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# WATERLOGGING IN WESTERN PUNJAB


By

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## CHAPTER I.

**Introductory.** Of the many problems causing great anxiety and concern to the Punjab Government and the public, waterlogging is not the least important. Despite all efforts, the sub-soil water-table still continues to rise. This not only reduces aeration of the soil with consequent adverse effect on the production of crops but it also increases evaporation and thus accelerates thur. Large sums of money are likely to be spent in the near future to meet this threat and so the time is opportune to make a fresh study of the problem.

2. **Historical.** A review of the various anti-waterlogging measures adopted in the Punjab has been given by Rai Bahadur Bawa Natha Singh.* This may be briefly summarised as follows.

**Period 1892-1905, Western Jumna Canal.** The situation was brought effectively under control by re-aligning irrigation channels that were obstructing drainages, introducing a more efficient system of distribution of supplies and providing an extensive system of surface drains throughout the affected area.

**Period 1908-1918, Lower Chenab Canal.** While the main emphasis was on surface drains, a push was given to the lining of main irrigation channels and about 12 miles scattered over different channels were lined. This was found to be prohibitive in cost and impossible of execution on a large scale and a subsequent examination revealed that the lining was fissured and cracked to such an extent that it became quite useless as a water proofing medium.

**Period 1918-1926** There was a lull in the activity owing to financial stringency resulting from the first World War.

**Period 1926-1933. Upper Chenab Canal.** Abnormal rains of 1926 made the situation worse and a number of measures such as provision of seepage drains along the Main Line, lowering the full supply of the Main Line, Tubewell Pumping, restriction of water supply for irrigation, provision of hydrautomats and pumping from Gujranwala and Sheikhupura ponds were adopted in the Upper Chenab Canal area. In the words of Rai Bahadur Bawa Natha Singh, "the policy was more dictated by panic than as a result of a well thought-out scheme. Consequently those areas were taken where complaints were

*Paper No. 197, Proceedings of the Punjab Engineering Congress.

loudest or damage was serious." The seepage drains along the Main Line had subsequently to be replaced by drains constructed at some distance from the Main Line as they increased seepage from the canal. Lowering of the water surface level of the Main Line had only a local effect extending not more than half a mile from the Main Line. Tubewells had also a purely local effect, which did not last after the pumping was stopped. Restriction of water supply for irrigation had very little effect on the water-table. Pumping from ponds was useful for the control of water-table locally near large towns but was quite useless for lowering the general water-table.

**1933-1941.** Heavy rains of 1933 and 1935 in Chaj and Rechna Doabs had a very adverse effect on the sub-soil water-table in the two Doabs and investigations were made for a very large number of new drains during the period 1933-36, the drains being actually constructed in the quinquenium 1936-1941.

**1944-46.** Heavy rainfall in 1944 again focussed attention on this important problem and, as a result, the Rasul Hydel Scheme, which will provide power to 1860 tubewells to be constructed in the Rechna and Chaj Doabs, has been taken in hand. A large number of surface drains are also being constructed in the two Doabs.

3. **Method of Analysis.** There has been much argument in the past regarding the relative responsibility of rainfall and irrigation towards the rise or the sub-soil water-table. While some authorities like Professor Wilsdon and Dr. McKenzie Taylor have held that the monsoon rainfall is primarily responsible for this rise, others, like Rai Bahadur Bawa Natha Singh are of the opinion that waterlogging is, to a large extent, due to seepage from the canal system. Engineers are far from agreed even now regarding the share contributed by each of these two factors. It is, therefore, proposed to analyse all the data available on the subject and to assess the contribution made by each of the factors.

Sources of inflow into the soil are :—

(*a*) Seepage from canals and branches.

(*b*) Seepage from distributaries.

(*c*) Seepage from watercourses.

(*d*) Absorption from the fields

(*e*) Absorption from rainfall

(*f*) Seepage from rivers.

(*g*) Sub-soil flow from upper regions.

The sources of outflow are :—

(*a*) Evaporation from soil

(*b*) Transpiration by crops in canal irrigated areas.

(*c*) Transpiration by barani and sailab crops.

(*d*) Surface and seepage drains.

(*e*) Irrigation from wells.

(*f*) Infiltration into the rivers.

(*g*) Sub-soil flow to the lower regions of the Doabs.

These factors have been studied in detail in Chapters III to VI and it has been shown in Chapter VI that inflow and the outflow into the soil balance each other economies of different anti-waterlogging measures, such as restriction of supply for irrigation, lining of channels, tubewell pumping in local areas, lowering of full supply level of irrigation channels, seepage drains along canals, seepage drains away from canals, surface drains, porous gallery, have been studied in Chapter VII. Before tackling the main problem, however, it is shown in Chapter II how movement of water takes place in soils.

## CHAPTER II

## MOVEMENT OF MOISTURE IN SOILS

1. **Hygroscopic Moisture.** If a thoroughly dried soil be exposed to air, which is always somewhat moist, the attraction between the soil surface and the water vapour in the air immediately becomes active and some of the water vapour condenses upon the surface of the soil grains. The water thus taken increases as the fineness of the sand increases. Thus Lyon and Fippin* found that very fine sand absorbed 1·8 per cent of hygroscopic moisture, silt 7·3 per cent and clay 16.5 per cent.

2. **Wilting Co-efficient.** If the soil moisture in a cropped field is less than a certain quantity depending upon the texture of the soil, the plants growing on the soil begin to wilt and their growth practically ceases. This is known as the wilting co-efficient and is about 1½ times the hygroscopic moisture. This co-efficient also varies with the soil. In sandy soils, it is low, often less than 3 per cent. In clay soils, it is often more than 16 per cent and in extremely heavy clay as much as 30 per cent. For average loam, it is about 10 per cent.

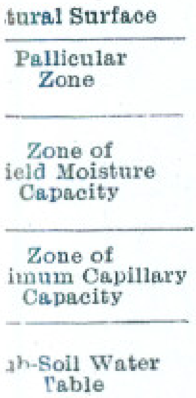
3. **Lento-capillary Point.** Percentage of moisture in the soil, above which water is readily available to plants so that they can secure their water with the least expenditure of energy, has been called Lento-capillary point by Widtsoe. For coarse soil, it is below 10 per cent for fine clay soil it may be 20 per cent or more : and for average loam soil it is 12 to 13 per cent. Irrigation is needed as soon as the moisture falls below this limit.

4. **Pallicular Zone** is the zone below N. S., where the percentage of moisture is less than field moisture capacity (para 4-A) and in which evaporation and transpiration by plants are effective. For sketch see para 5 below. Its thickness depends upon the nature of the soil and kind of vegetation.

4-A. **Field Moisture capacity.** This may be defined as the percentage of volume of water retained against gravity to total volume of material or, as defined by the Soil Scientists, the percentage of weight of water retained against gravity to the weight of the sample when dry when the top foot is kept in a saturated condition. This also varies with the soil. For a soil with a maximum capillary capacity of 25 per cent the field moisture capacity is 18 to 19 per cent while for a soil with a maximum capillary capacity of 32 to 39 per cent it varies from 22 to 29 per cent. The zone of field moisture capacity is situated between the pallicular zone and the zone of maximum capillary capacity (para 5). See also sketch in para 5.

5. **Maximum Capillary Capacity.** As more water is added above Lento-capillary point, the force with which the outer layer of water is

*Principles of Irrigation practice by Widtsoe, page 13.




held, becomes weaker and weaker. At last a point is reached when no more water can be taken up. This is the percentage corresponding to capillary capacity and varies with the soil. For coarse sandy soil, it is 10 to 12 per cent; for fine clay soil, 30 to 40 per cent and for average loam soil, not far from 23 per cent. Zone of maximum capillary capacity occurs just above the ground water and its thickness depends upon the nature of the soil, which in turn governs the height to which water can rise by capillarity. The marginal sketch shows the pallicular zone, zone of field moisture capacity and the zone of maximum capillary capacity.

6. **Downward movement of water**. C. F. Shaws' *experiments indicate that when water is added to a uniform soil and allowed to seep downward, a condition of distribution is reached at which the moisture content at all depths is approximately the same. Soil moisture must be completely built to field capacity before appreciable movement of water takes place. Under irrigated conditions, Veihmeyer **has shown that water applied to the soil surface moistens the soil to field capacity to a depth for which the water supplied is sufficient. This moisture content is established throughout the entire depth of soil penetrated by water.

Within the pallicular zone water is removed by transpiration and evaporation. After removal of this water, depleted films must be built up before further downward seepage takes place. Progressive regeneration of films takes place on an even front called the Pallicular front by Tolman*. Below the pallicular zone, transpiration is inactive and evaporation is very slight and except under unusual conditions, water is not abstracted. Hence after the flow reaches the base of the pallicular zone free passage of gravity water can take place to the water-table. In this connection, results of certain experiments given by H. R. Shaw† regarding the moisture content of Soil at various depths when calculated weight of water to bring the dry soil to required percentage of moisture was added to surface, will not be free from interest.

