broad spatula. Samples were allowed to stand in the tank for one hour after all samples had become wet, bringing each briquet to saturation.

The screen was raised carefully, so as not to jar the samples, and transferred to a forced draft oven at 50°C. After drying the briquets to constant weight (usually 24 hours), they were removed from the molds and the length and width were measured.

The breaking force (weight of lead shot accumulated in the can when each briquet was broken) was determined and the thickness at the surface of fracture was measured. The modulus of rupture was determined on six replicate samples.

Description of Equipment and Breaking Procedure

The machine for breaking the briquets consisted of two lower parallel bars for supporting the briquet. A third movable upper bar, centrally located and parallel to the lower supporting bars, supplied the breaking force. The overlying bar and one of the supporting bars are self-aligning to accomodate any slight lack of parallelism in the line of bearing of the sample. The edge of the bars in contact with the briquet was coated with a strip of rubber to distribute the breaking force rather than concentrating it at a few points of contact with projecting soil grains.

The complete modulus of rupture apparatus is shown in Figure 1. A

Fig. 2: The modulus of rupture apparatus showing the briquet after it had been broken.

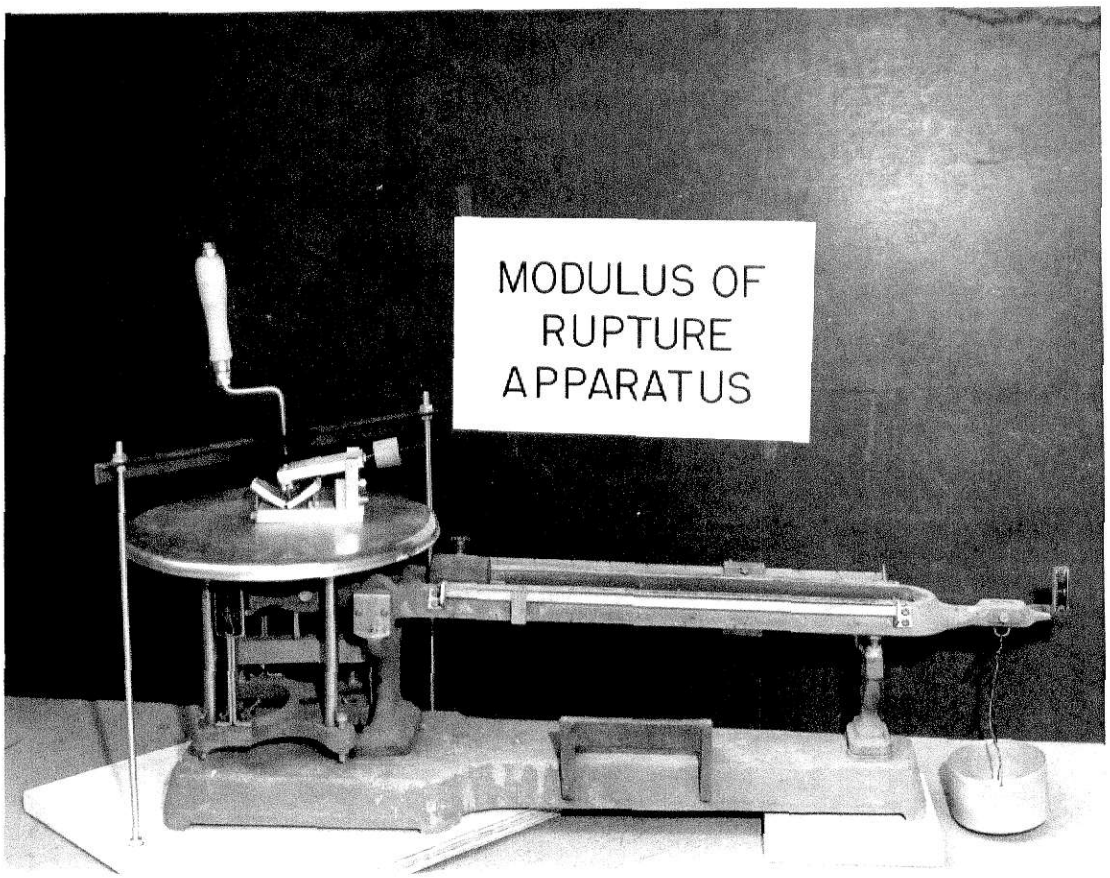
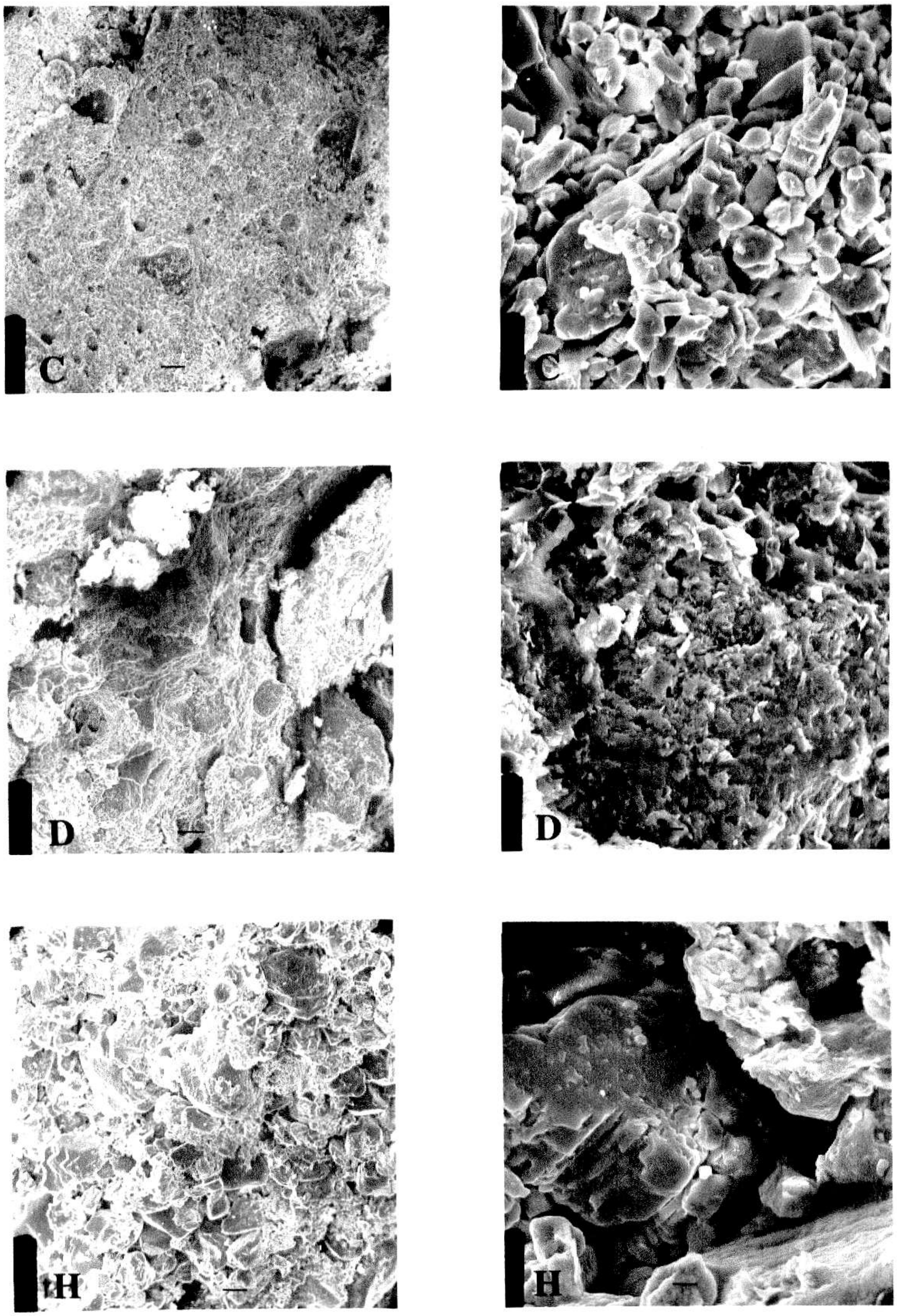

MODULUS OF
RUPTURE
APPARATUS

Fig. 3: Scanning electron micrographs of portions of samples C, D and H. Scale bars on the left micrographs represent 0.125 mm. while those on the right represent 0.005 mm.


