TILE DRAINAGE RESEARCH [1])

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Summary

A concise résumé has been made of the literature of the subject, showing the present position of the technical side of tile drainage. As regards the hydrological side – i.e., the water table to be obtained for a given spacing and depth of the tile series-accurate solutions to various cases have been provided. Not so much is known, however, regarding the agricultural consequences of tile drainage.

The depth of the tile series will necessarily depend on the soil's capacity to store moisture and the precipitation and evaporation to be expected in the summer. A method of computing this depth is being worked out.

The distance between the tile series depends very much on the discharge to be expected, but also on the highest permissible water table. The influence of the height and duration of the latter is not sufficiently known. In order to carry out calculations regarding the highest water table to be expected, and its duration, the soil's capacity for storing water will have to be taken into account.

Changes in the temperature of the soil as a result of tile drainage may be attributed to greater or lesser evaporation, or to alterations in the thermal properties of the soil owing to moisture changes.

No definite alterations have been found in the structure of the layer of soil above the level of the tiles. Moreover, such alterations as there may be only become noticeable to any appreciable extent after a very long time (for instance, 25 years).

The washing out of soil particles is important in connection with the silting up of the drains. The size of the particles, with respect to silting up is, however, not very important.

Introduction

During the last fifty years a large number of investigations have been carried out in the sphere of tile drainage. Rozansky (1934) and Russell (1934) both give a survey of research work done up to about 1930. Until that time most investigations were concerned with determining the right distance between tile drains. With this object, trial fields were laid down at first, crossed by tile series at varying distances apart. The distance producing the best results was considered to be the correct one. In regions with similar types of soil, the same drain distance was applied.

The distances thus determined were then correlated with the physical properties of the soil, such as hygroscopicity, percentage of particles $< 20\,\mu$ in size, heat of wetting, etc. Russell (1934) rightly points out that, by applying the above methods, the entire determination is based on the results of one single year, no account being taken of climatic and structural factors. Accordingly, it is not possible to apply the relations found directly to other regions, where precipitation and evaporation will be different from those in the region investigated.

Rothe (1929) and Hooghoudt (1940) based their calculations on the assumption of an elliptical water table between the tile series, and deduced for the

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drain distance formulas in which the permeability of the soil was taken into account. In doing this, it is stipulated that the soil should be homogeneously permeable, and that the same amount of water should be conducted away per unit of surface whatever the distance between the tile series may be. Various methods of determining permeability are described in the literature of the subject (see, for example, HOOGHOUDT (1936), KIRKHAM (1945), and BAVEL and KIRKHAM (1948).

KIRKHAM (1940, 1945, 1948), GUSTAFSON (1948), VAN DEEMTER (1950), KIRKHAM and GASKEL (1950) and ENGLUND (1951) deduced tile drainage formulas to suit various cases. CHILDS and O'DONNEL (1943–51) and LUTHIN (1953) made use of electric model tests, while HOOGHOUDT (1937), HARKING and WOOD (1942), DONNAN (1946) and GUSTAFSON (1948) tried out their formulas on sand models.

Various tile drainage problems in connection with stationary flow were solved in this way.

But tile drainage has an agricultural aspect as well as a hydrological one. The problems arising in this context are dealt with in the following pages. For this purpose they have been divided into two groups, viz., those connected with

a the influence of tile drainage on the yield of crops;
  and with
b the influence of tile drainage on the properties of the soil.

This division more or less corresponds with the points named by FAUSER (1929) in his proposals regarding international tile drainage research.

INFLUENCE OF TILE DRAINAGE ON THE YIELD OF CROPS

The object of tile drainage is to lower the water table and keep it, as far as is possible, at a constant level.

The first problem which presents itself here is: to what depth must the water table be lowered in order to obtain maximum crop production? When an attempt is made to answer this question two mutually opposed factors are encountered, namely:

a the degree of aeration of the soil required by plants;
b the quantity of water which plants require for good growth and productivity.

As regards the first factor, RUSSELL (1953) remarks that the qualitative influence of aeration is fairly well known, but that not much has been discovered as yet about its *quantitative* influence. Investigations carried out by CANNON indicated that most plants require the soil to possess an air content of 10% (2% oxygen). Actual requirements, however, depend on temperature and on the species of plant concerned. VISSER (1941) found, in general, an air content of 10% in highly productive clay soils at Groningen.

