Effective disruption is a major factor in the drainage of impermeable soils

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ABSTRACT

Water table measurements at two sites (Kanturk and Ballyroan) show a deterioration in water table control on mole drained plots when compared to gravel moled plots. The deterioration which is much more pronounced at Kanturk is attributed to the combined effects of a breakdown of drainage channels and of the vertical angled crack system. For the effective drainage of impermeable soils the provision of stable long-lasting channels is a major priority. Field investigations and theoretical considerations highlight the importance of a well-developed crack system and indicate the need for investigating the re-design of mole drainage equipment.

1. INTRODUCTION

In Ireland, the average annual rainfall varies from about 800 mm along the East coast to more than 1500 mm on the West coast. The annual potential evapotranspiration from grassland is of the order of 400 mm. The rainfall surplus therefore ranges from 400 mm to more than 1100 mm annually. Another aspect of Irish rainfall is that on average 40 to 45% of the annual total falls during the April to September period. This rather evenly distributed rainfall throughout the growing season coupled with the shallow topsoil depth of most of the impermeable soils results in most of these soils being used for grassland production.

In the undrained condition, major trafficability problems arise for both animals and machinery. Early nitrogen application is very often difficult and sometimes impossible and during wet summers, the land can become impassable for machinery with the result that forage is either lost or else harvested with difficulty and corresponding cost increases. In similar circumstances the grazing animals poach the soil surface badly and much of the grass is wasted. In both cases grass production for the following year is adversely affected. The problems are accentuated when greater than normal rainfall occurs over a number of consecutive growing seasons. This occurred in parts of the West of Ireland in the 1979-1981 period, and resulted in many fields becoming totally impassable for animals and machinery, leading to an enforced reduction in cow numbers and a corresponding income drop on many farms. In such circumstances the benefits of drainage must be considered in the context of both production and utilization, rather than in the context of production only.

1.1. Impermeable soils

In a survey on land drainge problems and drainage installations in Ireland (Galvin, 1969), it was found that 31% of all drainage problems in the country were classified as impermeable soils. Of these, the most important group consists of the glacial tills. These are usually overconsolidated to varying degrees and are also very impermeable with conductivities generally less than 1 cm/day.

1.2. Drainage systems

Traditional pipe drainage systems even if installed at uneconomically close spacings do not provide adequate drainage in these heavy impermeable soils. It is therefore necessary to resort to drainage systems that incorporate both soil disruption and the formation of drainage channels at relatively close spacings (1.3 to 2 m). The cracking and loosening achieved during soil disruption facilitates the transfer of water from the surface to the drainage channels, through which it is then transported to the pipe collector drains. The long-term effectiveness of such drainage systems obviously depends on the effectiveness and permanency of the crack structure and channel system. Mole drainage has been used in many parts of the world, over a number of years, as a method of providing a relatively inexpensive drainage system for impermeable soils. If installed properly it can be a very effective and efficient system of drainage where the soils are sufficiently stable to maintain an open crack structure and a mole channel which continues to discharge water over a period of 5 to 10 years. However, many soils are not stable.

In Ireland mole channels have collapsed completely within a period of 1 to 2 years after installation. Arising from this the gravel-mole system was developed by Mulqueen and Prunty and has been installed on a large number of farms in Northern Ireland and in the Republic of Ireland. The system is very effective in providing stable long lasting channels.

Pilot drainage trials incorporating mole drains ripping and gravel moles were installed at a number of sites in the West of Ireland in the period 1976-1978. The results of these trials were encouraging and on some sites, spectacular evidence was provided of widespread damage to the soil surface, arising from the breakdown of particular drainage treatments (Galvin, 1982). In 1981-1982 under a project, part-funded by the EEC, a number of instrumented experimental trials were installed (Galvin, 1983). Data from two of these trials (Kanturk and Ballyroan) are outlined and discussed.

2. EXPERIMENTAL SITES

Kanturk is situated in County Cork in the South West of Ireland whereas Ballyroan is located in County Laois in the South East midlands. Details of the rainfall pattern at each site and of major soil physical properties are given in Tables 1 and 2.

