Ir. J. agric. Res. **22:** 161-187, 1983

THE DRAINAGE OF IMPERMEABLE SOILS IN HIGH RAINFALL AREAS

L. F. Galvin
An Foras Talúntais, Kinseały Research Centre, Malahide Road, Dublin 5

ABSTRACT

The provision of reliable and effective systems for the drainage of impermeable soils is of urgent importance in the wetter disadvantaged areas of Ireland. Experimental drainage trials incorporating various disruption techniques (moles, gravel moles and ripping) were installed at six sites. Drainage effectiveness is assessed by water-level hydrographs, flow hydrographs and ground condition scoring. Excavations are also made to examine crack development and channel deterioration.

Initial results indicate that gravel moles are the most effective system. This arises from the fact that the mole drains and ripping are failing on all sites due to channel instability. The experimental trials also show the advantage of using disruption equipment fitted with wide legs. The wider leg slots and associated cracks developed by these machines are major factors in the drainage of impermeable soils that are subject to creep failure.

INTRODUCTION

Meteorological records (1) show that excess rainfall and small moisture deficits are dominant factors in Irish agriculture (see Tables 1 and 2 for locations in the West of Ireland). These lead to many problems particularly on the impermeable soils in the wetter regions of the country where the normal annual rainfall ranges from 1,200 to 2,000 mm. The provision of effective drainage for these soils is essential to enable agricultural development to be planned in a realistic and businesslike manner.

It should be remembered that on these undrained heavy soils, there is a continual upward movement of capillary water from the water-table as moisture is evaporated from the soil surface. Due to the predominance of very small pores, however, the upper soil layers remain close to saturation for long periods and relatively light rainfall can give rise to surface waterlogging due to the poor infiltration and permeability characteristics of the soils. In those circumstances the potential moisture deficits, as outlined in Table 2, do not realistically portray the actual situation in relation to the moisture status of the topsoil.

As a result, major trafficability problems arise for animals and machinery and the soils need to be intensively drained even for grass production. Under undrained conditions it is often impossible to spread fertilisers in the early spring, thus restricting early grass production. Furthermore, in a wet spring or summer the land can become impassable to vehicular traffic with the result that forage is either lost or else harvested under very difficult conditions, with correspondingly increased costs. Under similar conditions, the grazing animals damage the soil badly and much of the grass is wasted. In both cases the following year's production is adversely affected. In those situations the benefits of drainage must be considered in terms of production and utilization rather than in terms of production only.

Drainage experience

It is generally accepted that soils with hydraulic conductivities less than 0.1 m/day, common to many soils in the West of Ireland, are impermeable. The spacing of conventional piped drains to achieve adequate drainage in those soils is such that the installations would be uneconomic for normal farming and it is necessary to resort to drainage methods that incorporate soil disruption techniques. The basic objectives of these are (a) the fissuring and cracking of the soil to increase permeability and (b) the formation of a system of closely-spaced channels to provide for the rapid removal of water.

The usual systems of subsoil disruption (2) are: mole drains; subsoiling or ripping; and gravel moles. The long-term effectiveness of the drainage system, so provided, depends on the extent and permanency of the crack-structure developed during the disruption, and also on the capability of the channels formed, to continue to transport water to the piped catchment drains over an extended time period.

Mole drainage is a very efficient and effective method of draining impermeable soils, if the soils are stable and if an adequate system of cracks, to connect the

TABLE 1: Total annual and April-to-September rainfall figures for the experimental sites (mm)

	Ballinamore Drumcoura	Kilmaley	Cree	Knockanure	Kanturk
Jan-Dec (Annual)					
1979	1,234	1,786	1,272	1,401	1,202
1980	1,286	1,593	1,280	1,234	1,074
1981	1,242	1,617	1,126	1,090	1,013
1982	1,290	2,004	1,354	1,322	1,253
April-Sept					
1979	532	721	509	623	450
1980	529	658	534	533	414
1981	546	783	563	498	402
1982	419	774	520	455	458

TABLE 2: Monthly moisture surplus or deficit (−) at the experimental sites (mm)

