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INFILTRATION AND VARIATION OF SOIL MOISTURE IN A SANDY AQUIFER

by

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Abstract

The variations of soil moisture content, infiltration, cumulative percolation and wetting front movement in a sandy aquifer in southern Finland are presented. The soil moisture measurements were made in the upper 3 m layer. The groundwater table lay at a depth of 6.4... 7.8 m. On the basis of seventeen years of observations (1968–1984) the maximum April soil water storage was on the average 55 mm greater than the corresponding December value. The annual variation of the soil water storage was about 185 mm (6.2 volume per cent). The typical velocity of the wetting front movement during the melting period was about 10 cm/day. The presence of soil frost decreased the hydraulic conductivity, but did not totally prevent the infiltration during the snowmelt period. During the frozen period the cumulative infiltration was more dependent on the initial soil moisture content in the frost layer than on the depth of the frost layer. The mean annual uncorrected precipitation at the field was 613 mm, of which over 60 per cent percolated through the one meter layer. Mean cumulative percolated water amount during winter-spring months was about 95 per cent, during summer 20 per cent and during autumn 60 per cent of uncorrected precipitation.

Key words: soil moisture storage, infiltration, wetting front movement, percolation, soil frost.

1. *Introduction*

The Hyrylä experimental field station (60°23′N, 25°02′E) is located on a glacifluvial delta formation in southern Finland. The station itself is located in an open area surrounded by pine forest. The vegetation at the station consists of lichen and heather. Among others, the following measurements are made at the station: vertical soil moisture profile, infiltration, soil frost, groundwater level, water equivalent of snow and precipitation. The textural composition of the soil layers was analysed in the laboratory. Soil types are sand and silt, sand being dominating. The soil layers are nearly horizontal. The groundwater table varied between depths of 6.4 and 7.8 m during the course of the investigation.

Soil moisture measurements using a neutron scattering method were made at the station since 1968. This indirect way of determining soil moisture content was calibrated using gravimetric techniques (LEMMELÄ, 1970a).

The soil water content was measured along the vertical profile with a neutron probe at 10 cm intervals, usually once a month. During the melting period the soil moisture measurements were made about every fifth day.

In this study, infiltration during the frozen and unfrozen periods and data on soil water contents in the field station are presented. The seasonal variation of soil moisture in a layered sandy profile is studied. In addition, the wetting front movement in a vertical profile in 1969 and 1981 is presented.

2. *Variation of soil moisture*

On the basis of seventeen years of observations, the maximum soil moisture storage in April was on the average about 55 mm greater than the corresponding value in December (Fig. 1). The difference between the annual maximum and minimum soil water storage varied from 65 mm (2.2 volume per cent) to 350 mm (11.7 volume per cent), the average difference being 185 mm (6.2 volume per cent). The soil moisture storage was exceptionally small in 1975 and 1980. The wettest years were 1970, 1974 and 1981.

The typical seasonal variation of the soil moisture storage is presented in Fig. 2. The soil water storage in 1969 reached its maximum value, 670 mm (22.3 volume per cent) on April 19th and decreased only slightly during the next four weeks. Thereafter the storage started to decrease continuously. The rainfall events in July caused only a slight increase, and the storage reached its minimum, 490 mm (16.3 volume per cent) in the middle of September. Thereafter the storage increased, because of the decrease of evapotranspiration and because of the rainy periods in September and November. A small decrease in the soil water storage

