in the first 50 minutes = 3,872 × 10^8 or say 992·8 kg. or 19·9 kg./min. Similarly the depletion rate for the first 120 minutes is 8·1 kg./min.

Conclusions

The results of the fluorescent tracer investigation at Haldia anchorage indicate that at flood tide the predominant direction of movement is towards the north-east and a probable subsidiary direction towards the north. The former probably represents the direction of movement of sand and the latter the direction of movement of finer sediments, *i.e.*, silt and clay. Further studies, with bicoloured tracers of two different sizes, are planned to confirm this observation. The fluorescent grains were traced to a maximum distance of over one kilometre and the observed grain velocities range from 4·5 to 10·3 m./min. and are roughly 1/3 to 1/2 of the observed bed current velocities. The computed depletion rate of 19·9 and 8·1 kg./min. for the first 50 and 120 minutes indicate the large transporting capacity of the flood tide.

Acknowledgements

The authors thank the Commissioners for the Port of Calcutta for providing facilities on the *RV Anusandhani* for the investigation†; Dr. S. K. Bhattacharya, Chief Engineer, Hydraulics Study Department, for his keen interest in the investigation; Shri G. S. Paul, River Research Officer and Capt. H. C. Malhotra, Commander of *RV Anusandhani*.

The programme of fluorescent tracer investigation of sediment movement was taken up mainly due to the keen interest evinced by Shri G C. Chaterji, Director-General and Shri C. Karunakaran, Deputy Director-General, Geological Survey of India, to whom the authors are particularly grateful.

† The opinions expressed in the paper are those of the authors and not of the Commissioners.

1. Zenkovich, V. P., "Osnovi ucheniya razvetiye beregov (Basic studies on the development of marine coasts)," *Acad. Sci. USSR*, Moscow, **1962**, p. 1.
2. Aibulatov, N. A., "Issleduvaniye vodolberegovo peremesheniya pecchanikh nanocov more (Investigation of along shore movement of sand drifts in the sea)," *Nauka*, Moscow, 1966 p. 157.
3. Ingle, James C., *The Movement of Beach Sand*, Elsevier Publishing Co., Amsterdam, **1966**, p. 1.
4. Seibold, E., "Geological investigation of nearshore sand transport," in M. Sears (Ed.), *Progress in Oceanography*, Pergamon Press, New York, **1963**, p. I.
5. Gole, C. V., "Fluorescent tracer study at Mangalore Port," *Inter. Assoc. Hydraulic Res. Cong., 10th., London*, 1963, **1**, 275.

SOME RECENT STUDIES ON THE RESTORATION OF PERMEABILITY TO WATER OF SOILS RENDERED IMPERMEABLE EARLIER BY THE SWELLING ACTION OF SOIL COLLOIDS BY SODIUM CARBONATE

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Abstract

When the lower end of a column of soil packed in a glass tube is dipped in a 2% solution of sodium carbonate, it develops an impervious stratum at the bottom instantaneously and no capillary ascent takes place even after 30 days. In a similar soil column dipped in water, the water ascends rapidly, completing a capillary rise of 70 cm. within 23 days. A series of soil tubes initially rendered impermeable by dipping in sodium carbonate solution are later transferred to solutions of ammonium chloride, bromide, nitrate, sulphate and phosphate and of calcium, strontium and barium chlorides respectively. Within a short time, these solutions destroy the impermeable strata and resume capillary ascent with varying rapidity. Such restoration of permeability has immense potentiality for use in reclaiming the "alkali-ridden" soils of India.

1. Introduction

The movement of liquid water through a porous medium like the soil is of fundamental interest in Soil Physics as well as of immense practical importance to agriculture. While developing and directing the programme of research in Agricultural Meteorology at Poona (1932–1956), the present writer and collaborators had conducted extensive studies on many aspects of this topic. The results then obtained have been discussed in a series of published papers[1–18] and reviewed in a paper entitled "The movement of moisture through the soil".[14]

Recently, on being invited to a Symposium on "Reclamation and Use of Waste-lands in India" held in Delhi in 1968, my interest in this problem was revived and some fresh investigations were carried out. The results obtained are discussed in the present paper.

