

STUDIES ON SOILS—PART II: A MICROSCOPIC STUDY OF THE BEHAVIOUR OF THE BLACK COTTON SOIL IN SALT SOLUTIONS*

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1. Introduction

IN Part I of this series the ascent of water and solutions of some salts of lithium, sodium and potassium through columns of black cotton soil was discussed. It was found that of the salts experimented with, the carbonates of lithium and sodium caused a conspicuous decrease in the rate ascent of water. This led us to examine under the microscope the behaviour of the particles of the black cotton soil when placed in drops of various solutions.

It may be mentioned that the black or "regur" soils of India cover most of the cotton-growing tracts of the country. They are rich in clay (up to 70% consists of clay and fine silt) and in calcium (up to 4%).[†] During the wet season or after irrigation the field assumes an uneven appearance due to swelling of the soil. The water-holding capacity is very high. After the clear season sets in the soil crust becomes dry rapidly. Shrinkage during this process brings about the characteristic large cracks or the soil "ploughs itself" as the farmer would say. Though sticky and difficult to work when wet, on drying the soil becomes quite friable, unlike other clayey soils which become hard like brick. When dry, the soil absorbs moisture from the atmosphere so that the water lost by evaporation by day during the clear season is regained at night by absorption.

Before proceeding to discuss our results, reference may be made to the investigations of Annett¹ and Harrison and Ramaswamy Sivan² on the black cotton soil and to some recent work of Puri.^{3, 4} Annett concluded from his examination of a number of black cotton soils that their colour is mainly due to the presence of titaniferous magnetite and small quantities of soluble humus. Harrison and Sivan, on the other hand, after a more extensive investigation of the subject, found that not all black cotton soils contain

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† "Soils of the Bombay Presidency," by Rao Bahadur D. L. Sahasrabudde, *Bulletin No. 160 of 1929, Department of Agriculture, Bombay.*

titaniferous magnetite and that the black colour and peculiar physical properties of these soils are associated with (a) compound particles of low specific gravity in which the binding material is probably a colloidal hydrated double iron and aluminium silicate and (b) an organic compound of iron and aluminium. Harrison and Sivan also found that on ignition the black colour turns to a bright reddish brown colour and the soil loses weight due to the destruction of the contained organic matter (humus) and the loss of combined water. These observations are of great interest from the point of view of the present paper.

It may also be mentioned that the effect of sodium carbonate in making the soil water-logged and difficult to work is well known. Puri⁴ has shown that a lining of sodium carbonate along beds of canals prevents the seepage of water. In another interesting paper³ Puri has discussed the use of lithium and sodium ions for "auto-disintegrating" the colloidal fraction of a number of soils.

2. *The Microscopic Examination of the Behaviour of Particles of Black Cotton Soil in Solutions*

Soil particles passed through a piece of muslin were used in these experiments. A small quantity of the soil was placed on the microscope slide. To avoid crowding of the particles they were suitably scattered on the slide. Light from a small point source was focussed from above by a suitable condenser on the spot to be examined. The beam of light was incident at an angle of 85°, so that the illuminated particles could be seen against a dark background. A few drops of water or the solutions were introduced at the illuminated spot and the microscopic objective swung into position for examining the effect of the liquid medium on the appearance of the particles. A magnification of about 70 was used for taking the micro-photographs with the help of a photographic attachment. The latter was provided with a reflex arrangement and an eye-piece at the side so that even while photographing the slide could be under observation.

Effect of Lithium Carbonate.—When placed in a drop of distilled water and examined under the microscope the particles of soil are seen to consist of fragments of various minerals with sharp boundaries; most of these are covered with a gum-like layer of varying thickness, while a few are particles of quartz or other transparent minerals. Some of the transparent particles appear to have only a thin coating of the colloidal material. After the lapse of several minutes some of the particles show *very slight* swelling but no other change. Fig. (a) in Plate I shows the appearance of soil particles in water. When a drop of lithium carbonate solution is added, a *very rapid*