C
C
D
D
H
H

beam balance was used to measure and apply the load to the briquet-breaking apparatus which was mounted on the balance platform. The upper bar of the machine was constrained by a cross frame that was anchored externally and located above the balance platform. This prevented upward motion of the upper bar. The breaking force of the briquet was applied by adding lead shot to a can hung from the end of the balance beam. This force was applied at a slow rate to prevent adding excess lead shot when the briquet broke. Richards (1953) and Reeves (1965) used water instead of lead shot to measure the modulus of rupture. Using lead shot eliminated loss of water should the can be tipped over during weighing. However, using lead shot took more time than if water were used.

The lead shot accumulated in the can as long as the briquet remained unbroken. When the sample broke, the balance beam fell immediately and no more shot was added (Fig. 2). The weight of lead shot accumulating in the can at each measurement was determined.

After the briquets were broken, three of the 14 samples were chosen for comparing the degree of surface contacts between the particles. Samples C, D and H were chosen because of their high silt, clay and sand contents respectively. Fig. 3 shows the composite photograph of the scanning electron micrographs at 40 and 1000 magnification.

Calculation of Modulus of Rupture

The modulus of rupture for each briquet was calculated using the following formula:

$$s = 3FL/(2bd^2 \times 10^4)$$

$$\text{or } s = 1.47 \times 10^2 \frac{W_2}{W_1} \frac{L}{bd^2}$$

where s = modulus of rupture (millibars)

$F = 980 \times \frac{1000}{W_1} \times W_2$ (breaking force)

L = distance between the briquet end supports

b = width of briquet

d = thickness of briquet across breaking face

W_1 = weight on the end of beam required to counter-balance 1000 gms. on balance platform

W_2 = grams of lead shot added to break soil briquet

RESULTS AND DISCUSSION

The scanning electron micrographs (Fig. 3) show the amount of surface contacts between the soil particles. Attractive forces are generated directly between the soil particles, hence the finer the particles the closer they are to each other and the higher the forces of attraction between them.

Soil particles have different sizes, shapes and irregular surfaces. At low magnification (X40) only the sand particles are conspicuous. Under high magnification, their surfaces show high peaks alternating with depressions. The larger the particles the more pronounced is the roughness of the surface. These micrographs show that sample D has more surface contact than C and H. Likewise, C shows more surface contact than H. However, there are only weak forces binding silt particles together.

Table 3 gives the calculated mean bulk density and mean percent shrinkage of 6 replicates per sample. Samples (H, I, J and K) with high

Table 3: Average Bulk Density and Shrinkage of Dry Soil Briquets (6 replicates)

Sample	Bulk density (gm./cm.^{3})	Percent Shrinkage
A	1.561	47.3
B	1.586	47.9
C	1.533	35.1
D	1.809	46.9
E	1.677	32.0
F	1.781	39.7
G	1.631	44.5
H	1.739	15.1
I	1.727	14.7
J	1.568	14.4
K	1.730	21.0
L	1.682	33.9
M	1.793	47.7
N	1.640	31.5

sand and low clay contents showed the least shrinkage. Conversely, samples with high clay, and low silt and sand contents shrunk most. Samples with high silt and low clay contents did not shrink as a result of drying but showed high degree of settlement as water was added to the soaking tank. The briquets with high clay content shrunk considerably and were concave in shape after drying. Other briquets were relatively undistorted.

There is a distinct relationship between the percent shrinkage and modulus of rupture. Samples D, A, M and F had high shrinkage as well as high modulus of rupture while samples H, I, N, E, K and C, with low shrinkage of less than 40 percent, had low modulus of rupture. Sample B was an exception. It had a high volume change with low modulus of rupture, but its volume change was attributed to settlement rather than to shrinkage.

The bulk density, based on dry weight of briquet per unit volume, showed no consistent variations due to particle size. However, sample D (clay) had the highest average bulk density of 1.809 $gm./cm.^3$ while C (silt loam) had the lowest bulk density of 1.533 $gm./cm.^3$. There was no detectable relationship between bulk density and modulus of rupture except that D with the highest bulk density gave the highest modulus of rupture while C gave the lowest modulus of rupture.