2. Review of Earlier Experiments

While studying the movement of water through a soil column one has to reckon also with salts that may be present in the soil medium, occurring naturally or deliberately added. These dissolve in the water while it moves (*a*) *downwards* as percolation or (*b*) *upwards* by capillary ascent. It was observed that alkalies like sodium hydroxide, acids like dilute sulphuric acid, hydrochloric acid or nitric acid as well as their salts like sodium sulphate, sodium chloride or sodium nitrate, etc., if present in the soil as aqueous solutions, do not affect either the permeability or the rate of movement of water through the porous medium, although their presence will not be tolerated by living plants that may be growing on the soil. It was, however, noticed in the very earliest experiments that the presence of a trace (up to 2% or so) of *sodium or lithium carbonate* produces a dramatic change in the permeability of the soil; *these carbonates make the soil absolutely impervious to water.* This effect was soon traced to the swelling of the soil colloids which choke up the pore spaces between the soil particles. Some of the earlier experiments also suggested that under the influence of the sodium carbonate molecule a kind of semi-permeable coating is formed around each of the swelling particles and that the swelling is an osmotic effect. It was also found that when a 'swelled' soil is later treated with a solution of calcium, strontium or barium chloride, the 'soil-sodium-carbonate' complex causing swelling is destroyed permanently by the formation of insoluble calcium carbonate (or barium or strontium carbonate as the case may be) resulting in a permanent restoration of the permeability to water as verified by a series of percolation experiments. Obviously, the remaining salts being all soluble in water, they are easy to wash away by liberal doses of water at the top of the soil column (*i.e.*, heavy irrigation).

In passing, it may be stressed that we are fortunate that lithium carbonate which causes much more swelling than sodium carbonate is less abundant on the soil crust of the earth than the sodium carbonate; the latter, however, causes, as we have already remarked, sufficient swelling to bring about the impermeability condition in the soil column. Under natural or field conditions, in an arid zone there may be some sodium carbonate lying safely some feet below the surface. When such an area is suddenly brought under generous irrigation, as happened in the Punjab and adjoining areas after the turn of the present century, during intervals between the periodic irrigation when the water begins to ascend by capillary action, the salts dissolved in the irrigation water are also brought up through the upper layers of the soil towards the drying surface. Should an impervious layer form at any depth below the surface by the swelling action of sodium carbonate, a stage is soon reached when any water fed to the surface either as rain or irrigation water, it simply refuses to percolate and this leads to the well-known water-logging characteristic of what is designated as alakali-ridden tracts, of which there are now many millions of acres in N.W. India. Also, any subsoil water below the impervious layer is unable to come up to the surface. The experiments we have been conducting, though on a small laboratory scale, have therefore a large-scale potentiality for reclaiming such areas that have become unfit for agriculture.

3. Present Experiments

In our present experiments we adopt the simple technique of capillary ascent through soil columns packed in glass tubes dipping at the bottom into reservoirs of water or the several solutions used for testing their permeability. These experiments have been performed with the well-known black cotton soil of the Bombay Deccan which has a high clay-content. After air-drying, the coarser particles are removed by passing through a 1 mm. sieve. The glass tubes used are about 1 metre long with an internal diameter of 1·4 cm. with their lower end closed by stretching clean muslin pieces and tying them up with string. The soil is packed in a uniform manner by the technique of tapping described in one of our earlier papers.[5] Having prepared a sufficient number of soil-packed tubes (we shall refer to them hereafter as soil tubes), they are clamped in a vertical position and their lower ends dipped into water or the several solutions of salts as desired (*see* Fig. 1).

While one of the soil tubes was kept in water and the daily rate of rise of the capillary fringe noted, the other soil tubes were kept immersed in separate reservoirs containing 2% solution of sodium carbonate. The ascent of water in the first tube proceeded rapidly at the normal rate and attained a height of 70 cm. within 23 days after start. In all the other soil tubes no ascent at all was noticed even after 30 days, showing that in all of them the capillary ascent has been completely inhibited by the formation of an impervious stratum at the bottom of the soil columns. When one of these impervious tubes was kept immersed, as in Fig. 1, in water, there was no ascent at all even after another 30 days.