Year	Month	Ballinamore Drumcoura	Kilmaley	Cree	Knockanure	Kanturk
	April	47	43	26	37	24
	May	58	46	67	82	41
1979	June	−17	9	−8	2	7
	July	−41	−1	−44	−30	−70
	Aug	82	133	43	95	48
	Sept	53	89	26	36	0
	April	−21	−22	−43	−34	−17
	May	−48	−54	−67	−63	−65
1980	June	43	40	22	32	−6
	July	52	71	48	44	17
	Aug	27	75	37	53	34
	Sept	127	139	128	92	42
	April	−31	−30	−40	−50	−48
	May	91	111	58	97	101
1981	June	27	35	2	−19	−36
	July	0	43	−6	−18	−56
	Aug	−18	−15	−35	−41	−58
	Sept	127	206	150	96	67
	April	−30	−35	−46	−50	−52
	May	13	12	−13	−30	−17
1982	June	24	140	101	56	72
	July	−66	−57	−73	−73	−66
	Aug	20	150	31	42	26
	Sept	70	106	61	50	36

ground surface to the moles, can be produced. A large percentage of heavy Irish soils are however unstable. In those cases the mole channel has a limited life, of the order of less than 1 year to 3 years.

Where heavy soils are drained by subsoiling, the equipment used is often similar to that used for mole drainage; the mole and expander are replaced by a subsoiling shoe. The cracking is therefore unlikely to be a substantial improvement on that achieved by mole drainage and the channel is usually less stable. The installation of subsoiling instead of mole drains for the drainage of deep impermeable soils is therefore questionable. Ripping, which is a form of subsoiling using bigger and heavier equipment, was initially used for the drainage of over-compacted stoney soils (3). The channel however is usually more liable to deterioration than a mole drain.

During the latter periods of channel deterioration, the effectiveness of a drainage system decreases progressively. This is immediately apparent in wet years but may be less obvious in dry years, when the demands on any drainage system for water removal are reduced and the strength of the upper soil layers is generally greater than normal. In those circumstances a deteriorating drainage system may not exhibit obvious signs of breakdown until the deterioration has reached an advanced stage. The full effects of the deterioration however become very apparent in a subsequent wet period, during which "drained" fields can show obvious signs of total drainage breakdown within a short time. This delayed-action type of drainage breakdown was quite widespread throughout the West of Ireland during the 1979 to 1981 wet period (Table 1). The shortcomings of many drainage schemes were highlighted during those years when a large number of "drained" fields became almost impassable to animals and machinery. This resulted in an enforced reduction in cow numbers and a corresponding income drop on a large number of farms.

Gravel moles (2) do not suffer from channel collapse and no signs of deterioration are apparent in the gravel moles examined to date, some of which have been installed for more than 6 years. All disruption methods (moles, subsoiling, ripping and gravel moles), however, depend for continued effective drainage on the effectiveness of the initial cracking and on the permanency and size of the fissures connecting the ground surface to the disruption channels.

Pilot drainage trials incorporating various disruption treatments were installed at a number of locations in the West of Ireland in the 1975-78 period. Good results were obtained initially using heavy-duty rippers (3) but the long-term stability of the disruption channels, formed during the ripping operation, was variable. Consequently, further pilot trials incorporating moles, ripping and gravel moles were laid down. 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 (4). It was difficult however to produce objective scientific data on the drainage effectiveness of the various treatments or to determine the causes of success or failure in the absence of continuous records of drain-flow and water-table fluctuations. In 1980-81 therefore under a project, part-funded by the EEC, a number of instrumented experimental trials were installed on a variety of impermeable soils to provide this information.

EXPERIMENTAL

The experimental programme is designed to measure i) the effectiveness of moles, ripping and gravel moles for the drainage of impermeable soils and ii) to relate the variation in drainage performance to variations in the condition of the disruption channel and crack structure. The objective is to provide a basis for explaining the success or failure of the various treatments. The sites were selected to cover a variety of impermeable soils and climatic conditions. Details of particle size distribution, Atterberg limits and bulk densities of the various subsoils are given (Table 3). The soils on the Drumcoura site are very variable and data for two representative soils are outlined in Table 3.

