STUDIES ON SOILS, PART I: THE UPWARD MOVEMENT OF WATER AND SALT SOLUTIONS IN THE BLACK COTTON SOIL*

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Received February 16, 1942

1. *Introduction*

In the Deccan a dry surface crust containing only hygroscopic moisture is formed within a few weeks after the cessation of wet weather. This surface layer loses moisture by day and reabsorbs it from the atmosphere at night, thus tending to remain in equilibrium with the air layers above it and setting a limit to the continuous loss of moisture from the soil layers below. This protecting action makes dry farming possible in these areas where the soil rests on a hard layer of rock or murrum out of reach of any sub-soil water, the main source of moisture being the few post-monsoon showers. The Agricultural Meteorology Section at Poona has published the results of a detailed investigation of the above problem in a series of papers from 1934 onwards.[1–11]

A few years ago we took up the investigation of another equally important problem, *viz.*, the upward movement of moisture and salts through a soil layer resting on a water table. Such conditions exist in many parts of India where the water table is only a few feet below the soil surface. The problems connected with artificial sub-soil irrigation are also similar. In a recent publication[12] we reported the results of experiments on the effect of varying the distance between the soil surface and the water table on the rate of evaporation. Later, Mallik[13] discussed the movements of salts in columns of soil, originally uniform as regards their salt content, after a few months of ascent of moisture through the soil and continuous evaporation from the top of the soil surface. In the above papers it was shown that (1) the rate of evaporation after ascent of moisture through columns of Poona black cotton soil and normal alluvial and "bari" (alkali) soils of the Punjab decreases rapidly as the distance between the soil surface and the water table

* Read before the Annual Meeting of the Indian Academy of Sciences at Nagpur on the 25th December 1941.

is increased and (2) that the salts in the soil move with the ascending moisture and concentrate at the top of the soil columns. In these experiments the measurements were made with the help of soil evaporimeters. The soil columns 5″ in diameter and of different depths were packed in brass cylinders with perforated bottom and dipped in a lower vessel containing water up to a standard level.

To examine the ascent of water and the associated phenomena in greater detail *visually*, a series of experiments were undertaken recently at the Central Agricultural Meteorological Observatory, using glass tubes filled with the soil specimens. In Part I of this series we shall describe some of the preliminary experiments on the ascent of water and dilute salt solutions through the soil. In Part II the results of a microscopic examination of the swelling action of a number of salt solutions on the black cotton soil and some further experiments on the movement of these solutions through the soil will be discussed. Part III will contain a discussion of some physical and chemical aspects of these phenomena in the light of a number of detailed experiments on the effect of concentration of the salt dissolved in water on the rate of movement of the solution through the soil.

2. *The Movement of Water through the Soil in Relation to the Packing of the Soil*

In experiments of this nature it is very important to know the influence of packing on the rate of movement of water through the soil. Mr. P. S. Sreenivasan, working in our laboratory, is investigating the problem of the velocity of the movement of moisture through soils under (*a*) the combined action of gravity and capillarity (downward flow), (*b*) the opposing influences of gravity and capillarity (upward flow) and (*c*) the influence of capillarity alone (horizontal flow). A detailed discussion of his results will be presented in a separate communication. We may mention here that in one of his experiments on the horizontal flow of water through a soil column the length of the wetted column of soil (in a glass tube 1·3 cm. in diameter) in a given time was found to decrease with the length of the tube occupied by the same quantity of soil.

For *minimum* packing, the *maximum* volume occupied by four ounces (113·6 gr.) of the soil was 99·3 c.c. and for *maximum* possible packing the minimum volume of the same quantity of soil was 84·3 c.c. Thus 15·0 c.c. was the maximum possible change in the volume of the soil due to packing. The lengths of the wetted column of soil after 24 hours in tubes with soil of different degrees of packing are given below:—

Degree of packing	Length of the soil column wetted in 24 hours
	cm.
0% (minimum packing) ..	81·4
15%	72·3
33%	63·4
50%	55·3
66%	49·3
80%	35·7
100% (maximum packing) ..	26·6

It is clear that the length of the soil column wetted in 24 hours for minimum packing is nearly three times that for maximum packing. The importance of packing in our experiments is brought out very strikingly by these results. To ensure the uniformity of packing in a series of experiments, as far as possible, the following procedure was adopted for Poona soil.

