NASA TECHNICAL MEMORANDUM NASA TM- 76674

RELATIONSHIPS BETWEEN SOIL MOISTURE-HOLDING PROPERTIES AND SOIL TEXTURE, ORGANIC MATTER CONTENT, AND BULK DENSITY

Hugh C.F. Riley

Translation of "Sammenhengen mellom jordas vannholdende evne og dens mekaniske sa_enheng, moldinnhold og volumvekt", Statens Forskingsstason Kise, 2350 Nes pa Hedmar , Melding Nr. 49, (Kise Agriculture Station, N-2350 Nes Pa Hedmark, Norway, Report No. 49), March 13, 1979, pp 379-398

(NASA-TM-76674) RELATIONSHIPS BETWEEN SOIL MOISTURE-HOLDING PROPERTIES AND SOIL TEXTURE, ORGANIC MATTER CONTENT, AND BULK DENSITY (National Aeronautics and Space Administration) 26 p HC A03/MF A01 CSCL 08M G3/43 N82-16451 Unclas 05537

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, DC 20546 AUGUST 1981

ORIGINAL PAGE IS OF POOR QUALITY

STANDARD TITLE PAGE

1. Report No. NASA TM-76674	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle RELATIONSHIPS BETWEEN SOIL MOISTURE-HOLDING PROPERTIES AND SOIL TEXTURE, ORGANIC MATTER CONTENT AND BULK DENSITY		5. Report Date August 1981
		6. Performing Organization Code
7. Author(s) Hugh C.F. Riley		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address SCITRAN Box 5456 Santa Barbara, CA 93108		11. Contract or Grant No. NASw- 3198
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes Translation of 'Sammenhengen mellom jordas vannholdende evne og dens mekaniske sammenheng moldinnhold og volumvekt', Statens Forskingsstason Kise, 2350 Nes pa Hedmark, Melding nr. 49 (Kise Agricultural Research Station , N2350 Nes pa Hedmark, Norway, Report No. 49), March 13, 1979, pp 379-398

16. Abstract Specimens from the surface horizon and the subsoil of 62 soil horizons in Hedmark and Oppland were investigated to study how the mechanical composition of the soil , the organic matter content and the bulk density affect their porosity and air capacity and their total and available water content.

Most of the specimens belonged to the loam group , and a smaller number was from sandy and silty types of soil.

Equations have been established to make it possible to calculate the water retention curves and the amount of available water from the above mentioned parameters. As a rule, errors derived from the equations are no greater than those which are found in similar research in other countries.

17. Key Words (Selected by Author(s))	18. Distribution Statement Unclassified - Unlimited

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 24	22. Price

Content

I. Abstract

Specimens from the surface horizon and the subsoil of 62 soil horizons in Hedmark and Oppland were investigated to study how the mechanical composition of the soil, the organic matter content and the bulk density affect their porosity and air capacity and their total and available water content.

Most of the specimens belonged to the loam group, and a smaller number was from sandy and silty types of soil.

Equations have been established to make it possible to calculate the water retention curves and the amount of available water from the above-mentioned parameters. As a rule errors derived from the equations are no greater than those which are found in similar research in other countries.

II. Introduction

It is important to know which factors affect the water-retaining properties of the soil and other properties in order to be able to develop other methods to characterize soil, rather than the extremely time-consuming retention curve determination. Equations have been established for these properties with other physical soil parameters in a number of countries [1, 4, 7, 15, 16, 17, 18, 21 and 23], which can provide valuable solutions in this respect. If reliable results are needed, one is also compelled to investigate the soil in the area where the equations are intended to be used, because the water-retaining properties of the soil can be affected by local conditions, such as the deposition pattern, the mineralogy, the climate and the drainage pattern. In Norway some results have been published for relatively limited areas [2, 3], but there is little published material for large parts of Ostland. This report is based on material collected mainly in Hedmark and Oppland. The laboratory work was performed by the professional assistant Helge Olsen.

III. Methodology

A. Sampling Sites

The majority of the specimens are from morainic deposits, but some are of a different deposition type (fluvioglacial and marine deposits). A comparison of Figure 1, which shows the distribution of the specimens in texture triangles, with similar figures composed by Njos ahd Sveistrup [14] indicates that the material is quite precise for morainic deposits at Ostland, and also partially for silty and sandy soil at Romerike and in Sor-Osterdal, but is less representative for clay areas in Akershus and Ostfold.

The specimens were taken from two strata (0-15 cm and 25-50 cm) from 62 profiles and are here designated as surface horizon and subsoil specimens. Steel cylinders with an internal diameter of 58 mm and a height of 38 mm were used to take solid specimens. They were taken in the autumn, mainly from grain fields which were plowed in autumn the year before. A smaller number were from potato fields before harvesting.

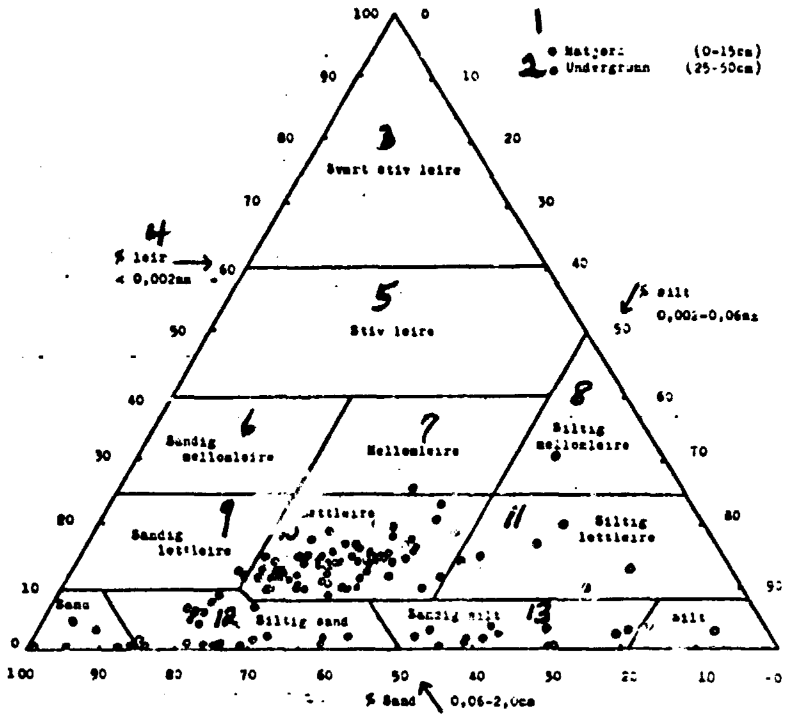

Figure 1. Distribution of samples in relation to mechanical composition on weight basis of material under 2 mm.

Key: 1-Surface horizon, 2-Subsoil, 3-Extremely stiff clay, 4-Clay, 5-Stiff clay, 6-Sandy medium clay, 7-Medium clay, 8-Silty medium clay, 9-Sandy light clay, 10-Light clay, 11-Silty light clay, 12-Silty sand, 13-Sandy silt

Each analysis number is based on three repetitions.