TABLE I.

| Sufficient water added to bring average soil moisture to :— | 10% | 20% | 25% | 30% | 40% |
|---|---|---|---|---|---|
| Depth below surface | Percentage of moisture at the depth given in Col: 1 | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 |
| 1′ | 27·5 | 31·0 | 32·5 | 35·9 | 38·1 |
| 2′ | 26·3 | 30·8 | 32·4 | 33·5 | 37·6 |
| 3′ | 17·7 | 30·2 | 32·6 | 33·6 | 39·2 |
| 4′ | 3·7 | 27·6 | 31·8 | 33·4 | 42·8 |
| 5′ | 0·8 | 12·9 | 27·7 | 31·4 | 39·7 |
| 6′ | 0 9 | 2·5 | 11·2 | 24·0 | 37·6 |
| 7′ | 0·0 | 1·0 | 3·7 | 11·0 | 35·9 |

*Ground water by Tolman.

**Some aspects of the Physics of Water-Table rise and salt Movement in the Soil under irrigated conditions by Dr. Mckenzie Taylor.

†Distribution of Soil Moisture after Irrigation by H. R. Shaw.

Some interesting experiments *have been performed at Lethridge, Canada, regarding the depth of penetration of a 6″ irrigation. The depth to which water penetrated was determined by comparing the percentage of moisture in each foot of the top 6′ of soil before irrigation and after irrigation. The soil of the different depths secured after irrigation that had appreciably more moisture than the soil from the same depth before irrigation, was considered to have received the additional water from the irrigation, *i.e.*, the water had penetrated to that depth. The soil samples taken before irrigation were secured either on the day before irrigation or on the day that the water was applied, Samples after irrigation were obtained from 3 to 5 days after irrigation. Table II shows the data :—

TABLE II.

**Relation of the depth of penetration of a 6″ irrigation to the percentage of moisture in the soil, immediately before irrigation :—**

Name of Crop : Wheat.

| Percentage of moisture in the soil before irrigation. | Depth of penetration (Ft :) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | Total |
| | Number of cases where water penetrated to depth given above. | | | | | | |
| 7·1— 8·0 | ... | ... | ... | ... | ... | 1 | 1 |
| 8·1— 9·0 | ... | ... | 2 | 3 | 2 | 1 | 8 |
| 9·1—10·0 | ... | ... | 4 | ... | ... | 3 | 7 |
| 10·1—11·0 | 1 | 5 | 4 | ... | ... | 7 | 17 |
| 11·1—12·0 | ... | 3 | 2 | 6 | 3 | 13 | 27 |
| 12·1—13·0 | ... | 4 | 3 | 4 | 5 | 20 | 36 |
| 13·1—14·0 | ... | 1 | 1 | ... | 1 | 24 | 27 |
| 14·1—15·0 | ... | ... | 1 | ... | ... | 15 | 16 |
| 15·1—16·0 | ... | 2 | 2 | ... | ... | 29 | 33 |
| 16·1—17·0 | ... | ... | ... | ... | ... | 30 | 30 |
| 17·1—18·0 | ... | ... | ... | ... | ... | 18 | 18 |
| 18·1—19·0 | ... | ... | ... | ... | ... | 9 | 9 |
| 19·1—20·0 | ... | ... | ... | 1 | ... | 10 | 11 |
| 20·1—21·0 | ... | ... | ... | ... | ... | 1 | 1 |
| 21·1—22·0 | ... | ... | ... | ... | ... | ... | ... |
| 22·1—23·0 | ... | ... | ... | ... | 1 | 2 | 3 |
| 23·1—24·0 | ... | ... | ... | ... | 1 | ... | 1 |

It will thus be seen from Tables I and II that greater the quantity of water added to the surface the greater is the depth up to which water reaches and higher the initial saturation of soil, the less water it will retain and the more water will pass to the sub-soil water-table. *This conclusion is very important and may be specially noted.*

Special attention is invited to the word "appreciable" used in line 5 of this paragraph. If two soil Samples A and B with varying moisture percentages (Sample A having higher percentage of moisture than Sample

*Use of Irrigation Water on Farm Crops by A. E. Palmer.

B) are placed in contact with each other and insulated against other influences, movement of moisture takes place from Sample A to Sample B as the attraction of Sample B for moisture is greater than that of Sample A. This movement, however, is extremely slow if the moisture percentage of Sample A is less than its field moisture capacity. More the difference between the actual moisture and the field moisture capacity of Sample A, the greater is the difficulty with which moisture will be released by Sample A. The movement also depends upon the difference of moisture in Samples A and B. The greater this difference, the faster is the movement. "Appreciable" movement takes place only when Sample A is at its field moisture capacity.

6. (A) **Effect of irrigation on percentage of moisture at various depths.** A study of what happens when land is irrigated will be of interest. In this connection, profile given in Table V of Dr. Mckenzie Taylor's note* will be studied. Moisture distribution of the profile is given in Table III below.

TABLE III.

**Moisture distribution at various depths in a soil profile which has never been irrigated.**

| Depth in feet below N. S. | | Percentage of moisture in soil. |
|---|---|---|
| 1′ | | 7.2 |
| 2′ | | 10.4 |
| 3′ | | 11.3 |
| 4′ | | 11.8 |
| 5′ | | 11.7 |
| 6′ | | 12.2 |
| 7′ | | 13.6 |
| 8′ | | 10.9 |
| 9′ | | 14.6 |
| 10′ | | 16.5 |
| 11′ | | 19.0 |
| 12′ | | 18.4 |
| 13′ | | 20.2 |
| 14′ | | 19.8 |
| 15′ | | 20.0 |
| 16′ | | 18.0 |
| 17′ | | 20.9 |
| 18′ | | 21.0 |
| 19′ | | 22.1 |
| 20′ | | 22.9 |
| 21′ | Water-table 22′ deep | 24.8 |

*Some Aspects of the Physics of water-table rise and salt movement in the soil under irrigated conditions by Dr. Mckenzie Taylor. Proceedings of the India Academy of Sciences, 1940.

Plate I shows the percentage of moisture at various depths.

The pallicular zone occupies the first ten feet and there is a well marked zone of field moisture capacity between the 11th and the 16th foot. 17th to 21st feet are in the zone of maximum capillary capacity, When the field is irrigated the first foot attains maximum capillary capacity of say 23 per cent but, as soon as, this percentage rises above 10.4 per cent (percentage of moisture of second foot), movement of moisture starts from the first to the second foot but it is very slow till its moisture rises to field capacity when rapid movement results. As soon as moisture of second foot rises above 11. 3 per cent (percentage of moisture of third foot), a moisture gradient is established and slow movement starts from second to third foot, rapid movement taking place only when the moisture of second foot goes above field capacity. The same process is repeated until moisture of 10th foot goes above field capacity. As 11th foot is at field capacity no movement can take place from 10th to 11th foot until the 10th foot is at field capacity. When this happens, any moisture added to the 10th foot will go straight to the water-table as 11th to 21st feet are at or above field capacity and by definition (Para 4-A) no more water can be held against gravity. It should be noted that 10th foot cannot attain its field capacity until the 9th foot is at field capacity, as, should the moisture in 9th foot be less than that of 10th foot, the moisture gradient will be from the 10th to the 9th foot, and not vice versa. Same reasoning applies to the horizons above the 9th foot. This means that no water can be added to the water-table until sufficient water has been added to bring all the horizons from the surface to the 10th foot to their field capacity.

After irrigation ceases, process of evaporation and transpiration by plants begins. As soon as the moisture in the first foot is less than that of the second foot, a reverse gradient is established and movement takes place from the second to the first foot. This process is repeated until the 10th foot is reached. No movement can take place from 11th to 10th foot as 11th foot is beyond the effect of evaporation, and no water can be brought from the 11th foot to the surface by capillarity. When irrigation is given again, the process already, described is repeated. Normally, the depth of irrigation given is not sufficient to bring all the horizons to the 10th foot to their field capacity and no water can be added to the water-table. Should heavy rainfall occur after an irrigation, it is possible, however, that sufficient water may be added to bring all the horizons to their field capacity. In this case, some water will be added to the water-table.

A few examples of moisture distribution in a soil profile when water-table is at various depths below natural surface, will also be of interest. These are reproduced from Dr. Mckenzie Taylor's note*.

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*Some aspects of the physics of water-table rise and salt movements in the soil under irrigated conditions.

TABLE IV.

**Water-table within 6′ of the surface.**

| Depth in feet | Moisture percentage. | |
|---|---|---|
| 1 | 15.2 | Water-Table 5′—9″ |
| 2 | 21.2 | |
| 3 | 19.2 | |
| 4 | 24.7 | |
| 5 | 26.1 | |
| 6 | 29.1 | |

In this case, there is no well marked zone of field moisture capacity. The 2nd and 3rd feet are below and the 4th and 5th feet are above the field moisture capacity, due to the high sub-soil water-table.

TABLE V.

