THE RELATIONSHIPS OF TEXTURE AND MOISTURE TO STRENGTH OF SOIL

By

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CHAPTER ONE

INTRODUCTION

Strength of soils is important to many disciplines of science. Scientists and engineers have attributed strength of a soil to aging, moisture loss, clay content, and surface area (7, 8, 9, 10, 19, 21, 22, and 26). High strength layers in soil profiles have been reported in many areas in the United States. These layers may prevent plant emergence, restrict root penetration, or restrict radial root expansion which reduce yield and increase tillage costs.

Since moisture is an ever-changing constituent in solid and high strength layers occur in a wide range of textures, these investigations present data relating moisture and texture to strength.

CHAPTER TWO

LITERATURE REVIEW

Many research workers have studied soil strength by measuring several intrinsic properties. Their procedures have been developed to aid in predicting trafficability, tillage, problems, and restricting plant growth. Procedures included tensile, shear, triaxial, penetration, and confined and unconfined compression strength measurements.

Several factors influencing the cohesive property of soils have been reported. Amount and kind of clay and moisture content has been recognized as contributing most to the strength of a soil. The clay species influence the surface area per unit weight, effectiveness of water bonding and retention of cations. Water aids in the lubrication of particles so that they may be oriented to produce maximum contact surfaces.

Baver (3) reported that the colloidal material in soil acts as a lubricant between the coarser particles. The plate-shaped colloids were oriented in such a way that their flat surfaces were in contact. This orientation, therefore, increased the amount of contact between colloidal particles. The increased contact, together with an increased proportion of water film in the mass, may be considered as producing the plastic effects. Coherence of soil was dependent upon the amount of surface contacts per unit volume of the soil mass and the magnitude of the attractive forces along the surfaces. Coherence in dried soil samples took place in the absence of water molecules on the surface. This attraction was between solid particles and was evident by the fact that the addition of small amounts of water to form a thin layer of water molecules on the surface of the individual particles, caused a decrease in coherence.

Research in the foundry industry has presented a hypothesis to explain why certain soil textures form stronger bonds than others. Paresi et. al. (23) proposed than when sands, lubricated with moist clay, were compacted, the grains tend to assume a rhombohedral close-packed arrangement with a maximum of 12 contact points and a small quantity of clay inhanced the bonding of sand particles. The addition of smaller particles that just fit the (interstitial) voids between close-packed sand particles increased the number of contact points per unit volume thus increasing the strength. This reasoning suggested that a range of particle sizes increased the strength of sand-clay mixtures. If the interstitial grains were large enough to prevent the larger grains from making contact with each other, the bonds were weakened because the clay is not as effective as when sand grains were in contact. Morey and Taylor (21) reported that oven-dry strength increased as grain size decreased, and small amounts of bentonite added to sands containing other clays gave strengths higher than the sum of the strengths of the two clays separately. Grim and Cuthbert (8, 9, and 10) suggested that clay wedges were formed around the points of contact of sand grains. The strength of the clay wedges depended upon the saturating cation, percent moisture, and kind and amount of clay. Strength of wet sand-clay mixtures was increased due to the bonding of oriented water. The maximum wet strength was obtained at 3 to 5 molecular layers of water depending on the saturating cation. Sodium saturated clays required 3 layers of water and calcium, 4 layers. Wet strength reached a plateau at 10 - 14 percent clay depending on the kind of clay. Heine et. al. (11) reported that increasing the molding moisture content above that for maximum wet strength increased oven-dry strength.

Mortland (22) reported that moisture retention, cation exchange capacity, and modulus of rupture were correlated with surface area of soils. Carnes (4) found that the modulus of rupture was proportional to the surface area of the fine particles in contact. Gill and Reeves (7) found good correlation of specific surface to modulus of rupture, cation exchange capacity, sticky point, plastic index, and moisture retention. Lemos and Lutz (15) reported a large increase in the modulus of rupture values when soils were puddled. Richards (24) reported that as the surface crust strength increased from 100 to 273 millibars, the emergence of bean seedlings decreased from 100 to 0 percent over this strength. Taylor and Gardner (26) reported that roots ceased to penetrate soil layers when penetration values were greater than about 30 bars.

These investigations suggest that an understanding of the factors affecting soil strength would give insight into such soil problems as plow pans, hardpans, and surface crusting. The purpose of this investigation was to determine the influence of the following factors on soil strength (i) moisture content near molding (ii) amount of moisture loss (iii) texture (i. e. surface area) and (iv) shrinkage.

CHAPTER THREE

MATERIALS AND METHODS

The B horizons of the Miles Fine Sandy Loam[1], prone to exhibit a root restricting layer was selected for this investigation. The sample was dispersed in distilled water and the clay was separated by the sedimentation method. The silt was separated by wet sieving. The silt and clay fractions were treated with 3 percent hydrogen peroxide to destroy organic matter. The sand separate showed negligible organic matter content and was not treated with hydrogen peroxide. Again the clay was separated from the silt by sedimentation. The clay was saturated with calcium by repeated washing with 1 N $CaCl_2$ and subsequent washing with distilled water until most of the clay stayed in suspension after standing seven hours for each 10 cm depth of suspension. The concentration of clay suspension was determined on an aliquot. Sufficient air-dry sand and silt were mixed with the appropriate volumes of the clay suspension to produce the following combinations: 10, 20, 30, and 40 percent clay, and 0, 15, and 30 percent silt by weight. The excess water was removed with the aid of a ceramic filter candle. The resulting paste was thoroughly mixed and allowed to air dry. The samples were crushed to pass a 2 mm sieve. The total surface area of the samples was determined by the

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[1] Identification by Roy Smith, Soil Coordinator. Sample Collected 1-1/2 miles ENE of Altus, Oklahoma, NW 1/4 of Section 31, T3N, R19W, Jackson County.

