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A study of the effect of aggregate size and bulk density on moisture retention characteristics of selected soils

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The influence of soil structure on moisture retention characteristics of soils has drawn attention of several workers in recent years. Various parameters characteristic of soil structure have been used to describe the relationship between soil structure and moisture retention.

AMEMIYA[1]) and TAMBOLI *et al.*[5]) used aggregates of various sizes separated from natural soils to study moisture retention. Other studies include those of TAYLOR and BOX[6]), HILL and SUMNER[3]) and MASLOV[4]) wherein the effect of soil bulk density on matric potential of soil water has been evaluated. In the present study an attempt has been made to see the effect of these two structural parameters on the moisture retention characteristics of varying soil types with a view to further the results obtained by earlier workers.

MATERIAL AND METHODS. — Surface soil samples varying in texture from loamy sand to silty loam were collected from seven locations. The physico-chemical characteristics of these soils are presented in Table 1.

Preparation of aggregates. — Aggregates of four soils (Nagrota, Dharamshala, Pantnagar and Gurdaspur) were prepared artificially by treating

TABLE 1. — *Physico-chemical characteristics of different soils.*

Location	pH (1:2 suspension)	$CaCO_3$ %	Organic carbon %	Mechanical composition				Textural class (¹)
				Clay	Silt	Fine sand	Coarse sand	
Dharamshala	6.60	0.40	2.36	12.21	20.39	58.62	5.42	Loamy sand
Gurdaspur	7.95	0.88	0.33	9.70	28.45	53.33	8.67	Silty loam
Narnaul	7.70	1.05	0.34	23.79	29.13	45.36	0.12	Silty loam
Patiala	7.50	Nil	0.20	15.87	25.19	44.03	13.47	Loam
Nagrota	6.60	0.30	0.96	13.32	31.18	41.76	13.76	Silty loam
Pant Nagar	7.95	4.20	0.45	16.85	32.04	40.70	6.92	Silty loam
Hansi	7.80	0.90	0.58	13.58	29.68	56.24	0.10	Silty loam

(¹) According to International system of textural classification.

the soil with krilium at the rate of 0.001 percent. 2 g. krilium dissolved in 500 ml of hot water was applied after cooling with the help of a hand sprayer to 2 Kg. soil. The soil was hand mixed thoroughly to ensure uniform distribution of added krilium followed by additions of water with sprayer till the aggregates formed appeared to glisten. The aggregates were air dried and sieved to get the following five aggregate sizes: 0.25 to 0.50, 0.50 to 1.00, 1 to 2, 2 to 5 and more than 5 mm. Aggregates of size smaller than 0.25 mm were discarded since these invariably tended to have a mechanical composition widely different from the larger sized aggregates.

Maintenance of different bulk densities. — Varying bulk densities were maintained in metallic boxes 1.3 cm. high and 3.4 cm. in diameter having a perforated base. Bulk densities of 1.4, 1.5, 1.6 and 1.7 g. $cm.^{-3}$ were maintained for Dharamshala and Pantnagar soils and 1.5, 1.6, 1.7, and 1.8 g. $cm.^{-3}$ for other soils studied. The lowest bulk density was attained by tapping a known quantity of air dried soil while higher densities were attained by compacting a known amount of moistened soil with a flat based metallic compactor. Moisture equivalent values of soils maintained at different bulk densities were determined after saturating the soil for 48 hours in a moisture equivalent centrifuge (Supplied by Messers International Equipment Company, U.S.A.). Moisture retention at various suctions was determined by placing 25 to 30 g. of aggregates in metallic rings 2.5 cm. high and 4.0 cm. diameter. Aggregates were saturated for 48 hours before the required pressure was applied. Equilibrium was supposed to have been attained when no water came out continuously for eight hours. Moisture in the samples was determined gravimetrically by drying at 105°C. Richard's pressure plate extractor was used for moisture retention measurements at low suctions (below 23 lb/sq. inch) while pressure membrane apparatus was used for evaluating moisture retention at higher tensions. International pipette method was adopted for determining the mechanical composition of soils. Organic carbon was determined by Walkley and Black's rapid titration procedure. Porosity measurements were made by glass bead displacement method developed by Voorhees et al. [7]).