Table 4 summarizes the data on mean modulus of rupture. There was a direct relationship between clay contents and modulus of rupture. High clay content resulted in high modulus of rupture. Clay and silt exhibit a cohesive property and, therefore, seldom exist as individual particles but act as binding agents holding other particles together. It is difficult to say which of the two was a more effective binding agent for sand. The quality of the briquets depended on which of the two was more abundant. Where clay content was higher than the silt content, as in samples D, A, M,

Table 4: Modulus of Rupture Totals and Means of Six Replicates (Millibars)

Sample	Textural Class	Total	Mean
D	Clay	7740.996	1290.166
A	Clay	4247.585	707.931
M	Sandy clay	4016.110	669.352
F	Sandy clay loam	3060.126	510.021
L	Sandy clay loam	2768.207	461.368
J	Sandy loam	2418.916	403.153
G	Clay loam	1938.093	323.016
H	Sand	1483.090	247.182
B	Silty clay loam	1311.183	218.531
I	Loamy sand	1311.058	218.510
N	Loam	1158.296	193.049
E	Sandy loam	871.185	145.198
K	Sandy loam	672.967	112.161
C	Silt loam	612.771	102.129
		LSD 0.05 =	75.351

F, L, and J, the briquets showed a decided hardness. In comparing the following pairs of samples, A and B, C and D, E and F, I and J, K and L, and M and N, (each pair had the same sand content but the silt and clay contents were reversed), the modulus of rupture increased with increased clay content in each pair.

The low specific surface of sands and silts tends to dilute the binding action of clays. The forces of attraction between clay particles is thus much reduced and there exists a strong tendency for briquets formed with high sand and silt contents to be softer than those formed with high clay content. This agrees with the findings of Chepil (1955) that clods formed with clay and sand were harder and less subject to abrasion by wind-blown sand than those formed from silt and sand. Contrary, Lemos and Lutz (1957) found modulus of rupture to increase with increasing silt content.

If the modulus of rupture data are superimposed on the textural triangle (USDA) as in Fig. 4, there is a definite decrease in soil hardness from the apex to the base of the triangle. The data also decrease from left to right, that is, with increased silt percentage.

The type of clay plays an important role in determining soil consistence. Kaolinite clay minerals possess a low specific surface activity hence only weak attractive forces exist on the surface. A low cohesion between particles should be expected. But kaolinite produces a platy effect while montmorillonite favors formation of blocky units (Baver, et al. 1972). If the particles are plate-shaped the specific-surface area increases even faster, and plate-shaped particles can be oriented to give a close packing during formation of the briquets. This confirms the findings of Peterson (1944), who reported that montmorillonite draws away from quartz grains to form individual clay aggregates while kaolinite tightly coats the grains.

Fig. 4: Modulus of rupture data superimposed on soil textural classes (USDA)