**Water-table being situated below a depth of 10′.**

| Depth in feet. | Moisture percentage. |
|---|---|
| 1 | 6.2 |
| 2 | 4.1 |
| 3 | 5.5 |
| 4 | 8.1 |
| 5 | 9.1 |
| 6 | 13.2 |
| 7 | 15.2 |
| 8 | 23.2 |
| 9 | 26.4 |
| 10 | 25.4 |
| 11 | 24.0 |
| 12 | 26.4 |
| 13 | 29.3 |
| 14 | 34.5 |
| 15 | 39.8 |

Here the pallicular zone (that is the zone where evaporation and transpiration by plants are effective) has extended to the 8th foot. Between the 8th and 12th feet, the soil is at field capacity. The 13th and 14th feet are in the capillary zone and the water-table was encountered at the 15th feet.

**Seepage under saturated and unsaturated conditions.** Experiments on seepage losses under saturated and unsaturated conditions were carried out a few years ago by Nand Gopal and K.R. Sharma showed and the results

*Paper No. 209 Punjab Engineering Congress, 1938, and
Paper No. 231 Punjab Engineering Congress, 1940.

that when sub-soil water-table is not lower than about 3′ below bed level, seepage loss varied directly as the head, that is, the difference of water surface level in the canal and the sub-soil water-table. It did not depend upon the depth of the channel. The maximum loss occurred when the sub-soil water-table was at a distance of 3½′ below bed in the case of the falling water-table and 2½′ when the sub-soil water-table is rising. Loss in cusecs per million square feet was approximately equal to the head in feet.

Conditions of partial saturation occurred when the spring level was from 5′ to about 3′ below bed. Losses rapidly declined from the critical position giving the maximum losses in the saturated phase.

The soil may be said to be unsaturated when the water-table is more than 5′ below bed. Experiments were carried out up to 7′ below bed and it was found that the absorption loss remained constant both in the case of rising as well as falling water-tables. The loss did not depend upon the head. The depth of the channel did not also directly affect the loss except that it tended to increase the area of sides and consequently the area exposed to evaporation. The losses depended upon the strata and were of the order of 2 to 5 cusecs per million square feet.

The limits of saturated, partially saturated and unsaturated zones given above apply only to the particular case of the experiments. They are not necessarily the same where the conditions are different. More experiments are needed to determine these for other conditions.

Movement of water also depends upon chemical reactions that take place between the soil particles and the salts dissolved in the soil solution.

**8. Depth up to which evaporation and transpiration by plants are effective.** Mitscheralisch (1901) calculated on theoretical grounds that the maximum possible capillary rise in heavy clay and loam can be two miles.

Sir David Hall (1912) supported the idea but considered that movement may be expected from a depth of 200.′

Keen estimated that in an "ideal" clay capillarity would be effective over a theoretical maximum depth of 150.′

Field and experimental evidence does not fortunately support these theories. When tubes containing dry soil are placed with their lower ends in water, capillary rise occurs but the rise, according to Teakle and Bervill,* is generally of the order of 2 to 3 feet. More powdry and silty soils are more active and may raise water to a height of 4′ to 5′.

*Movement of Soluble Salts in Soil under light rainfall conditions by Teakle and Bervill.

Leather* found at Pusa that the maximum distance from which water moved upwards was 7′.

Vaidhayanathan and Luthra** found that water could be brought up to the surface from a depth of 22′ but the quantity or water thus evaporated was very little.

It has been found that deterioration of soil due to salinity may take place when the water-table reaches a depth of 13′ from the surface.†

An interesting series of experiments by Shaw and Smith provide valuable data for sandy loam and loam soils. Columns of soil 4′ to 10′ high at field capacity were placed in water and a current of warm air was gently blown across the surface of the soil. The resulting loss of water measured from free water surface showed that the loss was rapid when the water-table was within 4′ of the surface. Less loss occurred when the column of soil was 6′ above the free water level. A significant loss was measured in the loam soil from a depth of 8′. Practically no loss was observed when the water-table was at 10′.

From field tests in Washington, Thom and Holtz‡ concluded that the depth from which field crops took moisture was: wheat 9′, oats 8½′, barley 8′, peas 6′, millets 5½′, corn 5′ and beans 5′. They state "that crops that took the soil moisture from the greatest depth had also the greatest water requirements."

It may thus be stated that normally evaporation and transpiration by plants are effective for a depth of not more than 10′ below natural surface.

**9. Evaporation from free water surface.** This depends upon :—

(*o*) Temperature of the air.

(*b*) Sunshine.

(*c*) Relative humidity.

(*d*) Velocity of wind.

Higher the temperature, and more the sunshine, less is the humidity; higher the velocity of the wind, the more is the evaporation.

Buckley∅ gives the loss noted below from evaporation alone for Pashan Tank near Poona.

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*Memoirs of the Department of Agriculture in India Chemical Series Vol. 1 No. 6. The loss of water from soil during dry weather by Leather.

**Study of the Evaporation of water from a soil surface withe reference to the fluctuations of water-table.

†Annual Report of Punjab Irrigation Research Institute, 1936.

‡Use of IrrigationWater on Farm Crops by A. E. Palmer.

∅Irrigation Pocket Book by R. B. Buckley.

TABLE VI.

**Loss from evaporation—Pashan Tank near Poona.**

| Name of Month. | Daily evaporation loss in inches. |
|---|---|
| October | 0.25" |
| November | 0.19" |
| December | 0.14" |
| January | 0.17" |
| February | 0.14" |
| March | 0.17" |
| April | 0.27" |
| May | 0.38" |

Table VII* was prepared by the Engineer In-charge of the Foy Sagar Reservoir in Ajmere.

TABLE VII.

**Loss from evaporation --Foy Sagar Reservoir Ajmere.**

| Season. | | Vertical loss in feet from the surface of the tank. |
|---|---|---|
| October to March. | | 2.73' |
| April to June | | 3.40' |
| July to September | | 0.79' |
| | Total for the year= | 6.92'=83.04' |

This gives a daily loss of 0.20" from October to March and 0.40" from April to June.

For the Bangalore Tank, the evaporation and absorption loss varies from 0.25" to 0.37" per day.

Table VIII* gives the evaporation loss from the surface of Assuan Reservoir in Egypt.

*Irrigation Pocket Book by R. B. Buckley.

TABLE VIII.

**Loss from evaporation—Assuan Reservoir in Egypt.**

| Name of Month | Daily evaporation loss in inches |
|---|---|
| January | 0.17 |
| February | 0.20 |
| March | 0.26 |
| April | 0.32 |
| May | 0.36 |
| June | 0.42 |
| July | 0.42 |
| August | 0.40 |
| Septemper | 0.33 |
| October | 0.31 |
| November | 0.24 |
| December | 0.16 |

Mean loss for June to September is 0.39″ and for October to May, it is 0.25″, Total loss for the year is 108.33″.

Table IX* gives the average daily evaporation from free water surface (during rainless days) at Lyallpur for the years 1941, 1942 and 1943.

TABLE IX.

| Name of Month | Daily evaporation loss in inches from free water surface at Lyallpur | | | |
|---|---|---|---|---|
| | 1941 | 1942 | 1943 | Average |
| January ... | 0·13 | 0·11 | 0·09 | 0·11 |
| February ... | 0·18 | 0·13 | 0·16 | 0 18 |
| March ... | 0·30 | 0·26 | Not available | 0·28 |
| April ... | 0·46 | 0·48 | 0·38 | 0·44 |
| May ... | 0·63 | 0·54 | 0·47 | 0·55 |
| June ... | 0·62 | 0·57 | 0·54 | 0·58 |
| July ... | 0·43 | 0·42 | 0·43 | 0·44 |
| August ... | 0·40 | 0·37 | 0·40 | 0·39 |
| September ... | 0·33 | 0·32 | 0·37 | 0·34 |
| October ... | 0·30 | 0·26 | 0·33 | 0·30 |
| November ... | 0·19 | 0·18 | 0·18 | 0·18 |
| December ... | 0·12 | 0·12 | 0·12 | 0·12 |

*Data received with letter from the Principal, Agricultural College Lyallpur, to the address of Officer on Special Duty (West), I. B.

| | | |
|---|---|---|
| Mean daily loss June to September | ... | 0.44″ |
| Mean daily loss October to May | ... | 0.27″ |
| Total loss June to September | ... | 53.68″ |
| Total loss October to May | ... | 65.61″ |
| Total loss for the year | ... | 119.29″ |

This loss is on the high side as the size of the evaporimeter used (4″ diameter) was too small. It has been found by White* in Escanlante Valley, Utah, that evaporation from 4′ diameter evaporimeter is 1.5 times of the evaporation from a 12′ diameter evaporimeter and he has further estimated that evaporation from a large surface is 99% of that given by a 12′ diameter pan.

Evaporation loss in U. C. C. and U. J. C. areas where the rainfall and the humidity are higher than at Lyallpur, will be less.

