TILE DRAINAGE AND SUBIRRIGATION[1]

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From the preceding paper in this issue it is clear that the topography and the climate of the Netherlands necessitate a permanent struggle to keep out water, on the one hand, and to supply water on the other. That paper deals with control in open waterways (main drainage); this paper deals with the corresponding tile drainage and with subirrigation.

The ground-water level of much of the Netherlands is high. In many regions it is at a depth of 0.5 m. in winter and of 1 to 1.5 m. in summer. A considerable part of the Netherlands, it must be remembered, is below sea level (fig. 1). In the higher sandy areas in the east the water table is several meters deep in many places, and in the loess soils of southern Limburg, more than 100 m. above sea level, it is more than 10 m. deep.

About 1845, mechanical tile-making in England paved the way for the application of tile drainage for land improvement on a large scale. In the Netherlands the first tiles were laid in 1852. Subirrigation was started much later, about the 1920's. Since then, the drained regions have been extended considerably (fig. 2). Subirrigation has made much slower progress.

A comparison of figure 2 with Edelman's new soil map of the Netherlands (5) shows that tile drainage has been applied almost exclusively to the heavier soils. Subirrigation, on the other hand, is used mainly on sandy soils, though peaty and even clayey soils (grassland) are now being subirrigated. Arable land, especially, is tile-drained; grassland, as well as some horticultural land, is subirrigated. This is because arable land is less subject to drought than is permanent grassland, though grassland should not be too wet in spring.

It follows that tile drainage and subirrigation are closely related and therefore can be best discussed together.[3] Both aim to control the ground-water level, but in opposite directions (fig. 3). Tile drainage and systematic subirrigation are not necessary with open waterways (usually ditches 100 to 300 m. apart), provided the soil is sufficiently permeable to an adequate depth. For subirrigation, the level of the ditches should be raised to about 40 cm. below the surface. For good drainage, the water level should generally be lower than 1 m. Where the permeability of the soil is low, tile drainage or systematic subirrigation will be necessary. In the Netherlands, tile drainage, mole drainage, and trenching by means of shallow ditches are used, the last almost exclusively for subirrigation. In subirrigation, the level of the trenches and of the ditches into which the tiles or the

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[1] The types of subirrigation discussed are known in the U. S. A. as *natural* subirrigation (by means of trenches) and *artificial* subirrigation (by means of lines of tile).

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[3] Other methods applied sometimes, such as flooding and sprinkling irrigation, are not discussed here.

moles issue, is lowered in autumn, winter, and spring, so that the system can be used for drainage. This lowering of the level is also necessary sometimes in wet periods during summer to prevent excess water.

Tile drainage as well as subirrigation is controlled especially by the following factors: (*a*) surplus rainfall (drainage) or shortage of water (subirrigation), (*b*) optimum ground-water level in relation to the crop cultivated, (*c*) permeability of the soil and the depth at which this is a negligible factor.