TABLE 1 Annual average rainfall (1951-1980) for Kanturk and Ballyroan (mm)

Month	Kanturk	Ballyroan
January	118	94
February	83	69
March	79	64
April	60	61
May	68	74
June	53	58
July	62	68
August	72	74
September	92	87
October	96	88
November	107	86
December	123	99
Total (annual)	1013	922
Total (April-September)	407	422

TABLE 2 Particle size distribution, Atterberg limits and bulk densities (Mg/m^3) of subsoils

		Kanturk	Ballyroan
Percentage passing	2 mm	100	100
	0.6	97	96
	0.2	92	90
	0.06	77	77
	0.02	65	65
	0.006	50	45
	0.002	34	31
Percentage >2 mm		9	5
Clay/silt ratio		0.52	0.48
Liquid limit		37	44
Plastic limit		21	25
Plasticity index		16	19
Bulk density		1.50-1.62	1.61-1.78

The rainfall data (Table 1) show that whereas the annual average rainfall at Kanturk exceeds that at Ballyroan by 90 mm, the rainfall during the growing season (April-September) at both locations is very similar. Both sites are however representative of the drier areas on which research on the drainage of impermeable soils is being carried out.

Table 2 shows that the physical properties of the soils are not very different. The particle size distribution data are practically identical over the 2-0.2 mm range and only vary to a maximum of 5% thereafter. The Atterberg limits are quite similar and clay/silt ratios are typical of many impermeable Irish soils.

On both sites similar disruption treatments are installed. These include:

- mole drains spaced at 1.3 m;
- gravel moles spaced at 1.3 m;
- gravel moles + ripping. The gravel moles are spaced at 2.6 m and ripping is then carried out between adjacent gravel moles;
- control.

The plots at Kanturk are 900 m^2 and those at Ballyroan 800 m^2. At each site the water flow from the individual plots is led through separate collector drains to continuous flow recorders. Each site is also equipped with a recording rain gauge and with maximum reading piezometers and/or water level recorders as detailed below.

In considering the water level data outlined in the paper, it should be remembered that the soil is not homogeneously disrupted. The maximum cracking and fissuring occurs in the immediate vicinity of the disruption channel and the effectiveness of disruption decreases as the distance from the disruption channel increases (Leeds-Harrison et al., 1982). All the water level recorders and piezometers are installed midway between adjacent disruption channels. The water level fluctuations are therefore measured at points where the cracking and consequently the drainage effect is minimised.

2.1. Kanturk

The pipe collector drains were installed at Kanturk in June 1981 and the disruption treatments in August 1981. The flow recorders and maximum reading piezometers were installed in March 1982. Water level recorders were installed on each plot in 1983.

2.2. Ballyroan

The collector drains were installed at Ballyroan in July 1982 and the disruption treatments in August 1982. Flow recorders and maximum reading piezometers were installed on all plots in February 1983 and water level recorders added in November 1983.

3. SITE INVESTIGATIONS AND RESULTS

The discharge and water table level charts are collected weekly. The maximum and current water levels in the maximum reading piezometers and the ground conditions are observed at the same time. The condition of the moles, gravel moles and rip channels is investigated by excavation and channel casting (where possible) at regular intervals.

3.1. Site investigations at Kanturk

Detailed investigations were carried out at the Kanturk site in June 1982, August 1983 and May 1985, during which randomly selected moles, gravel moles and rip channels were excavated. The condition of the channels and the crack structure in their vicinity were examined. However due to the rate at which the mole and rip channels had slurried up on this site, it was not possible to take polyurethane casts on any of the three occasions.

All the gravel moles examined were in good condition. The leg slot was invariably filled with topsoil which had migrated down to the top of the gravel and extended from there to the base of the topsoil horizon. This band of topsoil (up to 50 mm wide) was generally loose and permeable. The gravel in the mole had not been contaminated by the topsoil in the leg slot or by the surrounding subsoil. The vertical angled cracks which were observed in 1983 were approximately 0.25-0.30 m long, 6-9 mm wide and spaced at 0.20-0.25 m. These cracks were also found in 1985 but were then less distinguishable. This may be due to the fact that wereas the 1983 excavation was carried out at the end of a long dry period in August, the 1985 excavations were undertaken in early May when the soil moisture deficit was probably close to zero. However, the possibility that the width of the cracks is decreasing with time cannot be ignored.