**10. Evaporation from soils.** This depends upon a number of factor :—

(*a*) **Nature of Soil.** The finer the texture of the soil, the more rapidly does the water move upwards to be changed into vapour. The darker the colour of the soil the more rapid is the evaporation, for dark coloured soils absorb the heat and the sunshine much more quickly than do light coloured ones. The richer the soil is in soluble salts the slower is the evaporation of water. For that reason, evaporation from alkali lands is low.

(*b*) **Meteorological conditions.** such as :—

(1) temperature, (2) sunshine, (3) relative humidity, (4) winds and (5) showers.

The higher the temperature the more rapid is the conversion of water into water vapour. Of almost equal importance is the intensity and quantity of sunshine. Shade is extremely effective in checking evaporation. The drier the air the more rapidly will it take up water vapour. Winds have a strong drying effect on soils, particularly in parts where the humidity is low. Showers by establishing capillary connection with the lower soil layers hasten evaporation.

(*c*) **Initial percentage of water.** The wetter the soil is at the surface the more rapid is water evaporated from it. This a very important factor.

(*d*) **Conditions of top soil.** Evaporation decreases if the top soil is cultivated at frequent intervals. On the other hand, rolling increases evaporation as it compacts the top soil.

*A method of estimating ground water supply based on discharge by plants and evaporation from soils by W. A. White. Contribution to the Hydrology of U. S. A. 1932.

(*e*) **Depth of sub-soil water-table below natural surface.** The less the depth of water-table is below the natural surface the more is the evaporation loss.

Table X* gives the average evaporation from water-logged soils at Davis, California, expressed in inches per day.

Table X.

**Average evaporation from waterlogged soils at Davis, California.**

| Depth of water below natural surface | 1936 | May 15 to September 1, 1937 | March 29 to November 10, 1937 |
|---|---|---|---|
| feet | inch/day | inch/day | inch/day |
| 0.0 | 0.328 | 0.317 | 0.216 |
| 0.5 | 0.215 | 0.230 | 0.182 |
| 1.0 | 0.209 | 0.194 | 0.162 |
| 1.5 | 0.093 | 0.086 | 0.076 |
| 2.0 | 0.079 | 0.055 | 0.051 |
| 3.0 | ... | ... | 0.026 |
| 4.8 | ... | ... | 0.016 |

A similar result was found by Ramdas and Malik** of the Indian Meteorological Department, Poona Metallic cylinders 5″ in diameter and containing soil columns 6″, 1′, 1½′, 2′ and 3′ in length were kept with their perforated bottoms in contact with water in a close fitting reservoir. Evaporimeters were weighed daily at 8-0 a.m., replenished with water up to a reference mark on a side tube of glass and weighed again. Difference gives the actual loss of water by evaporation from the upper surface of the soil column.

*Evaporation from Soils and Transpiration by F. J. Veihmeyer.

**Loss of water by evaporation from the Upper Surfaces of soil columns resting on a water-table, Current Science June 1939,

Table XI gives the results :—

TABLE XI.

**Mean daily evaporation from top of Soil columns at Poona.**

| Month | Type of Soil | Mean daily evaporation in inches from the top of Soil columns with depths of | | | | | Piche evaporimeter 4′ above ground |
|---|---|---|---|---|---|---|---|
| | | 6″ | 1′ | 1½′ | 2′ | 3′ | |
| January 1939 | Poona Soil | ·30 | ·27 | ·18 | ·12 | ·01 | |
| | "Bari" Soil from Punjab | ·05 | ·02 | ·02 | ·01 | ·01 | ·45 |
| | Punjab Soil (Normal) | ·29 | ·23 | ·21 | ·18 | ·09 | |
| February 1939 | Poona Soil | ·30 | ·34 | ·22 | ·15 | ·02 | |
| | "Bari" Soil from Punjab | ·06 | ·02 | ·02 | ·02 | ·01 | ·50 |
| | Punjab Soil (Normal) | ·37 | ·26 | ·22 | ·18 | ·09 | |
| March 1939 | Poona Soil | ·48 | ·41 | ·23 | ·16 | ·02 | |
| | "Bari" Soil from Punjab | ·05 | ·03 | ·03 | ·02 | ·01 | ·71 |
| | Punjab Soil (Normal) | ·43 | ·30 | ·21 | ·17 | ·08 | |

Interesting experiments have also been carried out by W. N. White* in Escanlante Valley, Utah, which is a closed valley 90 miles long, 5 to 25 miles wide, area 1,000 square miles. The altitude of the valley floor is 4800 to 5500′ while the surrounding mountain are at R. L. 6500 to 10,000. Average temperature May to October in 62.5 F. Rainfall in April to October, 1927 was 5.10″. The evaporation losses from brown clay (undisturbed soil) are given in Table XII.

*A method of estimating ground water supply based on discharge by Plants and evaporation from soil by W. N. White.

TABLE XII.

**Evaporation from soil—Escanlante Valley, Utah.**

| Period | Average depth to water-table in inches. | Evaporation depth in inches | Percent of evaporation from water surface of 12 foot pan. |
|---|---|---|---|
| **1927 :** | | | |
| May | 20 | 1.57 | 19 |
| June | 19 | 1.77 | 17 |
| July | 20 | 1.80 | 18 |
| August | 33 | 0.91 | 10 |
| September | 35 | 0.54 | 8 |
| October | 22 | 0.39 | 9 |
| May to September | 25 | 6.59 | 14 |
| Average daily evaporation :— | | 0.05″ | |

Widtsoe* gives the following figures for evaporation from bare soils at Utah Agricultural College Experimental Station.

TABLE XIII.

**Evaporation from bare soils at Utah (U. S. A.).**

| Kind of Soil | Degree of saturation of soil. | Evaporation from bare soil in inches | Period |
|---|---|---|---|
| Sandy | 15% | 15.4″ | July to September 83 days |
| Loam | 20% | 7.0″ | ,, ,, |
| Clay | 30% | 21-0″ | ,, ,, |
| Loam | 10% | 3″ | July to September 92 days |
| Loam | 15% | 4″ | ,, ,, |
| Loam | 20% | 11.0″ | ,, ,, |

Luthra** has compared the rate of transpiration with evaporation and maximum temperature at Lyallpur and has found a high correlation between transpiration and these factors. Nearly 2076 tons of water were

*Factors influencing Evaporation and Transpiration by J. A. Widtsoe Utah Agricultural College Experimental Station Bulletin No. 105.

**J. C. Luthra "Water requirements of crop and an appreciation of the present position with suggestions for the future.'' Proceedings of the Second Meeting of Crops and Soil Wings of the Board of Agriculture and Animal Husbandry in India, 1937.

lost by transpiration from an acre of cotton crop during the period of growth. Total water applied to the crop was estimated at about 2,837 tons. This gives transpiration loss as 20.3″ and evapo-transpiration loss as 27.6″ or loss by evaporation alone as 7.3″.

**11. Transpiration by plants.** This depends upon :—

1. Initial percentage of soil moisture.
2. Distribution of water in the soil.
3. Time.
4. Depth of soil.
5. Physical composition of soil.
6. Chemical composition of soil.
7. Ploughing.
8. Cultivation.
9. Manuring.
10. Vigour of plants.
11. Development of root system.
12. Age of plants.
13. Nature of crops.
14. Season, including temperature, sun-shine, humidity and winds.

**Initial percentage of soil moisture.** The higher the initial percentage of moisture in the soil the greater is the transpiration by plants. A large number of experiments have been carried out at Utah Agricultural College Farm by Widtsoe*. Results of some of the experiments are recorded below.

TABLE XIV.

**Evaporation from bare soils and transpiration by various crops—Soil College Loam.**

| Degree of saturation | Evaporation from bare soil | Transpiration by | | | |
|---|---|---|---|---|---|
| | | Wheat | Corn | Peas | Sugar Beet |
| 10% | 3″ | 9″ | 10″ | 12″ | 12″ |
| 15% | 4″ | 22″ | 17″ | 19″ | 28″ |
| 20% | 11″ | 36′ | 35″ | 26″ | 47″ |

Number of days—92

*Utah Agricultural College Experimental Station Bulletin No. 105. Factors influencing evaporation and Transpiration by J, A. Widtsoe.

TABLE XV.

**Transpiration by Wheat from Sandy and clayey soils for different saturations.**

| Nature of Soil | Degree of Saturation | Transpiration by Wheat in inches of water used |
|---|---|---|
| *Sand* | 7.5 | 12 |
| | 10 | 17 |
| | 15 | 22 |
| *Clay* | 20 | 15 |
| | 25 | 19 |
| | 30 | 25 |

It will be seen that the transpiration increases as the soil becomes more saturated.

B. N. Singh and B. R. Singh* have carried out similar experiments at Benares Experimental Station and the results are recorded in Table XVI.

TABLE XVI.