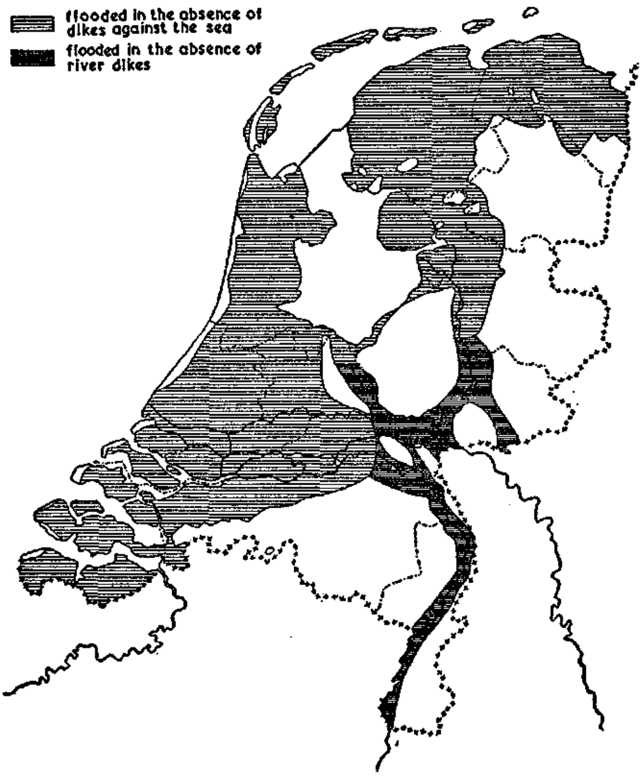

FIG. 1. REGIONS OF THE NETHERLANDS FLOODED IN ABSENCE OF DIKES

RELATION TO PRECIPITATION TO WATER CONTROL

In the Netherlands, rainfall, which is distributed rather regularly over the year, exceeds the sum of evaporation and transpiration. The difference, that is, the surplus rainfall, must be carried off, especially from November through February when evaporation and transpiration are both very low. The surplus rainfall is usually less than 5 mm. a day and scarcely ever more than 10 mm. Tile drainage is necessary when this quantity of water cannot be removed directly through the soil to the open waterways.

From May to August the sum of evaporation and transpiration exceeds the rainfall. The difference, 100 to 200 mm. depending on the rainfall, is withdrawn from the soil by the crops. Crops may suffer from drought when the water-holding capacity of the soil is insufficient. This occurs in the Netherlands in the lighter soil profiles and at low ground-water levels. If these levels are high enough or can be kept so by means of subirrigation, no bad effects from drought are experienced. In this case a sufficient amount of water is supplied to the crops by capillary rise from the ground-water level. The water supply needed for subirrigation may be estimated at 4 mm. a day for about 100 days, from the middle of May until the end of August.

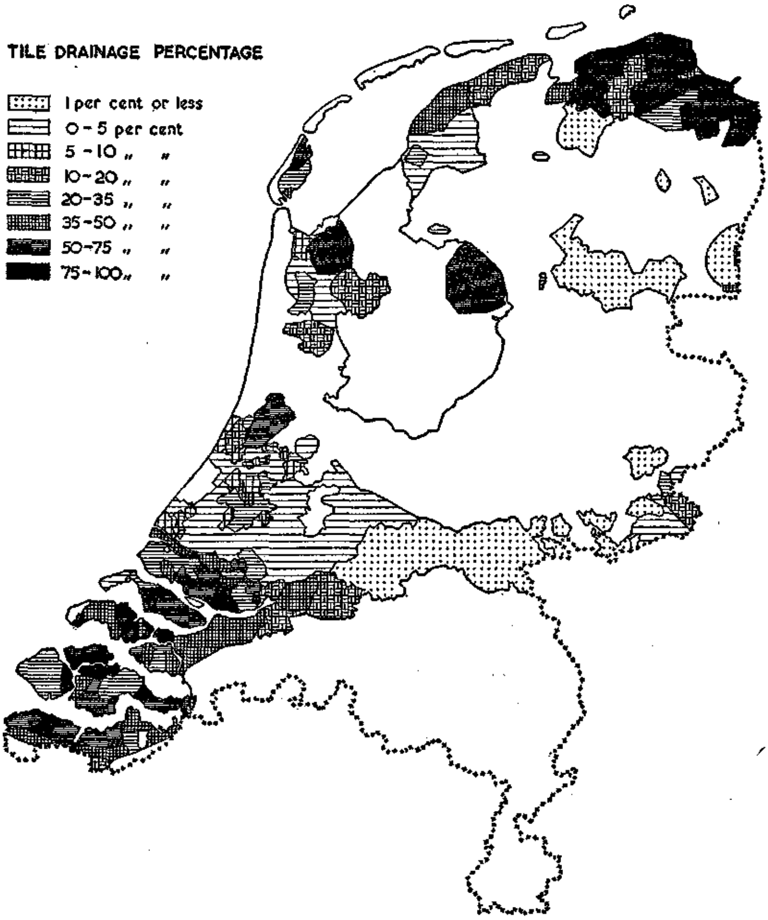

FIG. 2. REGIONS OF THE NETHERLANDS WITH TILE DRAINAGE AND PERCENTAGES OF THE SOILS DRAINED

Without subirrigation, water is withdrawn from the soil in summer. With decreasing evaporation and transpiration in autumn, this water must be replaced before surplus rainfall occurs. The tiles begin to carry off water generally late in autumn.