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

	Ballinamore	Drumcoura		Kilmaley	Cree	Knockanure	Kanturk
Size (microns)		*A*	*B*				
>2000	5	24	27	21	2	11	9
2000-600	2	4	6	7	4	2	2
600-200	3	3	6	5	1	3	5
200-60	2	7	10	8	10	9	14
60-20	5	5	8	13	14	19	11
20-6	14	11	11	15	20	20	14
6-2	15	10	10	11	16	13	14
<2	54	36	22	20	33	23	31
Clay as % of fine fraction (<2000)	57	47	30	25	34	26	34
Clay/silt ratio	0.65	0.63	0.51	0.43	0.48	0.41	0.53
Liquid limit	66	56	32	33	39	30	37
Plastic limit	29	27	21	22	29	20	21
Plasticity index	37	29	11	11	10	10	16
Bulk density	1.37	1.39	1.57	1.21	1.37	1.60	1.62

The disruption techniques under test are:

1. Mole drains spaced at 1.3 m;
2. Gravel moles spaced at 1.3 m;
3. Gravel moles + ripping. The gravel moles are spaced at 2.6 m with intermediate ripping (also spaced at 2.6 m) to produce cracking between adjacent gravel moles;
4. Ripping at 1.3 m; and
5. Control.

Plans were made to install the various disruption treatments under ideal soil moisture conditions at two sites in 1980 and at four further sites in 1981. Weather conditions were so unsuitable in 1980, however, that work had to be abandoned after the disruption of only one plot at Ballinamore in August. In 1981 the weather and soil conditions were again far from ideal throughout the summer but as some improvement occurred in August, it was decided to disrupt all six sites. The work was carried out between August 11 and September 1, 1981. The decision to disrupt all sites was influenced somewhat by the fact that many drainage contractors were installing disruption treatments under similar conditions. The project therefore has an added dimension of monitoring the effectiveness of some installations made under less than ideal conditions and of determining methods of rehabilitating installations that do not provide adequate drainage. A generalised site lay-out is shown in Fig. 1.

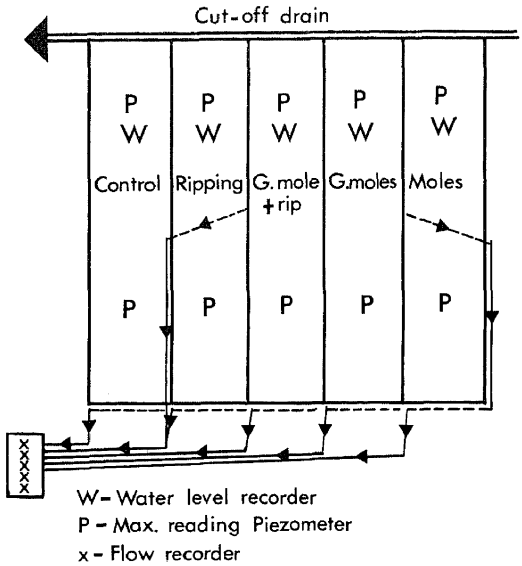

Fig. 1: General site layout

Measurements

The individual plot size ranges from 756 to 1000 sq. m on different sites and the plot length is of the order of 60 m. For the gravel mole treatments, only one catchment drain is provided at the lower end of each plot but two catchment drains are provided on the mole drainage and ripped plots (Fig. 1). Each catchment drain is backfilled with 20 to 12 mm gravel to within 200 mm of the surface. The drainage water from each plot is led through a separate collector drain to a continuous flow recorder (5). A tilting siphon recording rain gauge is also installed on each site. Watertable levels are measured by maximum-reading piezometers (6) installed at 30 cm, 50 cm and 70 cm depths at two locations on each plot. The piezometers are read at weekly intervals. The maximum water level reached during the previous week and the water level at the time of reading are both recorded. In January/February 1983 continuous water level recorders (5) were also installed. These provide a weekly chart record of water-level fluctuations on each plot.