Sor-Kemper Method (25). Then the amount of water to produce 1.4, 1.7, and 2.0 layers of water was calculated. Subsamples were weighed and spray wetted to the desired moisture levels. Emmett and Cline (5) reported the area of the water molecule to be 10.8 A^2 which was used for the calculations of the number of layers of water on the total surface. The subsamples of the moist soil were taken and compacted with a double end impact rammer (1) to produce a cylinder or core 1.63 cm in diameter and 3.7 cm in length. Each core was packed to a bulk density of 1.70 $\pm$ .025 g/cc. The rammer was modified to accommodate a vacuum while the cores were being molded to minimize trapping air within the cores. These cores were dried to the desired layers of water by varying the weight of $CaCl_2$ in closed containers at reduced pressure and then sealed in plastic vials. There was no difference in the moisture content with respect to length of cores when the $CaCl_2$ containers were as high or higher than the top of the cores. The drying process required 12 to 16 hours. The lapsed time from molding to strength measurement ranged from 20 to 24 hours. Weights and dimensions were measured before drying and prior to the strength measurement.

The unconfined compression strength was determined on a Soil Test U 160 Strength Machine[2] modified with strain gauge and recorders replacing the dial indicators. The loading rate was about 1.8 kg/sec up to a load of 61.3 kg/cm^2; then the rate increased to about 5 kg/sec. The change in loading rate resulted from the activation of the second proving ring. The strength was taken as the maximum force to produce breaking

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[2] Manufactured by Soil Test, Chicago, Illinois.

or no change in force during deformation. After strength was measured subsamples were taken and moisture content was determined.

CHAPTER FOUR
RESULTS AND DISCUSSION

Table I presents particle size distribution, surface area and percent water at the monomolecular layer state. The addition of silt did not increase the total surface measured. The size distribution of sand particles was not consistant for all samples, which may explain some of the non-uniformity of the results obtained. It was observed during the separation of the clay from the silt after the hydrogen peroxide treatment, that the nearly pure silt sediment had very high cohesion when wet. This suggested that the silt grains were plate-shaped.

The relationships of the effect of clay and drying on soil strength at three levels of moisture and three levels of silt are shown in Figures 1 to 9. For all combinations involving 10 percent clay the only evident characteristic was low strength values. At all other clay, silt, and water combinations strength increased to a maximum at approximately 0.9 molecular layers. Then the strength decreased until 0.4 to 0.5 layers of water remained on the total surface. The strength again increased approaching oven dryness. Mackenzie (18), Walker (27), and MacEwan (17) have shown that montmorillonite and vermiculite dehydrate stepwise. The dehydration of these clays between the monolayer (dual-interlayer) and 50 to 60 percent of the monolayer on the internal surface did not produce a change in the "d-spacing" and thus, a loss of water bonds and reduced strength. At the 50 to 60 percent monolayer the molecules

TABLE I

PARTICLE SIZE DISTRIBUTION, SURFACE AREA, AND PERCENT WATER AT MONOLAYER

Texture											Total Surface Area	Percent Water at Monolayer
Clay	Silt	Sand	>1mm	0.5-1	.25-.5	.1-.25	.05-.1	Total	Silt	Clay	m^2/g	
10	0	90	.16	9.94	32.94	29.14	13.98	86.16	3.71	9.97	88.7	2.46
10	15	75	.14	7.79	25.35	25.71	13.42	72.37	16.39	11.31	98.2	2.72
10	30	60	.18	7.39	21.11	19.22	8.94	56.84	31.48	11.64	98.9	2.74
20	0	80	.15	9.14	29.13	26.70	11.51	76.63	3.08	20.25	181.5	5.03
20	15	65	.13	7.10	23.61	21.98	10.20	63.02	17.29	20.37	180.3	4.99
20	30	50	.13	6.08	17.42	16.79	7.66	48.08	31.98	20.80	185.8	4.87
30	0	70	.18	8.89	26.25	21.95	10.05	67.32	3.24	29.35	260.1	7.20
30	15	55	.07	5.63	19.05	18.47	9.51	52.74	15.66	31.54	270.3	7.67
30	30	40	.06	3.52	11.15	12.10	8.76	35.63	32.70	31.01	277.4	7.68
40	0	60	.14	6.58	22.14	18.81	9.19	56.86	3.77	39.27	331.9	9.19
40	15	45	.09	5.37	16.08	16.49	6.36	44.35	16.74	39.28	336.7	9.33
40	30	30	.11	3.73	10.17	9.32	7.01	30.34	30.16	39.00	347.8	9.63

