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Movement of Moisture in Soils

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INTRODUCTION

Soil is the medium for growth of plant in which a certain amount of moisture is required for the healthy nourishment of vegetation. The function of the moisture is not only to promote chemical, physical and biological activities of the medium, but to act as a solvent as well as a carrier of nutrients. Thus an intimate information about the soil moisture relationship is of fundamental importance.

To understand soil moisture relationship, the first important factor is to have a clear insight of the medium. It is a common observation that soil is a collection of solid particles in the form of a compacted mass, containing intersticis called the pores, which contain air if not water. The pores are inter-connected through their neckshaped portions and thus form a net work of capillaries which are different in size and shape depending upon the structure of the soil particles.

When a field is irrigated artificially or it receives natural irrigation by rain, a portion of the water raises the moisture content of the medium as it passes through the soil profile and if the water applied is in excess a portion of it may go down and add itself to the water-table. Another portion of the surface application is lost by evaporation. The third part is used up by the plants for their nourishment. The complicated nature of the problem is thus evident from a number of variables involved.

A historical review of the subject would show that at different periods various hypothesis and theories have been in the field to explain the soil-moisture reactions. A brief account of these is given below :—

1. The Capillary Tube Hypothesis. Briggs (1) in 1897 conceived an idea that moisture existed as a continuous and tightly stretched film around the soil particles. This film formation is due to surface tension forces which would naturally depend upon the size of the particles of which a certain soil is made of. According to this concept the retention of the moisture is due to forces arising out of the curvature of the films and the movement of the moisture takes place from a thicker film to a thinner film. The rate of the movement of moisture would be determined by the curvature of the films, the surface tension and viscosity of water. The agencies like temperature and vapour pressure, which affect surface tension and viscosity will also influence the moisture movements. This hypothesis was in reality an attempt to understand the capillary rise of moisture from a free sub-soil water-table and the rate of movement of moisture through soil.

2. The Capillary Potential and the Analogy with flow of heat or Electricity. In 1907, Buckingham (2) thought of explaining certain anamolies in soil-moisture relationship on the lines of already existing hypothesis of potential and the quantitative units of heat and electricity. The capillary tube hypothesis failed to explain various aspects of the problem of moisture movement in soils. The flow of water would be compared to the flow of heat or electricity. The capillary potential was defined as the attraction of the soil, under given conditions, for water. If there existed a potential difference between any two points of a continuous soil medium the driving force would be proportional to the difference in potential and the moisture movement would take place. The quantitative relationship was worked out on the same lines as in heat and electricity.

3. Moisture Distribution in the Cellular Pore Spaces. The quantitative side of the problem of moisture distribution and retention becoming more important, the idea of moisture distribution in the cellular pore spaces was conceived quite recently. The hypothesis was based on the principle that water tends to reduce its free surface and hence its surface energy to a minimum. The idea of the arrangement of the particles of soil in a pattern was developed and the geometry of the soil frame work was considered an important factor which would control the quantitative movement as well as retention of moisture. Slichter (3) investigated the idea of a pattern and his work was supplemented by King (4), Haines (5) and others.

It is thus clear that a deep insight into the soil moisture relationship is not so simple a matter as it appears to be from a conception which a farmer has when he applies water for growing the crops. If the farmer has enough irrigation water at his disposal and by making use of it, can have his crops to his satisfaction, he has little concern with the deep scientific concept of supply of water, the retention power of the soil, the wastage of moisture and the consequences of over-using or under-using this chief nourishing material for the crop. An irrigation engineer, a soil scientist and an agricultural officer can ill-afford to overlook such an important subject which determines not only the prosperity but the very existence of an agricultural country.

It is suggested that for the study of the mechanism of moisture movement in soils the important contributions in this branch of soil physics by Briggs, (1) Buckingham (2) Gardner, (6) Haines, (5) Bouyoucos (7,) Keen (8) and others may be looked into. These workers have classified various types of soil moisture depending upon its behaviour and function in the soil. The main idea in all these classifications has been to gauge the availability of moisture for the plantgrowth and the moisture retention power of soils.

The country of India in general and the Province of Punjab in particular derives its prosperity from the soil. The industrial side of this sub-continent has not been developed due to several reasons, one of which is the dearth of raw material. In agriculture it is not only important to gauge the amount of crop produced, which depends upon the proper utilization of water, but also the soil fertility. The future life of the agricultural population should never be lost sight of which would depend upon a proper control on irrigation water available and used for the cultivation. Excessive use of irrigation water for crop production may produce water-logged conditions as has happened in the canal irrigated areas, while scanty irrigation may increase thur formation, as in areas with deep water-table but containing salts in the soil profile, which would first make the soil saline and then alkaline, thus producing Rakkar Soils, which are not easily reclaimable. The movement of soil-moisture under various conditions is thus an important subject from the point of view of irrigation engineer who controls the supply of water and from the point of view of a farmer who uses it for crop production.

Object. The problem of moisture movement in soils may be divided into two parts *(a)* the movement under saturated conditions *(b)* and the movement under unsaturated conditions. The object of this contribution is to give further support to the theoretical conception of the subject and to describe and discuss the experimental data collected in this connection.

Definitions. It would be useful to define some technical terms which will be used frequently in this paper. In some cases attempt has been made to deviate a little from the proper scientific concept and give meanings commonly followed by us in every day life.

1. *Soil profile.*—A soil profile is a column of natural undisturbed earth from the top surface up to the free water-table. In laboratory we may include, a disturbed soil column or artificially prepared soil column, in this definition.

2. *Soil sample.*—A soil sample is a representative soil portion taken from a certain point of the soil profile.

3. *Dry-bulk density.*—D. B. D. is the dry weight of a soil per unit volume. It is generally expressed in lbs per cubic foot but may be expressed as a ratio of weight to volume.

4. *Moisture content.*—Moisture content is the amount of moisture which a soil sample is capable of losing when heated in an air oven at 105° C. It is expressed in percentage on dry soil weight.

5. *Intensity of irrigation.*—Intensity is the amount of irrigation expressed in depth of water column.

6. *Capillary moisture.*—Capillary moisture is that moisture which moves in a soil medium under the effect of capillary forces without any consideration of the force of gravity.

7. *Gravitational moisture.*—Gravitational moisture is that portion of moisture which is over and above the capillary moisture and which moves under the effect of force of gravity.

8. *Free water-table* —Free water-table (F. W. T.) is the level of free water which appears when a hole is bored in a soil profile.

9. *Field capacity.*—Field capacity is the moisture content expressed in percentage on dry soil weight which a soil can retain after it has been thoroughly irrigated and then drained. Any addition of more water at the top will release the same amount at the bottom.