With regard to the water-level measurements it should be remembered that the soil is not homogeneously disrupted. The maximum disruptive effect occurs in the immediate vicinity of the disruption channel (mole, gravel mole or rip track) and the cracking and fissuring usually diminish as the distance from the disruption channel increases (7). It is sometimes assumed, where disruption channels are installed at a spacing of 1.3 to 2 m, that the cracking and fissuring overlap. Experience on the experimental sites is that while the type and extent of the cracking varied considerably, the major fissures from adjacent disruption channels did not overlap. The piezometers and water-table recorders are all installed mid-way between adjacent disruption channels. The water-level fluctuations are therefore measured at points where the cracking (and consequently the drainage effect) is minimised even though the piezometers are only 0.65 m distant from the disruption channels.

Ground condition measurements are also made at weekly intervals. The surface condition of each plot is scored in accordance with the following table:

1. Baked hard and dry;
2. Dry on top;
3. Damp but firm;
4. Damp and firm with occasional wet patches;
5. Damp and soft;
6. Squelchy or ponded patches on 20% of the plot;
7. Squelchy or ponded patches on 20-50% of the plot;
8. Squelchy or ponded patches on more than 50% of the plot;
9. Very soft and waterlogged; and
10. Hard frost and snow.

Although this scoring system is subjective to some extent, care was taken to ensure a uniform interpretation of the ground conditions at the different sites.

Two of the six experimental sites (Drumcoura and Cree) are installed in fields that were previously drained. The Drumcoura site had been mole drained in good conditions in 1978 and the Cree site had been ripped (also in good conditions) as part of a pilot trial, in 1977. In both cases the drainage was initially successful but deteriorated quite rapidly.

During the winter/early spring of 1981-82 it was obvious from site investigations and ground surface scoring at Kilmaley and Cree that the infiltration capacity of the topsoil between adjacent disruption channels was far from satisfactory. This was manifested by wet surface conditions, ponded water and squelchy patches. It was therefore decided to superimpose some form of shallow (25-30 cm deep) disruption without interfering with the existing disruption channels on both sites. The main objective was to crack the topsoil and upper subsoil layer between the existing disruption channels. April 1982 was a dry month and both sites were shallow-moled (approx. 28 cm deep) on April 29-30, when surface conditions had improved considerably.

RESULTS

Water level fluctuations

The water-level fluctuations recorded in the piezometers installed mid-way between the disruption channels at the six sites are shown in Figs 2-7. These cover the period

