Infiltration and redistribution of soil moisture following precipitation and its influence on groundwater flow

Infiltration et redistribution de l'humidité du sol après précipitations et son influence sur l'écoulement des eaux souterraines

Redistribution of moisture after infiltration in dry soils. Influence of gravity

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ABSTRACT: The classical theory implies that the water movement during redistribution is due to capillary (or suction) and gravity potential gradients.

In this paper we describe experiences in which the water movement during redistribution had to proceed either downwards or upwards. It is shown that the orientation of the soil column has no influence on moisture distribution after 24 hrs, except in coarse sandy soil.

It is therefore concluded that redistribution is mainly due to attractive forces of the dry soil.

RÉSUMÉ : La théorie classique implique que le mouvement de l'eau au cours de la redistribution est dû aux gradients du potentiel de capillarité (ou succion) et de gravité.

Dans cette étude, nous décrivons des expériences dans lesquelles le mouvement d'eau pendant la redistribution doit se produire soit vers le bas soit vers le haut. Il est montré que l'orientation de la colonne de sol n'exerce aucune influence sur la redistribution après 24 heures, à l'exception des sables grossiers.

On en conclut par conséquent que la redistribution est due principalement aux forces attractives du sol sec.
I. INTRODUCTION

After infiltration, i.e. complete penetration of rain or irrigation water goes on moving downwards. Previously often called 'drainage', this phenomenon is now usually referred to as 'redistribution', which emphasizes its isovolumetric character, without any further supply or loss of water.

In field conditions, redistribution leads to a rather constant moisture content, known as field capacity. But, in fact, it generally occurs simultaneously with evaporation, which makes its study rather complicated, in spite of its great practical interest.

Laboratory studies seem to be adapted to a better knowledge of this phenomenon, as some factors can be controlled and some measurements can be made. But, as pointed out by Gardner (1961), only a few experimental results have been published. In this paper we shall refer to those of Dolgov (1948) and Marshall and Stirk (1948).

From a theoretical standpoint, attempts have been made by Youngs (1957; 1958) and by Liakopoulos (1965). Both consider that redistribution might be described by a diffusion type formula, derived from Darcy's law, supposed to be applicable to the phenomenon studied. In both cases downward moisture movement is due to capillary potential and gravity gradients. But, as the authors point out, it is difficult to take into account the capillary potential gradients, because:

a) the initial moisture content is neither uniform nor saturated;

b) during the process of redistribution the upper part of the soil column drains and the lower part is wetted.

These two considerations imply the determination of the 'scanning' moisture characteristic curves involved.

Marshall and Stirk (1949) and more recently Liakopoulos (1965) used direct measurements of suction, by means of tensiometers inserted in soil columns. The results are unexpected: it appears that moisture movement proceeds against suction (or capillary potential) gradients. The first authors conclude that redistribution is mostly due to gravity. That is what we meant to control experimentally.

II. EXPERIMENTAL PROCEDURE

A series of dry soil columns (30 cm high and 3 cm in diameter) was irrigated from above. When infiltration was completed, two columns of each series were sliced to determine the initial moisture distribution gravimetrically. Another two columns were closed at the upper end by a rubber cork (to avoid evaporation) and were left for 24 hrs, with redistribution downwards. The last two columns were closed in the same way, with the cork in contact with the soil surface, and inverted to obtain an upward redistribution for 24 hrs.

<table>
<thead>
<tr>
<th>Soil</th>
<th>Maximum diameter of dry-sieved soil (in mm)</th>
<th>Mechanical analysis (%)</th>
<th>Soil columns</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>clay 0-2</td>
<td>silt 2-20</td>
<td>fine sand 20-50</td>
</tr>
<tr>
<td>Coarse sand</td>
<td>2</td>
<td>6.7</td>
<td>3.4</td>
</tr>
<tr>
<td>Silty-clay loam</td>
<td>2</td>
<td>28.7</td>
<td>26.4</td>
</tr>
<tr>
<td>Clay-loam</td>
<td>2</td>
<td>46.2</td>
<td>23.3</td>
</tr>
</tbody>
</table>

386
During redistribution, the position of the wetting front was measured. After 24 hrs, both pairs of columns were sliced and moisture distribution determined. By weighing the column before and after redistribution, it was ascertained that no loss by evaporation occurred.