10. *Field capacity zone.*—Field capacity zone is that part of a soil profile which is in equilibrium with respect to the soil moisture relationship and would not retain more moisture if allowed to attain equilibrium under the force of gravity which tends to draw water in the downward direction. This zone is of a constant moisture content.

11. *Pellicular deficiency.*—Pellicular deficiency of a soil profile is the intensity of irrigation expressed in column of inches which that soil profile would require to attend its field capacity.

12. *Pellicular zone.*—Pellicular zone is that part of a soil profile which has a moisture gradient and a moisture content less than its field capacity. This zone is formed under the effect of surface evaporation and includes funicular and pendular stages.

13. *Funicular stage.* —When the moisture condition of a soil block is such that the moisture film of one pore is connected to that of the neighbour, the soil moisture is in the funicular stage and is lower than field capacity moisture.

14. *Pendular stage* —When the moisture condition of a soil block is such that the moisture film of one pore is not connected to that of its neighbour, the soil moisture is in pendular stage and is lower than field capacity moisture.

15. *Moisture equivalent.*—Moisture equivalent is the moisture percentage on dry soil weight retained by a small sample of a soil after it is subjected to a centrifuge force of 1000 times the force of gravity for about half an hour.

16. *Wilting limit.*—Wilting limit is the moisture percentage on dry soil weight at which a plant wilts unless water is supplied.

Experimental.

To study the problem of moisture movement in soil profiles in detail the essential observations to be made are to gauge :—

1. The amount of irrigation applied.
2. The part of total irrigation which is lost by evaporation.
3. The part which is retained by the soil.
4. The part that passes through the soil medium and adds itself to the water-table.

For the collection of this information the arrangement of the experiments should be such that soil samples could be taken from time to time without disburting the profile. Soil samples are generally taken by means of soil augers, but one sample can be taken from the point and it cannot be repeated. The amount of moisture which a soil would retain depends upon the size of the particles comprising the soil. A higher percentage of fine particles increases the moisture holding capacity of a soil. Similarly the concentration and the nature of salines, the dry-bulk density of the soil, the surface condition of a natural soil column, the meteorological conditions and several other factors determine the moisture retaining power of a soil. To avoid as many variables as possible the experiments were carried out with a typical Punjab soil under controlled conditions.

Methods of Moisture Estimation

(*a*) **Tensiometer Method.** It is clear from the problem that estimation of moisture content at different depths from the natural surface of the soil profile was to be carried out. A simple method for this purpose would be to use tensiometers. These were made of a porous porceline tube of three inches length and three quarter inches internal diameter. On one end a metallic cone was provided to make it strong enough to be inserted conveniently in the soil medium. On the other end a brass cap having a delivery brass tube was fixed which was connected to a mercury manometer. The tensiometers, the rubber tube and the space above the mercury columns were completely filled with water. Such three tensiometers were fixed in a soil profile, by inserting the porous tube in the soil, at a depth of 5,10 and 15 feet from the top of the soil column.

As moisture was absorbed by the soil in contact with the porous tube a negative pressure was indicated in the manometer. The pressure thus created gave a measure of the moisture content of the soil *in situ* where the tensiometer was fixed. The calibration curve for one of these instruments is shown in Fig. I and moisture content as determined by the three tensiometers are given in Table I.

Discussion of Results. It is well known that there are limitations in the use of tensiometer for moisture determinations. Baker's remarks on pages 243-244 of "The Soil Physics" are :—

"The use of tensiometer is limited to moisture contents above the moisture equivalent. They cannot be employed at tensions greater than one atmosphere."

"The fact that they cannot be used within the moisture equivalent to the wilting percentage as well as the problem of overcoming hysterisis effects, are definite limitations in their usefulness in the field."

During a short period in which observations were recorded the instruments failed many times and had to be refilled with water. The comparison of the results of moisture contents as determined directly by taking soil samples and as given by tensiometer readings are included in Table I. Before discussing these results we may consider one important source of error in the working of tensiometers. The readings recorded by tensiometers are greatly effected by the degree of compaction of the soil. When the moisture travels from the porous clay pipe to the soil in contact with it, the moisture content of the soil increases. The power of attraction for moisture would be controlled by the difference in the actual moisture content and the moisture holding capacity of the soil. The greater the difference the greater will be the absorption of moisture by the soil. The moisture from the soil layer adjacent to the porous pipe surface is then slowly transmitted to the rest of the soil, layer after layer, till the system attains an equilibrium. It is quite easy to visualize the conditions of moisture distribution when the system has reached a stage of equilibrium. The moisture distribution is illustrated in Fig. 2 and graphically represented in Fig. 3.

Under these circumstances tensiometer should not be used for moisture determinations, as the results will be affected by the following soil factors:—

(*a*) The degree of compaction *i.e.*, the dry-bulk density of the soil.

(*b*) The nature of the soil : the moisture movement is a function of the capillary forces, it would therefore vary with soil fineness and would be greater in clay than in sand.

In addition to the above there is a possibility of the moisture content of the soil in contact with the tensiometer surface being always higher than the rest of the soil.

This objection would not hold good if the amount of water taken up by the soil was negligible. It was observed that for a pressure difference of 30 cms. column of mercury the amount of water taken up by the soil was 3.75 c.c. This volume of water would depend upon the size of tensiometer tube as well as the rubber and manometer tubes. Hence for moisture estimations until and unless some other satisfactory method is developed the direct determination of moisture should be preferred. We are mainly concerned with moisture contents within the range from moisture equivalent to the wilting limit where tensiometers cannot be employed.

(*b*) **Direct Method.** An alternate method for the determination of moisture is the direct method worked out by Puri and Syrup (9). It consists of weighing the moist soil in a collapsible lead tube, drying at 105°C temperature and reweighing the dry soil to a constant weight. In this method it would be necessary to take the soil samples out of the soil profile and transfer to the lead tubes. The technique of taking the soil samples will be described later.

Preparation of Soil Profiles. The experiments performed in this study were conducted in earthen pipes, glazed from outside to avoid evaporation from the outer surface. The inner diameter of the pipe was four inches. The total height of the pipes was made up by joining two feet long pieces by means of cement mortars. One end of one piece was placed in upper end of the second piece which was shaped in the form of a socket and space was filled in with rich cement mortar. It was further covered with wax to avoid evaporation from the joints. The lower end of this long pipe was placed in a trough made of bricks plastered with cement, in which water was allowed to stand to provide a free water-table. Two holes at each foot from the top of the pipe were made which were closed with waxed plugs. These plugs could be removed whenever desired.