B. Laboratory Analyses

After saturation with water, the water content of the specimen was measured at 0.02, 0.1, 1.0 and 15 bars (respectively approximately pF 1.3, 2.0, 3.0 and 4.2). The entire cylinder specimens were used in pressure plate equipment in the first three levels, and circles with sieved material less than 2 mm were used in pressure membrane equipment at 15 bars. The bulk density was determined after drying the cylinder specimens at 105° C. The water content was expressed on a volume basis and the porosity (total pore volume), air capacity (air-filled pores at 0.1 bar), specific weight and available water were computed. Petersen et al. [15] ve proposed that the water content for soil rich in gravel and stone expressed on the basis of the volume of fine material, but this requires a knowledge of the special volume weights of the fractions, which is very difficult to determine for gravel mixed with fine soil. Instead the values for the water content at 15 bars were corrected for gravel content according to the formula:

Percentage of water in sieved material · (100 weight percentage of gravel in the entire specimen).

Here it is assumed that there would not be any water in direct contact with the gravel at 15 bar. In the lack of pycnometer determinations for specific weight, the percentage of water at full saturation was used to express the porosity, something which could have entailed an underestimate in some cases. Mechanical analysis of the fine material was performed by sifting and hydrometer methods [12], and the glow loss was determined after two hours at 550° C.

C. Further Calculations and Statistical Analyses

The seven initial particle size groups used are the same as in Atterberg's classification. In addition an attempt at grouping was made according to other information and some lesser used classification systems, altogether 23 groups (Figure 2). This produced an approximation to the USDA case, since silt-sand limits of 0.06 mm were used instead of 0.05 mm, and to the Wentworth case, where the clay-silt limit of 0.006 was used instead of 0.004 mm.

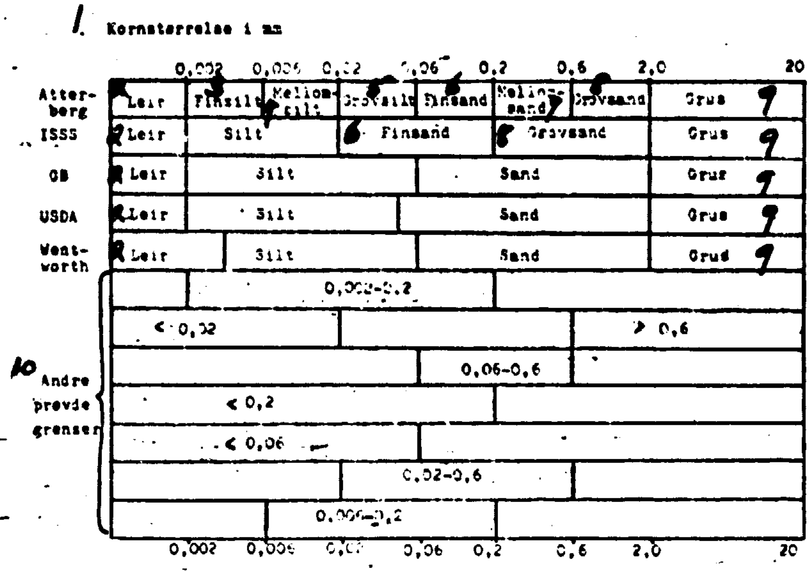

Figure 2. Different systems of mechanical analysis classification.

(GB = Soil Survey of Great Britain)

(USDA = United States Department of Agriculture)

(ISSS = International Society of Soil Science)

Key: 1-Particle size, 2-Clay, 3-Fine silt, 4-Medium silt, 5-Coarse silt 6-Fine sand, 7-Intermediate sand, 8-Coarse sand, 9-Gravel, 10-Other tested limits

On the basis of this large gravel content in many of the specimens, the tables for mechanical analysis were computed in two ways. First the fine material (under 2 mm) was expressed in the usual way, as a mutual weight percentage with the gravel content as a percentage of the entire specimen. Afterwards the fine material was also expressed as a percentage of the entire specimen. Here consideration had to be given to the organic matter content of the specimen, since the fine material was orginally expressed as a weight percentage of the mineral material alone. This took into account possible unoxidized organic material which can slightly distort these values because its light specific weight makes little impression on the hydrometer in comparison to, for example, clay. The glow loss, corrected for clay content after Ekeberg (personal communication) and Lag [10], was used as an expression of organic matter content:

Organic matter (1) = glow loss - (1 + (0.05 · clay))

This is the weight percentage of all material under 2 mm, so that another correction was necessary in order to obtain the organic matter content as a weight percentage of the entire specimen:

Organic matter (2) = organic matter (1) · (100 - gravel)/100

Then the corrected values for the fine material could be calculated as a weight percentage of the entire specimen:

Fine material (2) = fine material (1) · (100 - organic matter (2) - gravel)/100

Other calculations were made with both sets of data. A simple correlation was made and a "gradual advance" multiple regression with selected variables. Calculations were made for the surface horizon and the subsoil individually and together. The choice of a collective or individual equation depends partially on which independent variables are involved and partially on the relative error from the equations. In particular we should be careful in using a collective equation with variables, if the means are not alike in the surface horizon and the subsoil, if they do not occur in both individual equations with the same sign and coefficients of like value.

The distribution of the values of the parameters are shown in Table 1. There was little difference between the surface horizon and the subsoil specimens in mechanical composition, air capacity and readily available water, but there were significant differences in the organic matter content, volume weight, porosity, strongly-held and total available water and the slopes of the water retention curves.

Table 1. Distribution of the Analyzed Parameter Values

Parameter	1 Matjord		2 Undergrunn		SA diff.	Signif.	3 Samlet			Min
	4 Middel	SA	4 Middel	SA			4 Middel	SA	5 Maks	
6 Grovsand	9,8	7,7	11,7	12,4	1,86	—	10,7	10,3	75	0
7 Mellomsand	20,1	12,3	21,1	13,5	2,82	—	20,5	10,2	65	0
8 Finsand	21,6	9,8	22,0	10,7	1,31	—	21,9	10,2	55	4
9 Grovsilt	17,3	10,8	16,7	12,4	2,00	—	17,0	11,6	64	0
10 Mellomsilt	12,8	5,1	12,9	6,4	1,03	—	12,8	5,7	30	0
11 Finsilt	7,2	3,4	6,5	3,7	0,63	—	6,9	3,5	17	0
12 Leir	11,2	5,9	9,1	6,8	1,14	—	10,1	6,4	31	0
13 Grus	16,1	13,5	21,0	18,5	2,01	—	18,5	16,3	87	0
14 Mold	5,38	3,22	1,78	-,98	0,48	•••	3,58	3,22	17	0
15 Volumvekt	1,25	0,17	1,39	0,19	0,03	•••	1,32	0,19	1,77	0,75
16 Spesifikk vekt	2,51	—	2,60	—	—		2,56	0,23	3,96	2,03
17 Porøsitet	50,3	6,75	46,0	8,90	1,42	••	48,1	8,1	72	34
18 Luftinnhold ved 0,1 bar	18,8	8,14	20,6	6,85	1,35	—	19,4	7,6	37	3
19 Vanninnhold ved 0,02 bar	39,7	6,65	33,3	10,1	1,53	•••	36,5	9,1	58	9,9
» » 0,1 »	31,5	7,74	25,4	10,8	1,69	•	28,5	9,9	51	6,0
» » 1,0 »	25,6	7,30	18,7	9,1	1,48	•••	22,2	8,9	44	4,0
» » 15 »	8,35	3,40	5,72	3,51	0,44	•••	7,03	3,7	18	0,7
20 Lett tilgjengelig vann	5,92	3,22	6,04	5,85	0,85	—	6,23	4,7	28	0,5
21 Tyngre » »	17,3	5,27	13,0	6,31	1,04	•••	15,6	6,7	32	3,1
22 Totalt » »	23,2	6,29	19,7	9,11	1,40	•	21,4	8,0	43	5,1

23 Finmaterialet (< 2 mm) er vektprosent av mineralmaterialet, etter Atterbergs skala.
24 Moldinnhold er vektprosent av alt materiale under 2 mm.
25 Grusinnhold er vektprosent av hele prøven.
26 Luft- og vanninnhold er volumprosent av hele prøven.