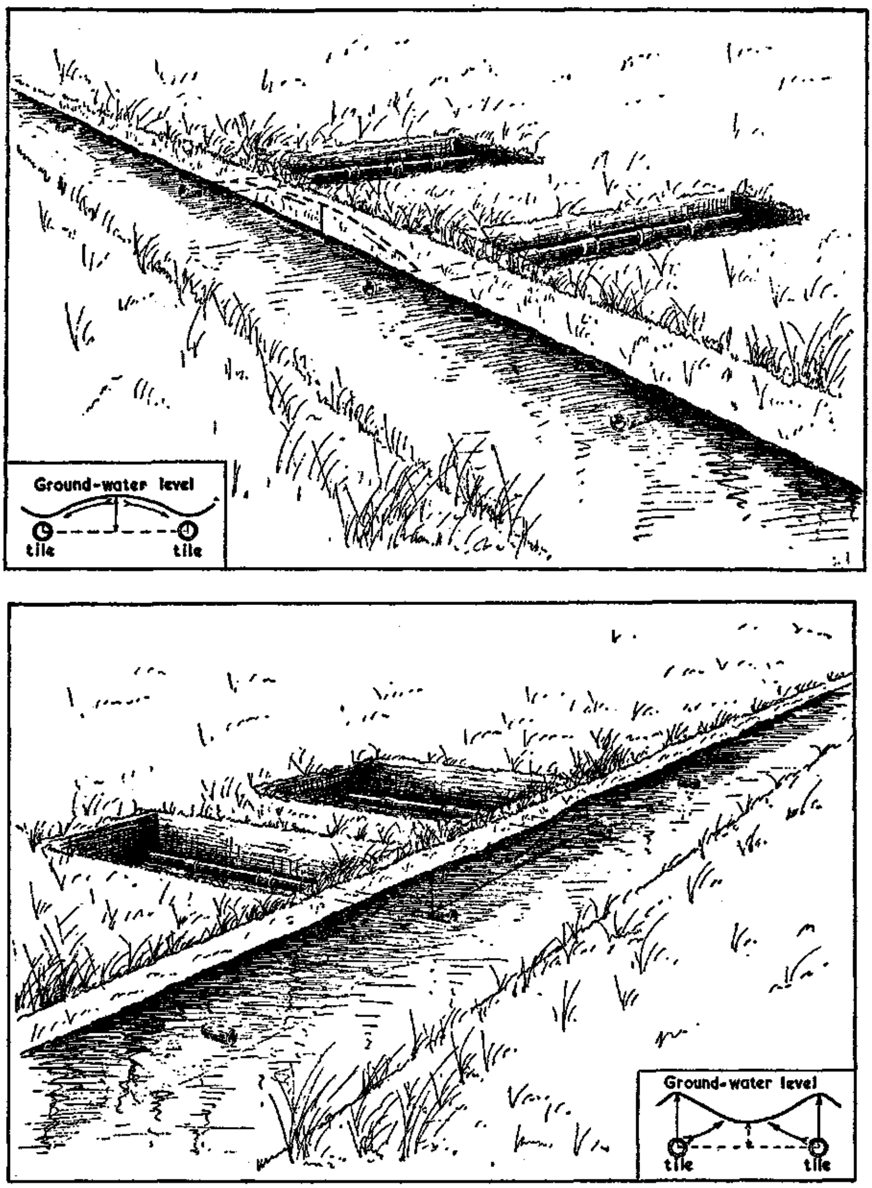

Fig. 3. Schemes of Tile Drainage (Top) and of Subirrigation (Bottom)
In view of the mutual relation of the two systems, the lines of tile are supposed to discharge below the water level.

RELATION BETWEEN GROUND-WATER LEVEL AND CROP YIELD

The primary purpose of drainage is to prevent too high ground-water levels in winter and spring, and that of subirrigation is to keep these levels sufficiently high in summer. The presence of adequate moisture in the soil layers containing crop roots and, at the same time, sufficient aeration of the soil are important plant-growth needs which, in the Netherlands, are best met by control of the ground-water level.

To determine the optimum ground-water level is a complicated problem, for one has to cope with normal variations in the level during the year—high in winter, decreasing in spring and summer, rising again in autumn—and also with the influence of temporary periods of rain and drought. Moreover, the effect of the ground-water level may vary for different crops, such as winter and spring cereals and root crops.

The problem can be solved by two methods: (*a*) by providing, in the soil of an experimental field, different ground-water levels that are constant during longer or shorter periods; (*b*) by determining statistically by measurements on many fields under different conditions the effect of the ground-water level on crop yield (6). In this case the average ground-water level in a certain part of the growth period is usually correlated with the yield, the variation of this level being taken into account.

To give some idea of what is known about this problem, the year is divided into two parts, namely, summer, or the actual growing period, and the rest of the year.