A typical Punjab soil containing about 15 per cent clay and 0.1 per cent salts was sun dried and passed through 1 m.m. seive. A weighed quantity of the soil was thoroughly mixed with a desired amount of moisture and a quantity which would fill six inches of the pipe at a desired dry-bulk density was put into the pipe from the top. The moist soil was thrown in gently in the form of lumps made by squeezing in hand to avoid the coarser particles reaching the bottom first. After each addition the soil was compacted by means of a long iron bar carrying an iron disc at the lower end. The volume up to which the soil was compacted was observed by the help of the length of the iron bar which was precalibrated with reference to the diameter of the pipe. Generally a fixed number of strokes gave a uniform compaction throughout the soil column. The final dry-bulk density checking was carried out by actually taking the soil samples by means of a suitable borer to determine the weight of the dry soil per unit volume. All the pipes were filled with soil in this manner with the exception of the bottom one foot in which six inches of stone ballast and then six inches of sand was put to avoid chocking of the lower end of the pipes. These pipes, filled with soil, will be referred to as "soil profiles" heretoafter.

Collection of Soil Samples. The soil samples, for the moisture estimations, were taken from time to time by removing plugs from the holes and taking out the soil by means of a suitable borer, a knife or a spatula. After the moisture determination either the same soil was put back after mixing with the determined amount of moisture or as the original soil was kept in stock a desired sample was prepared and introduced through the holes.

A. Experiments on Soil Profiles.

(1) Movement of Moisture through a Soil Profile under 5 feet Water-Head. Moisture movement was studied on a soil profile of 20.5 feet height having a dry-bulk density of 1.7. The first sampling was done on 4th May, 1943, after which six inches of irrigation was applied at the top on 5th May, 1943. Water disappeared from the surface on 10th May, 1943. The soil samples were taken on the 6th, 10th and 15th May.

Another six inches of irrigation was done on the 15th, which disappeared on the 24th. During this period the samples were taken on the 19th and 25th.

The third six inches of irrigation was done on the 25th, after taking the soil samples. Water disappeared from the surface on 5th June, 1943, and the samples were taken on 31st May, 1943 and 7th June, 1943.

On 5th June, 1943, a water head of 18 inches was provided at the top which was increased further to five feet on the 20th of June, 1943. This water head was maintained up to 5th December, 1945, that is for a period of 2 years 5 months and 15 days. Soil samples were taken and examined from time to time during this period and the complete results of moisture estimation are given in Table II. To avoid confusion due to overlapping some of the moisture curves are represented in Fig. I to show how the moisture distribution varied during the experimental period.

Discussion of Results. The results show that although 18 inches of irrigation was done the moisture hardly reached the second foot by 7th June, 1943. Taking the dry-bulk density of the soil profile as 1.7 and considering the top five feet of soil strata the moisture should have increased by 17.6 per cent, *i.e.*, the moisture after 18 inches irrigation should have been 24.6 per cent, provided there were no losses due to evaporation.

With the third irrigation of six inches the rate of evaporation was also determined, which amounted to 56.4 per cent. This rate should have been determined throughout the experimental period, but this was not done. It will be seen that in the first instance the water disappeared after five days, in the second after nine days and in the third after eleven days. There was no free water at the soil surface for five days after the first irrigation, and for one day after the second irrigation. Taking 56.4 per cent loss due to evaporation as an approximate figure the total water added to the soil should be 0.65 feet. This much water would have added 19.4 per cent moisture up to the top two feet of soil profile. Including the original moisture of the soil the total moisture would be 19.4 plus 6.0 = 25.4 per cent. Taking 50 per cent as the moisture under saturated conditions at soil surface and 8·0 per cent at the second foot the mean moisture would be 29 per cent. Considering all the approximations, the two results show a reasonable agreement.

When a constant water head of five feet was maintained the experiment may be considered to represent running channel condition or a soil on which pond conditions were created. The results show that the moisture hardly reached the 12th foot from the top. When irrigation is applied to a soil profile the portion immediately in contact with water takes up moisture and retains as much as it can. The excess of water passes to the lower strata which satisfies its own moisture retaining capacity and leaves the rest to pass on. Thus the soil takes up moisture to fulfil its "Field Capacity" before it allows the excess of water to pass to the lower strata, and if the soil is not moistened up to its "Field Capacity" no water will pass through it. The portion of the profile under discussion from 9 feet to 13 feet being at 10 per cent mean moisture which is about 10 per cent less than field capacity would not allow any transmission of moisture through it. Thus it may be concluded that during 2½ years there has been no addition of water from the surface application to the sub-soil water. It is important to note that no field or a water channel remains under water for such long periods without a break. It may be possible to create certain conditions under which percolation of water and its addition to the water-table may be restricted.

There are certain conditions in the field which must be considered before any definite conclusion can be arrived at. The density of a natural soil profile may vary from foot to foot. The texture of the soil is also different throughout the soil column. These characteristics may have a pronounced effect on the rate and extent of moisture movement. To illustrate this point the results of examination of a natural profile are given in Table III. It will be seen that clay varies from foot to foot and the dry-bulk density is also different at different depths. This soil profile seems to be extraordinarily hard otherwise the average density of of Punjab profiles is about 1.5. The higher degree of compaction may be one of the reasons of restricted transmission of moisture.

Our experience has shown that the soil deterioration (10) in the Punjab starts from the accumulation of salts in the top strata of the soil. The formation of saline soil, which may be defined as soil containing high percentage of soluble salts of sodium, is the first stage of deterioration. If the salts remain in contact with the soil for a long time the next stage of determination is reached when the exchange reactions take place. This results in the formation of alkaline soils. The formation of hard pan at a certain depth from the surface in natural soils is sometimes observed under rapid base exchange conditions. Reclamation of such soils is likely to be difficult as the transmission of moisture would be restricted. " There are fields particularly in the Upper Chenab Canal and Lower Chenab Canal areas which have carried rice year after year during the last 30 or even 40 years." There is a possibility of some structural changes in such areas which would control the moisture transmission.

The results further show that in the period of 2½ years the capillary moisture has moved up to a height of seven feet from the free water-table. It may also be observed that the rate of rise of this moisture decreases with time till it becomes quite negligible.

The moisture contents at 8th, and 9th foot from the top are of a higher order than the upper and the lower stratum since 8th July, 1943. This peculiar behaviour cannot be explained. The only possible explanation is that probably during rains, which we had to a great extent during July 1943, water entered the soil column somehow through an unnoticed space near the holes or the joint of the pipes. The moisture has remained confined to the 8th and 9th foot from the top.

It may be concluded from the results discussed above that transmission of moisture may be restricted under certain conditions of soil profile so much so that under a water head of 5 feet no water may reach the water-table within a reasonable time period.