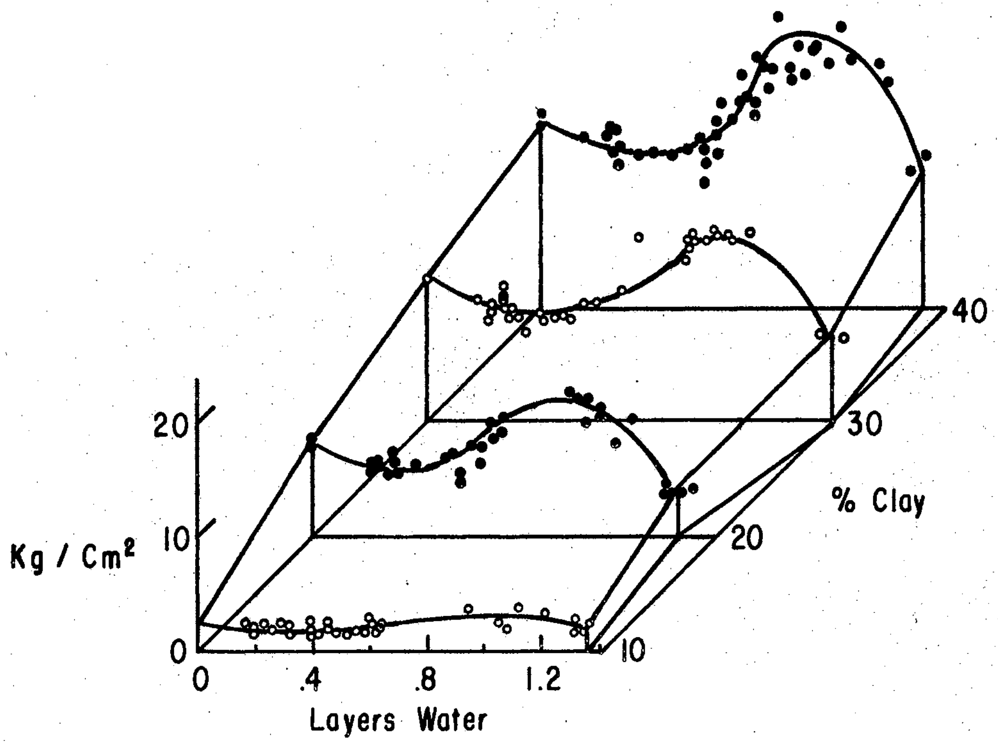

Figure 1. Strength Versus Layers of Water for the Four Clay Percentages Containing 0 Percent Silt and 1.4 Layers of Water at Moulding.

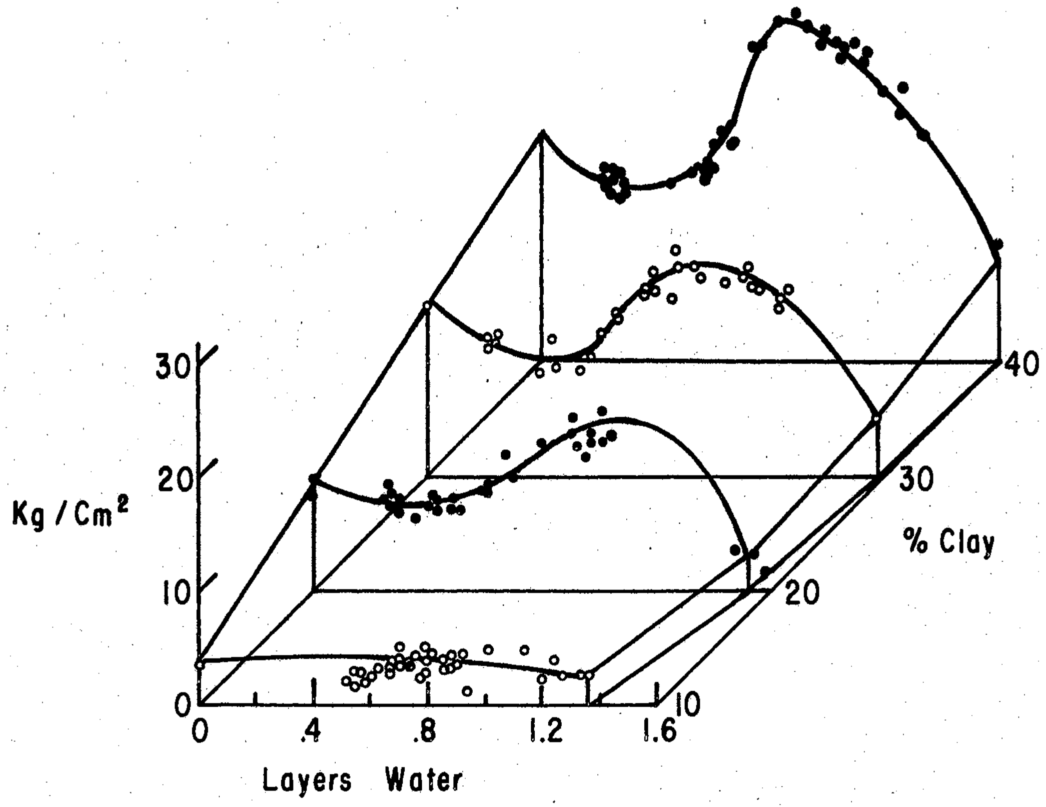

Figure 2. Strength Versus Layers of Water for the Four Clay Percentages Containing 0 Percent Silt and 1.7 Layers of Water at Moulding.