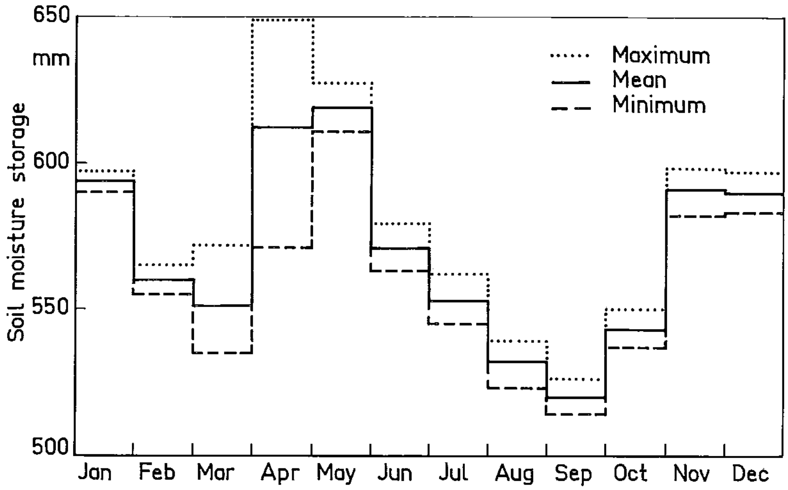

Fig. 1. The average monthly mean, minimum and maximum soil water storages during the seventeen years period (1968–1984) at the experimental field station of Hyrylä.

occurred in late October, after a relatively dry period. The field capacity value (LEMMELÄ 1970b), 605 mm (20.2 volume per cent), was exceeded on three occasions, during the melting period (April-May), during the rainy late autumn months (November-December), and also after a January thaw.

3. *Infiltration during frozen and unfrozen periods*

Infiltration measurements at the area were made with a double ring infiltrometer. The diameters of the inner and outer cylinders were 225 mm and 350 mm, respectively. The height of the cylinders was 350 mm. When measuring the infiltration the cylinders were pressed into the ground to a depth of 10 cm. Water was added to the double ring infiltrometer in such a way that the water table was about two millimeters above the soil surface and at the same level in both of the rings in order to obtain a small and equal water pressure on both cylinders. A burette with valves was installed above the inner cylinder as shown in Fig. 3, in order to maintain a constant water table during the measuring experiment. The infiltration was calculated from the amount of water needed to maintain the water level at a constant level in the inner cylinder. The function of the outer cylinder

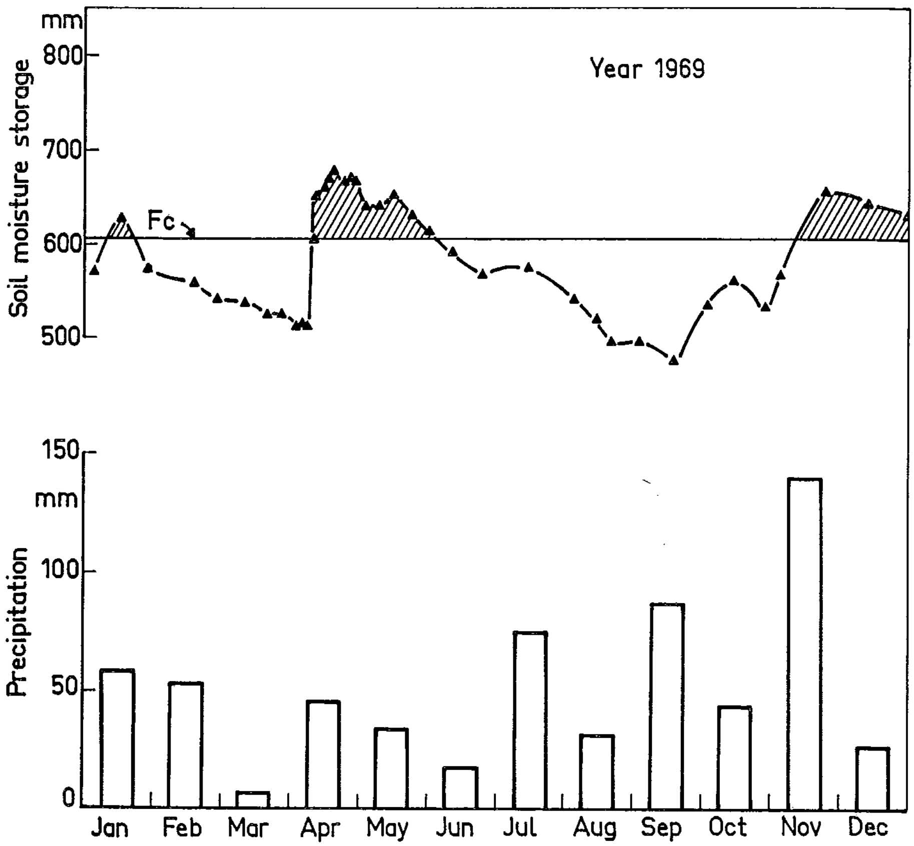

Fig. 2. Variation of soil moisture storage in a 3 m soil column and monthly precipitation in 1969 (Fc is field capacity).

was to prevent the water within the inner space from spreading in horizontal directions.

