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SUB-SECTION I i

MISCELLANEOUS

I i i

THE CONCEPT OF SOIL MOISTURE DEFICIT

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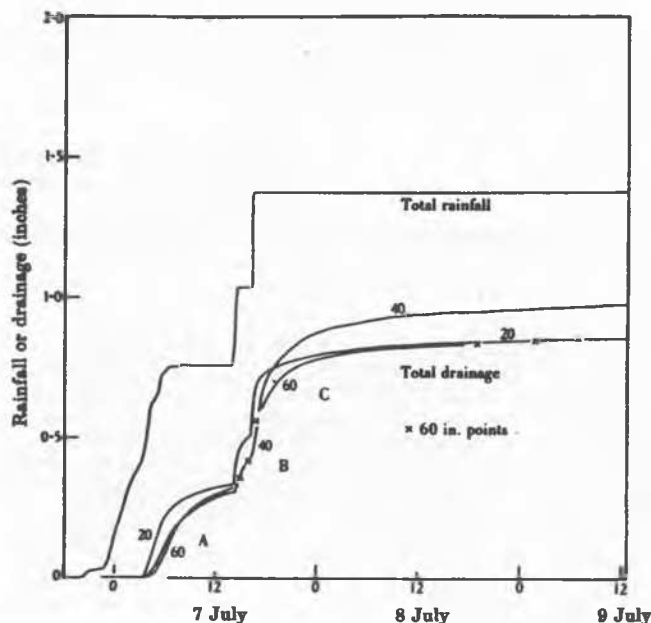
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When evaporation takes place, either directly from a bare soil surface or from the leaves of plants rooted in the soil, water is withdrawn from the soil. Water applied to the soil surface, or falling on it as rain, must first make good the loss due to evaporation before through drainage occurs. No doubt the broad truth of the above statement is generally conceded, but it is not easy to cite quantitative data from which the precision of the statement may be judged.

1. SOIL MOISTURE DEFICIT IN BARE SOIL.

A recent examination of the records of the Rothamsted Drain Gauges (Penman and Schofield, 1941) has been of value in this connection. These installations contain three blocks of undisturbed soil, each 1/1,000th acre (4 square metres) in area and respectively 20 in. (0.5 metres), 40 in. (1 metre) and 60 in. (1.5 metres) deep. The soil blocks rest on perforated plates, and are separated from the surrounding soil by impermeable side walls. Collecting funnels under the perforated plates lead the drainage water into measuring tanks. Daily records of drainage have been made since 1871 and continuous recording gear was installed in 1925. During the whole period the soil surfaces have been kept free of vegetation by hand-weeding.

In order to illustrate the type of evidence furnished by these drain gauges, Fig. 1 has been prepared from the automatic traces of drainage and rainfall for the period July 6-9, 1927. The effect of previous evaporation from the bare soil surface is shown in the difference between rainfall and drainage. Since the "die away" curves for the drainage have a form that is constant except for a seasonal variation, it is possible to estimate that the rain, totalling 0.76 in., that fell up to noon on July 7 would have caused a total drainage of 0.35 in. had no more rain fallen during the next 48 hours. Thus we obtain a value of 0.41 in. for the soil moisture deficit existing on the night of July 6 when rain first started to fall. Drainage in the 20 in. gauge did not start until 0.45 in. of rain had fallen. This is a reflection of the time taken for water to move down from the surface sufficiently to produce the pressure head needed to cause



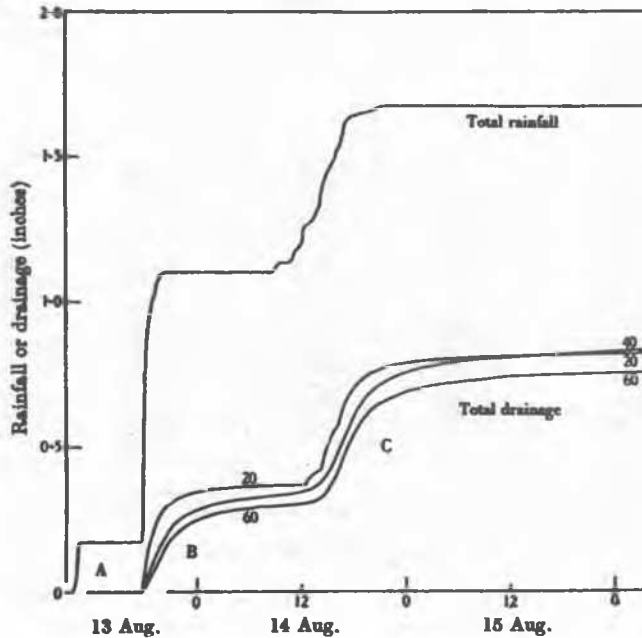
Typical continuous records of rainfall and drainage from Rothamsted gauges (July, 1927).