The "yield/drainage tests" carried out by ROE (1936), HOOGHOUDT (1950), and EDEN et al. (1951), may also give an idea of requirements. In these tests the water table was kept at almost constant depth throughout the whole year or the whole growing season. Thus, HOOGHOUDT (1950) found maximum yields from crops on heavy clay with a water table between 120 and 150 cm below the surface of the ground. EDEN et al. (1951) found that maximum grass crops could be produced on peat soil with a water table 60 to 90 cm below the surface. Assuming no drought occurred in the above cases, the water table in these types of soil will have to be situated at the depths mentioned in order to satisfy the demands of the plants in the matter of aeration. If an air content of 10% is taken as essential requirement, the requisite depth will be approximately determinable from the pF curves of the type of soil concerned, viz. at the sub-atmospheric pressure at which 10% of the pores are filled with air.

As regards the second factor, the above-mentioned tests give a somewhat incorrect picture, because artificial maintenance of the water table at a certain level enables the plant to take up water from the ground water. For, under normal circumstances, the water table will sink during the summer to below the level of the tile series. In this case, at the moment at which evaporation exceeds precipitation, the tile drain depth (water table) will decide the quantity of moisture which is at the disposal of the plant. The drain depth necessary in this respect will therefore depend on the moisture-storing capacity of the soil, the depth to which the crop sends roots, and the climatic conditions (precipitation and evaporation). A method of calculating this depth will be described in a later article. Up till now, little attention has been given to the water requirements of plants in the literature of tile drainage.

The limits to the depth of a tile drainage system are also dictated by the risk of the drains being affected by frost, machines and animals (upper limit), and by costs of construction (lower limit).

Once the *depth* of the drainage system has been determined, the horizontal distance between the tile drains depends, inter alia, on the permissible height of the water table. For in winter the water table will, as a rule, lie above the level of the drains. Here, the question arises: what influence has a high water table – as regards both height and duration – on harvests? In the Netherlands, tile drainage calculations are carried out for a water table which, at the most, is no higher than 50 cm below the surface in the case of ploughland, and 40 cm in the case of grassland. These conditions are the same as those laid down by ROTHE (1929). In the trial field of HOOGHOUDT (1950), a winter water table 50 cm below the surface of the ground proved to have no effect on the yield from the crops. NEAL (1931) found there was not even any effect when the water table rose to 30 cm, provided it remained belom 60 cm for 75% of the time.

In the new Zuider Zee polders, the basic drainage condition assumed, in the case of a discharge of 10 mm per twenty-four hours, is, that the water table may not rise higher than to 20 cm below the surface of ground drained by ditches, or to 30 cm below the surface of ground drained by tiles (VAN DER MOLEN, 1953). This condition results in almost the same distances being chosen between tile drains as in the case of 7 mm discharge with a water table 50 cm below the surface, as mentioned above. However, the fact that the tile drainage distance depends considerably on the permissible highest water table can be seen from Table 1. In this table the tile drainage distance has been determined for various permeabilities by means of the nomograms devised by BOUMANS (VISSER, 1954). The tile drainage depth chosen is 1 m, while an impermeable layer is assumed to be present 2 m below the drains (see Fig. 1).

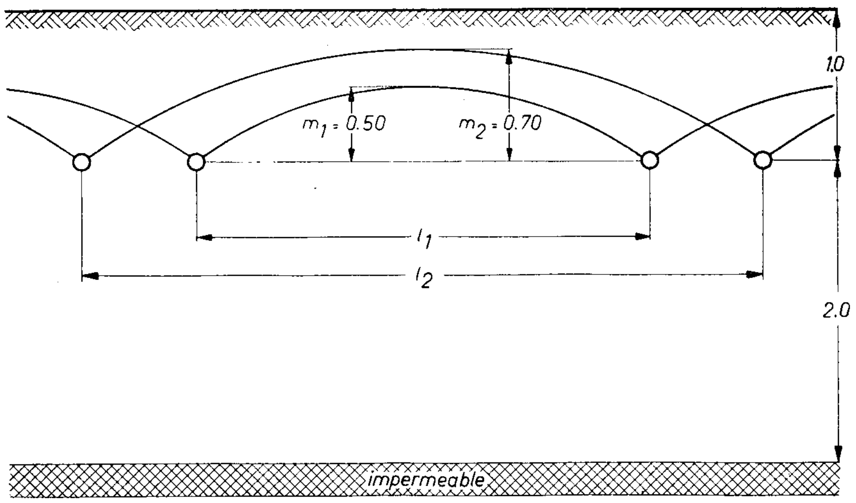

Table 1. Tile drain distances in the case of various permeability constants K, for a tile drain depth of 1 m and permissible water tables of 50 and 30 cm, respectively, below the surface of the ground.