Because of their structure, the frozen coarse-grained soils are relatively permeable. In addition, ecological channels increase the permeability (Fig. 4). Examples of the mean infiltration capacity both during an unfrozen period and during a frozen period are shown in Fig. 5. The approximate mean value of the final infiltration capacity during the frost period (frost depth 53 cm) was about 3 mm/min and during the unfrozen period between 5 and 6 mm/min. The infiltration reached its final capacity between 1 and 1.5 hours after the start of each experiment both during the frost and in the unfrozen period. If the frost layer melted

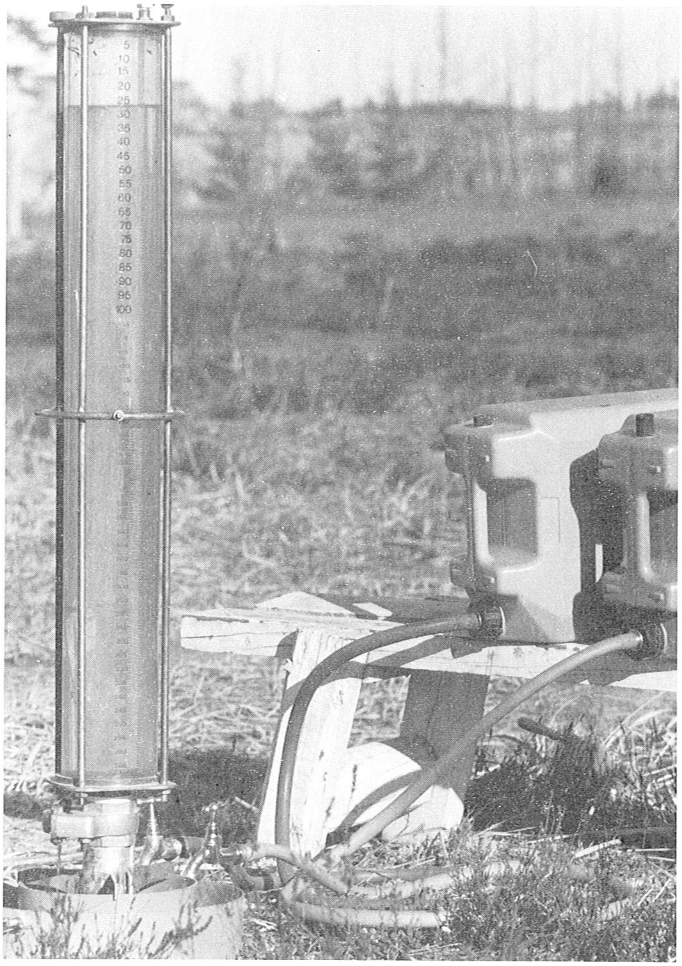

Fig. 3. The double ring infiltrometer.

during the infiltration measurements, either because of the heat transfer or because of the downward movement of water, the infiltration capacity increased markedly and reached the final unfrozen infiltration capacity in about half an hour. The temperature of the water used in these experiments varied between 0.0 and 3.2°C according to the climatological conditions and according to the prevailing soil temperature. Because the changes in water temperature were small, no viscosity corrections were made. During the mean maximum frost depth date the mean temperature of the frost layer (1968–1973) was –0.7 °C. Towards the beginning