The rip channels examined in 1983 were filled with topsoil. Topsoil was also found to varying heights in the leg slot. In 1985 the channels examined were filled with topsoil as were the leg slots. The band of topsoil in the leg slot was up to 60 mm wide. It was relatively uncompacted and capable of transporting water. The ripping had been carried out by the same machine as that used to install the gravel moles. In those circumstances the vertical angled cracks found radiating from the rip channels were similar to those found on the gravel mole plot.

The moles excavated in 1982 were filled with a loose slurried material. They appeared to be quite capable of transporting water to the collector drains. The moles excavated in 1983 were more solidly clogged. Occasional gaps were found between this infill material and the original wall of the mole channel. Three moles were examined in 1985. Two were completely clogged with material (mainly subsoil and some stones, with occasional traces of topsoil). The third mole was also clogged but had a slight (10 mm high) gap between the top of the infill material and the subsoil above it. This gap did not appear to be continuous but was observed at a number of points along the mole. The dimensions of the plug of infill material varied from 80 x 80 mm to 150 x 80 mm. This indicates that although the width of the original channel has not altered, substantially the vertical dimension has changed. On examination it would appear that the soft material extends below the original channel (due to water softening) and upwards due to the collapse of the roof. The problem in this regard at Kanturk are accentuated by the stony nature of the subsoil. This is borne out by the number of stones up to 30 mm diameter found in the infill material.

The leg slot crack was sometimes difficult to distinguish within the soil mass but, on excavation, the soil mass usually sheared open along this vertical plane. In one mole, however, the leg crack was readily observed and in another mole a very narrow band of topsoil indicated its position. The vertical angled cracks were also difficult to find on many moles but were very evident in the mole on which the narrow band of topsoil had been observed.

During the 1985 excavations, a very slight seepage of clear water was observed in most moles. However, the general impression created was that the moles are almost totally clogged up.

3.2. Site investigations at Ballyroan

Excavations were carried out at Ballyroan on 3 May 1985, during which the crack structure and the condition of the various disruption channels were checked.

The gravel moles are in good condition. There has been no contamination of the gravel in the mole by the surrounding soil. Topsoil has migrated into the wide leg crack to the top of the gravel mole and provides a direct connection from topsoil horizon to the gravel. The cracking and shattering of the subsoil in the vicinity of the gravel mole is also very good.

The cracking around the rip channel is well-developed. However, the channels were almost completely blocked up by a combination of subsoil swelling and the ingress of topsoil through the leg crack. In one of the rip channels examined, there was a considerable amount of topsoil in the leg crack and rip channel. This was generally approximately 20 mm wide but at one point had expanded to a diameter of 45 mm to fill a large hole about 12 cm above the channel base. The topsoil was relatively uncompacted and seemed quite capable of transporting water to the collector drains.