2. **Effect of Clay on the Vertical Movement of Moisture.** Four soil profiles of 15 feet height, provided with a free water-table at the bottom were prepared according to the procedure mentioned in the foregoing. A soil containing 16.9 per cent clay was compacted at a dry-bulk density of 1.5 in one of the pipes. An appropriate mixture of silt and sand was mixed with the natural soil to lower its clay content. Mixtures containing 9.4, 7.0 and 5.0 per cent of clay were made and each one of these was compacted to the same density (1.5) in the rest of the three pipes separately. Irrigation in three inches lots was generally applied at the top and the gradual movement of moisture was observed by estimating the moisture content of the soil samples collected from various depths from time to time. The complete results are given in Table IV and a few of these are represented graphically in Fig. 5 for 16.85 per cent clay. The actual irrigation applied and the total irrigation calculated from the moisture estimations is also given. The experiment was started in 6th March, 1944, and completed after three months when the total irrigation applied was 46.5 inches of water.

Discussion of Results. The relation between the irrigation applied and calculated is plotted in Fig. 6, which shows that for the first four months the calculated moisture is practically the same as the irrigation actually applied. After this the two curves separate showing an appreciable amount of surface application unaccounted for. Some of the water might have been lost through evaporation. The loss due to evaporation was decreased as far as possible by covering the upper ends of the pipes with wooden discs perforated at various places. A further protection was given by covering them by jute bags to avoid the sun rays falling directly on the exposed soil surface. The holes, through which the soil samples were to be taken were closed by waxed corks. Although the arrangement for protection was quite satisfactory yet it may not be taken scientifically perfect for avoiding evaporation The amount of water unaccounted for is too much to be taken as evaporation losses.

The capacity of a soil to hold moisture varies with the fineness of the soil and is particularly dependent on the clay portion of the soil complex. Hence we should expect a lesser amount of water passing through a clayey profile as compared to sandy soil, but the curves in Fig. 6 show just the reverse. In the profiles containing higher percentage of clay the portion of water unaccounted for is higher than in the less clayey profiles. The difference is not very large and can be explained from the data of observations. It will be seen that in the case of clayey profiles the irrigation applied at the top took longer time to disappear than in the case of sandy profiles. Under these circumstances one may expect higher evaporation losses from the surface of clayey profiles.

It may therefore be concluded that moisture transmission would be easier in soils containing less amount of clay than in those having more clay.

3. Effect of Dry-Bulk Density on the Vertical Movement of Moisture. A similar arrangement as in No. 2 was made for studying the effect of dry-bulk density of the soil in the moisture movement. A soil containing 16 per cent of clay was compacted to 1.45, 1.60 and 1.80 dry-bulk density in separate pipes of 15 feet height provided with free water-table at the bottom. The experiment was started in April 1944 and three inches of irrigation was generally applied at a time. The observations were completed in three months after 45.0 inches of total irrigation. The complete results of moisture estimations are given in Table V and a few of the moisture curves are plotted in Fig. 7 for 1.8 B.B.D. The comparison between the irrigation applied and moisture observed from the actual determinations is made in Fig. 8.

In this case also there is a certain amount of water unaccounted for. This difference between the irrigation applied and the water actually determined is higher for the profile compacted to a higher dry-bulk density. It may be seen that the surface application has taken longer period to disappear from the surface of denser profiles. Further that the soil at a higher dry-bulk density has taken more time for wilting although there is no difference in the final moisture content in the three cases. The experiment thus shows an easier transmission of moisture through profiles of low degree of compaction than those of high dry-bulk density.

4. Effect of Intensity of Irrigation on the depth to which Moisture moves in Soil Profiles. To study the effect of intensity of irrigation in moisture movement a laboratory experiment was conducted in glass tube segments of 3" length, connected to one another by rubber bands covered with wax, to avoid evaporation at the joints. A typical Punjab soil was compacted in five separate sets of glass tube segments at 1.5 dry-bulk density. Increasing amounts of irrigation were applied at the top. The downward movement of moisture was observed by the colour change in the moistened soil. The extent up to which the moisture travelled, was finally determined by disconnecting the glass segments after 48 hours of the disappearance of the free water from the surface and estimating the moisture contents. The results are given in Table VI.

Discussion of Results. The depths up to which moisture has moved for various intensities of irrigation are as follows :—

Intensity (in inches)	Depth (in inches)
1	9.6
2	14.4
3	19.2
4	24.0
6	33.6

The question of intensity of irrigation has become an important factor in soil management during recent years. The availability and the actual supply of water were stressed to a great length in the meeting of "The crops and Soil Wing of the Board of Agriculture and Animal Husbandry in India" held in December, 1945. During discussion on the subject it was pointed out that sometimes water is available, but a cultivator does not need it. However he cannot refuse the supply and is supposed to make use of it, somehow or other, with the result that generally an overdoze of surface application is given, without considering the future consequences. It is also possible that when water supply is essential for the crop growth, it cannot be ensured. The solution for such a problem is undoubtedly ensured supply of water and its use in proper intensities on a scientific basis.

The problem becomes more complicated in a province like the Punjab, where soil profiles differ from place to place and the same intensity of irrigation be used in all cases with the sure result of bringing about changes which may not appear harmful presently, but may ruin the soil in the long run. It has been observed that wherever a cultivator can control the water supply, different intensities of irrigation are used for various crops and for the same crop in different parts of the Province. The author had an opportunity of discussing the subject with a cultivator of Mianwali District where an intensity of 1.25 inches of water was being practised in fields of as small an area as 32 sq. feet at a time. In the canal irrigated areas, the usual intensity is three to four inches of irrigation. The reason for fixing high intensity is not known; probably the present distribution system of "Wara Bandi" is responsible for such a practice.

The examination of soil profiles in the Punjab reveals that the alluvial deposits contain salts mixed with soil material at variable depth from the natural ground surface. In some cases the salts stratum is within thin layers while in others it may exist within several feet below the ground surface. If the moisture applied at the surface for crop production is allowed to reach the saline stratum it is quite obvious that under the effect of surface evaporation the moisture would move upward from the lower stratum and would bring the dissolved salts along with it. The accumulation of harmful salts within the root zone of crops would thus result into "Thur" formation, which might increase rapidly if no precautionary measures are adopted to wash the salts down to the water-table. However, well controlled intensity and frequency of irrigation may not only restrict the upwards movement of salts but may wash them down towards water-table.

It has been noticed in some areas that the cultivators have actually antagonised the salts by controlling the intensity and the frequency of irrigation. They have reduced the size of their fields to prevent unequal distribution of water during surface application. The zamindar who describes his soil to have been "strangled" by an irrigation of high intensity and greater interval of watering wishes to explain the movement of saits from the sub-soil towards the ground surface and their accumulation within the root zone of crops.