and conspicuous swelling of the particles immediately sets in. The maximum swelling is attained in a drop saturated or nearly saturated with lithium carbonate. Fig. (b) in Plate I shows the appearance of the swollen particles in a drop of lithium carbonate solution. The ratio of the size *after* swelling to that *before* swelling is seen to depend upon the thickness of the colloidal coating around the particle. If the swelled material is agitated with a pin or otherwise mechanically, it gets detached in pieces from the particle and gets scattered, leaving the particle with an appearance similar to that before the addition of lithium carbonate. It thus appears that it is only the colloidal coating which undergoes swelling. When the colloidal cover is thick the swelling is indeed several times the original size of the particle. This will be clear from Figs. e, f and g of Plate I, where the swelling of a single particle is shown. The mean radius of the particle has roughly doubled itself in the course of four minutes.

It is well known that when a mass of the soil is kneaded with water up to the sticky point, a plug of the kneaded soil when inserted in a glass tube can support a column of water without much drainage occurring. Fig. c, Plate I, shows the appearance under the microscope of a smudge of kneaded soil. It is seen that the interspace between the bigger particles is filled with broken down debris of smaller particles, thus rendering the soil less permeable to water. That the kneaded soil can be rendered still less permeable under the influence of lithium carbonate is seen clearly from Fig. d, Plate I, where the additional effect of swelling is visible.

We may now consider the effect of lithium carbonate on Poona soil which has turned red after being subjected to prolonged heating. It is found that even a saturated solution of lithium carbonate has no *swelling* action on the soil particles. On ignition the air-dry soil lost 14% of its weight. Of this, 10% represents loss of organic matter and combined water and 4% represents the hygroscopic moisture. The absence of swelling in lithium carbonate must therefore be due to the destruction of the organic colloidal coating during heating.

After making the above observations an experiment was made on the ascent of a 0.5% solution of lithium carbonate through unheated and heated samples of black cotton soil packed in glass tubes according to the standard method described in Part I. Four replications were used as usual. Table I gives the result of this experiment.

There is hardly any ascent in the unheated soil; negative values are due to the upper edge of the wet column being below the level of the solution outside the tube. The actual rise above this level is only 0.1 cm. even

TABLE I
Ascent of Lithium Carbonate Solution (0.5%) in Poona Soil
(a) before heating and (b) after heating

Time after commencement of experiment	Before heating		After heating	
	Mean height of wetted column in cm.	C.V.	Mean height of wetted column in cm.	C.V.
10 mts.	- 1.0	0	5.5	15
20 "	- 0.9	15	6.0	13
30 "	- 0.8	36	6.4	12
40 "	- 0.7	40	6.6	12
1 hour	- 0.5	36	6.9	11
2 hours	- 0.4	35	7.4	11
3 "	- 0.2	100	7.7	11
4 "	0.1	0	8.1	11
6 "	0.1	0	8.5	10
8 "	0.1	0	8.7	10
14 "	0.1	0	9.3	9

after 14 hours. On the other hand, in the heated soil there is a rapid rise of the solution and the height of the wet soil is 9.3 cm. in 14 hours. The effect of heating in destroying to a large extent the colloidal coating of the soil particles and the consequent increase in the permeability of the soil even to lithium carbonate are thus brought out strikingly by the results quoted in Table I. It may be remarked that in another experiment with unheated and heated soils, water also was found to move upwards more rapidly in the heated soil than in the unheated soil. In this connection reference may be made to a recent note entitled "Fired soil as fertilizer".* The decrease in the colloidal content of the soil on heating was also tested by another method. Earlier work at Poona referred to at the beginning of Part I showed that when a soil containing only hygroscopic moisture is exposed fully to the atmosphere on a clear day it loses moisture by evaporation during day up to about 2 P.M. and later in the evening and night re-absorbs from the atmosphere practically all this moisture. Thus air-dry soil will attain its maximum weight early in the morning and its minimum weight in the afternoon. The difference between these weights shows the diurnal exchange of moisture between the soil and the atmosphere. Soils containing a large amount of colloidal matter exchange more water vapour with the atmosphere than those with a smaller amount. This experiment was made with the unheated and heated soils during the period 17th to 23rd

* *Indian Farming*, October 1941, 2, No. 10.