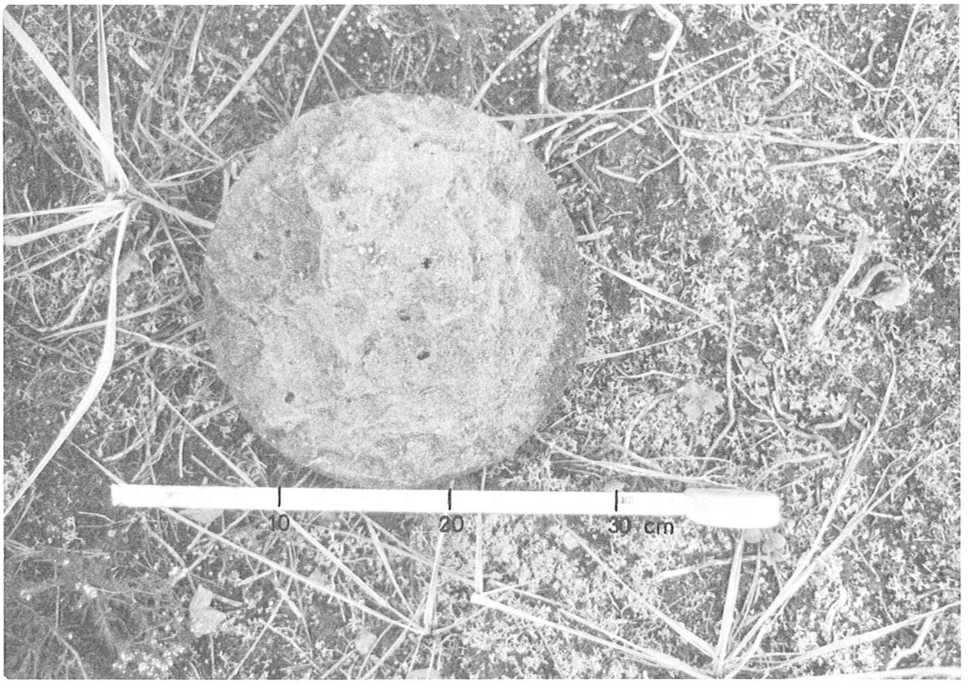

Fig. 4. Structure of the frozen soil on the freezing boundary.

of the melting period the frost temperature amounted to 0.0 °C. This temperature difference with the mean maximum frost depth of 66 cm has a cold content which is able to freeze only about 2 mm of infiltrated water, (LEMMELÄ and SUCKSDORFF, in press).

According to the field measurements made in different spring seasons during the frost period, the depth of frost did not influence infiltration capacity as much as the initial water content of the frost layer. Fig. 6 shows the final infiltration capacity as a function of initial moisture content of the soil frost layer.

At the experimental field station the maximum daily melting as registered with a snow pillow and drip-pans varied during the melting periods 1968...1973 from 8.4 mm (1971) to 29.3 mm (1968) (LEMMELÄ and KUUSISTO, 1974). Although the results concerning the infiltration capacity do not necessarily correspond with those occurring under natural conditions, it can be concluded that in springtime the infiltration capacity was more than two orders of magnitude greater than the maximum snowmelt intensity. Therefore all the meltwaters could easily infiltrate into the soil, without the occurrence of any surface flow.

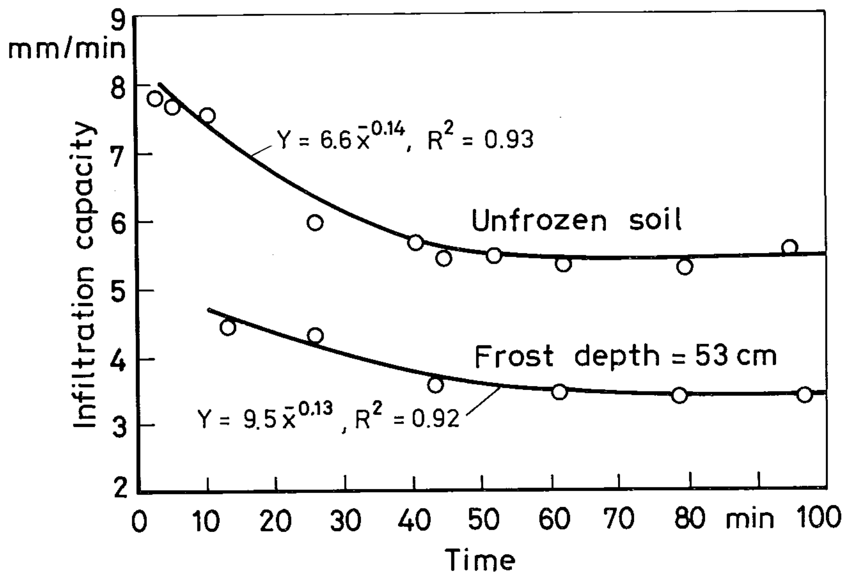

Fig. 5. The mean infiltration capacity during the frozen and unfrozen periods.