**Weekly Transpiration **under varying soil moisture contents. (Crop Wheat).**

| Soil moisture in percentage of water holding capacity | Seedling Stage | 28 days after germination | 56 days after germination |
|---|---|---|---|
| 25 | 392 | 376 | 238 |
| 31 | 509 | 485 | 288 |
| 37 | 625 | 576 | 349 |
| 43 | 703 | 625 | 428 |
| 50 | 805 | 712 | 486 |
| 55 | 696 | 767 | 598 |
| 60 | 1,004 | 839 | 625 |
| 65 | 1,098 | 995 | 658 |
| 70 | 1,206 | 1,076 | 715 |
| 80 | 1,276 | 1,105 | 792 |
| 90 | 1,271 | 1,118 | 726 |
| 100 | 1,278 | 1,122 | 796 |

These experiments also prove that the the higher the initial percentage of moisture the greater are the transpiration losses.

*"Growth and Water Requirements of Crop Plants in Relation to Soil Moisture" by B. N. Singh, D.Sc. and B. R. Singh, M.Sc., Proceedings of India Academy of Science, November, 1936

**Calculated per 1,000 sq. em. of leaf area.

**Distribution of water in the Soil.** The distribution of water in the soil is also important in determining the rate at which plants use water. Two soils may each contain approximately the same percentage of water to say a depth of 8′ but the distribution may be different. In such a case more water is lost in the soil in which the water is heaped up near the surface.

**Time.** The rate of loss of soil moisture becomes smaller and smaller as time goes on. In the beginning when the soil is moist much water is lost. As the soil becomes drier loss of moisture decreases. This follows from the law of initial percentage of soil moisture.

**Depth of Soil.** The deeper the soil, the average percentage of soil moisture being the same, the larger is the loss of water in a given period of time.

**Physical Composition of Soil.** Water will be absorbed at a lower rate from a fine soil than from a coarse grained soil. In case of fine soil, a given quantity of water will be spread over a much larger surface of soil particles and the film will, therefore, be thinner than the film in the case of coarse grained soil, which exposes a smaller surface and over which the same quantity of water forms a much thicker film.

**Chemical Composition of Soil.** Different substances influence the transpiration ratio differently. Acids, for instance tend to accelerate transpiration. Alkalis have the opposite effect. Further, the more concentrated the soil solution is, the less rapidly do the plants take moisture from the soil.

**Ploughing and Cultivation.** Ploughing permits an easier descent of water into the soil and consequently a more rapid and uniform distribution throughout the soil. This results in a smaller rate of loss. Thorough and careful ploughing will, therefore, reduce transpiration. Similarly, cultivation diminishes the rate at which plants take water.

**Manuring** has a similar effect.

**Vigour of Plants.** The rate of loss of soil moisture depends very largely upon the vigour of the plant itself. A sickly plant does not require nor can it use so large quantities of water as a strong and healthy plant.

**Development of Root System.** If the roots have been developed near the surface more water will be used from the top soil than if the roots have been more evenly distributed throughout the soil and the energy expended in lifting the water from the lower depth is increased. To drive the roots downward, water should not be applied too early in the season nor should it be applied in such quantities as to make it unnecessary for the lowers roots to continue their work.

**Age of Plants.** The age of a plant determines largely the rate at which transpiration takes place. Plant increases very rapidly in weight up to the time of flowering. After this, the increase is slight and finally diminishes. The transpiration rate varies somewhat in the same way. There is a steady increase in the rate at which plants use water up to the time of flowering after which there is a diminution until the plant is old.

**Nature of Crop.** Transpiration naturally depends upon the nature of the crop. Widtsoe* gives the following transpiration ratios for different crops.

TABLE XVII.

**Evaporation—Transpiration ratios for different crops.**

| Name of Crop | | Pounds of water required to produce one pound of dry matter. (evapo-transpiration ratio) |
|---|---|---|
| Maize | ... | 275 |
| Carrot | ... | 569 |
| Sugar Beet | ... | 571 |
| Barley | ... | 604 |
| Oats | ... | 872 |
| Wheat | ... | 869 |
| Potatoes | | 1,225 |

**Seasons.** Whenever the season is favourable for the production of much dry crop the water cost is reduced. That is, a good season produces not only a large yield but also produces it with a relatively small quantity of water. It was thus found at Utah Station* that, under conditions otherwise nearly identical, the transpiration ratio for wheat varied from season to season, the variation being from 280 to 577.

Where there are so many factors influencing transpiration it is no wonder that the range of variation of the transpiration ratio is so large. Thus Leather** has found at Pusa that the transpiration ratio for different crops and the range of variation in the same locality are as given in Table XVIII.

TABLE XVIII.

**Transpiration ratios and range of transpiration ratios at Pusa.**

| Crop. | | Average transpiration ratio. | Range of transpiration ratio. |
|---|---|---|---|
| Wheat | ... | 850 | 422 to 1,133 |
| Barley | ... | 680 | 422 to 679 |
| Oats | ... | 870 | 490 to 1,117 |
| Maize | ... | 450 | 246 to 804 |
| Peas | ... | 830 | 453 to 973 |

*Principles of Irrigation Practice by Wodtsoe.

** Memoirs of the Department of Agriculture in India Chemical Series Vol. I, Nos. 8 and 9 Water requirements of crops in India by Leather.

Range of variation at Utah* is given in table XIX.

TABLE XIX.

**Range of variation of transpiration ratio at Utah, U. S. A.**

| Crop. | | Range at Utah . |
|---|---|---|
| Wheat | ... | 258-2,017 |
| Maize | ... | 151-1012 |
| Peas | ... | 269-1,658 |

Table XX gives the mean amount of water used by various plants in Wisconsin, U. S. A.

TABLE XX.

**Mean amount of water used by various plants in Wisconsin.**

| Name of Crop- | | Water used in inches. |
|---|---|---|
| Barley | ... | 20·69 |
| Oats | ... | 39·53 |
| Maize | ... | 15·76 |
| Clover | ... | 22·34 |
| Peas | ... | 14·89 |
| Potatoes | ... | 23·78 |

*Irrigation and Drainage by King, page 46.

## CHAPTER III.

## EFFECT OF IRRIGATION ON SUB-SOIL WATER-TABLE

Addition to sub-soil water-table may take place in case of irrigation from :—

(*a*) Main Canal and Branches.

(*b*) Distributaries.

(*c*) Watercourses and

(*d*) Irrigated fields.

2. Losses from these sources have been estimated by various authorities. Thus Sir John Benton's* estimate of the losses is given in the Table below

TABLE XXI.

**Absorption on Upper Bari Doab Canal.**

| | Canal. | Distributaries. | Watercourses. | Fields. | Total. |
|---|---|---|---|---|---|
| Percolation | 16·4% | 6·1% | 20·2% | 19·1% | 61·8% |
| Evaporation | 1·1% | 0·4% | 1·3% | 35·4% | 38·2% |
| Total | 17·5% | 6·5% | 21·5% | 54·5% | 100.0% |

Sir Thomas Higham* estimated these losses as 12·1 to 14% for Main Line, U. B. D. C.

Kennedy† estimated that in the rabi season of 1881-82 out of 100 cft. entering the head of the U. B. D. C. 20 cft. were lost in the canal proper, 6 cft. in distributaries and 21 cft. in village watercourses. This left 53 cft. on the fields of which it was estimated that 25 cft. were wasted in various ways.

The conditions in Rechna and Chaj Doabs are different. The soil on the U. B. D. C. is much more porous than of these two doabs and absorption losses are consequently higher on U. B. D. C. An attempt will be made to assess these losses in the two doabs.

3. **Losses from Main Canal and Branches.** Actual absorption-cum-evaporation losses have been worked out on Statements III.1, III.2, III.3 and III.4 prepared from the official statistics. The supply utilised in the distributaries of the canal, the supply passed to other canals and the escapage are deducted from the mean discharge at head of the canal. This gives the absorption-cum-evaporation loss on Main Line and Branches. Figures have been worked out for the 8-year period 1935-36 to 1942-43 for the four canals, L. C. C., U. C. C., L. J. C. and U. J. C. The averages have also been worked out at the bottom of these

* Irrigation Pocket Book by Buckley, pages 398 and 419.

† Note on Irrigation Duty of the Bari Doab Canal by Mr. R. G Kennedy, 1883.

Statements. It is estimated that out of this loss about 10 % is due to evaporation, the remaining 90 % goes to the sub-soil water-table.

It will be noticed that the absorption loss on U. C. C. is very low. This is partly due to the fact that the length of the Main Line and Branches is comparatively small but the main reason is that the sub-soil water-table is so high in the region traversed by the Main Line that saturated conditions obtain and the head that is the difference between the water surface level of the canal and the sub-soil water-table is so small that the absorption loss is less than the loss had the conditions been unsaturated.

**4. Losses from Distributaries and Minors.** Although the distributaries are usually designed with a 10 % allowance for absorption and evaporation yet the actual loss is considerably less than this where the soil is normal. Of course, in very porous soil, the loss may be even higher than 10 %. Normally the losses do not exceed 8 % in Kharif and 6% in Rabi.