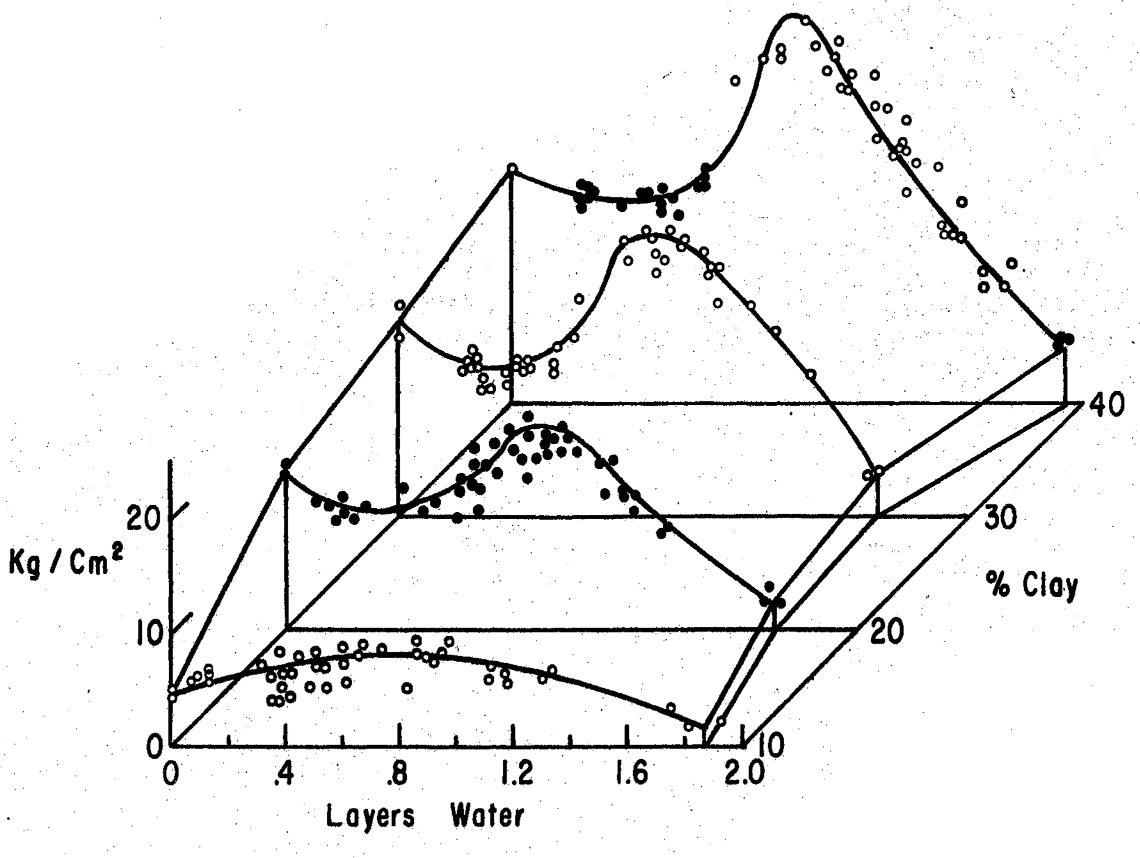

Figure 3. Strength Versus Layers of Water for the Four Clay Percentages Containing 0 Percent Silt and 2.0 Layers of Water at Moulding.

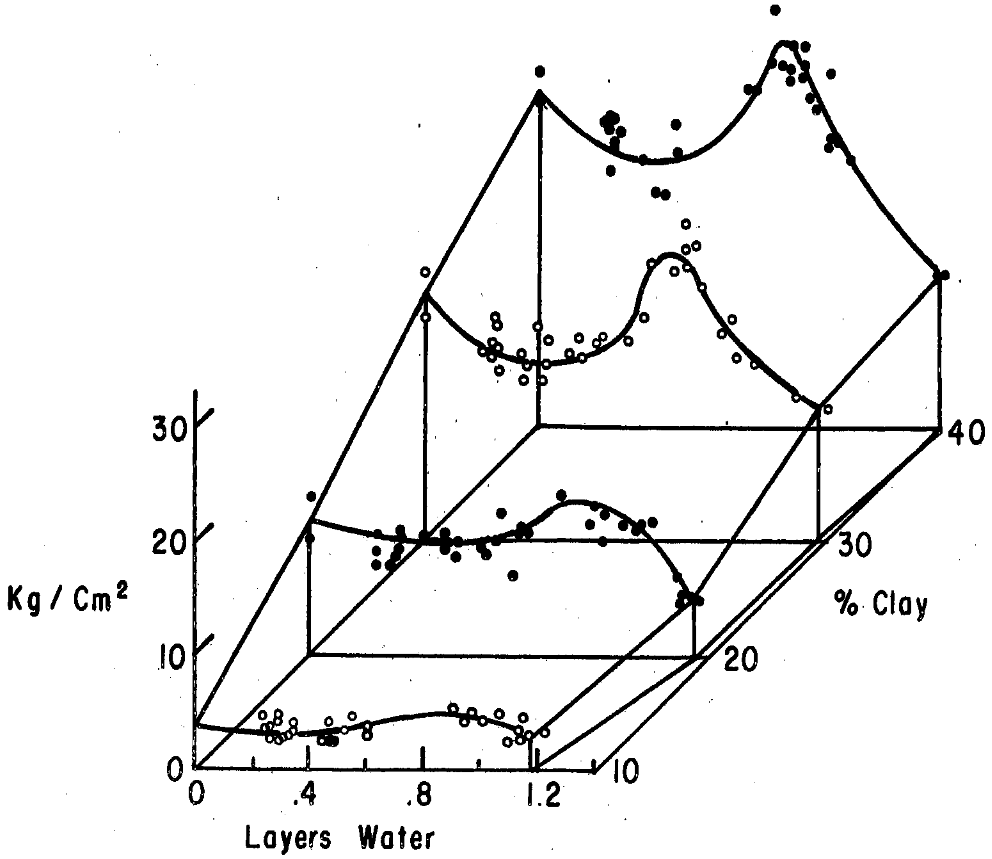

Figure 4. Strength Versus Layers of Water for the Four Clay Percentages Containing 15 Percent Silt and 1.4 layers of Water at Moulding.