Key: 1-Surface horizon, 2-Subsoil, 3-Combined horizons, 4-Mean, 5-Maximum, 6-Coarse sand, 7-Medium sand, 8-Fine sand, 9-Coarse silt, 10-Medium silt, 11-Fine silt, 12-Clay, 13-Gravel, 14-Organic matter, 15-Bulk density, 16-Specific weight, 17-Porosity, 18-Air content at 0.1 bar, 19-Water content at 0.02 bar, 20-Readily available water, 21-Strongly-held available water, 22-Total available water. 23-Fine material (< 2mm) is weight percentage of mineral material, according to Atterberg's classification. 24-Organic matter content is weight percentage of all material under 2mm. 25-Gravel content is weight percentage of entire specimen. 26-Air and water content are volume percentage of entire specimen.

IV. Results

Simple correlation coefficients between the dependent variables studied and mechanical analysis, organic matter content and bulk density are not given here because of space considerations. In general there were somewhat higher correlations when the mechanical composition of the soil was calculated as a weight percentage of the entire specimen. In individual cases it was better with other groupings of mechanical analysis than Atterberg's classification, but as a rule the differences were not significant. Therefore the equations were calculated according to Atterberg's classification for most variables, but with mechanical analysis as a weight percentage of the entire specimen. The equations for available water, which can be presumed to be most used in practice, were calculated according to two other additional classifications (ISSS and GB/USDA), and with mechanical analysis according to both methods of calculation discussed above. This makes it easier to compare with other published material where the mechanical composition is often given as a weight percentage of the fine material. In the tables the equations are presented with variables in order of their contribution to the variation expounded, and all are significant at $p = 0.05$.

A. Porosity, Air Capacity and Total Water Content

The correlations between water content and the different ring sizes were dependent on pressure. At 0.02 bars there were strong negative effects from gravel and coarse sand (0.6-2 mm), but as pressure increased the coarse grain effect diminished and the fine grain material effect increased. In view of the high negative correlation between porosity and bulk density, only the latter was used as an independent variable.

The equations (Table 2) show a negative effect from increased bulk density on porosity and air capacity in both strata, along with a positive effect on water content at 0.1, 1.0 and 15 bars in the surface horizon. Larger coefficients at 0.1 and 1.0 bars than at 0.02 and 15 bars indicate that the pores in the interval of 0.2-160 μm were affected

Table 2. Regression Equations for Soil Porosity, Water and Air Capacities (%).

1 Variabel	Sjikt 2	3 Ligning	R^2	SAy
4 Porositet	5 Matjord	Y = 96,9 — 37,3 V. VKT.	89	2,27
	6 Undergr.	Y = 81,9 — 28,7 V. VKT. + 0,29 G. SILT	83	3,06
	7 Samlet	Y = 89,3 — 33,0 V. VKT + 0,17 G. SILT	83	3,36
8 Vann ved 0,02 bar	5 Matjord	Y = 30,3 + 1,3 MOLD + 0,18 G. SILT + 0,19 F. SAND — 0,16 GRUS	78	3,26
	6 Undergr.	Y = 45,5 — 0,32 GRUS — 0,57 G. SAND · 0,17 M. SAND + 1,1 MOLD	88	3,69
	7 Samlet	Y = 44,2 — 0,32 GRUS + 1,2 MOLD — 0,44 G. SAND — 0,12 M. SAND	84	3,76
9 Vann ved 0,1 bar	5 Matjord	Y = — 4,61 + 2,0 MOLD + 0,33 G. SILT + 14,2 V. VKT + 0,46 M. SILT	80	3,57
	6 Undergr.	Y = — 6,13 + 0,63 G. SILT + 1,0 LEIR + 1,1 MOLD	89	3,66
	7 Samlet	Y = — 0,445 + 0,57 G. SILT + 0,82 LEIR + 1,7 MOLD + 8,2 V. VKT — 0,069 GRUS	85	3,87
10 Vann ved 1,0 bar	5 Matjord	Y = — 12,2 + 1,9 MOLD + 0,37 G. SILT + 16,7 V. VKT + 0,52 LEIR	74	3,85
	6 Undergr.	Y = — 5,06 + 1,2 LEIR + 0,31 G. SILT + 1,0 MOLD	86	3,58
	7 Samlet	P = — 9,97 + 0,95 LEIR + 0,39 G. SILT + 1,8 MOLD + 10,7 V.VKT	81	3,97
11 Vann ved 15 bar	5 Matjord	Y = — 3,61 + 0,87 MOLD + 0,26 LEIR + 4,7 V. VKT	79	1,60
	6 Undergr.	Y = 1,85 + 0,50 LEIR + 0,35 MOLD	88	1,24
	7 Samlet	Y = — 4,94 + 0,43 LEIR + 0,79 MOLD + 4,5 V. VKT. + 0,036 G. SILT	85	1,45
12 Luft ved 0,1 bar	5 Matjord	Y = 103,5 — 49,9 V. VKT. 1,6 MOLD — 0,29 G. SILT — 0,49 M. SILT — 0,45 LEIR — 0,14 F. SAND	67	3,10
	6 Undergr.	Y = 78,6 — 31,8 V. VKT. — 1,3 F. SILT — 1,5 MOLD — 0,16 G. SILT — 0,31 M. SILT	82	3,02
	7 Samlet	Y = 91,4 — 39,8 V. VKT. — 1,6 MOLD — 0,?2 LEIR — 0,25 G. SILT — 0,42 M. SILT — 0,1? F. SAND	78	3,63

13 G. = grov F. = middels F. = fin V. VKT = volumvekt.
14 Mekanisk analyse etter Atterbergs skala.
15 Uavhengige variabler beregnet som vektprosent av hele prøven.

Key: 1-Variable, 2-Stratum, 3-Equation, 4-Porosity, 5-Surface horizon, 6-Subsoil, 7-Combined horizons, 8-Water at 0.02 bar, 9-Water at 0.1 bar, 10-Water at 1.0 bar, 11-Water at 15 bar, 12-Air at 0.1 bar, 13-G=gravel, M=Medium, F=Fine, V.VKT=bulk density, 14-Mechanical analysis according to Atterberg's classification. 15-Independent variables calculated as weight percentage of the whole specimen.

most by the variation in the bulk density. In the subsoil the bulk density was more thoroughly correlated with the organic matter content than in the surface horizon, and showed less specific effect on pore distribution.