The distributaries do not run thoroughout the year, so to get the actual loss, the loss calculated by multiplying $\frac{8\%}{6\%}$ and the discharge utilised in them in Kharif/Rabi has to be further multiplied by the time factor in Kharif/Rabi. This has been done and the results are given in Column 7 of the four statements. Whole of this loss is not added to the water-table. Part of it is evaporated from the free water surface when the distributary is running. Part is evaporated from the bed and sides of the distributary when it is closed. So evaporation from the distributaries is comparatively more than that from canals. Also more transpiration occurs from grass on the berms. It is estimated that the loss due to evaporation and transpiration is about 25% and only 75% of the figures given in Column 7 of the statements reaches the sub-soil water-table.

**5. Losses from Watercourses.** Due to frequent silt-clearance and frequent opening and closing of the various branches of the watercourse, the loss per million square feet is higher on the watercourses than on the distributaries. It is estimated that this loss is of the order of 12 cusecs per million square ft. in kharif and 8 cusecs per million square ft. in rabi. The whole of the watercourse is not, however, in use throughout the year. In the first place, there are the rotational closures of the distributaries when supply is short. Secondly, even when the outlet is open, the whole of the watercourse is not always in use. The whole length of the main watercourse is in use only when the rectangle at the tail of the watercourse is receiving irrigation. In other cases, various lengths of the watercourse will be in use. The average may be taken as 50%. Taking average length of a watercourse as two miles and wetted perimeter as 4 ft., average loss from the watercourse is :

$$\text{Kharif} = \frac{10000 \times 4 \times 50\% \times 12}{1,000,000} = 0{\cdot}24 \text{ cusecs};$$

$$\text{and Rabi} = \frac{10000 \times 4 \times 50\% \times 8}{1,000,000} = 0{\cdot}16 \text{ cusecs}$$

Total loss from the watercourses of the canal in Kharif = No. of Kharif outlets on the canal × 0.24 × kharif time factor.

Total loss from the watercourses of the canal in Rabi = No. of perennial outlets on the canal × 0.16 × rabi time factor.

Losses have been calculated and the results are recorded in Column 8 of the statements.

The watercourses are, as a rule, very badly maintained. Their banks and berms are full of jungle and transpiration losses are consequently very heavy. A pool is formed at every nakka. Considerable evaporation takes place from these pools and from free water surface of the watercourse. Considerable evaporation also takes place from the beds and sides of the watercourse when it is closed. It is estimated that not more than 50% of the figures given in Column 8 reaches the water-table.

**6. Total Contribution to sub-soil water-table by Main Canal and Branches, Distributaries and Watercourses.** This has been worked out by taking 90% of the figures given in Column 6 (loss from Main Canal and Branches), 75% of Column 7 (loss from distributaries) and 50% of Column 8 (loss from watercourses.) The results have been recorded in Column 9 of the Statements.

**7. Absorption from Irrigated Fields.** As soon as irrigation of a cropped field ceases, evaporation and transpiration by plants come into play. Factors governing evaporation from soil have already been mentioned in para 10 of Chapter 11 while transpiration has been dealt with in para 11 of the same Chapter.

The principal factors influencing these are:—

(*a*) Initial percentage of soil moisture.

(*b*) Depth of sub-soil water-table below natural surface.

(*c*) Meteorological conditions.

(*d*) Kind of crop.

To start with, since there is free water on the surface of the field, considerable evaporation takes place. At that time, the laws governing evaporation from free water surface apply. As moisture is reduced, evaporation and transpiration become less and less. As the kind of crop plays a very important part in governing transpiration by plants, each of the main crops will be separately dealt with.

**Cotton.** Experiments were carried out by Punjab Irrigation Department a few years ago and it was found that cotton required the total depth of water given below :—

| | | |
|---|---|---|
| Lower Jhelum Canal | ... | 23·47″ |
| Upper Chenab Canal | ... | 23·80″ |
| Lower Chenab Canal | ... | 18·70″ |

Recent experiments performed by the Department of Agriculture and described in Leaflet No. 262/45* show, as expected, that the depth of water depends upon the size of the kiari. The figures are given in Table XXII.

TABLE XXII.

**Total depth of water required by cotton near Lyallpur.**

| Size of Kiari. | Total depth of water in inches. |
|---|---|
| 1/16 acre. | 16·69 |
| 1/8 ,, | 17·25 |
| 1/4 ,, | 18·08 |
| 1/2 ,, | 19·88 |

Luthra** has shown that near Lyallpur cotton transpires 20·3″ of water and the total evapo-transpiration losses are 27·6″. This gives loss by evaporation alone as 7·3″. It will be seen that cotton transpires almost as much water as is given to it, that is, no portion of the water used for irrigation finds its way to the sub-soil water-table. As a matter of fact, a portion of the rainfall (up to 7·3″ during the period when cotton is in the field) is also evaporated from the cotton field.

**Wheat.** According to experiments performed by the Punjab Irrigation Branch, wheat requires total depth of water given below :—

| | | |
|---|---|---|
| Lower Jhelum Canal | ... | 14·13″ |
| Upper Chenab Canal | ... | 13·70″ |
| Lower Chenab Canal | ... | 10·60″ |

According to the experiments of the Department of Agriculture already quoted, wheat requires the depth of water given in the Table below :

TABLE XXIII.

**Total depth of water required by wheat near Lyallpur.**

| Size of kiari. | Total depth of water in inches. |
|---|---|
| 1/16 acre. | 12·06″ |
| 1/8 ,, | 12·18″ |
| 1/4 ,, | 12·71″ |
| 1/2 ,, | 13·72″ |

* Leaflet No. 262/45. "Improved methods of applying Rain water and saving of water affected by small kiaris in irrigated fields."

** J. C. Luthra. "Water requirements of crops and an appreciation of the present position with suggestions for the future." Proceedings of the Second Meeting of the Crop and Soil Wings of the Board of Agriculture and Animal Husbandry in India, 1937.

It is not known if any experiments regarding transpiration by wheat near Lyallpur have been performed. At any rate, no results of any experiments are available. Recourse must, therefore, be taken to the experiments performed at Pusa, the results of which have been given in Table XVIII, paragraph 11 of Chapter II. Average transpiration ratio for wheat is 850. The average yield for wheat may be taken as :—

| | | |
|---|---|---|
| Grain | ... | 18 maunds per acre |
| Straw | ... | 27 ,, ,, ,, |
| Total dry matter... | | 45 maunds per acre. |

Then total depth of water required in

$$\text{inches} = \frac{45 \times 850 \times 82{\cdot}3 \times 12}{62{\cdot}5 \times 43{,}560} = 14''$$

Temperature in the Punjab is higher than that at Pusa and the air is less humid. Transpiration losses in the Punjab are, therefore, likely to be higher than 14", *i.e.*, more than the total depth of water given to wheat. Hence it is clear that no portion of irrigation water goes to sub-soil water-table. It should be noted that 14" is the transpiration loss alone. Evaporation loss will be in addition and will deal with whole or part of the rainfall.

**Maize.** According to the Punjab experiments, maize requires :—

| | | |
|---|---|---|
| Lower Jhelum Canal | ... | 15·42" |
| Upper Chenab Canal | ... | 17·10" |
| Lower Chenab Canal | ... | 11·30" |

As far as it is known, no experiments to determine transpiration loss from a maize field have been performed in the Punjab. Pusa experiments give 450 as the average transpiration ratio for maize.

Average yield for maize is :—

| | | |
|---|---|---|
| Grain | ... | 25 maunds per acre |
| Straw | ... | 50 ,, ,, ,, |
| Total | ... | 75 maunds per acre. |

$$\text{Transpiration loss} = \frac{75 \times 450 \times 82{\cdot}3 \times 12}{62{\cdot}5 \times 43{,}560} = 12{\cdot}5''$$

Transpiration in the Punjab will be higher. The depth of water transpired is very nearly equal to the depth of irrigation given and no portion of the water applied for irrigation will be added to the water-table

**Bajra.** Bajra requires a total depth of 8" of canal water. The Department of Agriculture has performed some experiments at Rohtak to determine the transpiration ratio for bajra. The results are recorded in Table XXIV below

TABLE XXIV.

**Transpiration ratio of bajra at Rohtak.**

| Year of experiment | Variety. | Total dry matter per plant., gms. | Weight of grain per plant, gms. | Transpiration ratio. |
|---|---|---|---|---|
| 1936-37 ... | Local bajra | 39·60 | 6·98 | 303 |
| 1938-39 ... | do | 51·20 | 10·50 | 550 |
| 1937-38 ... | Bajra A13 | 31·57 | 18·40 | 410 |
| 1938-39 ... | do | 64·90 | 4·75 | 488 |
| 1939-40 ... | do | 180·36 | 35·33 | 323 |
| | Average ... | 73·52 | 15·19 | 415 |

Yield of bajra :—

Grain = 12 maunds per acre.

$$\text{Then total dry matter} = \frac{73 \cdot 52}{15 \cdot 19} \times 12 = 58 \text{ maunds per acre.}$$

$$\text{Transpiration loss} = \frac{58 \times 415 \times 82 \cdot 3 \times 12}{62 \cdot 5 \times 43{,}560} = 9''$$

Thus the transpiration loss and the depth of water applied are almost equal and no portion of irrigation water finds its way to the sub-soil water-table.