Generally, a low ground-water level in autumn, winter, and spring will have no detrimental effect on soils and crops. This does not hold for some peaty soils which show shrinking or irreversible drying at too low ground-water levels. Moreover, on some soils it may be useful to store water for the crop in summer by maintaining the highest justified level in winter.

About 70 years ago drainage in the Netherlands left much to be desired. A high ground-water level used to occur in autumn, winter, and spring, and many soils contained excess water, leading to poor structure, especially of clay soils. This is no longer generally true, as soil structure has greatly improved. Common practice now is to keep ground-water levels of clay soils as low as possible.

It remains to be seen, however, whether a high water level, especially in winter, affects later crop growth if the level does not rise into the topsoil. Investigations on a water-level trial field, which are discussed later, have shown that the crop yield obtained at a ground-water level kept at 40 cm. below the surface from November to March and followed by a decrease to 120 cm. below the surface was not significantly lower than the yield obtained at a water level kept at 120 cm. below the surface during the whole year. A similar result was obtained in the Northeastern Polder, an enclosed Zuiderzee polder. Admittedly, information on the maximum water level allowable during winter is still inadequate. The general recommendation is that drainage is adequate if 5 mm. of surplus rainfall can be carried off without raising the ground-water level higher than 50 cm. below the surface.

The foregoing comments apply not only to arable land but generally also to grassland, which requires less drainage. Grassland in the Netherlands, therefore, is usually not tile-drained.

Obviously, in spring a lowering of the ground-water level is advisable in view of the increasing root development of the crops. In summer the most desirable water level depends more on soil condition and profile.

For arable land important data have been obtained on a ground-water level trial field on heavy clay soil at Nieuw-Beerta (11). This field has been divided into five strips, 86 by 25 m., on each of which the ground-water level can be kept constant, within a few centimeters, to a different depth (40, 60, 90, 120, and 150 cm.). This is attained by means of tile drains only 2 m. apart that discharge below water level into deep sewers in which the desired water levels are maintained by small weirs. This is accomplished by drainage in winter and by subirrigation in summer. On three plots crossing the five strips three different crops are grown annually in the usual crop rotation.

During the first 7 years the ground-water levels were kept constant all year at the five depths mentioned. In the first 5 years no differences were noted in tillability and structure of the soil. After this, the 40-cm. strip and, to a lesser degree, the 60-cm. strip showed a more compact and sticky topsoil. On the other three strips the structure had not deteriorated. On all strips, germination and growth of winter and spring crops were the same until a certain time, usually late in spring, when differences were noted especially with cereals and peas. On the 40- and 60-cm. strips, the crops yellowed. Later, those on the 90-cm. strip were similarly affected. On the 120- and 150-cm. strips, normal, healthy color was maintained. On the strips with the highest ground-water levels, the crops ripened sooner and the yield was lower. The cause of yellowing and decrease in yield is partly nitrogen deficiency. With increasing depth of the water level, the increase in yield was great at first but later became smaller.

Other crops, like beans, rape seed, and caraway seed, showed less yellowing or none, but usually the yield was higher at the lower water levels.

During the last few years the ground-water level on the 60-, 90-, and 120-cm. strips has been kept at 40 cm. from November to March and at 60-, 90-, and 120-cm. for the rest of the year. For the most part, growth and yield of the crops appear to have been unchanged by this measure. The higher water level during winter, therefore, proved not to have been injurious. This experiment is being continued to determine whether the soil structure will eventually be affected by this treatment.

Table 1 shows the yields of winter wheat on this field. The maximum yield has not yet been reached.

At an insufficient water-holding capacity, an optimum ground-water level occurs. A case in point on sandy loam was placed at the author's disposal by W. C. Visser. The statistical method was used, taking into account many plots on this soil type showing a great variation of ground-water level. Figure 4 shows experimental results of the effect of different water levels on the yield of potatoes.

In most Netherlands soils, the water level in spring is too deep to fit the rising curve (fig. 4) for decreasing water levels. Another case is dealt with in table 2. This is concerned with oats on sandy soils having an upper layer rich in humus of different thickness underlain by sandy subsoil of varying degrees of fineness, expressed by *U*-number, or specific surface. The thickness of the humus layer

TABLE 1

Effect of ground-water level on yield of winter wheat

Grain and straw in kgm. per 100 sq. m.