The coarse silt fraction was important for water content at all pressures up to 1.0 bar, often in both strata. The porosity was also affected in a positive direction by the silt content, but the total amount of silt fractions and fine sand had a negative effect upon air capacity. In other words it is only the number of pores of capillary size which are increased by the silt and the fine sand content.

The water content seems to increase with the clay content at all pressures above 0.1 bar. The coefficients are greater for the subsoil than for the surface horizon. Since there was no difference in the clay content between the strata, this may be caused by dissimilar aggregation of clay, something reasonably taken into consideration in the variation in bulk density and organic matter content between them. The effect of the clay was greater at 0.1 and 1.0 bar than at 15 bars. This tendency was also found by Andersson and Wiklert [1] on soil with a clay content up to, but not above, 15-20%, and by Ekeberg and Njos [2]. This is probably typical of soil relatively poor in clay.

The organic matter content increased the water content at all pressures in both strata, and reduced the air capacity in both strata. The coefficients were all greater for the surface horizon than the subsoil, where the organic matter content was much lower. Such a displacement of the entire retention curve with increased organic matter content has been found by many authors [16, 17, 21], and explains why the addition of organic material does not always increase the available amount of water. Here. however, the effect of the organic matter is somewhat less at 15 bars, so that we can expect the organic matter to have an impact on available water.

The gravel content seems to reduce the water content at 0.02 bar, and can thus be of importance for infiltration qualities and air exchange when the soil is close to full saturation.

B. Available Water Content

The word available is here used in the sense of physically useful, with the normal limitations which this entails with respect to species of plants, root development, etc.

As suggested by most other researchers [2, 4, 7, 18], the silt content regularly had the greatest significance for available water. In the correlations and partially in the equations (Table 3) coarse silt (0.02–0.06 mm) and fine sand (0.06–0.2 mm) exhibited the strongest influence on the amount of readily available water, but the finer fractions were also involved with strongly-held available water. The closest correlations for total available water were found with groupings like Wentworth's silt (0.006–0.06 mm) and GB/USDA silt (0.002–0.06 mm). Using such groups makes it easier to avoid questionable regression coefficients which can occur because of distribution coincidences in the material. In the equations (Table 5) the coefficients for GB/USDA silt were greater for strongly-held water than for readily available water. For total available water they were of the same order of magnitude as given by Ekeberg and Njos [2], a little higher than that calculated by Haugbotn et al. [3] for silt soil and by Heinonen [4] for loam, and much higher than that of Salter et al. [18, 21] from a material which spanned a number of types of soil.

There was a negative relationship between available water and gravel, which caused the positive correlations with fine material and organic matter to be greater where they were expressed as a weight percentage of the entire specimen. On the other hand the coefficients for gravel and sand were less with this method of computation, so that

Table 3. Regression Equations for Available Water Against Mechanical Analysis (Atterberg's Classification), Organic Matter and Bulk Density.

			R^2	SAy
1 *Lett tilgjengelig vann (0,1—1,0 bar):*				
2	Matjord	I Y = 2,56 + 0,19 G. SILT	43	2,45
		II Y = 3,10 + 0,19 G. SILT	46	2,36
3	Undergr.	I Y = 1,83 + 0,32 G. SILT + 0,14 F. SAND	60	3,76
		II Y = 0,402 + 0,29 G. SILT + 0,11 F. SAND	62	3,64
4	Samlet	I Y = 0,11 + 0,25 G. SILT + 0,94 F. SAND	51	3,33
		II Y = 1,46 + 0,25 G. SILT + 0,17 F. SAND	54	3,24
5 *Tyngre tilgjengelig vann (1,0—15 bar):*				
2	Matjord	I Y = 8,12 —0,26 GRUS + 0,83 MOLD + 15,0 V. VKT. — 0,14 M. SAND + 0,33 M. SILT	70	3,02
		II Y = — 10,2 + 1,1 MOLD + 12,5 V. VKT + 0, 1 G. SILT + 0,40 M. SILT	67	3,12
3	Undergr.	I Y = 3,86 + 0,57 LEIR + 0,28 G. SILT — 0,083 GRUS + 0,55 MOLD	78	3,03
		II Y = 3,56 + 0,29 G. SILT + 0,56 LEIR + 0,72 MOLD	78	3,05
4	Samlet	I Y = 14,1 —0,22 M. SAND + 0,87 MOLD — 0,21 F. SAND — 0,18 G. SAND + 8,8 V. VKT — 0,17 G. SAND	71	3,38
		II Y = — 9,90 + 0,38 G. SILT + 1,1 MOLD + 7,7 V. VKT + 0,36 LEIR + 0,47 F. SILT + 0,06 M. SAND	73	3,28
6 *Totalt tilgjengelig vann (0,1—15 bar):*				
2	Matjord	I Y = 6,41 — 0,2 GRUS + 0,77 MOLD + 11,0 V. VKT + 0,19 G. SILT — 0,15 M. SAND + 0,22 M. SILT	85	2,53
		II Y = — 1,53 + 0,40 G. SILT + 1,0 MOLD + 8,6 V. VKT + 20,34 M. SILT	54	2,62
3	Undergr.	I Y = 8,91 + 0,55 G. SILT — 0,15 GRUS + 0,39 LEIR + 0,62 MOLD	88	3,23
		II Y = 6,60 + 0,61 G. SILT + 0,50 LEIR + 0,75 MOLD	88	3,23
4	Samlet	I Y = 9,73 —0,21 GRUS + 0,83 MOLD + 0,26 G. SILT + 0,27 M. SILT — 0,14 M SAND + 5,7 V. VKT	86	3,06
		II Y = 6,01 + 0,43 G. SILT + 0,84 MOLD + 0,32 LEIR + 0,27 M. SILT + 0,088 F. SAND	86	3,10

7 G. = grov M. = middels F. = fin V. VKT = volumvekt
8 I: Materiale under 2 mm = vektprosent mineraler under 2
9 Mold = vektprosent av mold + mineraler under 2 mm.
10 Grus = vektprosent av hele prøven.
11 II: Alle fraksjoner som vektprosent av hele prøven.

Key: 1-Readily available water, 2-Surface horizon, 3-Subsoil, 4-Combined horizons, 5-Tightly-held available water, 6-Total available water, 7-G=gravel, M=Medium, F=Fine, V.VKT=bulk density, 8-I: material under 2mm = weight percentage of minerals under 2mm. 9-Organic matter = weight percentage of organic matter plus minerals under 2mm. 10-Gravel = weight percentage of entire specimen. 11-II: all fractions as weight percentage of entire specimen.

the best method of computation is dependent on which variables participate in the equations.

The effects of bulk density and clay content varied with the water fraction. In the cases where they were in the equations, they had a negative effect on the readily available water and a positive effect on the strongly-held water. With respect to total available water the bulk

Table 4. Regression Equations for Available Water Against Mechanical Analysis (ISSS Classification), Organic Matter and Bulk Density.