K (m per 24 hrs)	m = 0.5	m = 0.7
0.2	11	15
0.4	17	22
0.6	22	28
0.8	27	33
1.0	30	38

From this it can be seen that it is very important to know the highest permissible water table and the rate of discharge to be expected.

Both the discharge and the extent to which the water table rises depend on

a quantity and distribution of precipitation,
b moisture content and water-holding capacity of the soil,
c permeability of the soil,
d transpiration and evaporation.

A large number of measurements of tile drain discharge are discussed in the literature of the subject, inter alia by Childs (1943), Engelhardt (1932), Fauser (1929, 1935, 1937), Feilberg and Borch (1928–1951), Flodkvist (1931), Hudig and Welt (1911), Nicholson (1934), Rothe and Philipp (1933), and Zavadil (1937).

The discharge measurements show that maximum discharge occurs at a time varying from some hours to some days after maximum precipitation. Rothe and Philipp (1933) found that location of the tile drainage system at a shallower depth resulted in a higher maximum discharge and a quicker decline in discharge. Childs (1943) and Nicholson (1935) remarked that mole drainage produced a quicker increase and decrease in discharge than tile drainage. The same was found to be true of grassland as compared with arable land. It can therefore be said that, in the case of a deeper tile drainage system, and on arable land, the water table rises less rapidly, but remains high for a longer period, than it does in the case of a shallow tile drainage system, and on grassland.

As a general rule, the quantity of water which the soil can store before a certain level of the water table is reached will be greater in the case of arable land – especially as regards the higher layers – than in that of grassland. Accordingly, in order to obtain an insight into the height and duration of high water tables, the storage capacity of the soil will have to be taken into consideration.

It should also be born in mind that standard data will have to be known regarding the height and duration of high water tables, owing to their influence on crops.

Effect of tile drainage on the properties of the soil

Kopecky (1908) declares that, in the spring, the temperature of land drained by tiles is 1° to 5° C higher than that of land not so drained. But observations carried out by Rothe and Philipp (1933) in summer and autumn revealed no differences in temperature.

The temperature of the soil is a function of its heat-absorbing capacity, its heat conductivity, and the amount of heat available for warming the soil. The last-mentioned factor depends on the quantity of heat consumed in vaporizing water from the soil. The figures quoted are not theoretically impossible.

Previous tile drainage investigations carried out by Jonata (1932) and Kopecky (1908) indicate an increase in the pore space of the soil above the level of the tile drains. Tile drainage formulas such as those of Rothe (1929) presuppose that the soil beneath the drains can be considered as impermeable.

Under normal circumstances, however, the above effect will be of little importance. Thus, Demortier and Droeven (1952), and Rozansky (1937), found no increase in pore space after one year. A test carried out by Engelhardt (1939) was terminated as inconclusive when it had been in progress for some years. Fauser (1933, 1936) found an increase of from 1 to 3% in the pore space of clay and loess over a period of 25 years. So it would appear that improvements in structure are difficult to demonstrate.

Jonata (1932) observed a movement of small particles of soil ($< 20\,\mu$ in size) towards the drains and towards greater depth, in soil drained by tiles. But Fauser (1933, 1936) found that the percentage of such small particles *decreased* with nearness to the drains and with depth, from which phenomenon he too deduced movement. Both investigators can be considered as observing the same effect if it is assumed that the first-mentioned investigation yielded a higher percentage of small particles owing to the presence of newly-formed colloids in the podsolic brown woodland soil on which the observations were carried out.

Maschaupt (1939) perceived no difference in texture between the matter found in the drains and the surrounding soil. Accordingly, it will only be possible for potential silt particles to be washed out to a relatively greater degree if they are carried though the tile drains by discharge water.

Another element in the soil which is liable to be washed out is ions. Hudig and Welt (1911) arrived at figures that were comparable with those derived from lysimetric examination. They reached the conclusion that the disadvantages of such washing out do not, nevertheless, counterbalance the advantages of better drainage – a verdict which was confirmed by Rothe and Philipp (1933).

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