RESULTS AND DISCUSSION. — The gravimetric moisture retained by various sized aggregates at different tensions are presented in Table 3. The data show that moisture retained at a particular tension increases as the aggregate size increases. This is true for all soils studied at least upto 22.9 lb/sq. inch applied pressure. These differences can be attributed to the variations in the internal porosity of the aggregates which decreases with decreasing aggregate size. Relatively rapid fall in the moisture retained by smallest aggregates compared to others is possibly due to greater amount of coarse sand associated with them. Data on porosity and mechanical composition of various sized aggregates for one of the soils (Negrota) is presented in Table 2.

TABLE 2. — *Physico-chemical properties of different sized aggregates (Nagrota soil).*

Aggregate size (mm)	Organic Carbon %	Porosity % (Internal)	Bulk density (gm. cm^{-3})	Particle size distribution (Percentage)			
				Clay	Silt	Fine sand	Coarse sand
5	1.55	45.85	1.34	14.62	29.50	35.30	13.57
2-5	1.37	40.47	1.51	14.87	31.01	35.30	12.70
1-2	1.38	39.09	1.55	13.52	32.28	32.66	14.74
0.5-1	1.46	32.69	1.71	13.87	31.08	32.48	16.50
0.25-0.50	1.02	26.84	1.81	14.41	29.52	30.53	21.85

Another possible reason for greater moisture retention by large sized aggregates is the presence of greater quantities of water in the blocked pores due to ink bottle effect or the dead end pores. That this effect might be of significances is shown by data in Table 4 and the curves for another soil in Fig. 1. In one set of the curves moisture retention at a particular suction was determined in the usual manner while in the other the external pressure in equiliberated aggregates was released for a period of twelve hours and remaintained with slightly higher pressure till the samples got re-equiliberated. From the curves presented in Fig. 1 it is obvious that for larger aggregates there is pronunced difference between the two curves compared to the curves for the smaller aggregates. It thus appears that under conditions of external pressure as obtained in pressure membrane and pressure plate apparatuses some moisture held in the dead end pores is not drained. When the external pressure is brought to atmospheric, water in these pores which is held at lower suctions gets reequiliberated and a portion

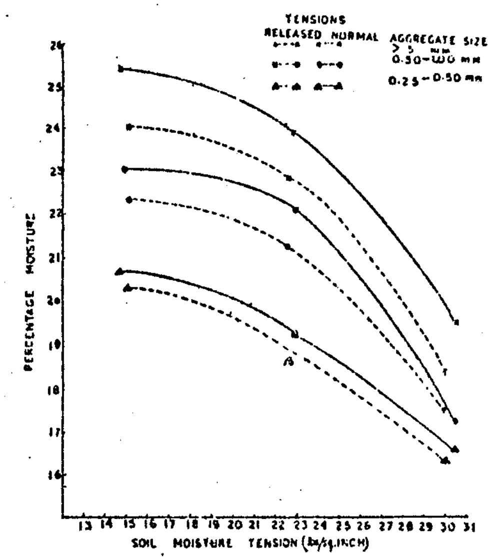

FIG. 1. — Normal and released moisture retention curves for different sized aggregates of dharamshala soil.

TABLE 3. — *The relationship between gravimetric moisture retained and the soil aggregate size at various soil moisture suctions.*