	DEPTH OF GROUND-WATER LEVEL (CM.)									
	Grain					Straw				
	40	60	90	120	150	40	60	90	120	150
1947–48*	19.8	27.3	31.9	36.5	41.9	43.1	53.1	60.8	70.6	78.2
1949–50†	31.3	37.6	42.5	45.8	51.3	57.5	64.3	73.8	76.5	89.9

* Ground-water level constant throughout the year.

† Ground-water level on the 60-, 90-, and 120-cm. strips, 40 cm. from November to March; at original depths for the rest of the year. Other strips kept at original depths all year.

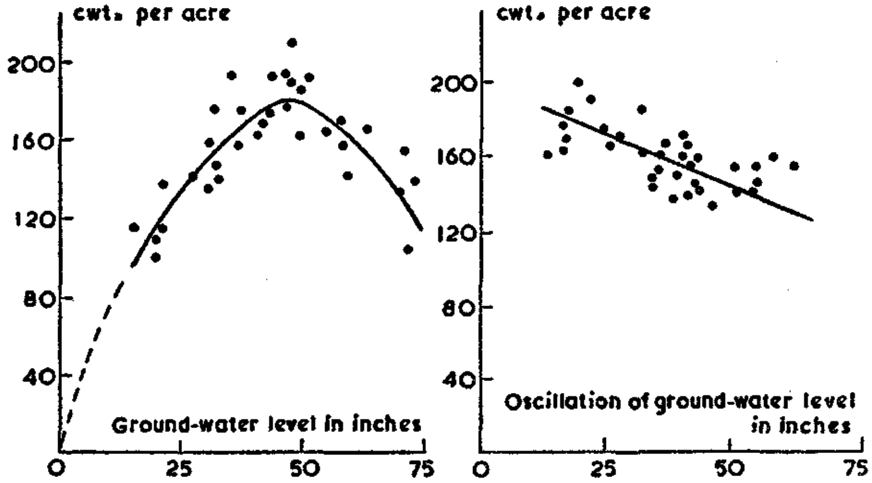

FIG. 4. RELATION OF YIELD OF POTATOES TO DEPTH OF THE GROUND-WATER LEVEL (LEFT) AND TO OSCILLATION OF THE LEVEL (RIGHT)

TABLE 2

Effect of thickness of sandy humus layer and of specific surface of sandy subsoil on optimum ground-water level of arable land

SPECIFIC SURFACE (*U*) OF SANDY SUBSOIL	DEPTH OF WATER LEVEL			
	Humus layer 20–40 cm.	Humus layer 41–60 cm.	Humus layer 61–80 cm.	Humus layer 81–100 cm.
	cm.	*cm.*	*cm.*	*cm.*
40–70	90	110	130	150
71–80	100	120	140	160
81–100	110	130	150	170

and the fineness of the sand are the factors dealt with statistically. Table 2 shows the water levels at which the depression in yield caused by water shortage does not exceed 10 per cent. The ground-water level at which this depression occurs is lower the thicker the humus layer and the greater the U-number of the underlying sand, that is, the finer the sand.

Permanent grassland probably does not show a maximum water level, but only an optimum for all soil profiles, even those of the heaviest clay. According to 't Hart (7), growth of grass of varying productivity in 3 years under different weather conditions and on clay, peaty, and sandy soils, reached a peak in May. This was followed in all cases by a decrease. In the latter part of summer, growth again increased. Productivity in summer appeared to be relatively low. To support as many cattle as possible and to increase their milk production, it is desirable to increase the yield of grass, especially in summer. For this purpose more water must be made available, though the decrease in grass yield is due to other factors also. Additional water is generally supplied by subirrigation, the necessity for which increases as the water-holding capacity of the soil decreases.

TABLE 3

Effect of subirrigation on yields per hectare of grassland and of arable land

	SUBIRRIGATED	NOT SUBIRRIGATED
Grassland		
Hay (two cuttings) .... *kgm.*	7,100	3,900
Grazing .... *days*	1,110	780
Arable land		
Winter wheat (grain) .... *kgm.*	3,920	3,630
Rye (grain) .... *kgm.*	3,525	3,510
Spring wheat (grain) .... *kgm.*	2,820	2,275
Spring barley (grain) .... *kgm.*	3,095	2,740
Mangolds (roots) .... *kgm.*	87,700	81,600
Potatoes (tubers) .... *kgm.*	35,900	35,800

TABLE 4

Effect of thickness of sandy humus layer and of specific surface of sandy subsoil on optimum ground-water level of grassland

SPECIFIC SURFACE (U) OF SANDY SUBSOIL	DEPTH OF WATER LEVEL		
	Humus layer 20–30 cm.	Humus layer 31–40 cm.	Humus layer 41–60 cm.
	cm.	*cm.*	*cm.*
40–60	85	100	100
61–75	100	115	115
76–90	100	115	115

The influence of subirrigation on yields of grassland and of cultivated crops is shown in table 3.