To obtain a high initial moisture content, irrigation was supplied at a very high intensity: 5 mm/min.

Three different soils were studied: a clay-loam, a silty clay loam and a coarse sand. Their composition is given in table 1, along with the conditions of water supply.

III. RESULTS

A. THE RATE OF ADVANCE OF THE WETTING FRONT

The rate of advance of the wetting front is shown in fig. 1. Time is plotted on a log scale, the origin corresponding to the moment when infiltration is complete. On the ordinate (linear) scale we have plotted the distance of the wetting front from its position at the end of infiltration.

![Graphs showing wetting front progression](image)

**Figure 1. Advance of wetting front**

In the time interval considered, the time dependence of the wetting front is roughly semi-logarithmic, corroborating previous results by Dolgov (1948) and corresponding to the second stage of redistribution described by him. This result is valid only for the coarse sand and the silty-clay loam. In the clay loam the relation is not linear on a semi-logarithmic scale.

Taking into account the time dependence of the wetting front during infiltration (Feodoroff, 1965) the position of the front at any moment after the beginning of infiltration could be described by the relation:

\[ Z = Z_i + V(t_n - t_i) + a \log(t - t_n) \]
with:

- \( Z \) distance of the front from the soil surface;
- \( Z_i \) depth with decreasing velocity of the front at the beginning of infiltration;
- \( V \) constant velocity of the front during infiltration;
- \( t_i \) time elapsed with decreasing velocity of infiltration;
- \( t_n \) total duration of infiltration plus first stage of redistribution;
- \( t \) time from the beginning of infiltration.

During the first stage of redistribution, the role of gravity can be seen on the graphs: the depth of the front at the end of this stage (i.e. the first experimental point on the linear semi-log relation) is greater with downward redistribution than with upward redistribution only in the case of coarse soil. One can conclude that gravity has only a small influence immediately after the end of the infiltration with this material.

During the second (linear) stage of infiltration it appears that the coefficient \( a \) is somewhat smaller in columns with an upwards flow than in columns with a downward flow.
flow. But the difference which appears with the three soils is very small. Thus one should only expect some small effects of gravity on moisture distribution. Experiments confirm this fully.

B. THE MOISTURE DISTRIBUTION BEFORE AND AFTER REDISTRIBUTION

The moisture distribution before and after redistribution may be seen in fig. 2. Each curve is an average of two replicates. The initial distribution shows a great excess of water in the top layers of the two loams. The moisture content is even higher than the total porosity of the dry soil, which can be explained by swelling.

After the redistribution, there is still a relative excess of water in the top layer of the two loams. Below, there is a noticeable zone with uniform moisture distribution. Above the wetting front, there is an increase of the moisture content.

In the coarse sandy soil the distribution is somewhat different: a zone with increased moisture content appears in the middle of the profile. This peculiar distribution has already been observed on sands and inert materials by Marshall and Stirck (1949), Youngs (1959) and Liakopoulos (1965). It seems related to the materials used and cannot be generalized to ordinary soils.

In the two loam soils, the moisture distribution appears quite similar with upward and downward redistribution. With the coarse sand there is a little more water near the initial surface of the soil after upward redistribution, which is probably the consequence of a gravity effect immediately after the end of the infiltration.

On the whole one can conclude that gravity has practically no influence during redistribution, at least in ‘non-inert’ materials, like the two loams studied.

IV. DISCUSSION AND CONCLUSION

Existing theory implies that water movement during redistribution is due to capillary (suction) and gravity potential gradients. However, experimental measurements of suction show that water moves against suction gradients, so that the main acting force should be gravity. The present experimental results demonstrate that gravity has no real influence on the process studied. For the moment one can conclude that the principal force is the attraction of dry soil in the wetting zone, which removes water retained by adhesive forces in the drying (or ‘drainage’) zone.

REFERENCES


