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Principles of Drainage with Special Reference to Peat

By W. BURKE

Any general discussion on the principles of drainage must take all factors of the hydrological cycle into account. These factors are precipitation, infiltration and run-off, evaporation and evapo-transpiration, soil permeability and the water retaining power of the soil. Of equal importance are the physiological factors and the functions of root systems in the soil.

In this paper an attempt has been made to give a brief summary of the more important of these factors and an account is given of the main results of drainage research at the Peat Station of the Irish Agricultural Institute at Glenamoy, Co. Mayo.

Permeability and waterflow in soil

In 1856 a French engineer called Darcy carried out some experiments on the flow of water through saturated beds of sand. As a result of these experiments he enunciated a law which has since been generalised and expressed in various forms but is always known as 'Darcy's Law'.

One method of writing it is

$$\frac{Q}{t} = \frac{K.A.h.}{d} \quad \dots\dots\dots (1)$$

Q is the quantity of water that flows in time t across an area A under a potential of h through a medium of thickness d. K is a coefficient that depends on the physical properties of the medium and is called the hydraulic conductivity.

Re-arranging equation (1) gives

$$\frac{Q}{A.t} = \frac{K.h}{d}$$

or V (velocity) = K.i. (i is called the hydraulic gradient.)

K is large for coarse materials e.g. coarse sand or soils with good structure. K is very small for fine materials e.g clay soils with poor structure and peat. We have measured K values which differed by a factor of more than 100,000,000.

In simple language Darcy's Law states that the velocity with which water flows through a porous medium is directly proportional to the product of the hydraulic conductivity of the medium and the potential energy of the water, and inversely proportional to the distance through which the water must travel. Darcy's experiments dealt with vertical flow but at a later stage various workers applied Darcy's Law to develop equations expressing the continuity of flow in porous media. The results gave new equations and their solutions described accurately the flow of water to drains in saturated soil. Data became available for various types of soil conditions e.g. layered soils and soils with drains at different depths and spacings. The correctness of the mathematical analysis can be demonstrated by models in the laboratory.

Saturated flow does not always occur. Unsaturated flow, which very often occurs here — probably more often than saturated flow still remains largely unsolved although recently the computer has enabled much progress to be made.

Non Darcy Flow

Recently it has been suggested that flow in very fine pores does not strictly obey Darcy's Law. It was suggested that under these conditions there is a minimum or threshold gradient required before any flow can take place. This theory has yet to be conclusively proved or disproved.

Water Retention

The second aspect of soil drainage to be discussed is soil water retention. It is a matter of observation that even after drainage has taken place the soil remains moist. This moisture is held by surface tension forces in soil pores. This water retention is governed by a fundamental principle of physics and has great implications in soil drainage.

If one end of a capillary tube is placed in water, water will rise in the tube and stay at a level which depends on the diameter of the tube. If a suction is applied to the upper end of the tube the water will rise higher but will return to its original level in the tube as soon as the suction is released. It can be easily demonstrated that there is a precise law relating the level at which water stands in the tube with the tube diameter. It is as follows

$$h = \frac{0.30}{d}$$

d is the tube diameter, h is the height of rise of water in the tube. The significance of this law in soil drainage is as follows. Soil consists of "grains" of material in contact. Thus there is pore space between these grains and the finer the grains the finer the pores. In effect the fine pores behave exactly like capillary tubes and the watertable corresponds to the water in which the end of the capillary tube is placed. In the simplest case if a drain is placed in soil that has a watertable, the watertable is lowered to the level of the drain bottom. Depending on effective pore diameters in the soil, water will stand at varying heights above the watertable in the finer pores but some of the larger pores will drain freely. The porosity of the soil affects permeability. Water moves more freely through large than through small pores, the difference is largely due to friction between the water and the walls of the pores. Thus a coarse textured open soil will drain faster than a fine textured one and the latter soil will hold more water by capillarity than the former after drainage has taken place.

Infiltration and Rainfall

So far water movement and water retention in soil has been discussed, but it also necessary to consider how water gets into the soil.