Table 4 shows the effect on optimum ground-water level of permanent grassland on sandy soil with humus layers of varying thickness and with underlying sand of different degrees of fineness. The table indicates the water levels at which decrease in yield will be not more than 10 per cent below the maximum.

That permanent grassland on a sufficiently permeable clay soil also may suffer from drought in dry periods when the ground-water level is 1 or more m. below the surface has been demonstrated. In this case subirrigation was by mole channels (7 cm. in diameter) 50 cm. below the surface discharging below the ditch-water level. The ground-water level on the subirrigated part was 40 to 45 cm., on the nonsubirrigated one more than 1 m. The great differences in yield are shown in table 5; rainfall in June, July, and August had been below average.

Serious drying out of grass on these soils is due to the so-called "nut" structure in the layer 15 to 40 cm. below the surface. This adversely affects deep root development and prevents capillary rise of water from deeper layers.

On clay soils of otherwise excellent quality, damage may result from heavy fertilization and intensive use of grassland, leading to trouble from drought, stagnation, or at least decreasing growth. When production is very high (10,000 kgm. of milk per hectare), this sort of clay soil shows an optimum ground-water level, which does not occur with a normal yield of 5,000 kgm of milk. These soils, therefore, have a maximum water level for normal yields.

TABLE 5

Effect of subirrigation on yield per hectare of grassland on clayey soil

DATE OF MOWING	YIELD OF FRESH GRASS	
	Subirrigated	Not subirrigated
	kgm.	*kgm.*
August 5	15,600	1,800
September 10	18,600	3,600
November 11	10,800	6,300

Apparently, then, the ground-water level, which depends on the soil profile and the ditch-water level, should be raised during the growing season. The optimum ground-water level, the ditch-water level, and the quantity of water required daily (about 4 mm. on grassland in dry periods and probably somewhat less for arable crops) are the fundamental data for calculating the necessary distance of the subirrigation tiles and trenches.

RELATION OF SOIL PERMEABILITY TO WATER CONTROL

If the required conditions for tile drainage or subirrigation are known, the distances between the lines of tile can be calculated, provided some other factors also are known. The problem has been reduced to the water flow in the soil (2, 3, 10).

The other factors that must be known are the permeability of the soil and the depth to which the soil retains this permeability. In soils that are homogeneously and isotropically permeable to a great depth, the intensity of flow to deeper layers decreases. Calculations have shown that the permeability of the soil is of no importance at a depth exceeding one fourth the distance between the tiles or the ditches in the drainage or subirrigation systems, since the flow from or to these systems at this depth is negligible. For example, if the tile drains are 10 m. apart, soil permeability at a depth of more than 2.5 m. below the tiles can be disregarded; if there is an impermeable layer nearer to the surface, the position of this layer must be determined.

If the impermeable layer is relatively close to the surface in comparison with the distance between tiles and ditches, the product of the permeability coefficient and the thickness of the permeable layer indicates the "conductivity for water" of the soil. In cases of equal permeability, this conductivity decreases as the level of the impermeable layer rises in the profile and the required distance between the tile drains consequently decreases at the same rate.

The calculations become more difficult if the soil, because of differences in the permeability of the profile, is not homogeneously permeable. Nevertheless they can be made.

It follows that it is important, for determining drainage as well as subirrigation, to know the permeability of the soil, the rate at which it changes in relation to depth, and the depth at which it may be disregarded.

Apart from sandy soils with a 16 μ fraction not exceeding 5 per cent, there are no methods for determining the permeability coefficient of the whole soil profile. Consequently, it is not yet possible to calculate the exact drainage distance required for other soils. There is a field method for determining the permeability to a depth of 2.5 m. below the surface, that is, to about 1.5 m. below tile drains set at a depth of 1 m. Nothing is known about permeability at a greater depth, although the kind of soil may provide some clue.