Location	Aggregate size (mm)	% age moisture at various soil moisture suctions (lbs/sq inch)								
		1.50	2.3	4.8	7.3	14.7	22.9	30.5	71	217
Dharamshala	More than 5	29.22	27.93	27.03	25.91	25.43	23.95	19.54	16.81	13.38
	2-5	28.98	27.56	26.45	24.94	24.38	23.40	18.40	17.41	12.39
	1-2	28.21	27.11	25.95	24.14	23.29	22.60	18.36	15.46	11.30
	0.5-1	28.20	26.93	26.14	24.08	23.03	22.09	17.26	15.33	10.88
	0.25-0.5	25.32	24.16	22.65	20.67	20.66	19.26	16.60	12.88	9.60
Nagrota	More than 5	27.49	25.29	24.03	22.78	22.32	20.95	16.70	11.56	9.04
	2-5	26.63	25.23	23.72	22.65	21.42	20.09	17.11	12.78	9.10
	1-2	26.02	24.20	23.13	21.55	20.13	19.18	16.60	11.98	8.38
	0.5-1	25.86	23.40	22.25	20.37	19.32	18.39	15.83	11.49	7.89
	0.25-0.5	22.06	21.26	19.59	18.87	17.41	16.59	14.90	10.94	7.58
Gurdaspur	More than 5	20.80	20.13	18.96	18.31	16.34	16.13	10.77	7.26	5.19
	2-5	20.08	19.50	18.75	17.32	15.60	14.73	10.53	7.83	5.22
	1-2	20.70	19.44	18.78	17.13	15.33	14.28	10.94	7.84	5.29
	0.5-1	19.57	18.56	18.27	16.72	15.09	13.54	10.89	8.38	5.58
	0.25-0.5	17.41	16.68	15.57	15.00	12.09	11.92	10.61	7.71	4.96
Pant Nagar	More than 5	—	—	27.47	25.93	24.71	23.45	20.67	18.41	12.77
	2-5	—	—	27.29	25.56	24.11	23.25	20.29	17.67	12.68
	1-2	—	—	27.43	24.86	23.50	22.52	20.37	17.47	12.79
	0.5-1	—	—	26.64	24.48	23.13	21.87	20.07	17.76	12.85
	0.25-0.5	—	—	25.12	24.00	22.01	20.57	19.25	16.87	12.81

TABLE 4. — *Percentage moisture retained by different sized aggregate before and after remaining higher pressures.*

Location	Size	Percentage moisture at different tension (lbs/sq inch)					
		N_1 14.7	R_{1a} 15.10	R_{1b} 14.8	N_2 22.9	R_{2a} 22.6	R_{2b} 23.1
Nagrota	5	22.32	21.33	19.74	20.95	20.50	17.63
	2-5	21.42	20.90	19.69	20.09	19.83	17.08
	1-2	20.13	20.14	19.39	19.18	19.65	16.85
	0.5-1	19.52	19.07	18.08	18.30	18.37	16.54
	0.25-0.5	17.41	17.54	16.59	16.59	16.83	15.41
Dharamshala	5	25.43	24.03	23.13	23.95	22.85	17.25
	2-5	24.38	22.95	22.52	23.40	22.28	17.22
	1-2	23.29	22.57	21.33	22.60	21.11	16.47
	0.5-1	23.03	22.39	20.75	22.09	21.20	16.66
	0.25-0.5	20.66	20.35	18.77	19.26	18.64	14.86
Gurdaspur	5	16.34	15.94	15.08	16.13	15.11	13.31
	2-5	15.60	14.96	14.91	14.73	14.27	13.29
	1-2	15.33	14.72	14.87	14.28	14.30	13.84
	0.5-1	15.09	14.72	14.45	13.54	13.96	12.71
	0.25-0.5	12.90	12.53	12.50	11.92	12.11	11.78

N_1N_2 - Moisture retained at tensions after equilibrating the water saturated aggregate samples.
R_{1a} - Samples equilibrated to 2.3 lbs/sq inch, pressure released and again equilibrated to 15.10 lbs/sq inch.
R_{1b} - Samples equilibrated to 2.3 lbs/sq inch, pressure released and again equilibrated to 4.7 lbs/sq inch, pressure released again and equilibrated to 14.8 lbs/sq inch.
R_{2a} - Pressure of R_{1a} released again and equilibrated to 22.60 lbs/sq inch.
R_{2b} - Pressure of R_{1b} released and again equilibrated to 23.1 lbs/sq inch.

TABLE 5. — *Moisture equivalent values for different soils maintained at different bulk densities.*

Location	Percentage moisture at different bulk densities (gm. cm⁻³)				
	1.40	1.50	1.60	1.70	1.80
Dharamshala	22.87	24.10	24.76	23.10	—
Narnaul	—	23.93	22.57	22.31	19.78
Patiala	—	16.59	16.23	16.01	14.83
Nagrota	—	23.41	21.35	20.24	19.60
Pant Nagar	26.83	25.73	24.41	22.96	—
Hansi	—	23.40	22.35	21.94	21.64

of it is drained once the aggregates are resubjected to external pressure. Data presented in Table 4 further confirms such a reasoning. Thus, for aggregate of various sizes, differences in moisture content were further reduced when the external pressure was released and remaintaned more than once. These results find support from those of CHANG[2]) who found large ink bottle hysterisis for samples prepared from larger aggregates at lower compression levels.