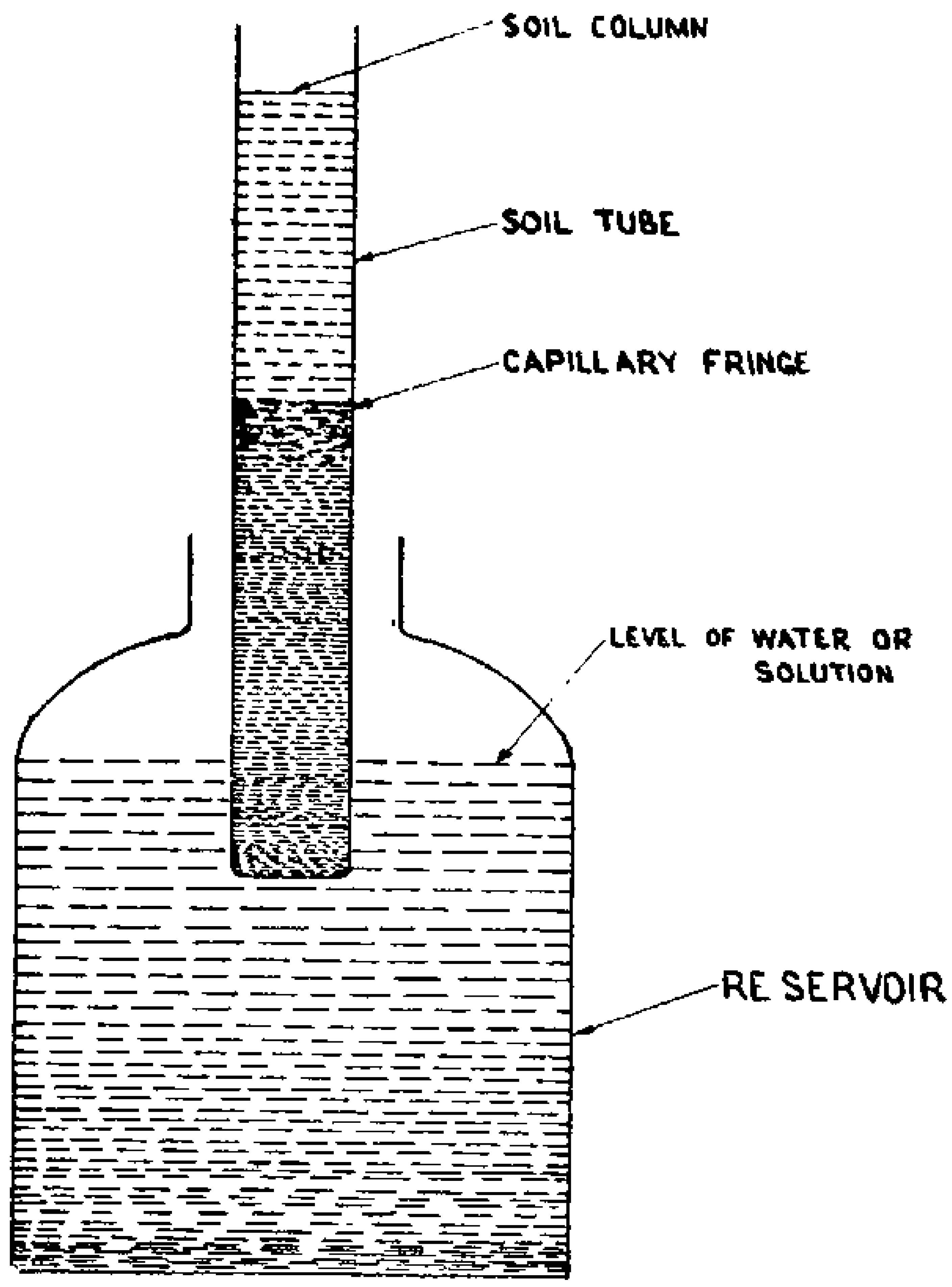

FIG. 1

The other impervious soil tubes were transferred separately into reservoirs containing 2% solutions of the following compounds:

Ammonium chloride; Ammonium nitrate; Ammonium bromide; Ammonium sulphate; Ammonium phosphate; Barium chloride; Strontium chloride; and Calcium chloride.