If the permeability is low and consequently the distance between the lines of tile is small, it may be safely assumed in computing the drainage distance that the soil retains the same permeability to a depth equal to one fourth this distance. If the permeability is high, this assumption is not valid because of the compression by overlying layers. In this case it is supposed that the soil retains its permeability to a somewhat greater depth than that to which permeability has been determined (rounded off to $\frac{1}{4}$ m.). Below this level, the soil is supposed to be impermeable. If the drainage distance is based upon this supposition, and if the soil actually is impermeable to the assumed depth, a condition rarely found in the Netherlands, the distance will be correct. If the soil remains permeable to a greater depth, the computed drainage distance is too small and consequently is safe. The computed distance figure is rounded off upward. To-day, drain distances are indicated satisfactorily by this method.

DETERMINATION OF SOIL PERMEABILITY

The definition of 'permeability" is based on Darcy's law, in which the permeability coefficient represents a layer of water at a definite temperature flowing per unit of time through a section in the soil perpendicular to the direction of flow, if the hydraulic gradient is equal to 1. At a definite ground-water temperature, and consequently at a definite viscosity of the water, this law can be expressed by the following formula:

$$V = \frac{Q}{F} = \mathrm{K}\,\frac{\Delta p}{l} = KI$$

in which Q represents the quantity of water per unit of time flowing through a column of soil of length l (in the direction of the current) and cross section F, if the difference in pressure of the water at both sides of the column is equal to Δp. I gives the hydraulic gradient and V the quantity of water flowing through the column. If this difference in pressure, Δp, is expressed in a column of pure water, I has no dimension. The permeability coefficient K is equal to V if $I = 1$. According to this definition, the permeability coefficient has the dimension of lt^{-1}. Usually this is expressed in meters per 24 hours.

For structureless sandy soils this determination is based on a direct application of Darcy's law, whereby all factors will be determined or are known and consequently K can be computed (8). If the soil in a natural situation has a pore volume different from that during the determination and if the ground water has a different temperature, then the individual factor must be adjusted accordingly. This determination of permeability has but little significance for computing the distance between the lines of tile, since sandy soils rarely require systematic drainage. The distances between tiles or moles of the subirrigation system are usually determined by means of experimental fields.

In other soils the permeability of which is determined by cracks and by root and worm holes instead of by pore spaces between the soil particles, the auger-hole method is used. In a vertical auger hole extending below the ground-water level, the velocity at which the water rises after the hole has been drained depends upon the permeability of the soil. If the relation of the velocity of rise, the permeability coefficient, and the other factors influencing this velocity is known, the permeability coefficient can be computed.

This method determines only the permeability of the soil below the ground-water level. In the main, it determines the permeability of the layer between the water level in the hole, that is, ground-water level, and the bottom of the hole. The radius of the column of soil around the auger hole, the permeability of which is measured, is relatively small, about 0.5 m.

The auger-hole method, originated by Diserens (4), was improved by the author (9, 10) and by Kirkham (12), Van Bavel (1), and Ernst.

As this method measures the permeability of only a small column of soil, it is necessary to repeat the determination on several spots, preferably five or six per hectare, unless large areas are under investigation. To determine the changes in permeability in relation to depth below surface level at these spots, holes of different depths at distances of 1 to 2 m. are bored on every plot.

The permeability varies from 0.1 m. per 24 hours in the finer sands to more than 30 m. in the coarse river sands. That of peaty soils ranges from 0.01 to more than 10 m. Phragmites peat is sufficiently permeable; sphagnum and carex peats are often much less permeable. In Dutch clay soils the variation is from 0.01 m. to more than 30 m. per 24 hours. Some clay soils have a better permeability than coarse sandy soils.

DETERMINATION OF LAYOUT OF DRAINAGE AND SUBIRRIGATION SYSTEMS

For systematic drainage, the drainage distance, in practice, is often based on results with similar soils. Sometimes special experimental fields are laid out. This is necessary if the soil before being drained has a high moisture content and is seriously desiccated by drainage and cultivation and if the permeability increases as a result of cracking, as in newly reclaimed clay soils. Sometimes the permeability varies so much from spot to spot that no average permeability coefficient can be determined, as in very young heavy marine clay soils. Drainage recommendations are being based more and more commonly and with satisfactory results on permeability determinations. The minimum applied drainage distance is about 7 m. The maximum distance is defined by the distance between the ditches. In this connection, a plot is not drained if the required drainage distance exceeds half the distance between the ditches.

When special experimental fields are used to determine distances for the subirrigation systems, the required ditch and ground-water levels as well as the most practical means of execution are deduced from the results.