Except in the case of seepage, springs and floods, water arrives at the soil surface as precipitation and enters or infiltrates into the top soil. The maximum rate which water can enter a soil is called the "infiltration capacity". This varies considerably with soils. For instance we have measured infiltration capacities that varied from 0 to $\frac{1}{3}$ inch per day on a Drumlin soil in Co. Leitrim to 10 inches per day on a good soil in Co. Cork. The importance of infiltration capacity lies in its relationship with rate of rainfall. While rainfall rate exceeds infiltration capacity all the water cannot soak into the soil. Instead it flows over the surface and usually collects in depressions. These depressions with their stored water act as reservoirs to keep the soil saturated in patches for long periods. This is particularly evident in persistent patches of water in fields through the winter or in the continually wet top soil that results from poaching and treading damage by animals' hooves.

Evaporation

One other aspect requires some attention. While this, strictly speaking, is not drainage it is a process that removes a large quantity of water from the soil and cannot be overlooked. This process is evaporation and on the average it removes from 15-18 inches of water from the soil in Ireland each year. Evaporation is a physical process and two operations are involved.

Firstly the water must change from the liquid to the vapour phase i.e. latent heat of vaporisation must be supplied. The amount of heat or energy required is 590 calories per cubic centimeter of water. This energy all comes from the sun.

The second factor is wind, or turbulence of the atmosphere, which removes the vapour to higher levels, thus permitting evaporation or evapotranspiration as it is sometimes called to proceed continually. The limiting factor in evaporation is energy for the supply of latent heat of vaporisation. Sometimes some of this energy can be supplied by a warm dry wind blowing across the country. This is often called advected energy. Because energy is limiting there is an absolute or "potential" evaporation that can occur. Measurements and calculations indicate that this *potential* evaporation for Ireland lies normally between 15 and 20 inches and three-quarters of it occurs from April to September inclusive. For various reasons actual evaporation will be lower. Thus the overall water balance for the country shows a big excess of precipitation from October to March inclusive, with an approximate balance between rainfall and evaporation during Summer, with considerable local variation in the Summer pattern.

Plant Physiological factors in drainage

The above gives a summary of the physical processes of soil and climate that govern soil drainage. The next aspect to be considered is the crop.

Some plants can tolerate poor drainage and some plants do best in conditions of poor drainage but the majority of economic crops demand good drainage. All of the physiological factors involved have not been clearly described, but aeration appears to be the most important. It is known for instance that root respiration depends on:

(a) Rate of oxygen supply.
(b) Concentration of Carbon dioxide present.
(c) The relative amounts of Oxygen and Carbon dioxide that are present.

Different plants appear to have different requirements and the morphology of the plant root appears to be of equal importance with the physical properties of the soil. Aquatic plants often have in them large intercellular cavities through which gaseous exchange can take place internally. Non-aquatic plants also have intercellular spaces but to a much lesser extent. It has been shown that in an average corn root with 8 percent intercellular space enough oxygen can diffuse down the root to supply 10 cm of root length while in an aquatic root with 75 per cent intercellular space enough oxygen can diffuse to supply 50 cms of root length (1). In a normal crop when flooding takes place the O_2/CO_2 balance for the deeper roots is quickly upset and if the condition persists permanent damage occurs to the plant. The condition appears to be due to an upset in the biochemistry of the plant leading to the production of phytotoxic chemicals.

Root Functions

The principal functions of the roots are:—

1. Anchorage.
2. Water absorption.
3. Mineral absorption.
4. Synthesis of hormones and other organic compounds (2).

The volume of soil occupied by the roots and therefore the depth of roots govern all of the above factors. When root depth of normally deep rooting plants is restricted it is usually for one of two reasons

(a) Mechanical impedance in the soil.

(b) A high watertable.

Evidence of mechanical impedence to roots is available from the failure of plants to penetrate iron pans, cemented layers or compact B horizons. Impedence due to a high watertable occurs because any roots that penerate, quickly die due to some type of physiological upset.

Whatever the cause of impedence the effects are the same. A restricted root system gives poor anchorage and the plants are easily toppled in a storm—very often the trees that are uprooted in a storm are seen to have shallow roots. Because of the small soil volume occupied by the roots, nutrients and, in dry weather, water may be in short supply, though the latter factor is seldom serious here. Regarding nutrients it may be possible to supply Phosphorus, Potassium and Nitrogen to a plant with a restricted root system but if the restriction is caused by waterlogging there is a probability of rapid de-nitrification with consequent Nitrogen deficiency which may be difficult to correct.