AMEMIYA[1]) reported that it is the pore size distribution and not the total pore volume which is responsible for variations in moisture retention by variously sized aggregates at low tensions. This he concluded since aggregates of all sizes had nearly the same bulk density being approximately 0.85 g cm^{-3}. It would appear that in these measurements both inter and intra aggregate pore volumes have been considered although the former do not really appear important for moisture retention by the aggregates under laboratory conditions. It could therefore be inferred from above considerations that differences in intra aggregate porosity are chiefly responsible for differences in moisture retention by variously sized aggregate and that these differences are magnified in laboratory conditions by the presence of large number of blocked pores in larges aggregates which retain water at lower suctions. At higher suctions, however, the differences are not well pronounced This is mainly due to the reason that at higher suctions moisture retention is more a function of surface adsorptive forces which effect is mainly determined by relative distribution of mechanical separates and nature of clay rather than the porosity.

Bulk density and moisture retention. — Table 5 gives the moisture equivalent values of different soils maintained at different bulk densities. For silty loam and loam soils (Narnaul, Hansi, Nagrota, Pantnagar and Patiala) this value decreased as the bulk density was increased from 1.4 to 1.8 g cm^{-3}. The reason for this again is the reduced pore space as the bulk density is increased. In case of loamy sand soil (Dharamshala) moisture equivalent value increased as the bulk density was increased from 1.4 to 1.6 g. $cm.^{-3}$. A further increase in bulk density to 1.7 g. $cm.^{-3}$ however resulted in decrease in moisture retained. An initial increase in bulk density results in increase in relative volume and total number of smaller pores and a decrease in relative volume and total number of larger pores. Increased retention as a result of this outweighs the possible decrease due to reduced total pore space resulting in a net increase in moisture retention.

The effect of bulk density on matric potential of soil water can also be inferred from the moisture retention data of variously sized aggregates. A plot of moisture content retained by aggregates of different bulk densities as a function of low and high tensions in Figs 2 and 3 show interesting results. At low tensions (Fig. 2) as the bulk density of aggregates increases the soil moisture tension decreases at a particular moisture content Thus a moisture content of 21 percent corresponds to a soil moisture tension of 9.8, 17.0, and 22.5 lb./sq. inch for bulk densities of 1.55, 1.51 and 1.34 respectively. This is due to the fact that with increase in bulk density, at low tensions, excess water is squeezed out of larger pores which are decrease in size. This water then enters and fills the additional smaller pores that have been created and overflows in the pores larger than the normally filled at that tension. This results in decrease in matric suction (HILL and SUMNER, 1967).

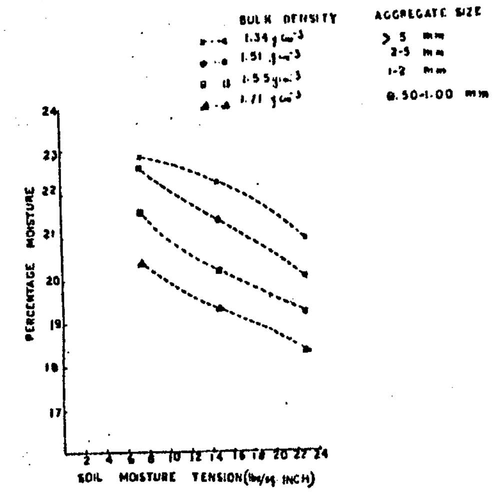

FIG. 2. — Moisture retension curves for different sized aggregates of nagrota soil (low tensions).