FIG. 1

drainage. Two further falls, totalling 0.62 in., caused the total drainage in both the 20 in. and 60 in. gauges to increase to 0.83 in., indicating that the soil moisture deficits at the times when the two rains began together amounted to 0.14 in. This represents the amount of water evaporated from the soil surface during July 7, which was on the whole a sunny day. There is, unfortunately, a leak through which foreign water enters the 40 in. gauge: records from this gauge are unreliable.

In the great majority of cases the estimates of soil moisture deficit obtained in these two ways are consistent and give amounts of evaporation that are reasonable. From time to time, however, usually when sudden heavy rain falls on a dry soil surface, drainage occurs before the deficit has been fully made good. Thus very heavy rain (0.17 in. + 0.93 in.) fell

in two periods during the evening of August 13, 1937, and the corresponding drainage was 0.38 in.



Continuous records showing drainage where there was still a soil moisture deficit (August, 1937)

FIG. 2

There was a further 0.58 in. of rain spread over about 12 hours on August 14, but the further drainage was only 0.44 in. As 0.14 in. is improbably high for the evaporation during the night and early morning before rain started again, part of it must be attributed to the failure of the earlier heavy rain to wet the profile completely. It can also be seen from the automatic records that the first drainage actually started at a time when there was still a soil moisture deficit of some 0.5 in. Most of this was made good by the rest of the rain of August 13, which was more gentle towards the end, but a small residue still remained unsatisfied when this rain ceased.

The records of the summer of 1921 are of special interest. Three months of almost continuous drought ended early in September when 2.0 in. of rain fell steadily during one day. The weather again became fine, and drainage ceased after 0.70, 0.63 and 0.59 in. had been collected from the 20, 40 and 60 inch gauges respectively. Under these exceptionally favourable conditions it was possible to evaluate rather precisely the soil moisture deficits as 1.30, 1.37 and 1.41 in. respectively. From the long series of records it is possible to obtain the soil moisture deficits developed by surface evaporation during dry periods of various lengths under different weather conditions. The figures given in Table I are representative of soil moisture deficits produced by evaporation from bare soil at Rothamsted in summer. Briefly, it may be said that the

first half inch of deficit is produced in 3 to 5 days, depending mainly on the amount of sunshine, the deficit only reaches one inch after several weeks, and even in three months did not reach 1.5 in.

Compared with other drain gauges, those at Rothamsted are peculiarly favourable for the determination of soil moisture deficits owing to the rapidity with which drainage dies away after rain. This is partly because the soil of these gauges is in its natural structure. Thus the bare soil gauge at the Cambridge Water Works at Fleam Dyke, of rammed chalk filled-in, may run for three weeks after rain. The drain gauges at Craibstone, Aberdeen and at Pusa and Cawnpore, India, were all built round undisturbed soil but these too give a slower die-away than the Rothamsted gauges, showing that natural soils differ considerably in this respect.

2. SOIL MOISTURE DEFICIT IN CROPPED SOIL.

It might be thought that soil moisture deficits in soils carrying grass, arable crops, or even forest, could readily be determined by finding the moisture contents of soil samples taken to the depth of root penetration, and using for comparison similar samples taken at a time when the soil moisture deficit could be taken as zero. In practice this method can only be applied with advantage in places where the soil is exceptionally uniform, as is the case in Youngmans Pasture on the Cambridge University Farm. From repeated samplings and observations on the performance of field drains Mr. H.H. Nicholson and his students have secured valuable data from which the total soil moisture deficit and its distribution with depth have been obtained on more than a dozen occasions during several seasons. Some of these data are used in a later section and are included in Fig. 4.

At Rothamsted the soil is not uniform enough for the same method to be applied, and a new technique has been developed. The soil samples are taken in the form of "clods" in their field structure, are immediately weighed, and are then allowed to take up moisture in the laboratory against a controlled "suction" of 50 cm. of water (pF 1.7). Clods taken in winter, when the soil moisture deficit was considered to be zero, neither lost nor gained weight on the average under these conditions. Clods of the same size taken from the same depth did not all take up exactly the same amount of water in the laboratory, but a fairly accurate measure of the soil moisture deficit could be obtained from the mean of the results.