Inadequate Drainage

The provision of an inadequate drainage system must be avoided. Such a system will lower the watertable during a moderately dry period but will permit the watertable to stay high in a prolonged wet period. Under such a system vigorous root development may take place in dry weather. Then comes a wet period, the roots are submerged with very serious consequences. A similar and even more serious consequence follows if an adequate drainage system deteriorates after a number of years. In this case the extensive root systems become swamped and the effect is disasterous. Small plantations of fruit trees and conifers that have been killed in this way are often seen.

Drainage at Glenamoy

The following is a brief account of research on drainage at Glenamoy and the above factors are referred to where applicable.

Drainage research at Glenamoy commenced in 1957 and the programme was directed completely towards drainage for agriculture —mainly grass production. It had three main objectives.

(i) To determine what drain spacing and depth was required to control the watertable in the peat.

(ii) What were the effects of this drainage on the peat and on crops.

(iii) To devise practical means of achieving this drainage.

At Glenamoy rainfall is in excess of 50 inches per annum and is fairly uniformly distributed. Measured and calculated evaporation shows values of about 16 inches most of which occurs in Summer. Thus drainage in Glenamoy involves the removal of some 35 inches of water per annum.

Physical Properties of Glenamoy Blanket Peat

The peat at the station varies in thickness from 4 to 20 feet. Most of the drainage experimentation was done where the peat is 12 to 16 feet thick. Bulk density values ranged from about 0.95 gm/cc at the surface to 1.01 gm/cc below 12". Ash contents is 2% and moisture content is about 90 gm water to 10 gm dry matter. Air filled pore space after drainage is about 5 to 8 percent by volume at the surface. The hydraulic conductivity of the peat is very low about 1 cm per day for undrained peat.

Effect of Drainage on Watertable

In the initial experiments three feet deep drains were installed at various spacings ranging from 8 to 100 feet and the shape of the watertable was measured. From this study it became obvious that a spacing of 12-15 feet was needed to achieve reasonable control of watertable. The initial trials were confined to 3 feet deep drains but in a subsequent experiment the watertable was lowered by pumping from a well. In this trial a depth of 7 feet was reached in stages and the net effect was that there was a disadvantage in drains deeper than about 3 feet. As the watertable was lowered the permeability of the peat was reduced to about .3 cm/day at a suction of 4 p.s.i. and rate of discharge from the well also fell off. Details are given in Table I.

Table I

Daily Discharge figures from Well (Steady state assumed) and corresponding permeability values

Well Drawdown (ft.)	Measured Discharge per day (ccs)	Average Permeability cms/day (Dupuit)
1	12,816	0.97
3	24,804	0.65
5	21,859	0.38
7	19,911	0.29

Effect of Drainage on Water Removal

Flow recorders were used to determine the characteristics of water removal from a drained and an undrained area. The drained area had 3 foot deep drains installed at 12′ centres. In the undrained area the water table remained near the surface and precipitation emerged almost immediately through the flow recorders. In the drained area the watertable was reasonably well controlled at a depth of about 1½′ to 2′ in summertime but the rate of removal of water was slower. The difference in water removal rate was probably due to the fact that in the undrained peat much of the water flowed overground while in the drained peat the water flowed through the peat to the drains.

Effect of drainage on crop yields

The effects of drains at 1', 2', 3' depth were compared with that of no drainage on the yield of Rye grass, Cocksfoot, Potatoes and Oats. An increase of about 20% was obtained at the 3' drainage over the no-drainage for all crops.

Practical Means of Achieving Drainage

The first system tried out was one of open drains. This system was completely unpractical for livestock because drain maintenance is expensive and livestock losses were very high.

An early development at Glenamoy was the tunnel plough. This was never fully developed and is now scarcely used but it gave excellent results when used properly where conditions were suitable.

About three years ago nearly several different materials were installed in drains at Glenamoy. These materials included (i) plastic pipes of various kinds with and without glass fibre wrapping, permeable fill etc. (ii) Drains made of peat sods and dried peat. (iii) Drains made of sand and gravel laid on a strip of polythene. All are working well so far and nearly all are expensive. Plastic costs £50 per acre for materials. Peat and sod drains have high labour costs. Gravel on polythene is cheaper but until a mechanical method of laying it is achieved it remains difficult to instal. A type of drain that gives good promise consists of two layers of expanded polystyrene mesh sandwiched between two layers of glass fibre. The material cost of this is about £25 per acre for 15 ft. spacing.

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