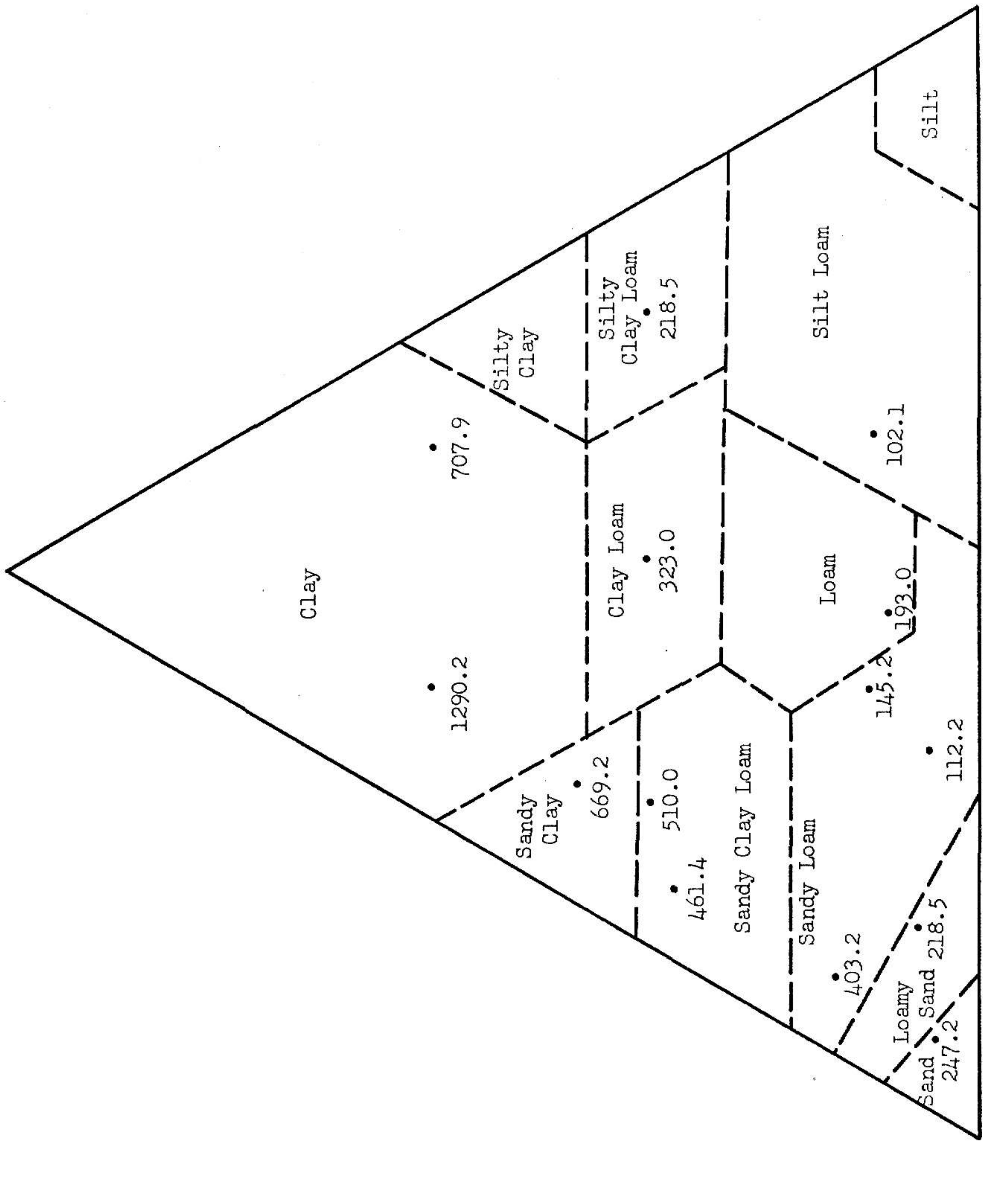

Clay
1290.2
707.9
Silty Clay
Silty Clay Loam
218.5
Silt
Silt Loam
102.1
Clay Loam
323.0
Loam
193.0
145.2
112.2
Sandy Clay
669.2
510.0
461.4
Sandy Clay Loam
Sandy Loam
403.2
Loamy Sand
218.5
Sand
247.2

Table 5: Means and their Standard Errors, Ranges, Confidence Intervals, and Coefficients of Variation

Sample	Means (Millibars)	Standard Error of the Mean ($S\bar{x}$)	Range	95% Confidence Interval on $\bar{x}$	Coefficients of Variation ($S_D/\bar{x}$) in %
D	1290.166	26.502	1205.34 - 1376.853	1222.029 - 1358.303	5.03
A	707.931	21.461	653.348 - 758.502	652.755 - 763.107	7.43
M	669.352	10.123	637.945 - 697.031	643.326 - 695.378	3.70
F	510.021	9.864	468.041 - 536.03	484.661 - 538.381	4.94
L	461.368	11.123	427.713 - 492.627	431.205 - 491.531	6.23
J	403.153	11.555	364.333 - 423.669	373.445 - 432.861	7.02
G	323.016	10.873	272.379 - 341.824	295.062 - 350.970	8.24
H	247.182	4.668	230.663 - 259.363	235.181 - 259.183	4.63
B	218.531	6.321	202.073 - 239.039	202.28 - 234.282	7.09
I	218.510	8.330	200.075 - 247.323	197.094 - 239.926	9.34
N	193.049	1.500	189.048 - 198.97	189.193 - 196.906	2.06
E	145.198	5.320	130.675 - 165.188	131.520 - 158.876	8.98
K	112.161	3.451	101.103 - 121.692	103.288 - 121.034	7.54
C	102.129	2.295	94.546 - 104.614	96.229 - 108.029	5.50

Table 6: Analysis of Variance Table for Consistence Measurements

Sources of Variation	Degrees of Freedom	Mean Squares	F
Between samples	13	663136.409	115.1375*
Among samples	5	1327.729	0.2173
Error	65	6107.516	
Total	83		

$F_{0.05}(13, 65) = 1.90$

$F_{0.05}(5, 65) = 2.36$

*Significant at 5% level

He ascribed these phenomena to the low hydration and low swelling of the kaolinite, and noted that some soil layers and natural clay deposits high in kaolinite are known to be very compact.