		Equation	R^2	SAy
1 *Lett tilgjengelig vann (0,1—1,0 bar):*				
2 Matjord	I	Y = 6,86 + 0,11 F. SAND — 4,1 V. VKT	44	2,46
	II	Y = 2,49 ÷ 0,11 F. SAND	40	2,51
3 Undergr.	I	Y = 6,99 + 0,22 F. SAND — 6,3 V. VKT	59	3,81
	II	Y = 2,39 + 0,19 F. SAND — 0,074 G. SAND	61	3,73
4 Samlet	I	Y = 5,26 + 0,17 F. SAND — 4,2 V. VKT	49	3,40
	II	Y = — 0,31 + 0,15 F. SAND ÷ 0,11 SILT	51	3,22
5 *Tyngre tilgjengelig vann (1,0—15 bar):*				
2 Matjord	I	Y = 3,51 — 0,23 GRUS + 0,81 MOLD ÷ 14,6 V. VKT + 0,26 SILT — 0,10 G. SAND	69	3,08
	II	Y = — 15,4 + 1,1 MOLD + 0,42 SILT + 0,14 F. SAND + 13,4 V. VKT	70	3,01
3 Undergr.	I	Y = 11,2 — 0,13 G. SAND + 0,25 SILT + 0,76 MOLD	67	3,70
	II	Y = 4,45 + 0,47 SILT + 1,0 MOLD	65	3,77
4 Samlet	I	Y = 19,8 — 0,27 G. SAND + 0,83 MOLD — 0,15 GRUS — 0,14 F. SAND + 6,9 V. VKT	67	3,59
	II	Y = — 10,0 + 1,2 MOLD + 0,14 F. SAND + 0,31 SILT + [illegible].7 V. VKT + 0,3 LEIR	69	3,49
6 *Totalt tilgjengelig vann (0,1—15 bar):*				
2 Matjord	I	Y = 18,9 — 0,26 G. SAND — 0,23 GRUS + 0,80 MOLD + 9,1 V. VKT	76	3,20
	II	Y = 19,8 — 0,29 G. SAND — 0,27 GRUS + 0,78 MOLD + 8,9 V. VKT	79	3,01
3 Undergr.	I	Y = 47,0 — 0,34 G. SAND — 11,5 V. VKT	82	3,87
	II	Y = 7,16 + 0,20 F. SAND + 0,46 SILT + 0,94 MOLD — 0,10 G. SAND	86	3,55
4 Samlet	I	Y = 30,9 — 0,29 G. SAND + 0,51 MOLD — 0,29 GRUS	79	3,71
	II	Y = 3,51 + 0,22 F. SAND + 0,51 SILT + 0,92 MOLD	82	3,45

7 G. = grov M. = middels F. = fin V. VKT = volumvekt
8 I: Materiale under 2 mm = vektprosent mineraler under 2 mm
9 Mold = vektprosent av mold + mineraler under 2 mm.
10 Grus = vektprosent av hele prøven.
11 II: Alle fraksjoner som vektprosent av hele prøven.

Key: 1-Readily available water, 2-Surface horizon, 3-Subsoil, 4-Combined horizons, 5-Tightly-held available water, 6-Total available water, 7-G=gravel, M=Medium, F=Fine, V.VKT=bulk density, 8-I: material under 2mm = weight percentage of minerals under 2mm. 9-Organic matter = weight percentage of organic matter plus minerals under 2mm. 10-Gravel = weight percentage of entire specimen. 11-II: all fractions as weight percentage of entire specimen.

density had a positive effect in the surface horizon and a negative effect in the subsoil (Table 4), but played a lower role in the material from combined horizons. This reflects essential differences in the packing of the two groups. Nor can anything be concluded about the "ideal" bulk density from the two mean values, since the organic matter content also varies between the groups. One implication of

Table 5. Regression Equations for Available Water Against Mechanical Analvsis (GB/USDA Classification), Organic Matter and Bulk Density.

		R^2	SAy
1 *Lett tilgjengelig vann (0,1–1,0 bar):*			
2 Matjord	I Y = 4,41 + 0,11 SILT – 0,22 LEIR	42	2,48
	II Y = 4,37 + 0,12 SILT 0,23 LEIR	45	2,42
3 Undergr.	I Y = 4,71 + 0,18 SILT – 0,37 LEIR 0,064 GRUS	61	3,72
	II Y = 2,80 + 0,22 SILT 0,39 LEIR	62	3,71
4 Samlet	I Y = 4,51 + 0,15 SILT 0,28 LEIR – 0,045 GRUS	52	3,32
	II Y = 3,39 + 0,18 SILT 0,32 LEIR	53	3,25
5 *Tyngre tilgjengelig vann (1,0–15 bar):*			
2 Matjord	I Y = – 10,3 + 0,22 SILT + 0,92 MOLD 0.20 GRUS + 14,1 V. VKT	69	3,03
	II Y = – 10,5 + 0,26 SILT 1,1 MOLD 12,2 V. VKT	68	3,03
3 Undergr.	I Y = 22,2 0,15 SAND – 0,090 GRUS + 0,57 MOLD – 0,19 LEIR	77	3,15
	II Y = 3,55 + 0,19 SILT + 0,44 LEIR + 0,75 MOLD	76	3,20
4 Samlet	I Y = 14,8 — 0,21 SAND + 0,88 MOLD — 0,16 GRUS + 8,5 V. VKT	71	3,36
	II Y = — 12,1 + 0,27 SILT + 1,2 MOLD + 0,35 LEIR +8,4 V. VKT +20,055 SAND	72	3,33
6 *Totalt tilgjengelig vann (0,1—15 bar):*			
2 Matjord	I Y = – 2,06 + 0,31 SILT – 0,25 GRUS + 0,75 MOLD + 11,1 V. VKT	82	2,74
	II Y = 9,97 + 0,41 SILT + 1,0 MOLD + 70,3 V. VKT + 0,078 SAND	84	2,58
3 Undergr.	I Y = 6,68 + 0,36 SILT 0,15 GRUS – 0,63 MOLD	87	3,34
	II Y = 6,49 + 0,41 SILT 0,86 MOLD	87	3,40
4 Samlet	I Y = 3,26 + 0,34 SILT – 0,20 GRUS + 0,74 MOLD + 5,14 V. VKT	85	3,19
	II Y = 2,94 + 0,36 SILT + 0,96 MOLD — 0,070 GRUS + 3,7 V. VKT	85	3,16

7 V. VKT = volumvekt.
8 I: Materiale under 2 mm = vektprosent mineraler under 2 mm.
9 Mold = vektprosent av mold + mineraler under 2 mm.
10 Grus = vektprosent av hele proven.
11 II: Alle fraksjoner som vektprosent av hele proven.

Key: 1-Readily available water, 2-Surface horizon, 3-Subsoil, 4-Combined horizons, 5-Tightly-held available water, 6-Total available water, 7-V.VKT = bulk density, 8-I: material under 2mm = weight percentage of minerals unde. 2mm. 9-Organic matter = weight percentage of organic matter pl ..nerals under 2mm. 10-Gravel = weight percentage of entire specimen. 11-II: all fractions as weight percentage of entire specimen.

practical interest is that perhaps it is easier to damage the subsoil than the surface horizon by packing (i.e., when ground is flattened).