**Jowar.** Jawar requires about 12" of water. The Department of Agriculture has performed experiments at Rohtak on jowar also. The results are recorded below.

TABLE XXV.

**Transpiration ratio of jawar at Rohtak.**

| Year of Experiment. | Variety. | Total dry matter per plant. | Weight of grain per plant. | Transpiration ratio. |
|---|---|---|---|---|
| 1936-37 ... | Jowar local | 71·0 | 13·67 | 254 |
| 1938-39 ... | do. | 111·42 | 16·32 | 399 |
| 1938-39 ... | J.S.21 | 110·81 | 13·16 | 399 |
| 1939-40 ... | J.S.21 | 189·70 | 12·41 | 337 |
| | Average ... | 120·23 | 13·89 | 347 |

Average yield of grain per acre = 15 maunds.

$$\text{Then dry matter per acre} = \frac{120{\cdot}23 \times 15}{13{\cdot}89} = 130 \text{ maunds.}$$

$$\text{Transpiration loss} = \frac{130 \times 347 \times 82{\cdot}3 \times 12}{62{\cdot}5 \times 43{,}560} = 16{\cdot}6''$$

Here again no irrigation water goes to the sub-soil water-table.

**Gram.** Results of experiments performed by the Department of Agriculture at Rohtak are recorded in the Table below :—

TABLE XXVI.

| Year of experiment | Total dry matter per plant. | Weight of grain per plant. | Transpiration ratio. |
|---|---|---|---|
| 1937-38 ... | 50·39 | 19·90 | 501 |
| 1938-39 ... | 40·01 | 18·42 | 471 |
| 1939-40 ... | 71·01 | 17·30 | 612 |
| Average ... | 43·46 | 18·54 | 528 |

Average yield of grain per acre = 9 maunds.

$$\text{Total dry matter per acre} = \frac{9 \times 43{\cdot}46}{18{\cdot}54} = 21 \text{ maunds.}$$

$$\text{Transpiration loss} = \frac{21 \times 528 \times 82{\cdot}3 \times 12}{62.5 \times 43{,}560} = 4''$$

Gram is usually sown in wadh wattar of rice and no additional watering is given. Thus it removes 4″ of water given to rice.

It will thus be seen that normally no water given to irrigate cotton, wheat, bajra, jawar and gram finds its way to the sub-soil water-table.

It is fully realised that the transpiration ratios used in the foregoing analysis are far from accurate and there is scope for a large margin of error as these ratios have been determined as a result of pot experiment. Some of the experiments have not been even performed in the Punjab but there is no alternative at present. Really these ratios should be determined under field conditions. Experiments have just (April 1946) been started near Moghalpura where a number of Lysemeters have been constructed. It will be a long time before the results of these experiments are known. Meanwhile, whatever data is available has to be used.

**Rice.** The evapo-transpiration losses in case of rice have been studied by E. W. Lane, T. T. Cheng and C. L. Pien*, who after studying the data for California (U. S A.), Arkansas (U. S. A.), Texas (U. S. A.), Loisinia (U. S. A.), Kiangsu (China), Kwangtung (China), Anam (Indo

*Water requirements of rice irrigation by E. W. Lane, T. T Cheng and C. L. Pien.

China), Tangerang (Java) and Madras (India) have deduced the formulae noted below :—

Evaporation in rice fields during period of submergence $= 1.8 \times E^{2/3}$.

Loss by transpiration $= 6.6 \times E^{1/3}$, where E is the total amount of evaporation in inches from free water surface during submergence period. The submergence period for Punjab conditions may be taken as 90 days from 15th June to 15th September. Results recorded in Table IX, paragraph 10, Chapter II, show that mean daily evaporation loss from free water surface at Lyallpur in the period June to September is 0.44″. Then total evaporation loss during the period of submergence from free water surface.

$$= 0.44 \times 90 \quad = 39.6''.$$

Then evaporation loss $= 1.8 \times 39.6^{2/3} = 20.9''$

Transpiration loss $= 6.6 \times 39.6^{1/3} = 22.4''$

Total evapo-transpiration loss $= 43.3''$.

Gram which is usually sown in the wadh wattar of rice will transpire about 4″ vide details given above. There will be some evaporation loss also in rabi. Rice is usually given 50 to 60″ of canal water. Rainfall is in addition. It will thus be seen that evaporation and transpiration cannot deal with all the irrigation and rainfall water applied to rice and some portion of it must go to the sub-soil water-table.

No experimental results regarding transpiration ratios of crops other than those dealt with above and applicable to Punjab conditions are available but it can be deduced from experiments performed elsewhere that the other crops will behave more or less on similar lines to cotton, wheat, maize, bajra, jawar and gram and that no irrigation water will find its way to the sub-soil water-table from irrigated fields bearing these crops.

In the Chaj and Rechna Doabs, the area under rice is very small compared to the total area under crops and water added to the sub-soil water-table by this comparatively small area under rice may be neglected.

## CHAPTER IV.

## EFFECT OF RAINFALL ON SUB-SOIL WATER-TABLE.

Table XXVII gives the average rainfall on the four canals in Rechna and Chaj Doabs.

TABLE XXVII.

**Rainfall in Chaj and Rechna Doabs.**

| Name of Canal | Rainfall in inches Kharif | Rabi | No. of years on which averages given in Cols. 2 and 3 have been struck. |
|---|---|---|---|
| 1 | 2 | 3 | 4 |
| Upper Chenab Canal | 13.7 | 4.3 | 26 |
| Lower Chenab Canal | 8.2 | 2·8 | 38 |
| Upper Jhelum Canal. | 18.1 | 6.4 | not known |
| Lower Jhelum Canal. | 9.1 | 3.9 | 38 |

Average weighted rainfall in the two Doabs is :

| | Kharif | Rabi |
|---|---|---|
| Rechna | 9.8 | 3.2 |
| Chaj | 11.6 | 4.7 |

Part of this rainfall is taken to the river by the surface or surface-cum-seepage drains in the two doabs. No accurate data is available as regards the amount of rain water thus removed. It is, however, estimated that about 630 cusecs are removed to the river by such drains (see Chapter VI, para 6). Part is transpired by barani crops, part is removed by irrigation wells : amount of water thus used is dealt with in Chapter V. Part collects in ponds and pools. The factors governing evaporation from free water surface have already been dealt with in paragraph 9 of Chapter II. Part soaks into the ground but is re-evaporated from the surface. The factors influencing this evaporation have been recorded in paragraph 10 of Chapter II.

The main factors are :--

(*a*) Meteorological conditions.

(*b*) Percentage of initial moisture.

(*c*) Depth of spring level below natural surface.

The nearer the sub-soil water-table is to the surface, the greater is the evaporation from the soil. Generally the sub-soil water-table in U.C.C. and U. J. C. area is higher than that in L. C. C. and L. J. C. areas. Rainfall is also more on the upper two canals. Hence the saturation of the ground will be more. For these two reasons, the evaporation loss on U. C. C. and U. J. C. will be considerably more than on L. C. C. and L J. C canals. It has been found by Luthra* that loss of evaporation

*J. C. Luthra. Water Requirements of Crops and an appreciation of the present position with suggestions for the Future.

alone in case of cotton near Lyallpur is 7.3″. Further Widtsoe found (Table XIII, Chapter II) that the transpiration loss at Utah (U. S. A,) for a period of 92 days in case of loam was :—

| Degree of saturation of soil | Evaporation. |
|---|---|
| 10% | 3″ |
| 13% | 4″ |
| 20% | 11″ |

Normal irrigated soils in the Punjab have an average saturation of 10 to 15 per cent. It would not, therefore, be far wrong to assume that evaporation loss for the four months, June to October, near Lyallpur is of the order of 5″. As already explained, evaporation loss on U. C. C. and U. J. C. will be considerably higher than on L. C. C. It may be taken as 8″.

3. Evaporation loss during the remaining 8 months will be considerably less than the figures given above. In the first place, the temperature is low and the air is more humid. Rainfall during this period is small compared to the rainfall during the four months of monsoon. Initial percentage of moisture in the soil will, therefore, be less. Hence evaporation losses will be much lower than during the monsoon. It would not, therefore, be incorrect to assume these losses as

| L. C. C. and L. J. C. Area | U. C. C. and U. J. C. area. |
|---|---|
| 3″ | 5″ |

4. Evaporation can deal with the losses given above during kharif and rabi and an addition is made to the water-table only if the rainfall during the monsoon and the non-monsoon periods is more than :—

| L. C. C. and L. J. C. area | | U. C. C. and J. J. C. area. | |
|---|---|---|---|
| Kharif | Rabi | Kharif | Rabi |
| 5″ | 3″ | 8″ | 5″ |

This is only generally true. There may be occasions when the soil is saturated to field moisture capacity. Then even a light rainfall will add to the water-table. Column 10 of statements III.1, III.2, III.3, III.4 shows the contribution to sub-soil water-table by rainfall. These figures have been calculated on the assumption that rainfall, over and above the figures already given, goes to the sub-soil water-table. In these calculations, only the rainfall precipated on the area within irrigation boundary of the canal concerned has been taken into consideration. The effect of rainfall on area outside this boundary is discussed in next Chapter.