The subject of " water requirement of crops " has attained a great importance during recent years and is under investigation in various Research Institutions in India as well as abroad. It is well known that the amount of moisture which a soil would retain depends upon the nature of the soil and the meteorological conditions of the area. In arid areas the moisture losses due to surface evaporation and transpiration in plants are high. Further that the actual water requirement depends upon the previous moisture condition of the soil before surface application. It can thus be realized that the problem though important is complicated and its scientific study under varying natural conditions would require accurate as well as laborious work. Some workers in this field have no doubt recommended higher amounts of water for higher crop yields but the importance of future life of the soil and its fertility should never be lost sight of for the sake of immediate higher rate of production. Our " Warabundi System " in the canal irrigated areas needs a thoughtful revision because the distribution of water should not be based only on the availability and the compulsory usage of the supply by the zamindar.

A reference may be made to some recent work which is being carried out at the Agricultural College, Punjab on the water requirements of crops. It has been observed that the yield of wheat can be increased by increasing the number of waterings applied. The experiments have been carried out with one, two and three irrigations but the point of maximum yield has not been reached as yet. The results are very good considering the immediate increase in production but may prove harmful in the long run. It would be far better if the farmers are persuaded to be careful in the use of water both from the economic as well as deterioration of soil considerations. This can only be achieved if the farmer is made aware of the wastage of water and the ultimate damage to the soil due to excessive irrigation. For this purpose of course the farmer would need an ensured supply of water for the crop. Economy in the use of water may well be illustrated by the Australian practice of moisture estimation in the soil profile of a field before putting it under irrigation. A calculated intensity of irrigation is applied which would moist the soil up to a predetermined depth and moisture content depending upon the existing moisture percentage of the soil and meteorological conditions.

To exercise maximum economy of water the point has been stressed in the meeting of the Central Board of Irrigation recently in New Delhi. The water resources of this country and the economical use of the harnessed water has been admitted to be the national wealth. It is true without any doubt, but the actual planning of the future policy rests on the clear understanding of the water requirements of the farmer on strictly scientific basis.

5. Rate of Evaporation and the Formation of Pellicular Zone in Soil Profiles. The rate of evaporation of moisture from soil surface depends upon various factors. The meteorological conditions like humidity of air in contact with soil surface, the temperature and the movement of wind are the major factors which control the evaporation losses. But there are some soil conditions and characteristics which make appreciable contributions to increase or decrease the loss of moisture from soil ; for instance FISHER (11) and KEEN (12) have studied the effect of the degree of saturation of the soil moisture. ESER (13) has shown that the rate of evaporation is two to four times greater in soil profiles in contact with ground water than in drained soils. KING (14) has studied the effect of surface conditions of the soil and has advocated the use of dry loose layer of earth for preservation of soil moisture and decreasing the rate of evaporation. The study of the effect of the mechanical gradation of the soil has revealed that coarser soil lose less moisture than those which are finer in texture.

The study of the rate of evaporation from soils under field conditions is an important problem as the evaporation losses control indirectly the availability of moisture for the plant growth. If the availability of moisture in soil for the plant growth decreases beyond a certain limit due to higher rate of evaporation the wilting of the plants is the obvious result. Unfortunately, this study has not been developed in the field as yet and our estimates of evaporation losses are only based on experiments in the laboratory under controlled humidity and temperature conditions or weighed lysimeters on a small scale in the field under natural conditions.

An attempt was made to study the rate of evaporation of moisture in soil profiles set up to study the movement of moisture discussed in experiments two and three. The arrangements for providing a free water-table were maintained as before and the evaporation was allowed to proceed from the upper surfaces under the natural atmospheric conditions. The profiles were protected from rain by providing covers at suitable heights from the tops. The rate of loss of moisture was studied by making moisture estimations at various depths from the top from time to time. The complete results are given in Tables VII, VIII for soils having different amounts of clay and compacted to different dry-bulk density respectively. In the beginning the exposed soil surfaces remained one foot below the upper edge of the glazed pipes but after first two observations, the upper two feet portions of the pipes were removed and the surfaces became fully exposed to the atmosphere. A few of the moisture curves are represented in Figures 9 and 10 to show how the moisture curves shifted from the saturated to the unsaturated condition.

Discussion of Results. When a soil column saturated with moisture and provided with a free water-table is exposed at the upper surface and allowed to remain under these conditions, the evaporation of moisture would first start at the surface, and then slowly affect the lower portions. The depth up to which the profile is affected depends upon its various physical characteristics. The moisture content of the top soil decreases till it reaches the " funicular stage " when the moisture film of a pore is connected with that of its neighbour. At this stage some pores may have more water than the others but there is no negative pressure produced.

If evaporation still proceeds the pores lose more water and pressure defficiency comes into play which increases till " Pendular stage " is reached when there is no connection between the moisture film of one pore with that of the other. Any further decrease in the moisture content decreases the thickness of the moisture film and increases the pressure defficiency. Both these moisture stages are below the " field capacity moisture." These stages are termed as " Pellicular Stage " and the depth up to which it exists is known as " Pellicular Zone."

According to Taylor's views a soil profile in contact with sub-soil water-table at the bottom and exposed to the atmospheric conditions at the top may have moisture zones as given below :--

(*a*) Starting from the free water-table the first portion of the profile is in the capillary zone up to a certain height depending upon the physical characteristics of the soil. The moisture content in this zone is higher than the field capacity moisture.

(*b*) The second portion is in the field capacity zone extending from the " capillary fringe " upwards in which the moisture is held up due to surface tension forces and contains the highest amount of moisture which a soil can hold against the force of gravity. This zone has a constant moisture content without a gradient.

(*c*) The third portion is the pellicular zone extending from the upper limit of the " field capacity zone " up to the exposed soil surface in which there is a moisture gradient. In this zone the moisture is lower than field capacity moisture. The soil in this zone is in the funicular and pendular stages of moisture.

In the light of the above remarks let us examine the moisture curves given in Fig. 9 and Fig. 10. In the case of soils containing varying amounts of clay it would be seen that surface evaporation has affected to a lesser depth in clayey soils. In other words if the evaporation at the surface is supplemented by moisture from the water-table the movement of moisture could take place more in sandy soil than in clayey soils. Further that the rate of evaporation is higher in profiles of lower clay content. The loss of moisture is of the same order during the first three months after which the rate increases with the decrease of clay content. As the total moisture present in the profiles of low clay content is less it appears that the formations of pellicular zone depends upon the percentage of soil fines. It is rather difficult to generalize this conclusion for the natural soils in which the clay, the dry-bulk density and several other factors vary from foot to foot.

It is a common observation in the Punjab that salts appear in the form of an efflorescence in areas where water-table is not very deep. Cases have also been observed where salt has appeared on the soil surface with deep water-tables. In certain areas the water-table was as low as 40 feet from the natural surface obviously nearness of water-table cannot be the only cause of salt appearance, which is commonly termed as " Thur."