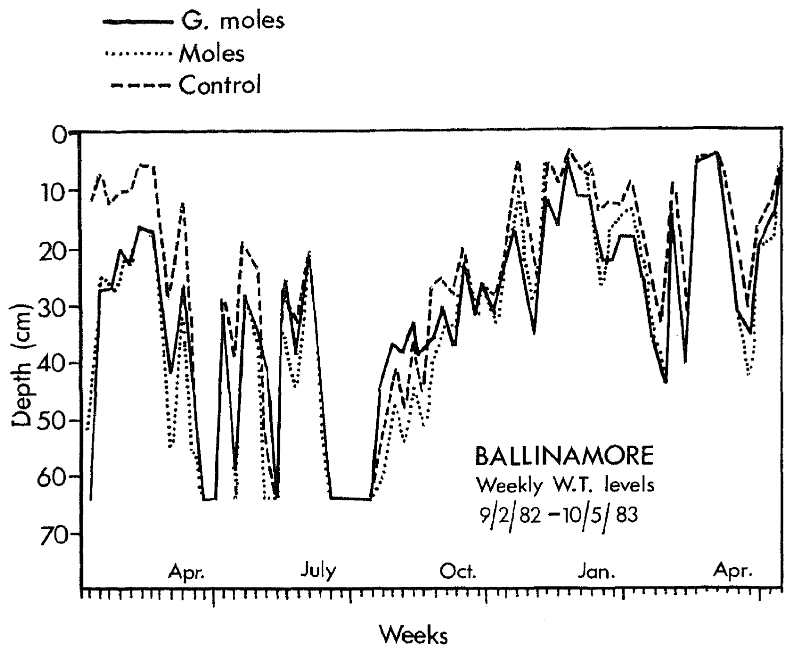

Fig. 2: Water level fluctuations at Ballinamore

from February/March 1982 to early May 1983. There was however a break in the readings at the Knockanure site during March/April 1983. To avoid confusion, only three hydrographs (representing gravel moles, moles and control) are plotted for each site. The location of the hydrographs for gravel moles + ripping and ripping relative to those plotted in Figs 2-7 may be interpreted from the following remarks and by reference to Table 4. At Ballinamore (Fig. 2) and Drumcoura (Fig. 3), the gravel mole + ripping hydrograph is similar to that for gravel moles, the ripping hydrograph, however, fluctuates considerably at Drumcoura. At Kilmaley (Fig. 4) and Cree (Fig. 5) the gravel mole + ripping hydrograph lies between the gravel mole and the mole hydrographs, the ripping and mole hydrographs being very similar. The gravel mole + ripping and the ripping hydrographs at Knockanure (Fig. 6) are similar and are positioned approx. mid-way between the gravel mole and the mole hydrographs. At Kanturk (Fig. 7) the gravel mole + ripping hydrograph is located between the gravel mole and the mole hydrographs but closer to the gravel mole hydrograph. There are no ripped plots at Ballinamore and Kanturk.

The data on water levels at all sites were analysed in detail for the period beginning October 1982 to early May 1983. Median values and the range of water levels measured on all plots are given in Table 4. These data, read in conjuction with Figs 2-7, indicate the effectiveness of the different disruption treatments at the various sites. Further evidence of drainage effectiveness is provided in Table 5, which shows the median and range of the maximum weekly water levels recorded between October 1982 and early May 1983.

Ground conditions
The overall average ground scoring value and the range of values recorded on each plot, for all sites, are given in Table 6. These are calculated from the weekly measurements over the February/March 1982 to May 1983 period. The average monthly values for the moled, gravel-moled and control plots are shown in Figs 8-13.

Flow measurements
Water discharge from each plot is continuously recorded on weekly charts. These are processed to produce hydrographs of discharge versus time and are correlated