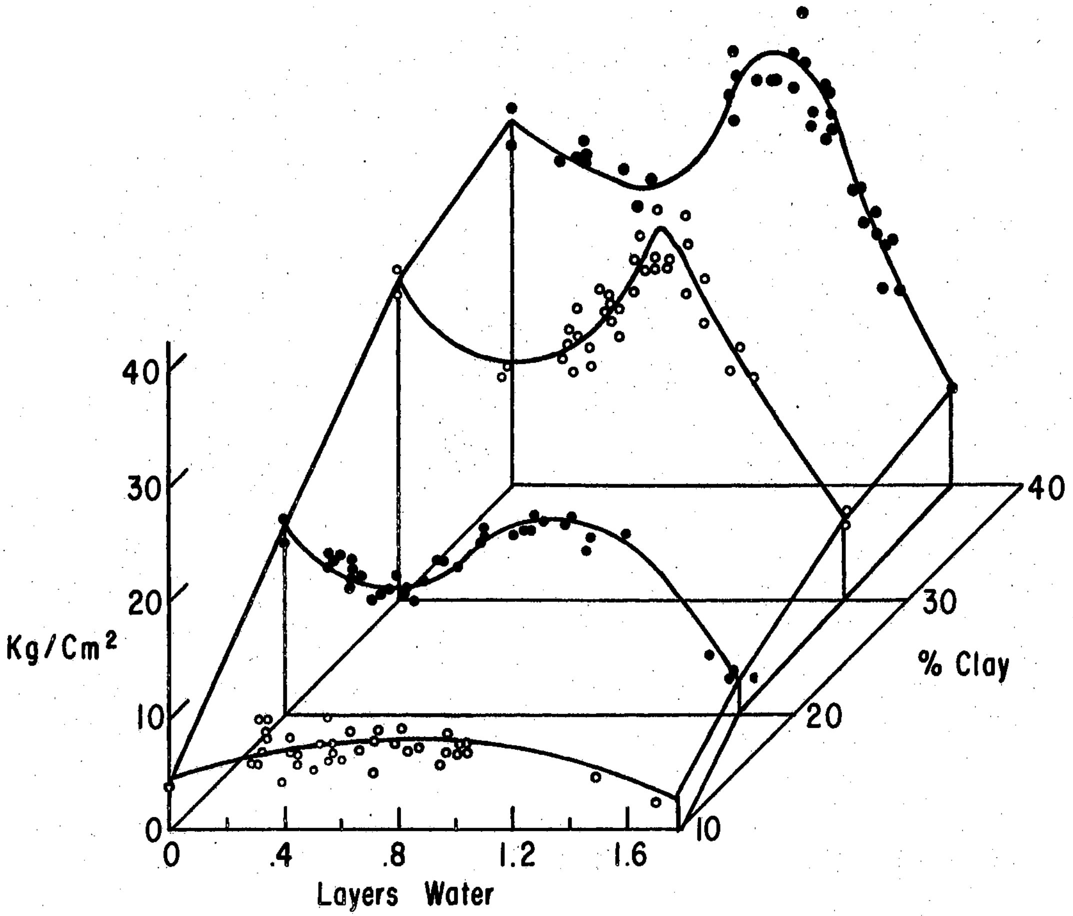

Figure 5. Strength Versus Layers of Water for the Four Clay Percentages Containing 15 Percent Silt and 1.7 Layers of Water at Moulding.