There are positive coefficients for the organic matter content in almost all equations for tightly-held and total available water, often in both the surface horizon and the subsoil, but without affect on readily available water. The coefficients are large in comparison to those for mineral fractions, but it must be emphasized here that this is due to the larger amounts of organic matter because of their low specific weight. Since we must usually deal with the addition of at least five times as much unconverted material (plus all the water this contains) as what remains in humus [22], the importance of the coefficients seems to diminish. Likewise the effect of organic material is of importance because such material is relatively easy to obtain in practice. The literature presents regression coefficients between organic matter and available water with a spread from 0 to 1.2, and many have indicated variations with the type of soil. Jamison [6] found improvements in available water only on soil with coarse grains, while Heinonen [4] found a relationship between clay and silt soil but not with sand soil. Salter et al. [19, 20] found a greater effect on sand soil than silt soil, and Petersen et al. [15] also found only a small effect on silt soil. The action of the organic material has also been assumed to depend on the type of soil. This leads to aggregations of clay soil [7] and affects sandstone by virtue of its own water-containing properties [9]. Even if the regression coefficients in this material were as high as many of those given in other places, there would be relatively poor correlation coefficients for organic matter. This indicates that this could be a matter of interrelationship with the type of soil, especially since silt soil specimens with their high available water capacity had a lower organic matter content than morainic soil specimens.

The material was not sufficient for an evaluation of each type of soil individually, but the 32 surface horizon and the 24 subsoil specimens in the loam class, with a clay content from 10 to 20 percent and silt content from 25 to 40 percent, provided a basis for evaluating the morainic soil individually in each case. For strongly-held and total available water, Table 6 shows little change in the coefficients for organic matter in the surface horizon, but much higher values in the subsoil for loam specimens alone. This indicates advantages in deeper organic matter mixture in loam. The silt content is still of importance, but is probably less important in the equations than organic matter, because its distribution is limited. Readily available water also has a positive, but small, effect from organic matter content, this time in the surface horizon. Finally, it should be stated that since both water conduction properties and root development deviate greatly with diminishing water content in the soil [5,8], while the organic content in all cases increases the total water-holding properties of the earth and the proportion of conducting pores of high suction, perhaps the organic matter content has a greater effect on biologically useful water than on mere physically useful water. This also implies fortunate results on the albedo of the soil and its aggregate stability. Moreover the fertilizer activity of applied organic material can reduce the water consumption because of dryness [13]. We can mention as a drawback the fact that soil with a high organic matter content makes it more difficult for plants to use precipitation which falls in light showers when the earth is dry, because the water can be bound too tightly. Worse moistening properties with increased organic matter content have also been recorded [17].

V. Conclusions

The equations presented in Table 2 can be used to design retention curves within the area which the material covers (Table 1). The standard errors were not the same for the entire curve, and increased in

Table 6. Regression Equations for Available Water Calculated from Morainic Loam Samples Only, in Relation to Mechanical Analysis (GB/USDA Classification), Organic Matter and Bulk Density.

		R^2	SAy
1 *Lett tilgjengelig vann (0,1—1,0 bar):*			
2 Matjord	Y = 4,07 + 0,17 MOLD	13	1,11
3 Undergr.	Y = 6,72 — 0,079 GRUS	37	1,31
4 Samlet	Y = 6,18 — 0,058 GRUS	22	1,22
5 *Tyngre tilgjengelig vann (1,0—15 bar):*			
2 Matjord	Y = — 13,3 + 13,7 V. VKT + 0,89 MOLD + 0,31 SILT	61	2,33
3 Undergr.	Y = — 13,1 + 2,3 MOLD + 0,34 SILT + 10,2 V. VKT	76	1,56
4 Samlet	Y = — 9,28 + 1,2 MOLD + 0,35 SILT + 8,6 V. VKT	56	2,48
6 *Totalt tilgjengelig vann (0,1—15 bar):*			
2 Matjord	Y = — 3,71 + 0,98 MOLD + 0,32 SILT + 9,6 V. VKT	57	2,42
3 Undergr.	Y = 6,44 + 1,7 MOLD + 0,37 SILT	73	2,34
4 Samlet	Y = 7,98 + 1,0 MOLD + 0,36 SILT	56	2,70

7 V. VKT = volumvekt.
8 Alle uavhengige variabler er beregnet som vektprosent av hele proven.

9 *Midler og SA av variablene for lettleire prøvene alene:*

	2 Matjord (n = 32)		3 Undergrunn (n = 24)	
	10 middel	SA	10 middel	SA
11 Lett tilgjengelig vann	4,85	1,17	4,49	1,61
12 Tyngre tilgjengelig vann	16,1	3,53	14,1	2,55
13 Totalt tilgjengelig vann	20,9	3,49	18,9	4,35
14 Leir	10,1	2,40	9,1	2,29
Silt	23,1	5,20	24,1	5,42
Sand	38,5	6,29	36,7	6,61
15 Mold	4,62	2,53	1,83	1,59
16 Grus	23,7	9,74	26,3	12,4
17 Volumvekt	1,32	0,16	1,45	0,17

Key: 1-Readily available water, 2-Surface horizons, 3-Subsoil, 4-Combined horizons, 5-Tightly-held available water, 6-Total available water, 7-V.VKT=volume weight, 8-All independent variables are calculated as weight percentage of the entire specimen. 9-Means and SA [standard error] of variables for light clay specimens alone: 10-Mean, 11-Readily available water, 12-Tightly-held available water, 13-Total available water, 14-Clay, 15-Organic matter, 16-Gravel, 17-Bulk density

relation to the mean value of the water content with increasing suction (Figure 3), because of the greater variation at low saturation. In contrast to this, the equations for readily available water explain variations less than the equations for strongly-held and total available water. This is presumably due to the fact that the distribution of the

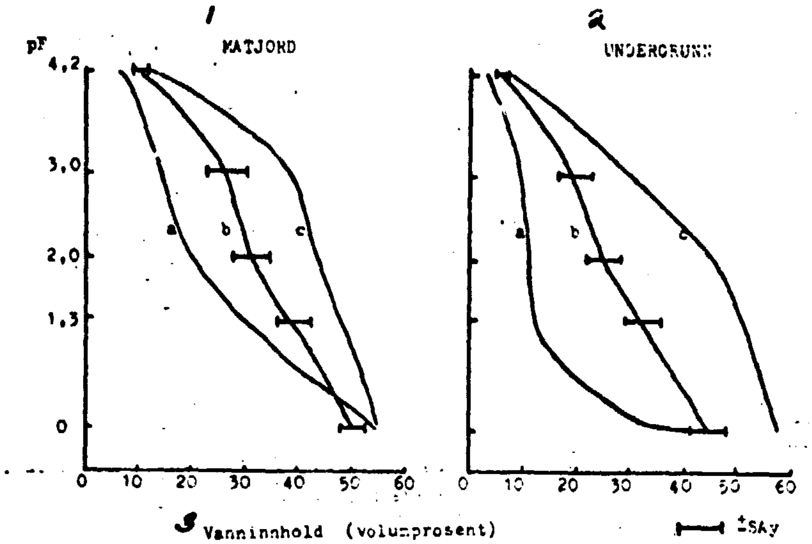

Figure 3. Moisture retention curves calculated for various soil textures.