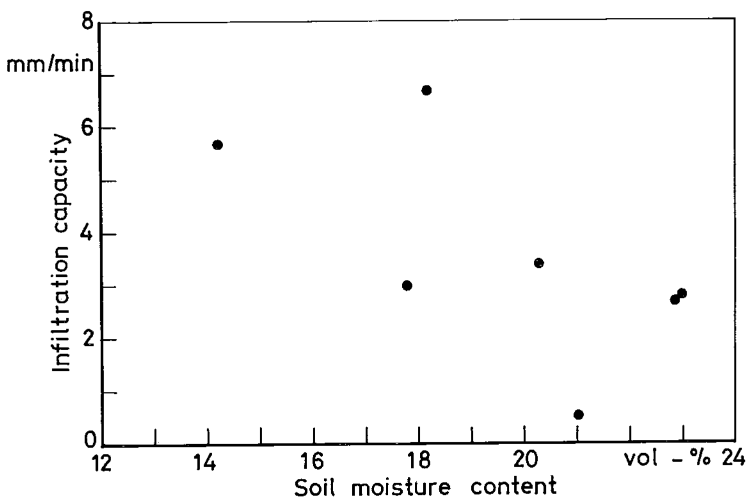

Fig. 6. The final infiltration capacity as a function of initial moisture content of the soil frost layer.

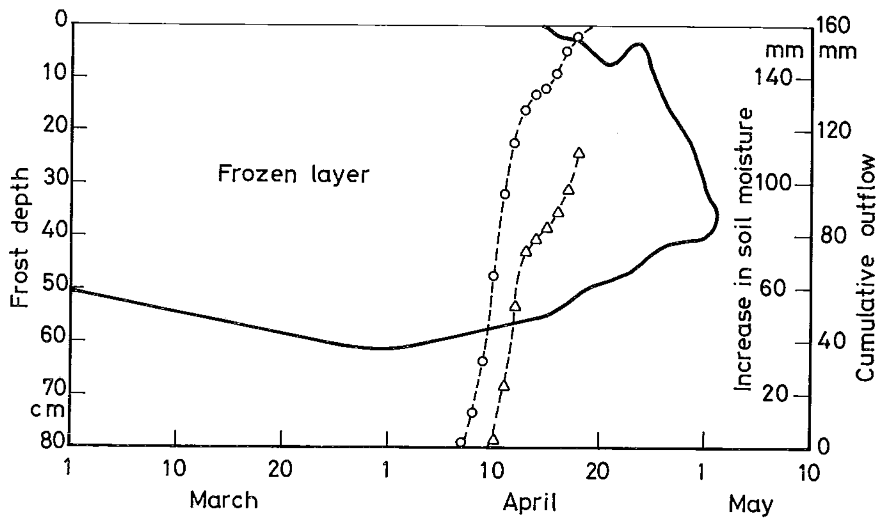

Fig. 7. Frost depth (——), increase in soil moisture (o- - -o) and cumulative outflow (△- - -△) from the uppermost 1 meter layer in the spring of 1969.

A cubical lysimeter with a volume of 1.0 m^3 was also used at the Hyrylä experimental station. Both the soil type and the vegetation of the surface layer in the lysimeter correspond to those prevailing in the area. The natural stratification of the sand in the lysimeter is disturbed. Fig. 7 shows the cumulative outflow from the depth of 1 meter from this lysimeter in the spring of 1969. When the 56 cm frost layer started to melt from the surface (on April 13th), the cumulative outflow from the lysimeter already amounted to 74 mm. Within the same period the average water content of the uppermost 1 m soil layer increased about 130 mm.

4. *Cumulative percolation*

The percolation from the lysimeter was analysed separately for winter-spring, summer and autumn periods (Fig. 8). The mean cumulative values of percolation during these periods were 220, 40 and 123 mm, respectively. These amounted to 94, 22 and 61 per cent of the corresponding totals of uncorrected precipitation. From the mean winter-spring value (220 mm) 182 mm percolated during the snowmelt period. On an annual basis, the percolation was 62 per cent of the uncorrected precipitation.