The necessary amount of air-dry soil, passed through a 0·5 mm. sieve, is poured into the glass tube. The bottom of the tube is closed before-hand by a piece of muslin stretched across the open end, folded up and tied suitably at the sides. The glass tube with the soil is then held vertically and dropped on the table four times from a height of 3 inches.

To study the variability of packing in the case of Poona soil, 110 gr. of the soil were poured into the same glass tube and the length of tube occupied by the soil after attaining the standard packing was measured repeatedly (20 times). The mean length and the standard deviation were 77·7 cm. and 0·23 cm., respectively, indicating a coefficient of variability of only 0·3%.

3. *Ascent of Water in 12 Glass Tubes filled with Soil and Packed as described in the Preceding Section*

To study the variability in the rate of ascent of moisture, twelve glass tubes of internal diameter 1·3 cm. (the size used in all the experiments discussed in this paper) were packed similarly with soil according to the method described above. The lower ends of these tubes were inserted in water contained in suitable bottles. The heights of the wetted column in the different tubes were recorded at short time intervals at the beginning when the rate of ascent is very rapid and at longer intervals later on. Table I gives the mean height of the wet column, its standard deviation as well as the coefficient of variability, (*i.e.*, $\frac{\text{standard deviation}}{\text{mean}} \times 100$)

Fig. 1 gives the mean height of the wet column at different times after the commencement of the above experiment. The curve is exponential,

TABLE I

Time after commencement of experiment	Mean height of wet column in cm.	Standard deviation	Coefficient of variability %
5 mts. ..	7·0	1·38	20
25 mts. ..	8·9	1·48	17
40 mts. ..	12·2	1·64	13
1 hr. 10 mts. ..	16·2	1·85	11
2 hrs. 10 mts. ..	21·5	1·75	8
3 hrs. 10 mts. ..	25·0	1·72	7
4 hrs. 40 mts. ..	28·8	1·43	5
6 hrs. 40 mts. ..	32·6	1·19	4
9 hrs. 40 mts. ..	36·6	1·04	3
11 hrs. 40 mts. ..	38·5	0·98	3
21 hrs. 40 mts. ..	44·7	1·09	2
45 hrs. 40 mts. ..	52·6	1·14	2
70 hrs. 25 mts. ..	57·0	1·28	2
93 hrs. 40 mts. ..	60·3	1·36	2