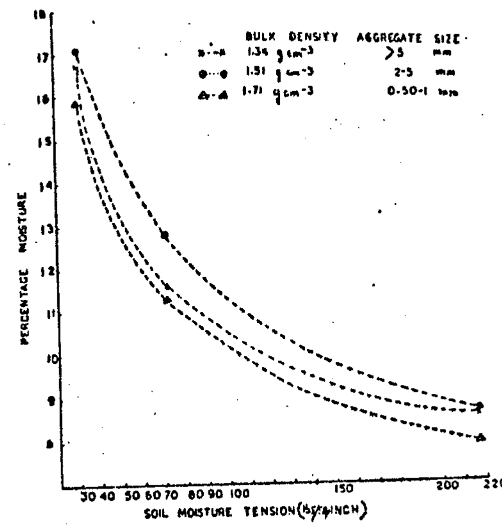

FIG. 3. — Moisture retention curves for different sized aggregates of nagrota soil (higher tensions).

At higher tensions (Fig. 3) as the bulk density increases from 1.34 to 1.51 g. $cm.^{-3}$ there is increase in soil moisture matric suction where as there is decrease in matric suction as bulk density increases from 1.51 to 1.71 g. cm.$^{-3}$. As pointed out by HILL and SUMNER[3]) this is due to the fact that at low moisture content increase in bulk density in these soils results in shifting of the moisture to the smaller pores and thereby increase in matric suction. Further increase in bulk density has the similar effect as that at lower tensions.

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SUMMARY — Effect of aggregate size on moisture retention characteristics has been evaluated using artificially prepared aggregates of various sizes. At low suctions moisture retained increased directly with aggregate size. It has been shown that internal porosity and blocked pore effect are the possible causes for variation in moisture contents retained by various sized aggregates. The effect of maintaining different bulk densities on the moisture equivalent values, however, depended chiefly on the textural composition of soils.

RÉSUMÉ — On a évalué l'influence du diamètre des agrégats sur la quantité d'eau retenue, en employant des agrégats artificiels de grandeur différente. En ce qui concerne les plus petits, la rétention augmente directement avec le diamètre des agrégats.

On a démontré que la porosité intérieure et l'effet envisagé de l'obstruction des pores répresentait les causes puossibles de la variation de la rétention de la part des agrégats. L'effet de maintenir la plupart des différentes densités sur les valeurs de l'équivalent d'humidité, dépendait, de toute façon, principalement, de la tissure des terrains.

ZUSAMMENFASSUNG — Man hat den Einfluss des Durchschnittes der Aggregaten in der Quantität des enthaltenen Wasser, in dem man künstliche Aggregaten von verschidener grösse gebrauchte. Für die kleineren, vermehrt die Einbehaltung in gerader Lines mit dem Durchschnitt der Aggregaten. Es ist beweist worden, dass die innere Porosität und die Wirkung der Verstopfung der Pore, die möglichen Gründe der verschiedenheit der Einbehaltung in den Aggregaten dar stellen. Die Wirkung, grösste Teils der verschiedenen Dichtigkeit auf den Werten der gleichgeltenden Feuchtigkeit, hängt jedoch hauptsächlich von dem Gewebe des Erdboden ab.

RESUMEN — Ha sido valuada la influencia del diámetro de los agregados sobre la cantidad de agua retenida, empleando agregados artificiales de varios tamaños. Para los más pequeños, la retención aumenta directamente con el diámetro de los agregados.

Ha sido demostrado que la porosidad interior y el efecto producido por la obstrucción de los poros, representaba las causas posibles de la variación de la retención por parte de los agregados. El efecto de mantener la mayor parte de las diversas densidades sobre los valores del equivalente de humedad, dependía, de todas maneras, principalmente de la conformación de los terrenos.

RIASSUNTO — È stata valutata l'influenza del diametro degli aggregati sulla quantità di acqua ritenuta, impiegando aggregati artificiali di varia grandezza. Per i più piccoli la ritenzione aumenta direttamente con il diametro degli aggregati.

È stato dimostrato che la porosità interna e l'effetto prodotto della ostruzione dei pori rappresentava le possibili cause della variazione della ritenzione da parte degli aggregati. L'effetto di mantenere la maggior parte delle differenti densità sui valori dell'equivalente di umidità, dipendeva, comunque, principalmente dalla tessitura dei terreni.

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