PRACTICAL OPERATION OF TILE DRAINAGE AND SUBIRRIGATION

Drainage

Systematic drainage was formerly executed by means of trenches. Nowadays, tile drains are most common, though sometimes moles are used. The advantages of tile and mole drainage over trenching are easier cultivation of the land, no loss of land, and less weed development. Trenching is sometimes practiced for a few years when the soil is very wet, is low in permeability, and is insufficiently cleared of salt, as in newly reclaimed heavy clay soil. In time, the drains may become inactive or blocked. Tile drainage is then applied as soon as the soil is sufficiently dried and cleared of salt.

Since the regions needing systematic drainage are intersected by ditches, simple drainage is usually applied rather than compound drainage, that is, primary and secondary lines of tile. In simple drainage, each row of tile discharges directly into a ditch. The advantage of this system is that the efficacy of each tile line can easily be verified. Moreover, the construction is simple. When lines of tile become inactive, they can easily be cleared by passing through them poles on which rubber disks have been fixed, followed by washing.

Unglazed brick tile 30 cm. long and with an inner diameter of 5 cm. and an outer diameter of 7 cm. are used. The drainage distance generally does not exceed 30 m. Only in compound drainage systems does the diameter vary according to the amount of water to be discharged.

The drain tile are sometimes flanged. Although more expensive than tile without flanges, they can be joined more securely. They are used especially in soft soils, such as peaty or clay soils with soft layers at drainage depth, if there is risk of local displacements due to unequal settling of the profile.

The lines of tile are generally 100 to 150 m. long. They may be laid horizontally and discharge below the water level in the ditches, though usually they slope about 10 to 20 cm. per 100 m. and discharge above the water level. The sloping tile lines do not become blocked so quickly as the horizontal ones, for the silt accumulation cracks during summer and is more readily removed by subsequent water flow. Moreover, the sloping lines are more easily laid. Their nearness to the surface is a drawback only where ditch-water levels are high.

The depth of the tile lines is determined by the ditch-water level during winter. This depth varies from 80 to 150 cm. below the surface.

Few data on the length of period of performance are available. In some places the tile lines function satisfactorily for more than 50 years. In other places, they become blocked after 1 or 2 years and have to be cleared. It is assumed that well-laid tile continue to function for 25 years on an average.

The lines of tile usually are laid in trenches dug by hand. In the reclaimed polders of the former Zuiderzee, mechanical excavation is practiced. After the bottoms of the ridges have been given the correct slope, the tile are laid. To prevent soil particles from penetrating into the tile, a thin layer of filtering material is sometimes deposited on the tile or around them. Frequently, coarse peat dust is used. On this, a thin layer of topsoil is deposited. Then the ridge is filled with the original soil. To maintain the permeability of the soil in the ridge, especially where permeability is low, lime is commonly applied during the filling if the pH is low.

Subirrigation

For systematic subirrigation of grassland, trenching to a depth of 60 to 80 cm. is most common, although use of lines of tile or mole channels is increasing, especially in peaty and clay soils. For horticultural use, subirrigation with tile is most common, especially on sandy soils. In clay and peaty soils, mole channels are more commonly used for subirrigation than for systematic drainage. This is because shallow mole channels are more satisfactory for subirrigation than for drainage. Moreover, mole channeling is much cheaper than tiling even if new channels have to be made every 2 years.

The depth of the tile lines or channels, 40 to 60 cm., for systematic subirrigation is less than that for drainage. The lines of tile or mole channels are always horizontal and discharge below the water level in the ditch.

In the Netherlands, considerable variation in the weather affects the time at which subirrigation in spring should be started. During hot, dry spells in summer, a ground-water level that will be too high during subsequent wet spells may be desirable. A high ground-water level in clay soils during the whole period of subirrigation is not desirable (11). It seems preferable to moisten these soils by a high ground-water level for short periods, followed by periods of low ground-water level.

In special cases, it is possible to subirrigate by raising to a sufficient height the water level of brooks in elevated, slightly sloping, but comparatively flat, sandy land. If the water level of the brook is raised early in spring, the winter water is stored and produces a higher ground-water level. The result of this rise will be better if the water level of the ditches is raised at the contour lines. These ditches discharge water into the brook at some distance upstream from the weirs. The effectiveness of this measure has been determined both by experiments and by calculations based on the permeability of the soil profile down to the impervious layer and by other tests.

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