3. EVAPORATION FROM GRASS AND OPEN WATER.

Seeing that any method based on the examination of soil samples is very laborious it is fortunate that soil moisture deficits under vegetation can be obtained to an accuracy that will be sufficient for many practical purposes by an indirect method based on estimates of evaporation. This estimate is possible because the evaporation from a green crop that

TABLE I
Typical soil moisture deficits built up
during rain-free periods in summer:
bare soil at Rothamsted

Length of period (days)	2	5	10	20	30	40
Deficit (inches)	0.30	0.50	0.65	0.80	0.90	1.00

effectively covers the soil and is not short of water depends on the weather but not on the height or rate of growth of the crop so long as it remains green. The truth of this statement has been proved by experiments at Rothamsted in which grass growing in soil tanks sunk flush with the surrounding grass covered soil has been continually supplied with water from a water table at 16 in. (40 cm) Each soil tank is in communication with a covered reservoir in which the water level is accurately measured. During rainless periods in summer a small moisture deficit develops in the top few inches of soil above the capillary fringe, but during a normal summer rain is sufficiently frequent and plentiful to wipe this out at times and cause a rise in the water table. From the records we know the net amount of water that was added to the reservoir (or taken from it) between two such occasions in order to keep the water at the standard level. In this way a measure is obtained of the excess of evaporation over rainfall for each interval between rises of the water table. The accumulated excess for the summers of 1944 and 1945 are plotted in Fig. 3.



Accumulated excess over rainfall of evaporation from sub-irrigated grass at Rothamsted.

FIG. 3

Alongside the soil tanks is an open water surface. The correspondence between the evaporation from the grass and the same area of open water is so close that the weather must be the controlling influence in both cases. The actual ratio is not fixed, but exhibits a seasonal trend. Values of the ratio appear in Table II. It is possible, therefore, to make a close estimate of the evaporation that would have taken place from grass plentifully supplied with water if the records are available for the evaporation from a well sited water surface.

At the Harrogate Water Works, situated at 549 ft. on Blubberhouses Moor, there is a grass-covered drain gauge and an open water evaporimeter alongside. Rain is sufficiently frequent to make it likely that the grass is rarely short of water and the records can be used to provide a check on the considerations of the foregoing paragraph. The monthly amounts of evaporation from the open water

TABLE II

Comparison of estimated evaporation from grass with excess of rainfall over drainage.

Month	E_o in.	f	$E_o f$ in.
Jan.	0.41	0.6	0.25
Feb.	0.45	0.6	0.27
Mar.	0.98	0.7	0.68
April	1.78	0.7	1.25
May	2.71	0.8	2.18
June	3.28	0.8	2.62
July	3.38	0.8	2.70
Aug.	2.73	0.8	2.17
Sept.	1.94	0.7	1.36
Oct.	1.25	0.7	0.88
Nov.	0.62	0.6	0.38
Dec.	0.43	0.6	0.26
Year	19.96		15.00

E_o = mean evaporation from open water.

$E_o f$ = estimated mean evaporation from grass.

inches

Mean annual rainfall	30.64
Mean annual drainage	<u>15.45</u>
Difference	<u>15.19</u>

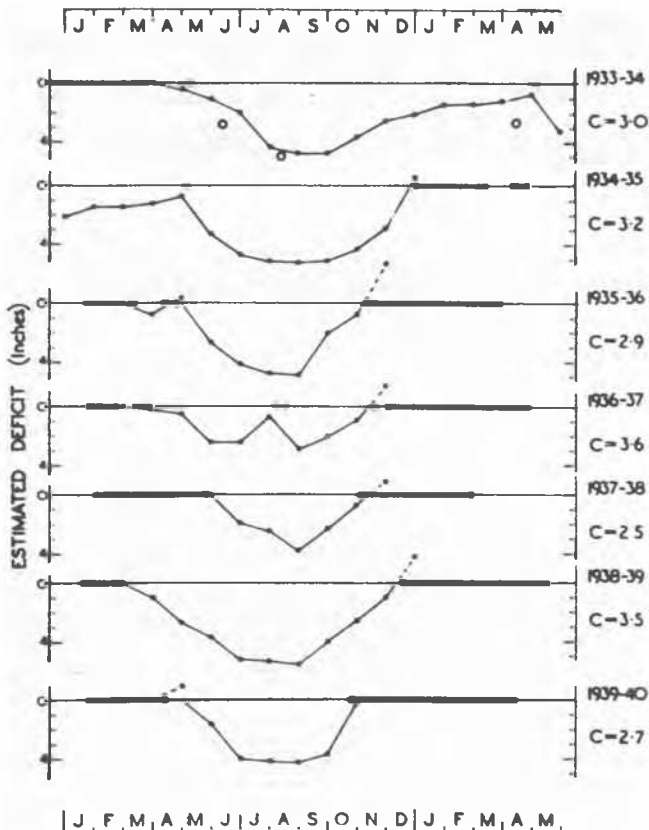
surface, entered under E_o in Table II are the means for 21 years up to 1943. The factors under f were obtained from the observations at Rothamsted. The entries under $E_o f$ are, therefore, estimates of mean monthly evaporation from the grass-covered drain gauge, which total 15.0 inches for the whole year. This estimate is in close agreement with the mean excess of annual rainfall over annual drainage which was 15.2 in. for the same 21 years.