It has been observed by Taylor (15) that under excessive irrigation before and during rice cultivation if the salts are once washed down beyond 10 feet in areas where the water-table is lower than 10 feet the salts will never move towards the surface to reappear at the top and to result in the formation of Thur. The field capacity zone acts as a buffer zone for the moisture movement and consquently for the salt movement. Further that the field capacity zone does not take up moisture from the capillary zone as the soil cannot hold more moisture against the gravity forces. Any moisture which it receives from the top when water is added for irrigation purposes will pass through to reach the water-table. The question whether the transmission of water through the field capacity zone is by displacement, in which case the same amount of moisture is released at the lower extremity of this zone as is received at the upper end c whether the moisture received at the upper end passes through this zone bodily may not be discussed here. Taylor's contention in a nutshell is that no movement of moisture takes place from the water-table towards the upper surface and that whatever passes through the field capacity zone towards the water-table will never rise to the upper surface again.

The curves show that the effect of evaporation and the formation of pellicular zone is evident up to a depth of 11 feet from the natural surface. The capillary moisture zone is in contact with the pellicular zone and the field capacitv zone, recognized by Taylor which is of constant moisture content and which acts as a buffer zone in moisture movements from the free water-table towards the natural surface, does not exist. The results have a direct bearing on the problem of reclamation of soils containing salts.

By examining the curves under discussion further it would be quite clear that starting from the water-table there is the capillary zone in which soil has saturated moisture near the water-table and very near saturation in the upper portion. That the moisture content is of the same order below the free water-table and for some height above has been observed by Scholfield (16) and experimently verified by the author.

Above the capillary zone there is no zone of constant moisture content and the pellicular zone extends from the capillary fringe up to the exposed soil surface. There may be a point at which the soil may be supposed to have moisture equal to its field capacity but absence of a zone is definite. The presence of such a zone is important as the permanency of the reclamation would depend upon this.

The general procedure (17) adopted in land reclamation is to level the field and allow water to stand in it for a period of about six weeks. During this leaching period the conductivity of the water is examined from time time to ensure that major portion of the salts is being removed. The rice transplantation is then carried out and the crop is produced under 3 inches irrigation being applied weekly for a period of three to four months. After harvesting rice legumnious crops like gram, berseem, etc.

are grown. If the land is found to be completely reclaimed it may then be put under crops requiring scanty irrigation. When the land is put under normal crops there is bound to be the formation of pellicular zone which in the light of the results under discussion will extend to more than 10 feet and if the free water-table is within the next 7 feet, there will be a direct connection between the capillary and the pellicular zones. If salts originally present in the soils have not been completely washed down to reach the water-table and from there disappear somehow these will move up again in a time period depending upon the cropping conditions and rotation which would be adopted. It may therefore be concluded from this discussion on the experimental results obtained in the laboratory that under the water-table conditions in the Punjab reclamation of thur lands may never be permanent. The cultivation of rice will have to be included in the rotation of crops whenever a scientific examination of the soil indicates an upward movement of salts. It would be far better to supplement these conclusions from field experiments to give a definite reply to the always asked question by the public about the permanency of reclamation. If the zemindar is aware of the real function of the reclamation operations and is educated to understand how a periodic rice cultivation would help to increase his prosperity there is no reason why he would not follow the instructions for the soil management. The land once reclaimed should not be neglected as there is every likelihood of its becoming "Thur" again. Reclamation of deteriorated soils in the province of Punjab has been in existence for a number of years. Although a lot of hard work has been put in, the ever increasing menace of Thur has out paced our workers. We have not been able to overtake this fast spreading disease. It is out of the scope of this paper to discuss the various reasons of our inability of making soil reclamation permanent and more useful. But there is no doubt that the question requires a careful consideration for proposing definite measures for reclamation of Thur lands.

Let us now consider the results of experiments on the soil profiles compacted to increasing dry-bulk density. The surface evaporation has affected to a greater depth in the profiles of higher dry-bulk density. The amount of the moisture lost in all the cases is practically the same in initial stage for a period of about four months but afterwards the rate is higher in profiles of low dry-bulk density. The total loss of moisture is lower in the case of high dry-bulk density.

The results are important from the engineering point of view as they give an indication that the soil material, compacted at high dry-bulk density for the construction of base or wearing courses, would retain moisture for a longer periods. In stabilized soil materials, if the compaction is carried out to the maximum attainable density, the initial moisture, which is essential for proper consolidation, would be retained longer than if the compaction has not been properly carried out. The performance of the material mainly depends upon the moisture condition it can retain. The maintenance of earth roads, kacha floors, earth aerodromes and canal banks is carried out by sprinkling water on soil surface from time to time. To give better service this moisture should not go out of the material under the effect of evaporation.

From the agriculture point of view the results are not less important. In the Punjab there are areas which are characterised by having a layer of hard soil at a variable depth from the natural surface. Such areas would neither allow the moisture to pass downward nor allow the surface evaporation to effect the formation of pellicular zone up to a greater depth. If such areas are saline, they can neither be easily reclaimed, nor allow the plant roots to penetrate through the stratum for healthy growth.

B. Experiments on Soil Blocks.

1. Movement of Moisture under unsaturated conditions in Soil—Soil system at various Initial Moistures. The amount of moisture passing through a soil section depends upon the forces of attraction which the soil particles have for water. By analogy with the conduction of heat and electricity, the flow of moisture would depend on the capillary conductivity and on the capillary potential (2) The relation between capillary potential and the moisture content of a soil could be measured by the determination of moisture-distribution in a vertical soil column with its lower face in contact with free water-table and the top protected from evaporation (2). When the capillary potential is zero the soil contains moisture to its full capacity and there is no more attraction in the soil particles for any additional moisture. If more moisture is added to the soil it would not be able to retain it, and the excess would move to strata where the capacity for the soil for holding moisture is still unsatisfied. In other words if a soil is at a lower moisture content than its field capacity it would take up moisture from a strata at a higher moisture content, thus initiating the moisture movement in the soil column. The moisture movement under these conditions would be controlled by the surface tension forces as it would be within the pellicular zone. The flow of moisture when the soil contains higher moisture than the field capacity would be governed by the gravitational forces.