## CHAPTER V.

### COMBINED EFFECT OF IRRIGATION AND RAINFALL ON SUB-SOIL WATER-TABLE

Effect of irrigation and rainfall on sub-soil water-table in U. C. L. C. C., U. J. C., and L. J. C. areas has been studied in Chapters and IV respectively. The results are recorded on Statements III. 1 III.4. Average rise of sub-soil water-table from June to June and discharge required to give this rise are also recorded in Columns 13 14 of the four Statements. Discharge required to give the rise has b calculated on the assumption that the specific yield of the soil is 20 cent. The averages are tabulated in Table XXVIII (see page 34) It wil seen that the effect of rainfall is greater on U. C. C. than on L. C Similarly it is more important on U. J. C. than on L. J. C. This is course due to the fact that rainfall is heavier on U. C. C. and U. J and canal irrigation is comparatively less on these two canals.

2. A study of Columns 9 and 11 of Statements III.I to III.4 reveal that rainfall is more important than irrigation in causing annual rise and fall of sub-soil water-table. This is because the contri tion from rainfall varies much more than the contribution from irri tion. Table XXIX shows this clearly.

Table XXIX.

| Name of Canal. | Variation of contribution to sub-soil water-table by irrigation. | Variation of cont bution to sub-s water-table by rainfall. |
|---|---|---|
| U. C. C. ... | 295—596 | 0—1,450 |
| L. C. C. ... | 1,530—2,214 | 107—3,800 |
| U. J. C. ... | 309—559 | 237—1,232 |
| L. J. C. ... | 557—678 | 185—1,740 |

## TABLE XXVIII.

*Effect of Irrigation and Rainfall on Sub-soil Water-Table.*

| Name of Canal. | Mean discharge at head of canal. | Discharge utilised in the distributaries of canal. | Additions to sub-soil Water-table from | | | | Contribution to subsoil water-table by rainfall on area within irrigation boundary. | Total contribution to sub-soil water-table Cols: 7+8. | Average rise of sub-soil water-table June—June in feet | Discharge required to give rise in Col: 10 assuming 20% specific yield. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Main Canal and Branches. | Distributaries | Water Courses | Total Cols. 4+5+6. | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| L.C.C. | K 9,315 | 7,736 | 1,372 | 465 | 571 | 2,408 | | | | |
| | R 6,898 | 5,874 | 889 | 266 | 318 | 1,473 | | | | |
| | Av. 8,106 | 6,805 | 1,130 | 366 | 444 | 1,940 | 1,474 | 3,414 | 0.33 | 478 |
| U.C.C. | K 9,143 | 3,516 | 215 | 211 | 228 | 654 | | | | |
| | R 4,858 | 1,132 | 109 | 51 | 49 | 209 | | | | |
| | Av. 7,000 | 2,324 | 162 | 131 | 139 | 432 | 809 | 1,241 | 0.025 | 11 |
| L.J.C. | K 2,981 | 2,539 | 372 | 152 | 188 | 712 | | | | |
| | R 2,561 | 2,210 | 309 | 100 | 120 | 529 | | | | |
| | Av. 2,771 | 2,375 | 340 | 126 | 154 | 620 | 732 | 1,352 | 0.12 | 41 |
| U.J.C. | K 5,626 | 1,283 | 329 | 77 | 102 | 508 | | | | |
| | R 5,662 | 653 | 281 | 29 | 40 | 350 | | | | |
| | Av. 5,644 | 968 | 305 | 53 | 71 | 429 | 680 | 1,109 | 0.022 | 17 |
| | | | | | | | | | 0.20 | |
| Total | 23,521 | 12,472 | 1,937 | 676 | 808 | 3,421 | | | | |

It is possibly for this reason that some authorities have been led t believe that rainfall is mainly responsible for the rise of spring leve Actually both Irrigation and rainfall are responsible for the rise. It do not matter if water seeps into the soil from irrigation channels or rainfa The result is the same. If the total seepage is more than the outflov sub-soil water-table will rise.

**3. Effect of Irrigation on Rainfall on the Sub-soil Water-Tab in Chaj and Rechna Doabs.** Table XXX* has been prepared show the effect of irrigation and rainfall on the rise of sub-soil water-tab in Chaj and Rechna Doabs as a whole. In this case rainfall over tl whole area to the south of Mangla and Merala has been taken in consideration. Contribution of rainfall over this area has been calcula ed as follows :—

$$\text{Contribution of rainfall over Chaj Doab} = \frac{\text{Whole area of Chaj Doab to south of Mangla}}{\text{Area of Chaj Doab within irrigation boundary of U. J. C. and L. J. C.}} \times \text{Contribution o}$$

rainfall within irrigation boundary of U.J.C. and L.J.C. = $\frac{116}{100}$ × Cont bution of rainfall within irrigation boundary of U.J.C. and L.J.C.

Similarly for Rechna Doab, contribution by rainfall on whole ar

$$\text{south of Merala} = \frac{\text{Area to south of Merala Contribution}}{\text{Area within irrigation boundary of U.C.C. and L.C}}$$

× Contribution of rainfall over area within irrigation boundary U.C.C. and L.C.C. = $\frac{112}{100}$ × Contribution of rainfall over area with irrigation boundary of U.C.C. and L.C.C.

4. Total contribution by irrigation and rainfall (Col. 13 of Tal XXX) and rise of sub-soil water-table in the two doabs (Col. 14 Table XXX) have been plotted on logarithmic paper, Plate II. Absor tion losses have been plotted as abscissae while rise in feet plus one fc has been plotted as ordinates (one foot has been added to facilita plotting). There is considerable scatter. This was to be expecte Absorption into the soil does not take place only from the area to sou of Mangla and Marala. Areas to north of these places but within t Doabs also makes a contribution. Rainfall here is heavy and soil porous. Further the W. S. level of the river in June has an importa effect on the spring level in the wells near the river. Should the river high, this spring level will also be high and the rise from preceding Ju will be higher than would have been the case had the river been hi in the preceding June and low in the year following. Average dischar of the rivers during the preceding year also effects spring level. Soı portion of the scatter is also due to the fact that contribution from r fields, though not appreciable, has been neglected. The same numb of wells has not been observed in each year. The averages calculat from different number of wells are likely to affect results. Anoth possible reason for the scatter is that the portion of rainfall removed

the drains and irrigation wells has been neglected. Lastly it is also possible that evaporation can deal with more or less than 5″, 3″, 8″ and 5″ of rainfall assumed in para 4 of Chapter IV. If all these factors are borne in mind then it will not be wrong to say that there is a fair correlation between the absorption losses as calculated and the actual rise. An attempt has been made to fit an average line and the equation of the line is

Rise in feet plus one foot = 0·011 × absorption 0·60. The line cuts zero rise plus one foot at 1,870.

This means that should the combined contribution from irrigation and rainfall be equal to 1,870 cusecs, the sub-soil water-table will remain steady. Should it be more, it will rise. On the other hand, if the absorption is less, the water-table will fall. This equation is of course only applicable to the present level of sub-soil water-table.

**5. Quantity of Water to be removed in order to lower the Sub-soil Water-table in Chaj and Rechna Doabs by one foot per annum.** It will be seen from column 14 of Table XXX that the average rise of sub-soil water-table in Chaj and Rechna Doabs during the 8-year period, 1935-36 to 1942-43 was 0·20′. The maximum rise took place between June 1941 and June 1942 when the water-table rose on an average by 0.61′. It has not been possible to get data for the year 1944-45. Rainfall was particularly heavy in 1944 and the rise from June 1944 to June 1945 was probably greater than 0.61.′ In order that there should be no appreciable rise of spring level at any time, any method adopted to lower the water-table must be capable of dealing with an average rise of at least 0·5. If it is desired that the water-table be lowered by one foot sufficient water should be removed to cope with 0.5 expected rise and 1.0′ fall of water-table or a total of 1.5′.

Gross area of Chaj and Rechna Doabs to south of Mangla and Marala is

| | |
|---|---|
| Chaj Doab | 21,90,655 acres |
| Rechna Doab | 58,58,076 acres |
| Total | 80,48,731 acres |
| or say | 80, 49,000 acres |

Discharge to be removed can be calculated by using what are called desorption curves by Russell* that is, graphs connecting percentage moisture of soil at distances above water-table or tables giving similar information. The principle is the same in both cases. Here second method will be adopted and the profile given in Table III, Chapter II, will be taken as representing the soil in the two Doabs.

* Predicting changes in water-table elevation in peat land by M. B. Russell, Agricultural Engineer, July 1945.