Key: 1-Surface horizon, 2-Subsoil, 3-Water content (volume percentage), a-Loamy sand, b-Sandy silt loam, c-Silty loam

pores which contain readily available water is more affected by factors like aggregate size than is the case for pores with strongly-held available water (11).

The equations for total available water appear especially promising, with R^2 between 0.8 and 0.9, compared to the published results where R^2 is seldom above 0.7. However, a better expression for the accuracy of the equations is the standard error in determining the dependent variables (SAy). The best equation of Salter and Williams [21] had a SAy of 15.2 % on the average for total available water, compared to 11.2, 16.5 and 14.4 percent respectively for the surface horizon, the subsoil and all tests together, calculated according to the best equations. The general dispersion of measured and calculated values is shown in Figure 4 for the combined equation.

The material of Ekeberg and Njos had SAy values more than 20% of the average while the SAy values were frequently under 10% for

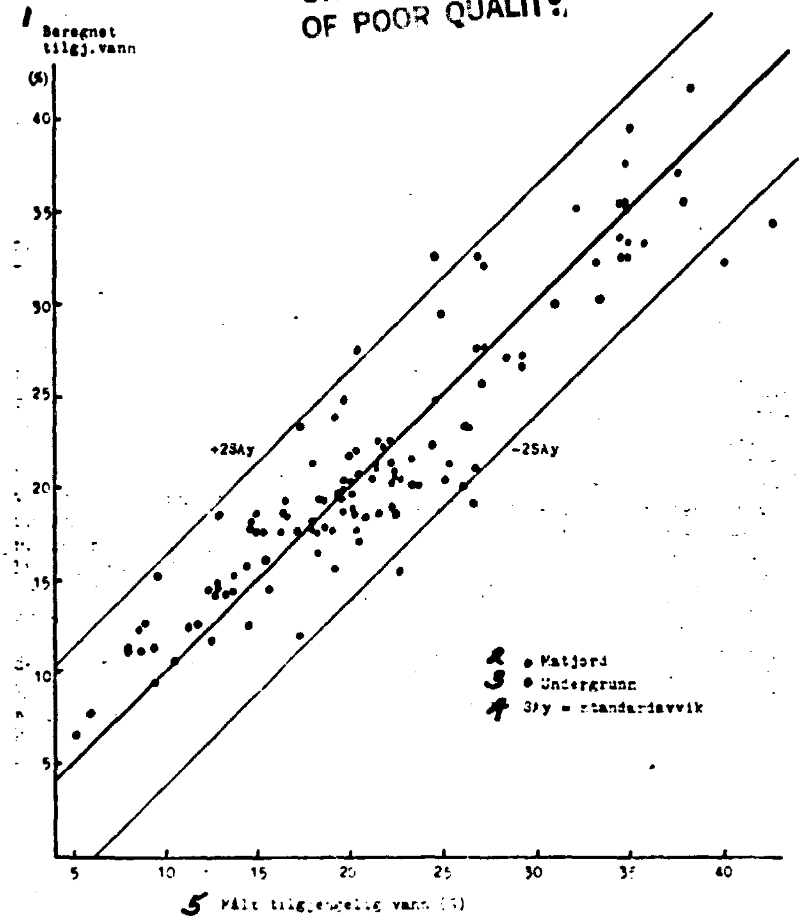

Figure 4. Estimated versus observed total available water capacity (using equation for combined horizons, mechanical analysis after Atterberg on whole sample weight basis).

Kay: 1-Calculated available water, 2-Surface horizon, 3-Subsoil, 4-SAy = standard error ; 5 - observed available water (%)

the equations of Heinonen [4], which were calculated for each type of soil individually. In this material the errors for readily and for strongly-held available water were considerably lower in the equations for loam alone than in those for the entire material, but only the subsoil equation was particularly improved for the total available water (SAy = 12.4 % of average). The errors were generally less for equations

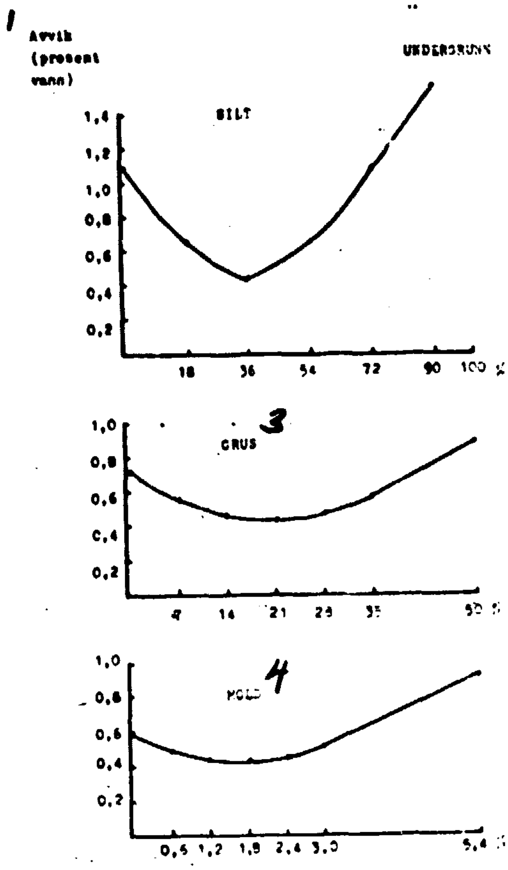

Figure 5. Standard errors of the predicted function at different levels of the variables in equations for total available water, with mechanical analysis after the GB/USDA classification.

Key: 1-Error (percentage water), 2-Subsoil, 3-Gravel, 4-Organic matter

with each type of soil separate, and this is to be recommended.

In the equations for available water the ISSS classification gave the poorest results, while the other two had similar values. Of these it is still safest to use the GB/USDA classification, since with Atterberg's classification it is possible that the smaller silt fractions are only slightly represented because of the high correlation with coarse silt. In such a case the available water could be underestimated in soil with more fine or medium silt than coarse silt.

ORIGINAL PAGE IS
OF POOR QUALITY

values. The curves are plotted with the X axis scaled to the reasonable deviation of the involved variable, so that the slopes can be directly compared.

The most conspicuous fact is that, while the errors do not change much with very large variations in the organic content and the gravel content, they are decidedly worse with variations in silt content and bulk density. Therefore the most uncertain results can be expected from sand and silt type soils and soil with an abnormal degree of packing. It is logical that the same pattern can be found for the other equations as well. The ideal would probably be to develop special equations for each type of soil.

VI. Summary

The dependence of total soil water content, available water fractions, air capacity and porosity upon soil mechanical analysis, organic matter content and bulk density, was studied in surface horizon and subsoil samples from 62 profiles in the counties of Hedmark and Oppland. The majority of samples were from morainic loam, with a minority from alluvial silts and sands.