Experimental. The moisture transmisson from a soil strata at a higher moisture content to that at a lower moisture content was studied by taking a typical Punjab soil after drying, powdering and passing it through one m.m. seive. Different amounts of moisture were added and the soil was thoroughly mixed with hand. Two such samples at different moisture contents were compacted in separate glass rings, 2.4 inches in length and 2 inches in diameter, open at both ends. The dry-bulk density was kept at 1.5. The circular soil blocks thus prepared were placed face to face with one another and pressed together slightly to bring them into complete contact. The two exposed faces of the blocks were waxed to prevent any loss of moisture due to evaporation. A number of such sets were prepared and allowed to remain under controlled conditions of temperature and humidity. The blocks were separated after 24 hours and the moisture contents determined. The results are given in Table IX. Another experiment on the same lines was carried out with the difference that while in the first experiment the soil block at a higher moisture content was placed at the top, in the second case the soil block of lower moisture content was placed on the top. The results of the second experiment are given in Table X.

Discussion of Results. It is quite evident that the moisture has moved from the soil at a higher moisture content to the soil at a lower moisture content irrespective of whether the soil at a lower moisture content was at the top or otherwise. The moisture movement has taken place within wide range of initial moisture content (6.6 % to 21.5 %).

A natural soil profile may be considered to be made up of soil strata differing in moisture contents and placed one over the other having a complete contact. The moisture movement would take place throughout the profile from the bottom where the profile is in contact with the water-table towards the top where the moisture content is very low due to surface evaporation. It is difficult to visualise as to how the moisture movement would not take place under any conditions as long as the soil profile has a moisture gradient continuously diminishing towards the top. The existence of a moisture gradient up to a depth of 11 feet has already been pointed out in experiments discussed in previous section, we may assume that there may be a possibility of the field capacity zone to be a point which may work as an insulating region or point between the pellicular zone and the capillary zone, but what would be the condition of the soil profile at the junction of the field capacity zone and the pellicular zone. The two portions, being at different moisture contents there will be a moisture movement from the soil at field capacity moisture to the soil at a lower moisture content. A similar explanation may be given for any point up to the capillary zone.

In all these experiments the moisture movement in the liquid phase has been studied. There may be a movement in the vapour phase depending upon the vapour pressure caused by the soil moisture. It would not only be interesting but useful to investigate if there is any moisture movement in the vapour phase. It is hoped that the whole outlook of the salt movement in soil profiles due to the moisture would be changed if an extensive study of moisture movement at very low moisture contents is undertaken. The subject being beyond the scope of the present contribution has been left out for a separate paper.

2. Quantitative Aspects of Moisture Movement in Soils under Unsaturated Conditions. The moisture movement under unsaturated ditions on the analogy of conduction of heat and electricity may be resented by the formula :—

$$Q = K.A. \frac{d\varnothing}{ds} \quad \ldots\ldots \quad (1)$$

re

Q = the discharge

A = the cross sectional area of the flow.

S = the distance in the direction of flow

K = a constant and

$\varnothing$ = the flow Potential, *i.e.*, the force with which the moisture is attracted to the soil.

The formula (1) is not of great practical value and Q is very difficult neasure, either in the laboratory or in the field, and unless Q is known, annot be calculated. As an alternative, the formula

$$Q = K.\ A.\ \frac{dM}{dS} \ldots\ldots (2)$$

y be used. In this M is the moisture content expressed as percentage soil volume or weight. As it is known that the potential depends on soil type, its compaction, temperature and moisture content, if the ee former are fixed, moisture content becomes a measure of potential, l its derivative a measure of the force causing the flow.

This important premise, can be utilized to derive the general iation of moisture movement in two dimensions in an unsaturated soil.

If the cross sectional area of the soil blocks is "A" in thickness S, npacted to a certain degree of compaction and certain initial moisture centages of $M-dM$ and $M+dM$ these soil blocks would have different isture contents of $M-pdM$ and $M+pdM$ after they have been in itact face to face for a time T. The value of K may then be determined m the relation —

$$K = \frac{1-p}{1+p}\ \frac{S^2}{T}$$

Experimental. Brass rings open on both ends, 1·5 inches in imeter, were closed by means of brass flangs. A piston was provided th a screw arrangements so that it could be adjusted at any depth from e open end. Soil was mixed with a known amount of moisture and mpacted in brass ring of which the depth was adjusted as required. As e volume of the block of soil was known, the density was adjusted by rying the amount of soil compacted in the ring.

A second ring was similarly filled but in this soil was kept at a lower oisture content. The two rings were put face to face and clamped at e joint. By means of screw arrangement provided with both the rings e soil blocks were pressed together very slightly, so that the two soil rfaces were in complete contact with each other.

A number of preliminary experiments were performed to work out the experimental details. To start with glass cylinders were used instead of brass rings but these could not be fitted with suitable screws. Aluminium could not stand the effect of moist soil.

(*i*) **Determination of time Factor**. A typical Punjab soil was dried and passed through 1 mm seive after powdering. A known amount of moisture was added and the soil blocks made in the brass moulds as described above. A number of such blocks were made and put in contact with one another in pairs. These were then detached after increasing intervals of time and moisture percentages were determined in the different soil blocks. The results are given in Tables XI and XII for two different cases, *i.e.*, in one case the soil at higher moisture content was kept at the top while in the other the soil at a lower moisture was kept at the top.

The results in both the cases show that moisture had moved from the soil at a higher moisture content to a soil at a lower moisture content. The decrease and the increase of moistures is nearly equal. A little difference here and there is due to experimental errors in carrying out the moisture estimations.

To ensure no loss of moisture from the soil blocks during the period of observations, the various sets were weighed from time to time and no change in weight was noticed. The maximum and minimum temperatures varied between 32.0°c and 36.0°c and the maximum difference in one day was of the order of 3.5°c.

There is gradual increase in the total moisture transferred with the passage of time and the rate of transfer of moisture rapidly decreases. This shows that with very low moisture differences the rate of transfer would be very slow indeed. Considering both the tables together it appears that there is a slight effect of gravity as the moisture movements have preferably taken place with the more moist soil at the top. But the effect is so small that for all practical purposes may be taken negligible when dealing with low moistures. The pull of attraction between the soil particles and the moisture at low initial moisture is far greater than the force of gravity. There is a state of equilibrium reached after five days.

(*ii*) **Determination of a suitable Thickness of the Soil Blocks.** A similar experiment was carried out by changing the thickness of the soil blocks by varying the depth of brass moulds with the help of screw arrangement. The observations were taken after the blocks were kept in contact with one another for a week. The results are presented in Table XIII. The decrease and increase of moisture is not the same in all the cases. There is no marked influence of the thickness of the soil blocks on the redistribution of moisture. The effect of gravity is almost absent. It was considered advisible to reduce the thickness of soil blocks to 1 c.m. to avoid differences in the loss and gain of moisture.