From the time of their immersion in the respective reservoirs containing the solutions referred to above, daily observations were recorded of the height of the capillary fringe as it continued to ascend in the soil columns. The daily upward movement of the capillary fringes in the different tubes are shown by the curves marked B, C, D, E, F, G, H and I respectively, in Fig. 2. The absence of any capillary ascent in these tubes in the first month when they had initially been immersed in solutions of sodium carbonate is indicated in Fig. 2 by the line marked KL along the horizontal axis. For comparison with these curves in the case of the different solutions, curve A shows the capillary ascent of pure water in the soil tube kept in water.

4. Discussion of Results

Curve A shows the normal capillary rise of pure water in the black cotton soil. The capillary rise is quite rapid in the early stages and slows down gradually in the manner shown by curve A. The height of 70 cm. (this was the height of the soil columns packed in all the tubes) was attained within 23 days. As regards the other tubes, the complete absence of any capillary rise while they had been immersed in sodium carbonate solution, as shown by the line KL in Fig. 2, has already been referred to. On later being transferred into the various solutions referred to, after a few hours needed for these solutions to destroy the impervious strata at the bottom of the respective soil columns, the capillary rise commences and proceeds with varying speeds, depending on the particular substance. The solutions of the three salts of ammonium, *viz.*, ammonium chloride, ammonium nitrate and ammonium bromide show the most spectacular capillary rise, their speeds being in the order in which the substances are mentioned above. They all complete the maximum rise of 70 cm. within an interval of just 20 days. The barium chloride and the strontium chloride solutions are almost as speedy as ammonium nitrate or bromide in completing the entire rise of 70 cm. within 30 and 32 days respectively. Calcium chloride solution acts somewhat more slowly, taking an interval of 66 days to rise to the top of the soil column. Finally, we have the two other ammonium salts, *viz.*, ammonium sulphate and ammonium phosphate which show a less rapid rise as compared to the other salts we have mentioned. Earlier results based on percolation rates have already shown that the restoration of permeability in the case of the chlorides of the alkaline earths is permanent. The rapid rise of the ammonium salts shown by curves B, C and D is very interesting and we have still to verify whether they will subsequently retain the permeability when water is later substituted for the solutions. All the soil tubes are at present available for fur-