Equations are presented which allow the construction of moisture retention curves and the direct assessment of available water capacity by volume, on the basis of the above parameters. Calculations were performet in relation to three commonly used particle size classifications, and with mechanical analysis expressed both as weight percentages of mineral matter under 2 mm, and of the whole sample. Due to the high proportion of gravel in some samples the latter method frequently gave better results, and the size classification of the soil survey of Great Britain and the US Dept. Agric. was considered most suitable.

The equations presented account for a considerable proportion (75—85 %) of the variation in total and strongly-held available water, but were less effective for predicting loosely-held available water. On the other hand total water content was better predicted at low than at high suctions. Gravel and silt exerted generally more influence on moisture properties than organic matter and bulk density, though the latter were also important. Whilst in most cases variables acted similarly in both surface and subsoil horizons, separate equations for each gave better precision. Standard errors of determination for total available water were between 11 and 17 % of the mean. Best prediction is possible for loam soils.

VII. Norwegian-English Key to Tables

Lett tilgjengelig vann	= *Readily available water (0.1—1.0 bar)*
Tyngre tilgjengelig vann	= *Strongly-held available water (1.0—15 bar)*
Totalt tilgjengelig vann	= *Total available water (0.1—15 bar)*
Luft kapasitet	= *Air capacity at 0.1 bar*

ORIGINAL PAGE IS
OF POOR QUALITY

Porositet	=	*Porosity*
Leir	=	*Clay (< 0.002 mm)*
Finsilt	=	*Fine silt (0.002—0.006 mm)*
Mellomsilt	=	*Medium silt (0.006—0.02 mm)*
Grovsilt	=	*Coarse silt (0.02—0.06 mm)*
Finsand	=	*Fine sand (0.06—0.2 mm)*
Mellomsand	=	*Medium sand (0.2— mm)*
Grovsand	=	*Coarse sand (0.6—2.0 mm)*
Grus	=	*Gravel (2—20 mm)*
Mold	=	*Organic matter*
Matjord	=	*Surface horizon*
Undergrunn	=	*Subsoil*
Samlet	=	*Combined horizons*

VIII. References

1. *Andersson, S. & P. Wiklert*, 1972: Markfysikaliske undersokninger i odlad jord, XXII. Om de vattenhållande egenskaperna hos svenska jordarter. Grundförbättring 2—3, 53—143, Oppsala.
2. *Ekeberg, E. & A. Njos*, 1970: Physical analyses of soil profiles from Landvik, Norway. Meld. Norg. Landbr. Hogsk. 49, 10, 11 s.
3. *Haugbotn, O., A. Njøs og E. Vigerust*, 1973: Morphological effects of frost on soils of lake beds in Lesja, Norway. Meld. Norg. Landbr. Hogsk. 52, 4, 15 s.
4. *Heinonen, R.*, 1954: (Moisture conditions in Finnish topsoils.) Agrogeol. julk. 62, 82 s. Fin. en, Helsinki.
5. *Hillel, D.*, 1971: Soil and Water, physical principles and processes. Academic Press, 288, s. Lond. & NY.
6. *Jamison, V. C.* (1953): Changes in air-water relationship due to structural improvement of soils. Soil Sci. 76, 143—151.
7. *Jamison, V. D. & E. M. Kroth* (1958): Available moisture storage to textural composition and organic matter content of several Missouri soils. Soil Sci. Soc. Amer. Proc. 22, 189—192.
8. *Kramer, P. J.* (1969): Plant & Soil Water Relationships: a modern synthesis McGraw-Hill 482 s. (NY).
9. *Lund, Z. F.* (1969): Available water-holding capacity of alluvial soils in Louisiana. Soil Sci. Soc. Amer. Proc. 23 1—3.
10. *Lag, J.* (1954): Forelesninger i jordbunnslære ved NLH. Del I, 49 s.
11. *Njos, A.* (1967): Aggregatstorrelse i såbedet i forhold til jordarbeiding og plantevekst. Foredrag Ved NJF-kongress København, forttykk seksjon VIII. 9—18.
12. *Njos, A.* (1971 a): Lisensiatkurs i jordfysikk AS - NLH. Felt og laboratoriearbeidet 17. 1.
13. *Njos, A.* (1971 b): Aggregatstorrelsen i såbedet i forhold til markvannet. Den norske komité for den int. hydrol. dekade Rpt. 2, 34—49 (Oslo).
14. *Njos, A. & T. E. Sveistrup* (1977): Kornstorrelsesgrupper i mineraljord. Jord og Myr 1, 1—16.
15. *Petersen, G. W., R. L. Cunningham & R. P. Matelski* (1968): Moisture characteristics of Pennsylvanian soils II: Soil factors affecting moisture retention within a single textural class - silt loam. Soil Sci. Soc. Amer. Proc. 32. 866—870.
16. *Russel, M. B., A. Klute & W. C. Jacob* (1952): Further studies on the effect of longtime organic matter additions on the physical properties of Sassafras silt loam. Soil Sci. Soc. Amer. Proc. 16, 156—159.
17. *Russel, B. J. & R. C. Shearer* (1964). Soil fertility changes in the longterm experimental plots by Kybybolite, South Australia IV: Changes in some moisture characteristics. Aust. J. Agric. Res. 15, 91—99.
18. *Salter, P. J., G. Berry & J. B. Williams* (1966): The influence of texture on the moisture characteristics of soils III: Quantitative relationships between particle size, composition and available water capacity. J. Soil Sci. 17, 1, 93—98.
19. *Salter, P. J., G. Berry & J. B. Williams* (1967): The effect of farmyard manure on matric suctions prevailing in a sandy loam soil. J. Soil Sci. 18, 318—328.
20. *Salter, P. J., J. B. Williams and D. J. Harrison* (1965): Effects of bulky organic manure on the available water capacity of a fine sandy loam. Exp. Hortic. 13, 69—75.
21. *Salter, P. J. & B. J. Williams* (1969): The influence of texture on the moisture characteristics of soil V: relationships between particle size composition and moisture contents at the upper & lower limits of available water. J. Soil Sci. 20, 1, 126—131.
22. *Rivijeman C. M. J. & G. J. Kolenbrander* (1976): De stikstoffwerking van stalmist op Korte en lange termign. Instituut voor bodemvruchtbaarheid, Haren—Groningen.
23. *Wilcox, J. C.* (1949): Soil moisture studies IV: indirect determination of field capacity for moisture. Sci. Agr. 29, 563—575.

Translation of titles of Swedish references:

1. "Physical soil research in cultivated soil, XXII. On the water-containing properties of Swedish types of earth.
10. Soil study lectures at the NLH Part I, 49 pages
11. Aggregate size in hot beds in relation to earth preparation and plant growth. Lecture at the NJF Congress in Copenhagen, section VIII 9-18.
12. Licentiate program in earth physics at AS-NLH.
13. Aggregate size in hot beds in comparison to ground water. The Norwegian committee for the International Hydrological Decade.
14. Particle size groups in mineral soil.
22. The short and long term effect of nitrogen from barnyard manure.