Determination of the Value of " K " :—

: value of " K " could be determined by making use of the formula

$$K = \frac{1-p}{1+p} \; \frac{S^2}{T}$$

From the theoretical consideration of the relation discussed in the :going and it would be seen that the value of " K " would end on the degree of compaction of the soil and the temperature which the experiments are carried out. The time factor T was :rmined by trial experiments and it was observed that 24 hours rval was quite suitable. A number of experiments at various peratures failed to show any effect of temperature.

The initial moisture content was varied from 5 per cent to 21 per cent ı a difference of about 2.5 per cent. Higher moisture than 21 per t could not be tried as the soil reached its liquid limit and beyond this sture stage blocks could not be made without deformation. The ılts given in Table XIV show that the value of " K " varies within e limits of. 12—·57 and the mean value is 0·34. The increase in the sture content of soil at lower initial moisture is not the same as the 'esponding decrease. The value of " K " changes with the change in the ial moisture but there is no regularity to bring out the relation between initial moisture and the value of " K."

The mean values of " K " at different dry-bulk densities are given in ıle XV. The experiments at higher degree of compaction of soil with r low and very high moisture contents could not be carried out ause firstly the desired dry-bulk density could not be attained and ındly the moisture squeezed out during compaction. The results show ncrease in the value of " K " with the increase in dry-bulk density.

In Table XV are given the value of " K " for soils containing different ounts of clay (·002 mm. particles). The amount of clay in the soil varied by the addition of requisite proportion of fine sand. The lts fail to show regularity to bring out the effect of clay in the value K."

(*iii*) **Objections and Sources of error in the Method.** The method pted for this study contains a number of accurate weighings and orate as well as sensitive manupulations of experimental details. nation of 1 c.m. thick soil blocks without deformation, keeping the al moisture content under control, the separation of the blocks after aining in contact and the estimation of moisture contents to a great ıracy are the main essentials of the procedure. The loss of initial sture during the formation of the blocks and the determination of sture contents are the chief sources of error in the method. The ideal ıod of overcoming these difficulties would be the invention of an omatic balance of Solly's type which would give moisture variations out taking out the soils from the brass rings. Some methods were l which showed that the initial weight of the rings and the soil blocks being of a high order the small changes in weight could not be easily determined by any sensitive spring balance. Further that the direct method of moisture estimation could not be improved upon.

The conclusions which may be drawn from this study are that the formula for moisture movement may be put down as

$$Q = 0.34A \frac{dM}{dS}$$

where Q = discharge in cc. per day.

A = cross sectional area in sq. cms.

M = Moisture content per cent by weight.

S = Distance in Cms.

There is no significant correlation of the co-efficient with temperature, soil type, etc.

The formula can be reduced in British units to

$$Q = \cdot 00037 \frac{dM}{dS}$$

where Q is in cubic feet per day and S is in feet. Expressing Q per year it will reduce to

$$Q = \cdot 00037 \times 365 \frac{dM}{dS}$$

$$= \cdot 14 \frac{dM}{dS}$$

A soil with the moisture content increasing from 5 per cent at the surface to 25 per cent at 5 feet depth, such might be expected with spring level at about 8 feet or more in case of clayey soils, would raise to the surface, about 3·4 inches of water in one year.

The original formula

$$Q = K A \frac{d\varnothing}{dS}$$

is dimensionally correct. The constant K and Q are not known but there is no doubt that both are functions of M. We can, therefore write :—

$$Q = f(M) A \frac{F(M)}{S}$$

and if this is identical with

$$Q = K A \frac{M}{S}$$

we have $KM = f(M) F(M)$

The details of the method and the experimental results mentioned above show that there may be errors in adopting such a procedure. It has also been pointed out that a more sensitive method of detecting small ıe value of " K " calculated by the help of the above relation are ːd in Table referred to above. The mean value for all these ments is ·36.

ıe values of all the quantities are positive and therefore the value of ld be positive and hence the moisture movement would always .ace from a soil strata at a higher moisture content to the other at r moisture content. The total discharge would depend upon the .ry potential in addition to the various soil factors.

General Conclusions

For moisture estimation in soils, tensiometer method is likely to ːrronuous results. Direct method of moisture estimation should ıpted as long as some other indirect satisfactory method is not ped.

Under certain conditions of soils profiles the transmission of may be restricted to such an extent that no water may add itself to :e W. T. within a reasonable time, even if a constant water head of is constantly maintained.

. In sandy soils the transmission of moisture from the natural e towards the sub-soil W. T. is easier than in clayey soils.

. A higher degree of compaction of a soil strata, which may be its al characteristic or of a small layer at variable depth from the al surface, hinders the movement of moisture.

. An appreciable amount of surface application reaches free W. T. a soil profiles is put under irrigation and if proper control is not ın the extension of soil reclamation projects on the one hand and wering of W. T. by some suitable means on the other, there is a :r of increasing waterlogging.

. The intensity of irrigation for various crops for a particular area or the same crop in different areas should be fixed, after taking into leration the soil characteristics and the climatic environments.

. The present system of water distribution needs a thoughtful leration, because of the questions of water requirements of various , the higher rate of production by increased irrigation intensity, soil .oration due to the presence of salts at variable depths from the al surface, the reclamation of saline soils during rice cultivation, the f water-table in the Province of the Punjab, and the most important , careful usage of available irrigation water by the cultivator.

3. The effect of the surface evaporation, which causes the formation ːllicular zone and the transmission of harmful salts from free W. T. ːds the natural surface of soil and the accumulation of salines, within ɔot zone of crops, is more in sandy soils and those having low dry-density.

). The formation of the pellicular zone extends beyond 10 feet ı in soil profiles.

10. The rise of capillary moisture has been observed up to a height of 7 feet in typical Punjab soil.

11. The existence of a "fixed capacity zone" has not been recognized in the various experiments carried out in glazed earthen pipes, and the capillary zone has been observed to be in contact with the pellicular zone.

12. The contention, that the salts once washed beyond 10 feet depth during leaching and rice cultivation, for reclamation of saline soils requires reconsideration, as there can be no guarantee for the Thur disappearing permanently. Under the effect of surface evaporation, the salts may reappear from depths of the order of 18 feet. Once reclaimed areas should be kept under keen observation, with proper crop rotation, which may include rice after a certain period, as revealed by the examination of distribution of salts from time to time.

13. Soils artificially compacted to high dry-bulk density retain moisture to a greater extent and as such are better stablized from engineering point of view.

14. Soil profiles having a high degree of compaction throughout or in a small layer, generally termed as hard pan, are neither easily reclamable nor useful for healthy crop growth.

15. Moisture movement in soil under unsaturated conditions can be worked out on the analogy of heat and electricity conduction.

16. The value of capillary potential (K) can be calculated for various types of soils under variable conditions.

17. The value of capillary potential being a positive and determinable quantity, there would be moisture movement within soil strata from a portion at a higher moisture content to that at lower moisture content.

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