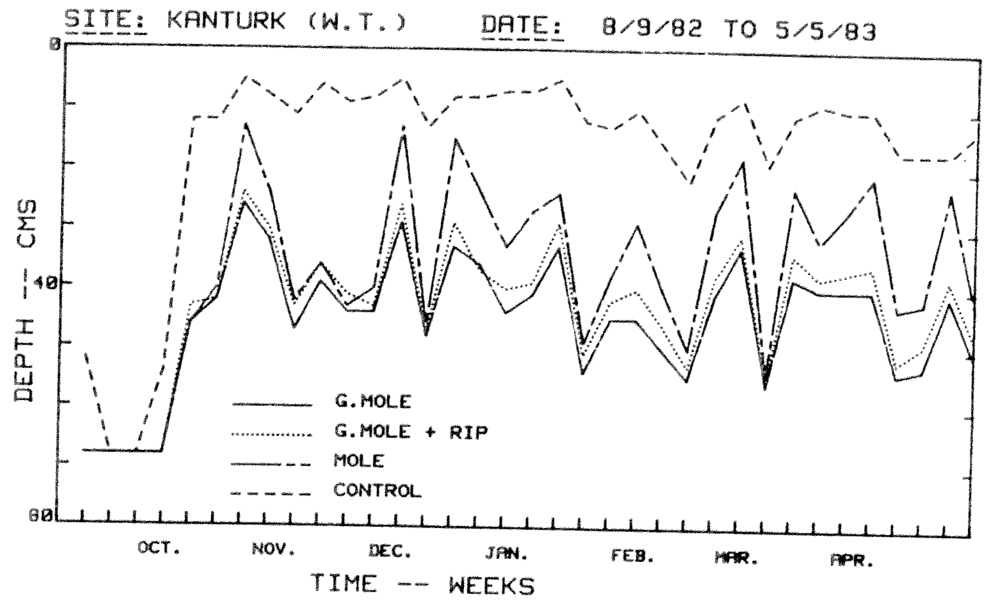
The mole drains were also in good condition although two blockages were found in those examined. One blockage had been caused by the disturbance of some large stones which resulted in a large quantity of soil being deposited in the channel, blocking it completely. A minor roof collapse appeared to be the main cause of the second (partial) blockage of the channel. The general average channel section observed was approximately 65 mm x 45 mm, ranging from a minimum of 25 x 25 mm to a maximum of 70 x 45 mm. The soft material around the channel varied in overall dimensions from 70 x 70 mm to 130 x 80 mm.

At Ballyroan the vertical angled cracks radiating from the moles were readily observed. They were well-developed with roots extending right down the cracks to the full depth, and were spaced approximately 0.17 m apart. Polyurethane casts were taken on three moles. The two blockages already referred to, were discovered during casting.

3.3. Water table fluctuations

The disruption treatments were installed at Kanturk in August 1981 and at Ballyroan in August 1982. The water table fluctuations over the September-May period for 1982/83 and 1983/84 (Kanturk) and for 1983/84 and 1984/85 (Ballyroan) are analysed.

The weekly water table levels at Kanturk for 1982/83 (Figure 1) and for 1983/84 (Figure 2) show quite clearly the deterioration in water table control that has occurred on the moled and gravel moled + rip plots relative to the gravel moled plot over that period. This deterioration is borne out by the SEW data outlined in Table 3. The SEW concept which is a measure of the water table height and duration above a given level was defined by Sieben (1964) and discussed by Wesseling (1974).