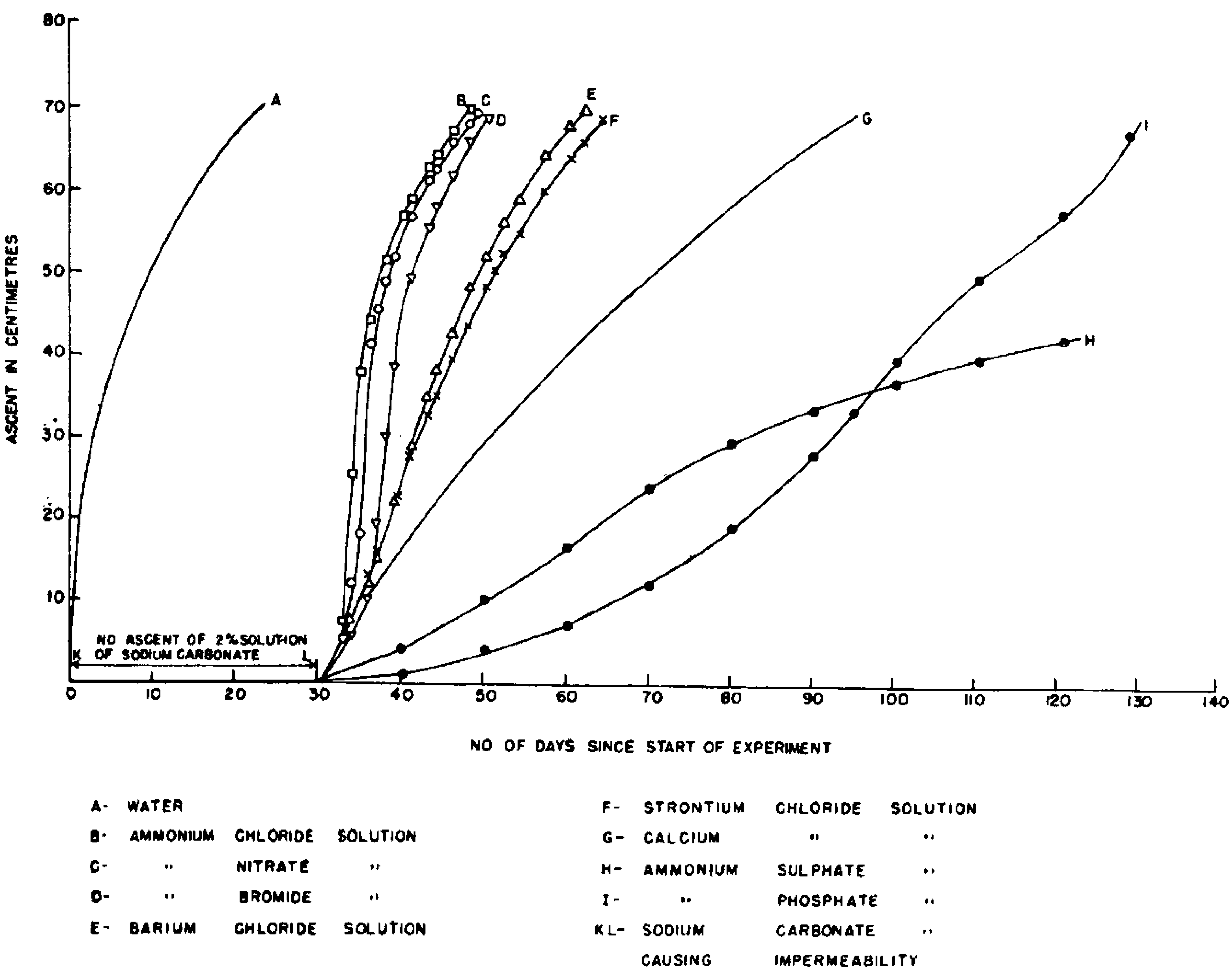

FIG. 2. Ascent of water and of various aqueous solutions through the black cotton soil.

ther experiments to test their subsequent permeability to draining (*i.e.*, percolation downwards). This phase of the investigation is now under way.

5. CONCLUDING REMARKS

In conclusion one observes that very striking and useful results have been obtained with the very simplest of techniques. The present writer hopes to discuss further results on this problem in the near future as soon as the remaining experiments are completed.

Thanks are due to the authorities of the National Physical Laboratory for providing all facilities.

1. Ramdas, L. A. and Mallik, A. K., *Curr. Sci.*, 1939, **8** (6).
2. Mallik, A. K., *Ind. Jour. Agric. Sci.*, **1942**, **12**, Pt. 4.
3. Ramdas, L. A., Mallik, A. K. and Pandit, U. P., *Curr. Sci.*, July 1942.
4. Sreenivasan, P. S., *Ibid.*, July 1942.
5. Ramdas, L. A. and Mallik, A. K., *Proc. Ind. Acad. Sci.* Part I of paper. 1942, **16** (1), 1.
6. — and —, *Ibid.*, Part II of paper, 1942, **16** (1), 16.
7. — and —, *Curr. Sci.*, February 1944.
8. Momin, A. U., *Proc. Ind. Acad. Sci.*, April 1947, **17**, 2.
9. Ramdas, L. A. and Mallik, A. K., *Curr. Sci.*, June 1947.
10. — and —, *Proc. Ind. Acad. Sci.*, 1947, **26**.
11. Katti, P. K., *Ibid.*, 1949, **29**.
12. Ramdas, L. A., *Jour. of CSIR.*, 1949, **3** (1).
13. Katti, P. K., *CBI Jour.*, 1948.
14. Ramdas, L. A., *Proc. Symposium on Ground Water*, Publn. No. 4, Central Board of Geophysics, 1955.