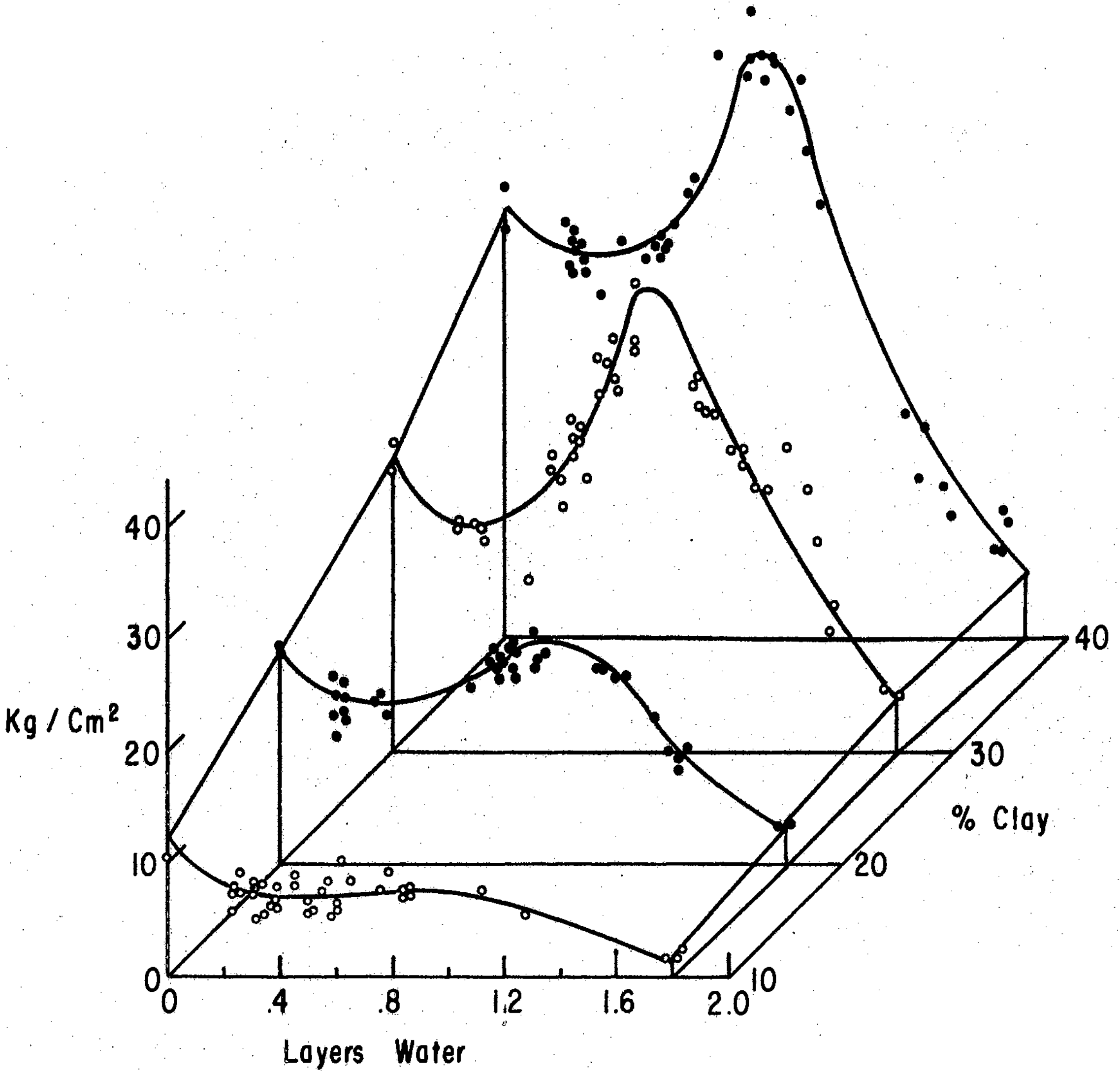

Figure 6. Strength Versus Layers of Water for the Four Clay Percentages Containing 15 Percent Silt and 2.0 Layers of Water at Moulding.

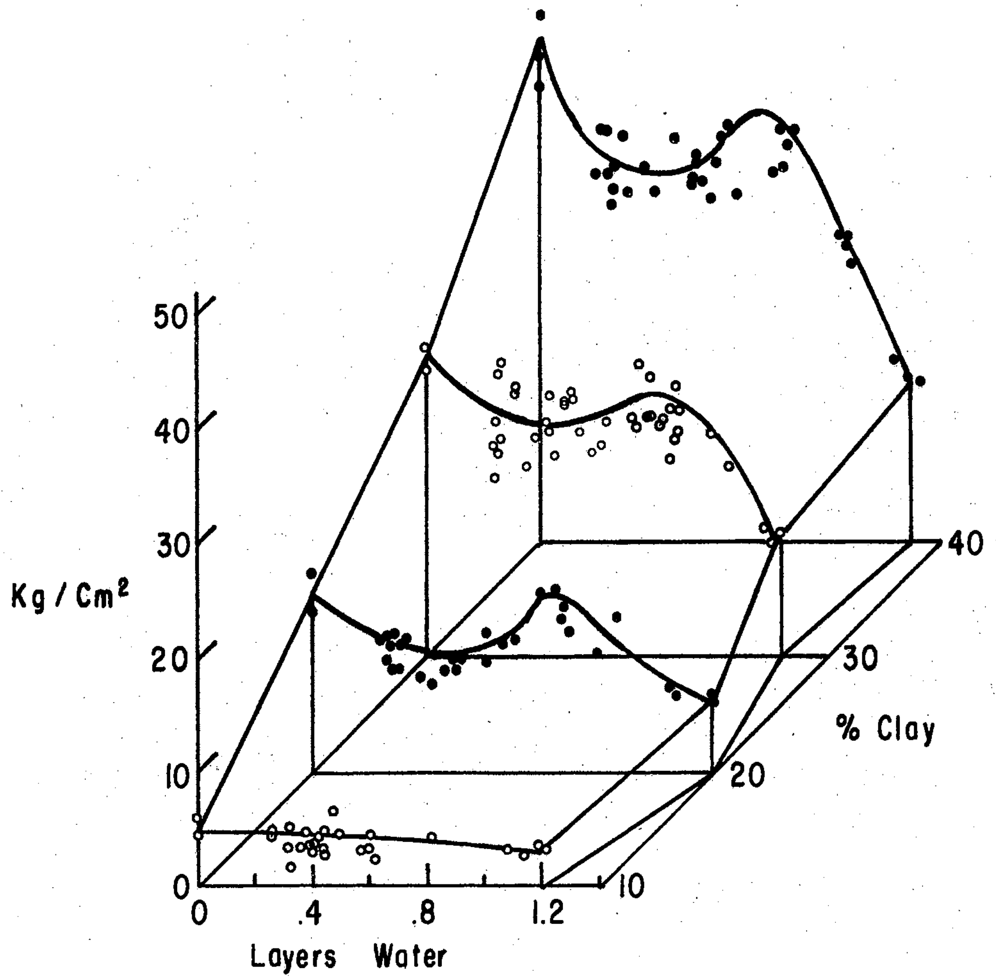

Figure 7. Strength Versus Layers of Water for the Four Clay Percentages Containing 30 Percent Silt and 1.4 Layers of Water at Moulding.