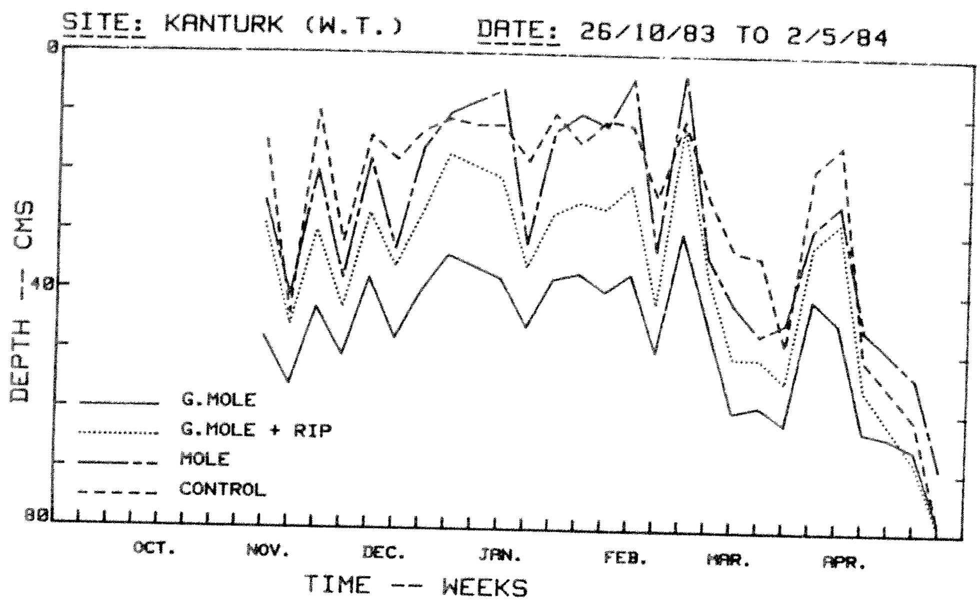
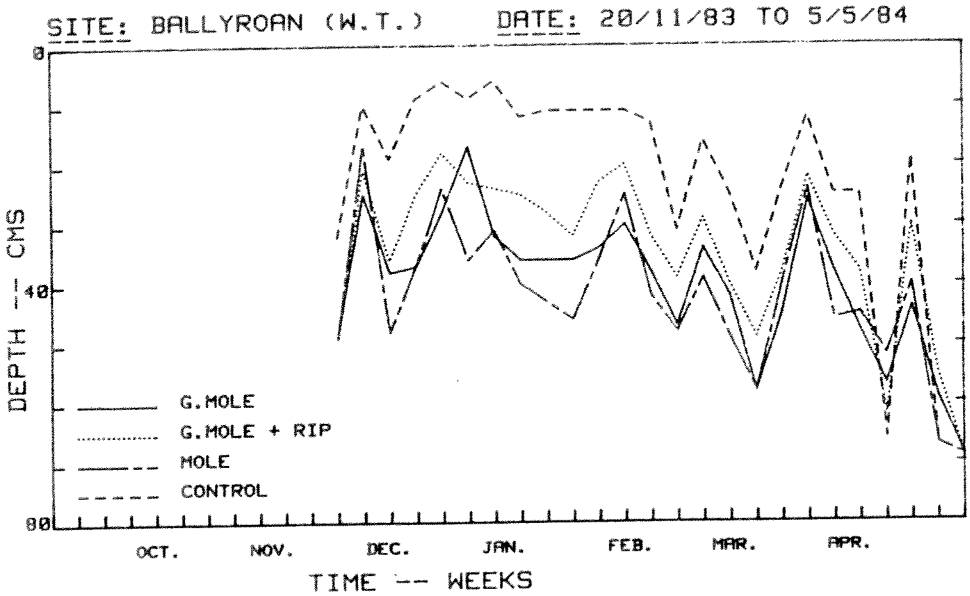
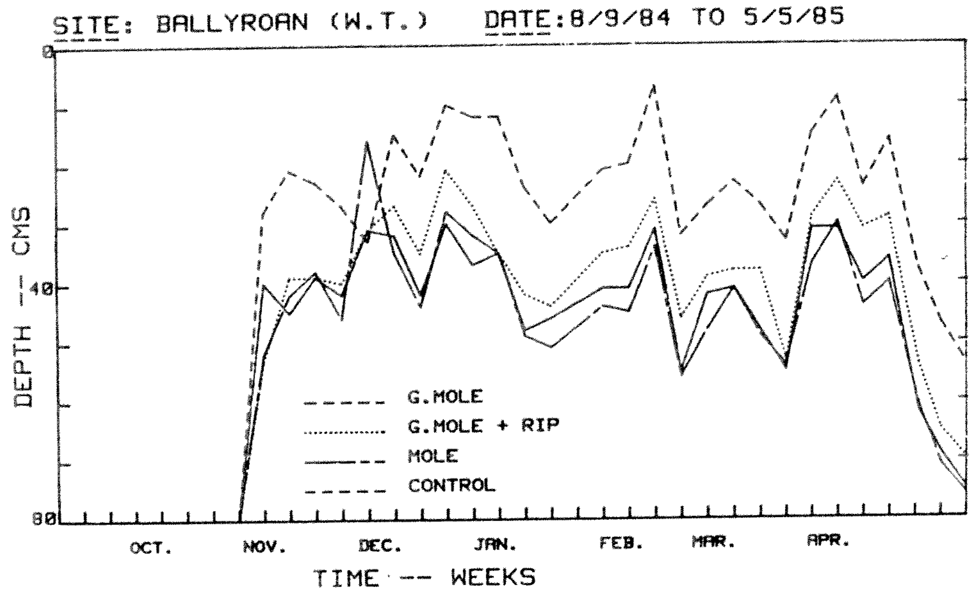