In tables 5 and 6, if standard error of the mean is considered as a measure of variability within samples, it is clearly indicated that the harder the briquets the greater the variability within samples. However, this variability within replicate samples is not significant at 5 percent level but the differences between samples is highly significant. The average of 14 coefficients of variation based on 6 replicates in each case was 6.25%. The coefficients ranged from 2.06 to 9.34%. For 14 standard errors of the means, each based upon 6 replicates and expressed as a percentage of the mean, the average was 2.55 and the range was 0.84 to 3.81.

When the differences between pairs of means of the modulus of rupture was compared to the Least Significant Difference at 5% level, there was no significant difference between the following pairs of sample means: A and M; F and L; J and L; H and N, I, and B; B and N; B and I; I and N; E and N; E and C; E and K; and K and C.

SUMMARY AND CONCLUSION

Researchers have used modulus of rupture determinations for various purposes. Many of the determinations have either used sieved field soils, or combined sand and silt, silt and clay, and sand and clay in various proportions. In the present research all sizes of clay, silt and sand passing the 2.00 mm. sieve were used as triple-constituent mixtures.

Thoroughly dried soils with normal compaction exhibit a decided hardness or coherence in the field. The extent of this coherence determines soil consistence which naturally varies with soil moisture, coagulating and cementing agents, soil structure and texture, and organic matter. The amount of surface contact is related to texture. However, climatic factors exert considerable and continuous influence over other factors. Each should be studied separately, with other factors being constant, such that they may serve as a general agrophysical evaluation of soil consistence and its agricultural significance.

To aid in eliminating the personal factor in describing soil consistence, standardized field or laboratory tests to determine the point at which a soil reaches each consistency limit is necessary. For example, Terzaghi and Peck (1962) gave some consistency limits for clay in terms of unconfined compression strength (kg per cm^2) as soft, less than 0.5; medium, 0.5-1.0; stiff, 1.0-2.0; very stiff, 2.0-4.0; and extremely stiff, over 4.0. A similar proposed grouping is given in table 7 for soil consistence in terms of modulus of rupture.

Since samples with 90% sand, 5% silt and 5% clay were able to form

Table 7: A Proposed Quantitative Rating of Soil Consistence in Terms of Modulus of Rupture

Common Consistence Terms	Modulus of Rupture (Millibars)
Very soft	Less than 100
Soft	100 - 150
Slightly hard	151 - 250
Hard	251 - 550
Very hard	551 - 750
Extremely hard	More than 750

briquets, kneading of briquets could be eliminated. This act of remolding may significantly change the characteristics of certain natural clays even when there is no change in moisture content. Some sensitive clays, for example, as they exist in an undisturbed condition, may be notably hard or firm, but on being remolded without change in water content may become very soft. Thus the practical significance of this measurement will depend on the relation between the physical status of the sample and the physical status of soil in the field.

The silt content of most Nigerian and other tropical soils is very low and the dominant clay mineral is kaolinite. The composition of the clay fraction is often reflected in the moderately low cation-exchange capacity, which is of the order of 4 to 10 m.e. per 100 gm. clay. These soils become very hard on drying even with low clay contents. From the results of the present study, it can be concluded that the absence of silt could be a major factor contributing to the hard to extremely hard consistence of soils in the tropics.

In Nigeria, for example, most soil classification is designed to meet the needs of the agriculturalist. Quantifying soil consistence terms could aid the engineer in selecting sites for roads, buildings and other structures. Thus if the needs of the engineer can be correlated with the soil associations and series of the agricultural classification, the engineer can derive much information from the agricultural soil map.

A high degree of hardness is often associated with poor soil structure. Soil hardness helps characterize the cohesiveness of particles upon drying, crust formation, and compaction. The harder the soil, the more energy will be required for its cultivation when dry and the more difficult it will be for roots to penetrate and develop within the soil.

In conclusion, therefore, the present study showed that

(1) in tri-constituent mixtures of sand, silt and clay, the absence of silt enhances the hardness of soils, and

(2) the modulus of rupture test has a high degree of reproductibility.

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