In early winter, rainfall and melting events rather often caused some percolation

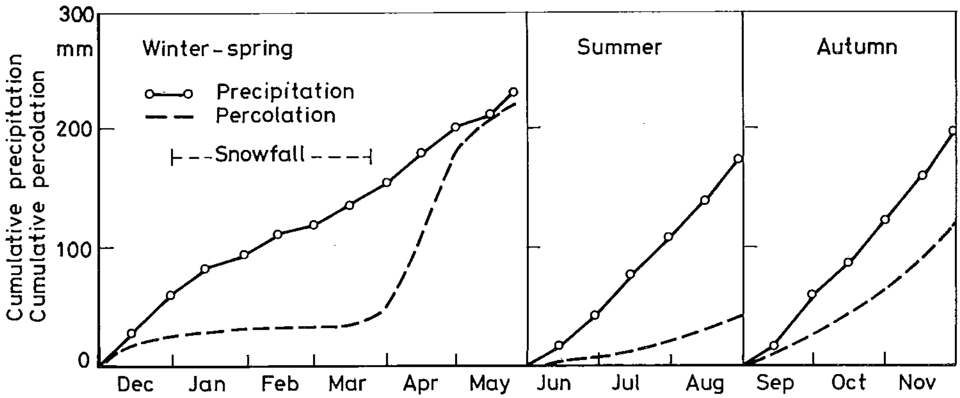

Fig. 8. Mean cumulative percolation and the uncorrected precipitation curves during winter–spring, summer and autumn months.

to occur. In January-March percolation was a rare phenomenon. About 50 per cent of the annual percolation occurred in April-May during and after the snowmelt period.

In summer the percolation usually occurred only when rainfall exceeded 25 mm per a single event. In autumn the decrease of evaporation and a smaller soil moisture deficit increased percolation considerably. The average total duration of percolation was 31 days in winter-spring, 14 days in summer and 24 days in autumn.

When calculating the real percentages of percolation from precipitation, the corrections for the precipitation according to 1968–1969 values were 7 per cent in the case of rainfall and 23 per cent of snowfall (LEMMELÄ, 1970a). The figures coincide with the results mentioned in the WMO publication, 1982.

5. *Wetting front movement*

In soils which have restricting layers, such as those in Hyrylä, the infiltration process is complex. When the wetting front reaches the restricting layer the water content above this layer starts to increase. The time taken for the wetting front to reach the groundwater table depends mainly on the melting rate and on the soil structure. When the soil is frozen, the conductivity of water is less than it is unfrozen.

The variation of soil moisture storage in three consecutive layers in Hyrylä during the melting periods of 1969 and 1981 is presented in Fig. 9. The thicknesses of the layers were 100, 80 and 100 cm, respectively. The textural compo-