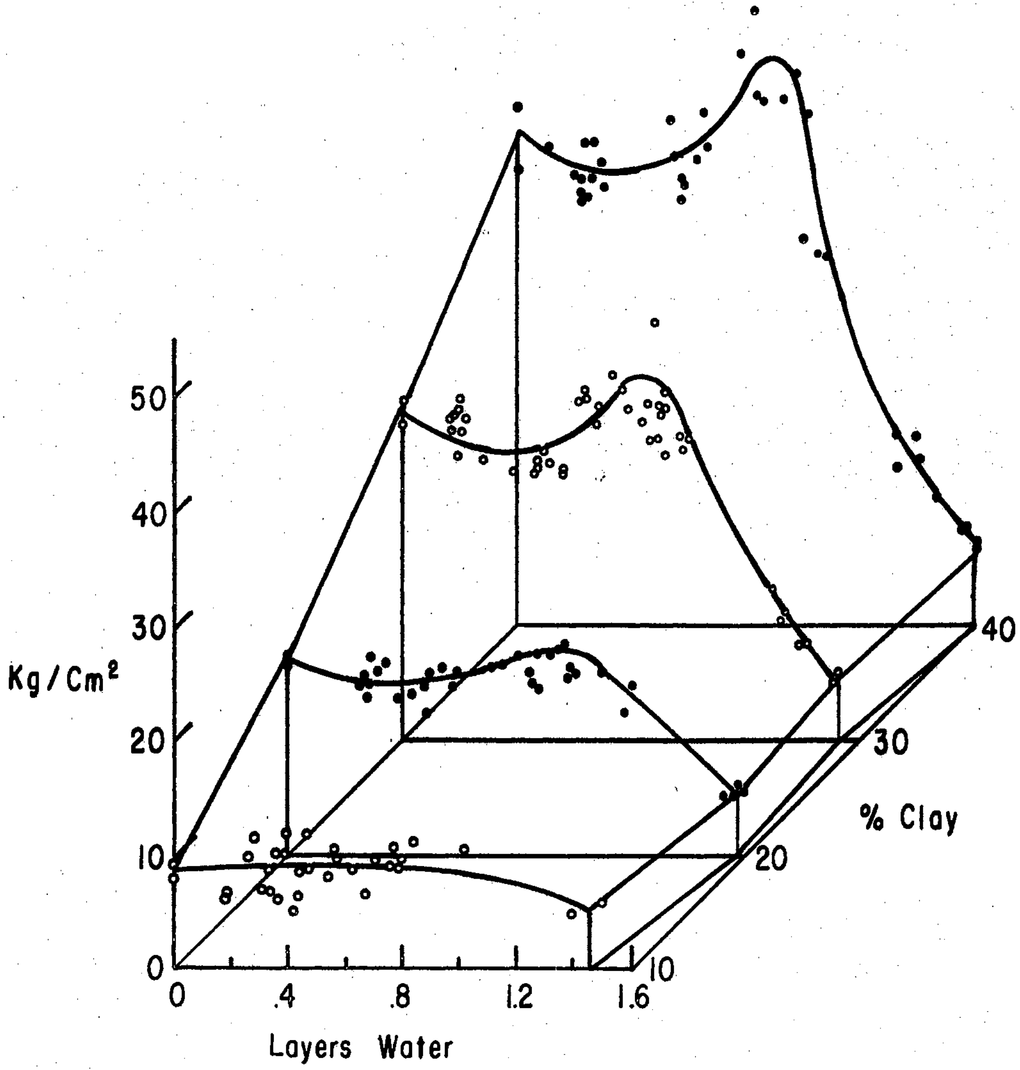

Figure 8. Strength Versus Layers of Water for the Four Clay Percentages Containing 30 Percent Silt and 1.7 Layers of Water at Moulding.