TABLE 3 SEW (30) figures for the September-May periods at Kanturk (1982/83 and 1983/84) and at Ballyroan (1983/84 and 1984/85)

	Kanturk		Ballyroan	
	1982/83	1983/84	1983/84	1984/85
Gravel moles	13	0	111	0
Gravel moles + rip	35	441	420	139
Moles	520	1.389	84	63
Control	4.042	1.751	1.961	1.492





The Ballyroan water table data are shown in Figure 3 (1983/84) and Figure 4 (1984/85). The SEW figures are detailed in Table 3. These data show that the water table control in the gravel moled + rip plot is slightly less effective than in the gravel moled plots. There seems to be some indication also that the mole drained plot is beginning to show slight signs of deterioration relative to the gravel moled plot. However, this is not clearcut at this stage, and the mole drainage is still very good.

4. DISCUSSION

At Kanturk the deterioration in water table control of the mole drains relative to the gravel moles could be attributed to the very obvious breakdown of the mole channels. Whether there is a corresponding reduction in the effectiveness of the crack system is not clear but it is reasonable to assume that the crack structure has also deteriorated to some extent. The slight fall-off in mole drainage efficiency at Ballyroan might also be attributed to crack deterioration since the mole channel system there is largely intact. In fact, the moles at Ballyroan show far less deterioration than those at Kanturk over the 3-year period.

The deterioration in water table control on the gravel moled + rip plots relative to the gravel moled plots at Kanturk appears to be mainly due to the infilling of the rip channels and some consequential crack deterioration in their vicinity.

It therefore appears that the deterioration in drainage effectiveness can be attributed to a combination of channel breakdown and crack closure. On that basis the priorities in disruption drainage are: 1) the provision of stable long-lasting channels for water transport and 2) the development of an adequate crack structure in the soil.

The transfer of water from the soil surface to the drainage channels depends to a large extent on the effectiveness of: a) the leg slot crack and b) the vertical angled cracks both of which are governed to some degree by the width of the leg of the disruption equipment. The wider leg (approx. 90 mm) of the machine used to install the gravel moles and ripping produces a much wider leg crack than that produced by the 25 mm wide leg of the mole plough. Site investigations have shown that the wider leg slot made by the gravel mole machine is very often filled with relatively loose topsoil whereas only traces of topsoil are found along some of the leg slots made by the mole plough. The wider-legged equipment therefore tends to produce a much more permeable and longer lasting leg slot. This is very useful when the machine is used to install gravel moles. However, where the machine is used as a ripper and the channel is not filled with gravel, the wide leg slot allows the channel and slot to fill with topsoil, thus reducing the flow capacity of the channel drastically.

The wider leg also has an advantage in the production of the vertical angled dracks, which tend to be wider and somewhat longer where the gravel mole machine is used. This is confirmed by soil in studies carried out at Silsoe College (Spoor, 1983) using vertical tines of differing widths in an artificial clay soil. This study showed that the size of cracks associated with the leg slot increased as the width of the leg increased. When the roughness of the leg was increased by glueing coarse sand to both faces, an increase in crack volume was measured. It was found that a 6 mm roughened tine could give a volume of cracks equivalent to a 25 mm smooth tine. However, the 6 mm roughened tine produced a large number of small cracks whereas the 25 mm smooth tine produced a smaller number of wide cracks.

Youngs (1984) has shown that the length of the angled vertical cracks and to a lesser extent their spacing are major factors in the effectiveness of mole drainage. It would appear therefore both from theoretical considerations and experimental investigations that the length, spacing and rate of deterioration of these vertical cracks is of vital importance in the drainage of impermeable soils by disruption methods. As the rate of crack deterioration is probably related to the initial crack width, this is also a factor. The re-design of mole drainage equipment to produce a stable long-lasting channel and to maximise on the production of the most effective combination of length, spacing and width of vertical angled cracks under a variety of soil conditions would therefore seem to be a priority.

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