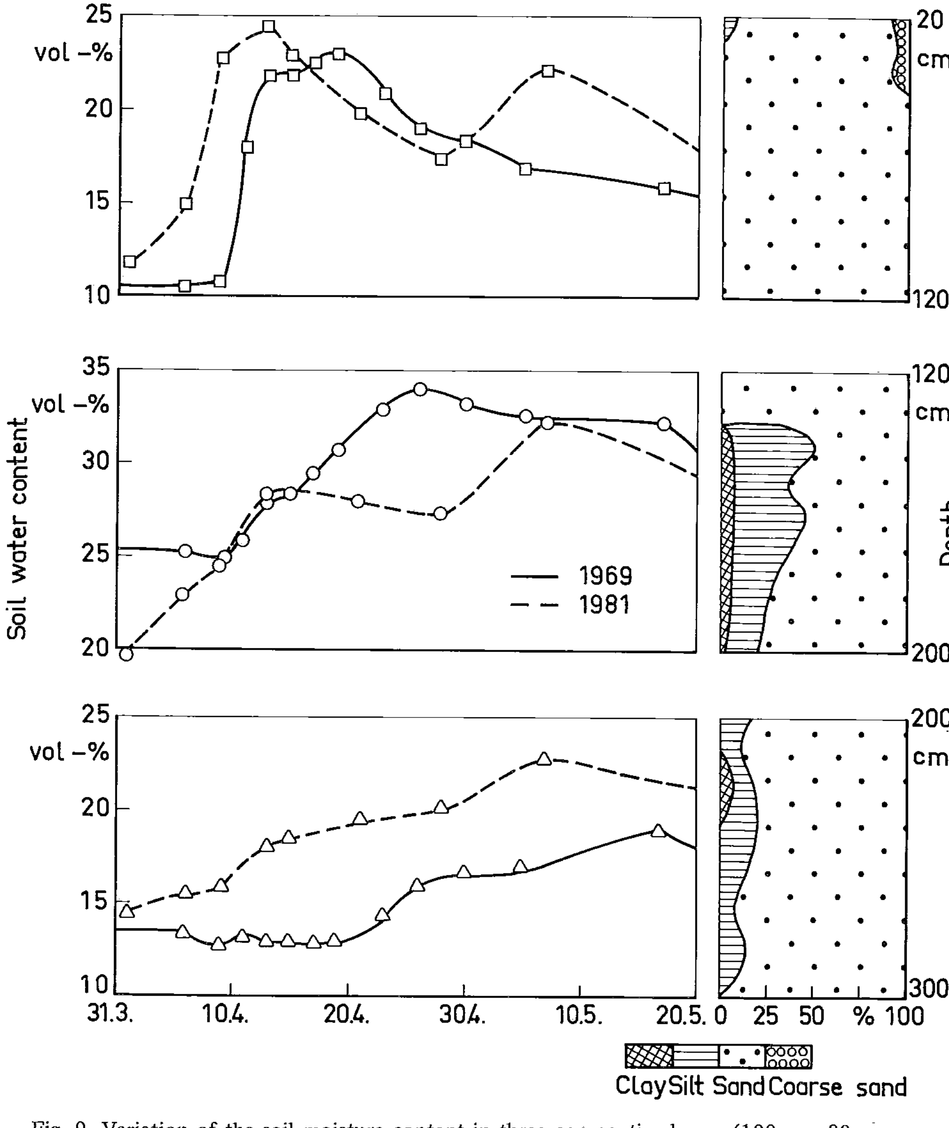

Fig. 9. Variation of the soil moisture content in three consecutive layers (100 cm, 80 cm and 100 cm respectively) during the melting periods of 1969 and 1981.

sitions of the soil layers are also shown. The soil moisture content reached its maximum value in the upper layer 8 days after the wetting front started to move (April 11th, 1969). In the second layer, the corresponding maximum was reached after 15 days and in the third layer after about 35 days. Thus a clear delay between the layers was observed. The fine grained silty layer within the layer 2 did not considerably affect the delay.

The increments in the soil water contents were 12, 9 and 6 volume per cent, respectively. In the first layer the soil moisture storage increased very rapidly, whereas in the second layer the increase was slower. In the third layer the storage remained approximately constant for about one week and then started to increase. The average daily velocity of the wetting front for the whole profile in 1969 was 8 cm/day.

In 1981 the wetting front started to move on April 1st. Due to the occurrence of two melting seasons, two water storage maxima could also be distinquished in the two uppermost soil layers. They occurred almost simultaneously in both layers. In the third only one wide maximum occurred. In this case the increments of water contents above the winter averages were 13, 12 and 8 volume per cent, respectively. The average daily velocity of the wetting front for the whole profile was 10 cm/day.

6. *Conclusions*

The following conclusions can be drawn concerning the infiltration and variation of soil moisture in a sandy aquifer in southern Finland in 1968–1984.

(1) The soil moisture storage varied with an average annual amplitude of 185 mm. The largest increases of this storage occured in springtime, but considerably high values were also reached in November–January.

(2) The infiltration capacity was considerably smaller in the frozen period than in unfrozen period. However, even in the frozen period in springtime, it exceeded the rate of snowmelt by more than two orders of magnitude. A considerable amount of meltwater infiltrated even before the soil frost started to melt from the surface.

(3) The cumulative percolation in springtime was on the average 182 mm; its duration was typically one month. On an average more than sixty per cent of the annual uncorrected precipitation percolated through the one meter layer into the soil. Fifty per cent of this value percolated during the melting period.

(4) A typical velocity of the wetting front movement in the springtime was 10 cm/day. The layered structure of the soil disturbed the wetting front movement to some extent.

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