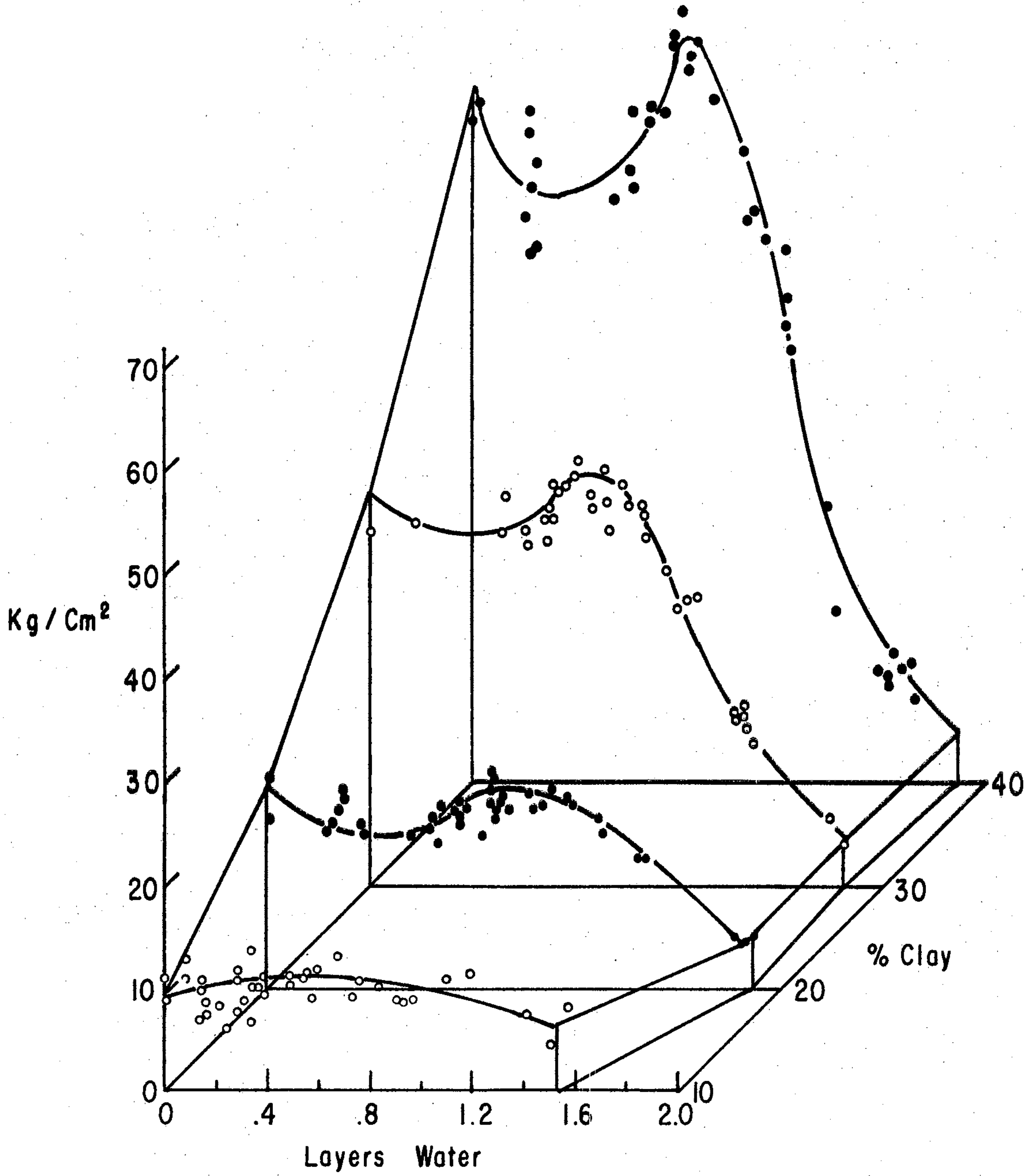

Figure 9. Strength Versus Layers of Water for the Four Clay Percentages Containing 30 Percent Silt and 2. 0 Layers of Water at Moulding.

reoriented into a single-interlayer and consequently a collapse of the "d-spacing". Further dehydration caused continuous collapse of the "d-spacing". These Authors have shown that the spacing did not change with water loss in the same range as the decreased strength reported here suggesting that the dehydration of these samples were similar.

As anticedent moisture increased with little or no drying, strength decreased. Maximum strength increased as initial moisture, clay content, and silt content increased. Maximum strength was greater than oven-dry strength except for the samples containing 30 percent silt and the lowest initial moisture level (Figure 7). As silt increased, the percent reduction of strength during the dehydration from 0.9 to 0.4 layer decreased. A plausible explanation for this phenomonon is that the frictional forces are greater in the higher silt samples. There was no consistant trend with respect to moisture on the percent reduction of strength.

Table II presents the maximum percent change in volume or drying for the samples containing 20 percent or more clay. About 75 percent of the maximum change in volume occurred before 20 percent of the initial moisture was lost. Shrinkage was observed to be present in all textures except those containing 10 percent clay. As the silt, clay, and moisture components increased, shrinkage increased. This suggests that sufficient clay is not present between the contact surfaces of the sand and/or silt grains at the lowest clay content to measure shrinkage.

Mathers et. al. (19) reported the same general trends as this report presents for the Amarillo fine sandy loam. Their maximum strength was reported at the monolayer water content using 11.53 A^2 as the area of the water molecules. When their data was calculated using

TABLE II

PERCENT MAXIMUM SHRINKAGE OF CORES FOR EACH MOISTURE AND TEXTURE

			Initial Layers of Water		
Texture			1.4	1.7	2.0
Clay	Silt	Sand	Percent Maximum Shrinkage		
40	30	30	6.3	10.1	13.7
40	15	45	5.8	8.3	12.0
40	0	60	4.2	6.0	8.6
30	30	40	3.4	5.8	8.0
30	15	55	3.0	5.8	7.8
30	0	70	3.3	3.9	4.7
20	30	50	2.9	2.7	3.6
20	15	65	2.6	3.0	3.9
20	0	80	2.0	3.1	2.7

the 10.8 A^2 for water, close agreement with this data was obtained. It is more reasonable to find a maximum strength curve to have a plateau rather than a sharp peak since the contact surface area was not likely to equal the total surface area. Gerard (6), using modulus of rupture to measure strength, reported maximum strength to be at 2 to 3 layers of water depending upon the texture, cations, and drying conditions. The discrepency between his data and the data presented here may result from the presence of organic matter and a different clay-mineral suite in his samples. The data presented did not show readily recognizable maximums since lower moisture to strength relationships data were not presented for all conditions reported.

Bassett and McDaniel (2) reported good correlations between percent moisture and rating cone index (a strength measurement). Since these data show that the strength of the lower clay content cores was weak and the observations of Taylor (26) showed extremely strong soil layers in the field, then two factors must be different to explain the discrepancy between his data and the data reported here. These factors probably were: (1) Particle segregation suggested by Jenny (12); and (2) orientation of particles to produce a maximum contact surface area, thus, greater strength. The laminar structure of several of the soils that Taylor investigated suggests that both of these factors were present.

CHAPTER FIVE

CONCLUSIONS

These data agree with that reported by Mathers et. al. (19, 20) in the maximum and a minimum strength. It adds to the evidence that a stepwise dehydration of the clays present in this soil occurs. With increasing molding water content the maximum strength increased. Increasing the clay content increased the maximum strength. The effect of increasing the silt content on the strength was not consistent.

Tillage must be performed at some moisture content which will not induce compaction and thus a strong layer in the soil. Once a strong layer is produced, the soil must be kept moist in order to prevent root restriction or the compacted layer must be broken up.

In order to be able to obtain a mathematical relationship of moisture and surface area to strength a more exact measurement of contact surface area, precise and uniform packing for a range of bulk densities must be developed. Investigation of the influence of pure and mixed clay species must be undertaken in order that more precise predictions of the formation and effect of root restricting layers can be understood.

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