Even when the evaporation from open water has not been observed on the site it is possible, with the aid of recent developments in the theory of evaporation, to make a close estimate of open water evaporation from records of hours of sunshine, mean wind speed, mean air temperature and dew-point (Penman, 1948).

Soil Moisture Deficit Obtained from Estimates of Evaporation.

In arriving at an estimate of the soil moisture deficits in places where rainfall is often insufficient to maintain full evaporation from grass, it seems reasonable to assume that until the soil moisture deficit has reached a value, C, the evaporation is that for a plentiful water supply, but that for deficits greater than C the evaporation falls progressively below that for plentiful supply.

The result of an attempt to estimate the trend of the deficit during summer appears in Fig. 4. Details are being published elsewhere, but it should be noted that the value of C was chosen empirically to have slightly higher values for years in which a dry spring would encourage root developments. A successful estimate of C would result in the estimated deficit being reduced to zero when the soil reached field capacity in the autumn: in Fig. 4 the return to zero deficit is represented by



Estimated and observed soil moisture deficits in grassland at Cambridge. Thick horizontal lines show when the field drains were running. Open circle show values of deficit measured by soil sampling (1933-34).

FIG.4

the onset of autumn running of the field drains.

It is both reasonable and necessary to consider that C depends on the character of the soil, the nature (mainly the rooting habit) of the crop and perhaps the nature of the growing weather early in the year. Table III gives the values of C for a number of grass-covered surfaces together with the dates and amounts of the largest soil moisture deficits.

In some cases the distribution of rain throughout the year prevented large deficits from being built up and the readily available water can only be stated to be at least as great as the maximum estimated deficit. Otherwise the value of C for grass surfaces appears to be about 3 or 4 in. The large value (6.0) deduced for the 48 in. deep gauge at Farlington is unexpected. It may reflect the properties of disintegrated chalk studied recently by Locket (1946), but further investigation is needed to elucidate this case.

4. DIFFICULTY IN SANDY SOILS.

The clay soil of the Cambridge University Farm is favourable for studies of soil moisture deficit because of the rapidity with which the discharge of the mole drainage system dies away after rain. Here it is easy to distinguish the times when the soil moisture deficit is zero. It is, however, much harder to do this when the soil is sandy with a deep water table. In such cases downward movement of water may persist below the level of root penetration throughout the year, although the rate of movement varies considerably. Where this occurs there is no state of moisture that

TABLE III

Value of Readily Available Water, and Maximum Water Deficit for Grass-Covered Surfaces (inches).

Site	Nature of surface	Year	Readily available water (C)	Max. deficit	Date of maximum deficit
Craibstone, Aberdeen	Turfed gauge, 40 in. deep granitic soil, undisturbed	1938	> 1.5	1.5	August
Harrogate, Yorks	Turfed gauge, 36 in. deep, clay soil, filled in	1921	2.0	3.6	July
		1941	> 2.8	2.8	July
		1942	> 1.7	1.7	June, July
University Farm, Cambridge	Pasture on clay mole-drained	1933	3.0	4.7	September
		1934	3.2	5.2	August
		1939	2.7	4.3	August
Harpenden, Herts	Catchment area clay over chalk	1944	3.5	4.7	June
Compton, Sussex	Grassed gauge, 36 in deep chalk filled in	1933	4.0	5.5	August
		1934	3.0	4.6	July
Farlington, Hants.	Grassed gauge, 24 in. deep chalk filled in	1933	2.0	3.9	August
		1934	2.0	3.5	June, July, Aug.
		1933)	7.5	7.5	August
		1934)	6.0	7.3	July, August

can be uniquely identified as the condition of zero deficit, although it may be possible to select a condition more or less arbitrarily which will serve as a zero of reckoning for practical purposes.

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