November 1941. The mean values of the maximum weight in the morning and the minimum weight in the afternoon of the unheated and heated soils are given in Table II.

TABLE II

	Maximum weight of the soil at the minimum temperature epoch	Minimum weight of the soil at the maximum temperature epoch	Difference indicating diurnal exchange with atmosphere
Unheated ..	gr. 21.71	gr. 20.97	gr. 0.74
Heated ..	18.31	17.93	0.38

The amount of moisture exchanged is found to decrease to 50% after the heat treatment.

3. *A Comparison of the Effect of Lithium, Sodium, Potassium, Cæsium and Ammonium Carbonates*

An examination of particles of black cotton soil in solutions of lithium, sodium, potassium, cæsium† and ammonium carbonates respectively is very instructive. As the weight of the metallic radical increases the swelling effect is seen to decrease very rapidly. Thus the effect is very pronounced in lithium carbonate, less so in sodium carbonate, perhaps a trace in potassium carbonate and practically absent in cæsium carbonate. Figs. *a*, *b* and *c* of Plate II show the behaviour in lithium, sodium and potassium carbonates. Fig. *d* shows the effect in ammonium carbonate solution. There is a trace of swelling and this is accompanied by the evolution of the bubbles of ammonia gas which are visible in the micro-photograph.

4. *Effect in Oxalic Acid and Various Oxalates*

In the case of the carbonates it is not possible to compare their swelling effects with that in carbonic acid which is not stable in water. Even in water under compressed carbon dioxide the amount of the CO_3 ion is very small when compared to that in solutions of the carbonates.

In the case of oxalic acid and the oxalates such a comparison is, however, possible. The micro-photographs of soil particles under water, oxalic acid, sodium oxalate and potassium oxalate are shown in Figs. *e*, *f*,

† Later, rubidium carbonate was also tried; it comes between potassium and cæsium as regards its swelling effect.

g and *h* respectively of Plate II. It is remarkable that of all these substances the solution of *oxalic acid shows the maximum swelling*. The effect of sodium oxalate solution is similar to that of sodium carbonate, but much less than that of oxalic acid solution. Going further in the series one finds that particles in potassium oxalate solution show little swelling and that particles in ammonium oxalate are very similar to those in water. Thus the H-ion in oxalic acid is much more efficient in causing the swelling of the colloidal cover of the soil particles than the Na⁺ or K⁺ ions. This result is indeed very interesting.

We have similarly examined the effects of tartaric acid and sodium and potassium tartarates, formic acid and sodium formate and citric acid and sodium citrate. In these cases also the acid is a more efficient swelling agent than the salt. The study of the phenomenon in the case of other related series of compounds is in progress.

5. *Swelling in Solutions of a Number of Organic Acids*

It was possible to secure pure samples of tartaric, oxalic, citric, lactic, malic and oleic acids. Figs. *a* to *f* of Plate III show the extent of swelling in saturated solutions of the first five acids and in oleic acid in the order in which they are mentioned above. It is obvious that tartaric, oxalic, citric and lactic acids are quite efficient as swelling agents. The effect in malic and oleic acids is not very noticeable.

6. *Summary and Conclusions*

In this paper the swelling of the colloidal material in black cotton soils in solutions of a number of substances has been described. Lithium carbonate is found to be the most efficient swelling agent amongst the substances tried so far. In any group of related compounds like acid and its alkali salts it is found that the acid causes much more swelling than the salts. Amongst the salts the swelling decreases rapidly in the order Li, Na⁺, K⁺, Rb, Cs.

The effect of prolonged heating is to destroy the organic colloids covering the particles. This leads to the absence of swelling even in lithium carbonate solution and a marked increase of permeability.

The paper summarises the result of a preliminary survey of these related phenomena in the case of the black cotton soil. A more detailed and systematic investigation in the case of a number of typical Indian soils, particularly from the point of view of applications to agricultural practice, is in progress.

The physical and chemical aspects of swelling will be discussed in the next part, in the light of the detailed experiments on the effect of concentration of the salt on the movement of the solution through the soil.

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