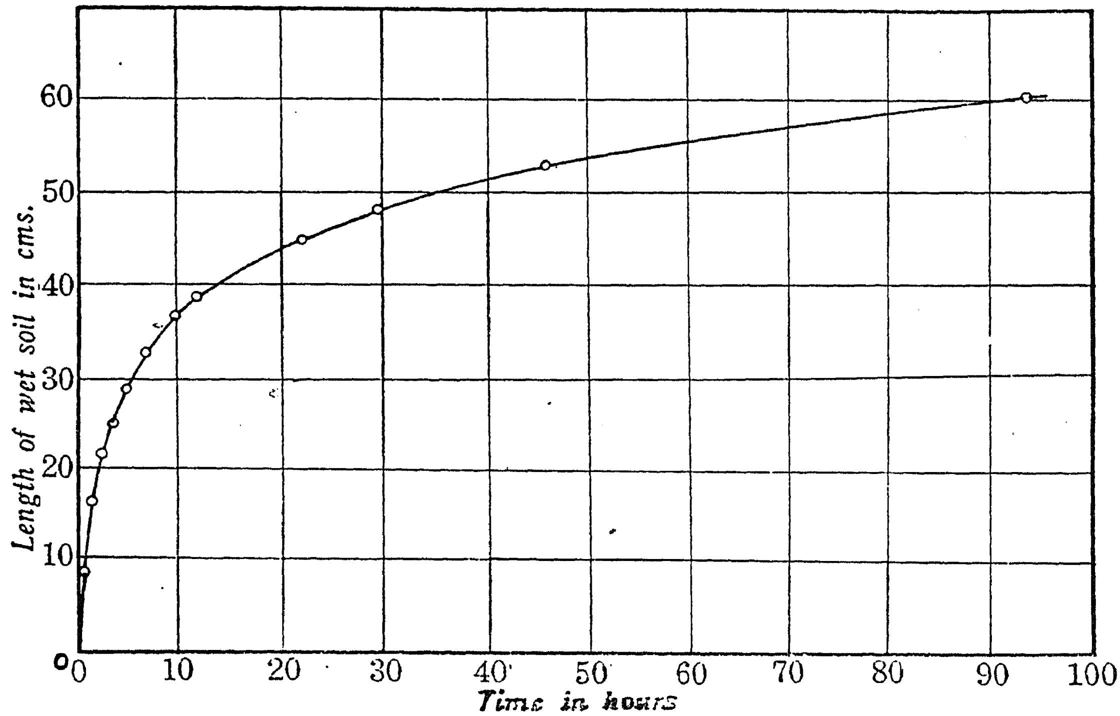

FIG. 1

with a rapid rise in the beginning and a gradual flattening later. The coefficient of variability is of the order of 20% to start with but decreases very rapidly to about 10% after an hour and to 5% in 5 hours. The variability is only 2% towards the end of the experiment. The standard deviations are more or less of the same order of magnitude.

If four replications are used the percentage variability in the later stages will be of the order of 4%. As will be clear later on, the variations due to specific causes will be much higher than 4% so that four replications will be sufficient for estimating the variability due to random causes. With a few exceptions, four replications were generally used.

4. *Rate of Ascent of Moisture in Poona Soil in Sand and in Mixtures of the Two in Different Proportions*

Permeability and pore space are important factors in controlling the movement of water through the soil. It is common experience that in a sandy medium the rate of movement is more rapid at the beginning although the maximum ascent will be larger ultimately in a clayey medium. To illustrate this the results obtained in Poona soil, sand and mixtures of the two in varying proportions may be cited.

The material used in this experiment was as follows:—

(i) 100 % Poona soil
(ii) 85·7% Poona soil the rest being sand
(iii) 71·4% ,, ,, ,, ,, ,, ,,
(iv) 57·1% ,, ,, ,, ,, ,, ,,
(v) 42·9% ,, ,, ,, ,, ,, ,,
(vi) 28·6% ,, ,, ,, ,, ,, ,,
(vii) 14·3% ,, ,, ,, ,, ,, ,,
(viii) 0 % ,, ,, ,, ,, ,, 100% sand

The above samples were filled in eight sets of two tubes each, in all 16 tubes, according to the standard method described at the end of Section 2. Only water was used as the ascending fluid. Table II gives the mean heights of the wet columns of soil after various time intervals up to 30 hours.

TABLE II

Ascent of Moisture in cm. in Poona Soil, Sand and in Mixtures of the Two in Different Proportions

Time after commencement of experiment	Percentage of Poona soil							
	100% Poona soil	85·7%	71·4%	57·1%	42·9%	28·6%	14·3%	0%
10 mts. ..	2·7	6·8	8·3	11·7	12·5	**15·3**	13·3	6·3
20 mts. ..	5·8	10·0	11·9	16·1	16·9	**19·5**	15·9	6·7
30 mts. ..	8·0	12·9	14·8	19·4	20·0	**22·3**	16·9	6·8
45 mts. ..	10·7	15·7	17·6	22·3	23·4	**25·3**	18·5	6·9
1 hr. 00 mt. ..	12·8	18·1	19·9	24·2	25·8	**26·8**	19·7	6·9
2 hrs. 00 mt. ..	18·4	24·4	25·9	30·4	**31·1**	30·6	21·8	7·0
3 hrs. 00 mt. ..	21·7	28·6	29·6	33·9	**34·3**	32·7	23·1	7·2
5 hrs. 30 mts. ..	27·2	35·5	35·5	**38·8**	**39·0**	35·3	24·3	7·3
8 hrs. 00 mt. ..	32·4	39·2	38·6	**41·4**	**41·2**	36·4	24·9	7·6
12 hrs. 30 mts. ..	37·5	43·4	41·9	**43·5**	**43·8**	37·9	27·3	8·0
24 hrs. 00 mt. ..	43·4	**51·3**	47·5	48·3	47·7	40·7	28·9	8·5
30 hrs. 00 mt. ..	45·2	**53·3**	49·6	49·6	48·5	41·8	29·2	8·6

It may be seen that:—

(i) the movement of moisture is initially more rapid in pure sand than in pure Poona soil; while the ascent continues uniformly in the Poona soil, it slows down in sand after the first 10 minutes.

(ii) in the mixtures of Poona soil and sand, the ascent is more rapid than in the pure samples, the rate to start with increasing with decrease in the percentage of Poona soil down to 28·6% and decreasing for smaller values. This continues during the first hour after the commencement of the experiment. Later on, the maximum rate of ascent shifts gradually towards the mixtures containing larger and larger proportions of Poona soil. If the experiment had been continued sufficiently long it would have been found that ultimately the height of the wet column is maximum in the Poona soil. These results are indeed very interesting and further experiments on these lines are being arranged with other typical soils of the country.

5. *Rate of Ascent of Water and Dilute Solutions of Some Salts*

Before starting replicated experiments with solutions of salts, etc., a preliminary experiment was done with 2% solutions of a number of available salts using only one tube filled with Poona soil in each case. The heights up to which water and the solutions ascended in 26 hours are given below:—

TABLE III

Nature of ascending fluid	Height of wet column in cm. at the end of 26 hours	Nature of ascending fluid	Height of wet column in cm. at the end of 26 hours
	cm.		cm.
Water	37·8	Sodium borate	42·3
Lithium carbonate	**0·0**	Sodium phosphate	35·6
Sodium chloride	43·8	Sodium carbonate	**1·8**
Sodium sulphate	35·2	Potassium carbonate	37·8
Sodium nitrate	43·0	Potassium hydroxide	44·7
Sodium hydroxide	40·8	Potassium chlorate	48·5

It is obvious that while many compounds do not affect the rate of ascent materially *there are a few very conspicuous instances like the lithium and sodium carbonate* in which the flow of water is almost completely impeded.

Effect of Lithium Carbonate, Sodium Carbonate, and Potassium Carbonate Solutions.—We may now examine in more detail the effect of equivalent solutions of lithium carbonate (0·35%), sodium carbonate (0·50%), potassium carbonate (0·72%) and water. The ascent of the above solutions and water in Poona soil under standard packing was measured with four replications. Table IV gives the mean heights of the wet columns and the coefficients of variability (C.V.).

TABLE IV

Time	Lithium carbonate 0·35%		Sodium carbonate 0·50%		Potassium carbonate 0·72%		Water	
	h. in cm.	C.V. %	h. in cm.	C.V. %	h. in cm.	C.V. %	h. in cm.	C.V. %
30 mts.	0·7	73	1·2	21	4·5	19	3·8	18
1 hr. 15 mts.	1·1	56	1·5	17	6·8	13	7·0	14
2 hrs. ..	1·2	50	1·7	16	7·6	13	8·9	11
4 hrs. ..	1·7	39	2·2	19	8·6	14	13·7	8
7 hrs. ..	2·1	37	2·4	17	9·6	15	18·8	7
14 hrs. ..	2·6	33	3·0	12	11·1	15	26·9	5
24 hrs. ..	2·9	33	3·2	15	12·9	15	35·5	4
32 hrs. ..	3·0	33	3·5	14	14·3	16	40·0	6
48 hrs. ..	3·4	25	3·7	13	16·3	16	47·9	3
72 hrs. ..	3·8	22	4·1	14	19·1	15	56·1	2

Lithium carbonate affects the rise of water more than sodium carbonate. The rise of the potassium carbonate solution is much more rapid, but not quite as fast as that of water. The regular sequence in the effect of the salts of the different metals of the same group may be noticed, but we shall refer to this point at greater length in the second part of this paper.

Effect of Different Concentrations of Sodium Carbonate.—Next we shall consider an experiment with four replications in which the effect of different concentrations of sodium carbonate was studied. The concentrations used were 1·000%, 0·500%, 0·125% and zero per cent. (water). Table V gives

TABLE V

Rise of Sodium Carbonate Solutions of Different Strengths

Time	1·000%		0·500%		0·250%		0·125%		0%	
	Mean	C.V.%	Mean	C.V.%	Mean	C.V.%	Mean	C.V.%	Mean	C.V.%
	cm.									
10 mts. ..	0·8	25	0·7	27	1·1	9	1·3	18	1·1	27
20 mts. ..	1·5	9	1·4	7	2·0	9	2·9	11	2·7	20
30 mts. ..	1·8	12	1·5	7	2·3	7	3·9	7	3·6	18
45 mts. ..	1·9	11	1·8	8	2·6	10	5·0	3	5·1	17
1 hr. ..	2·0	7	2·0	0	2·7	8	5·5	3	6·0	18
2 hrs.	2·3	6	2·5	4	3·4	10	6·9	2	9·3	16
3 hrs.	2·5	4	2·7	5	3·7	9	7·7	3	11·7	14
4 hrs.	2·5	4	2·9	6	4·0	9	8·3	2	13·8	12
6 hrs.	2·5	4	3·1	6	4·5	9	9·2	3	16·7	10
8 hrs.	2·7	4	3·2	4	4·7	10	9·9	3	19·8	8
14 hrs.	3·0	3	3·9	4	5·3	8	11·2	3	26·1	6
25 hrs.	3·3	3	4·3	5	5·9	8	12·7	3	34·3	6
32 hrs.	3·3	4	4·5	4	6·3	9	13·5	4	38·4	6
48 hrs. 45 mts. ..	3·7	5	4·7	4	6·7	7	14·4	4	45·7	8

the mean ascent of the solutions and water in Poona soil and the co-efficients of variability (C.V.). The mean heights reached by the different solutions and water at different time intervals are shown by the series of curves in Fig. 2. These curves show very clearly the rapid decrease in the rise of the solutions

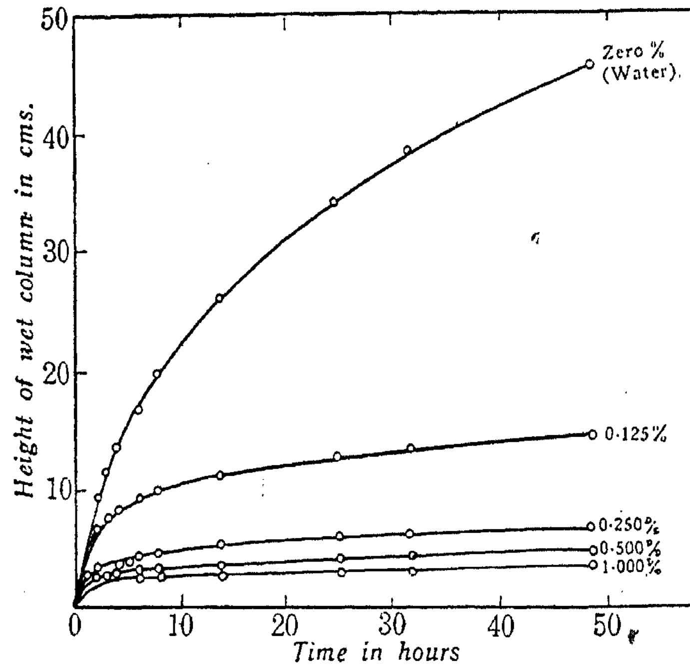

FIG. 2. Rise of differeut concentrations of sodium carbonate solutions in Poona soil

in soil on changing from water to 0·125% and ·250%. The effect of increasing the concentration is to decrease the ascent of moisture further; but most of the variation takes place from zero to 0·125%.*

5. *Conclusion*

In the present paper a simple laboratory method of studying the ascent of moisture and aqueous solutions through the soil is described. The effect of packing on the rate of upward movement has been discussed; it is shown that at *maximum* packing the rate of movement is only one third of that at *minimum* packing. To estimate error, four replications of each treatment are generally used. The influence of various percentages of sand mixed with the black cotton soil in increasing the permeability and rate of upward movement of moisture is discussed. The influence of small quantities of

* *N.B.*—The effect of concentration of the solute on the rate of ascent of solutions through the soil is under more detailed investigation, with a number of compounds. It is found that very dilute solutions actually cause an *increase* in the rate of ascent and that the decrease in ascent comes into effect only when the concentration is increased beyond a critical value, which varies with the substance. The critical concentration in the case of sodium carbonate is found to be about 0·02%. The results will be discussed in Part III of this series.

certain compounds is examined and it is shown, for example, that a small quantity of lithium or sodium carbonate reduces the rise of water very conspicuously. Lithium carbonate is more efficient in this respect than sodium carbonate. Other salts like nitrate, chloride, sulphate, borate, phosphate of sodium or sodium hydroxide do not affect the rise of moisture like the carbonate.

As compared to lithium and sodium carbonates, potassium carbonate shows little effect on the movement of water through the soil. The effect of concentration has also been referred to in the case of sodium carbonate.

These experiments are being repeated with a series of other compounds and different typical soils and the results obtained will be discussed later on. The importance of these phenomena in irrigation practice and in agriculture may be emphasized.

Experiments have been made to elucidate further the actual effect of some salts in checking the rise and movement of water. Microchemical methods have been freely used in this connection. A discussion of this work is being given in Part II of this series.

In conclusion, our best thanks are due to the Director-General of Observatories for providing the necessary facilities for this investigation.

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