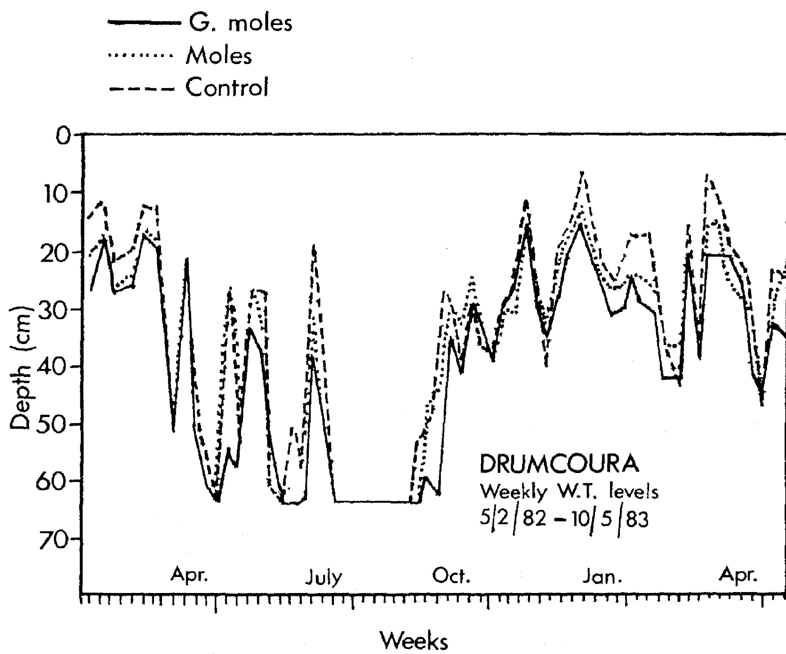

Fig. 3: Water level fluctuations at Drumcoura

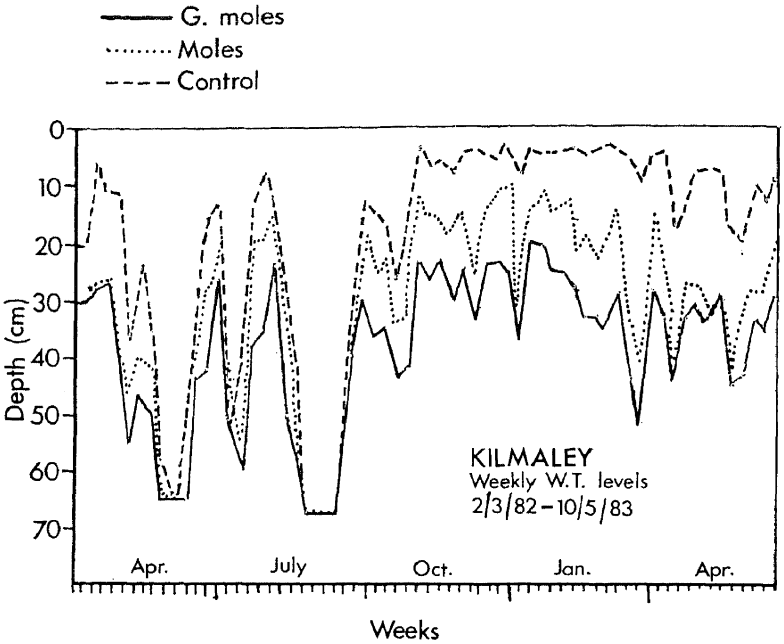

Fig. 4: Water level fluctuations at Kilmaley

with the rainfall which is measured on the tilting siphon rainfall recorders. From these records the discharge patterns arising from particular rainfall events are plotted (Figs 14-16).

DISCUSSION

The project is still at an early stage but the initial results show that the effectiveness of the disruption treatments varies considerably at the different sites. The indications are that the variation is partly due to local soil conditions (see Table 3) but more particularly to the moisture status of the soils at the time of disruption (August 11 to September 1, 1981). This is borne out by reference to Table 2, from which the following accumulated monthly deficits (mm) at the end of August 1981, have been abstracted.

Ballinamore and Drumcoura	18
Kilmaley	15

Cree	41
Knockanure	78
Kanturk	150

Although these figures cannot be taken as definitive for particular sites, they nevertheless provide an indication of the probable range of soil moisture conditons prevailing at the sites in August 1981.

During the summers of 1982 and 1983, excavations were undertaken on all sites to investigate the condition of the disruption channels (mole, gravel mole, rip track) and the corresponding crack structure. Spot checks were also made during the winter months. On the basis of these investigations and the analyses of water-level records (Figs 2-7 and Tables 3 and 4), ground condition scoring (Figs 8-13 and Table 5) and discharge hydrographs (Figs 14-16) the following observations are made in relation to the effectiveness of the various drainage treatments at each site.

Ballinamore

The disruption treatments were installed at this site on 11 August, 1981. An examination of Table 2 and a detailed inspection of the daily records shows that the

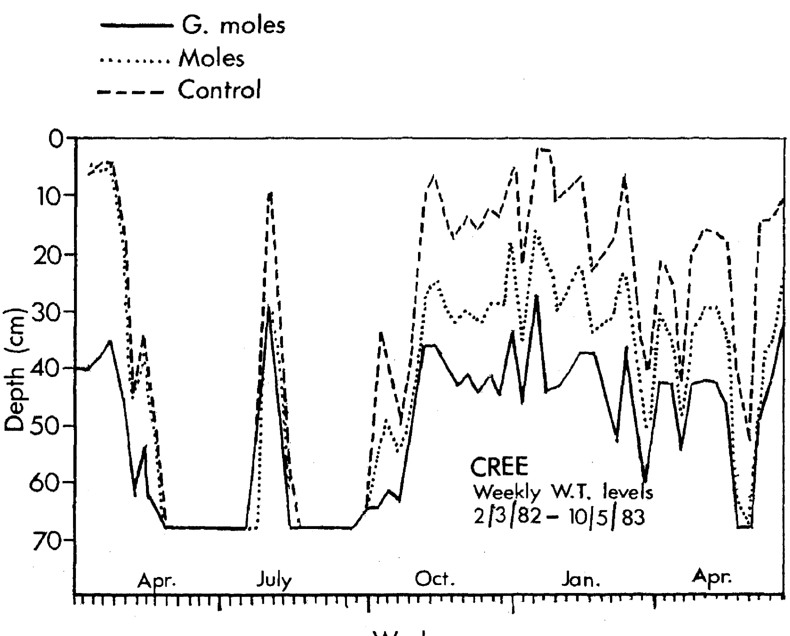

Fig. 5: Water level fluctuations at Cree

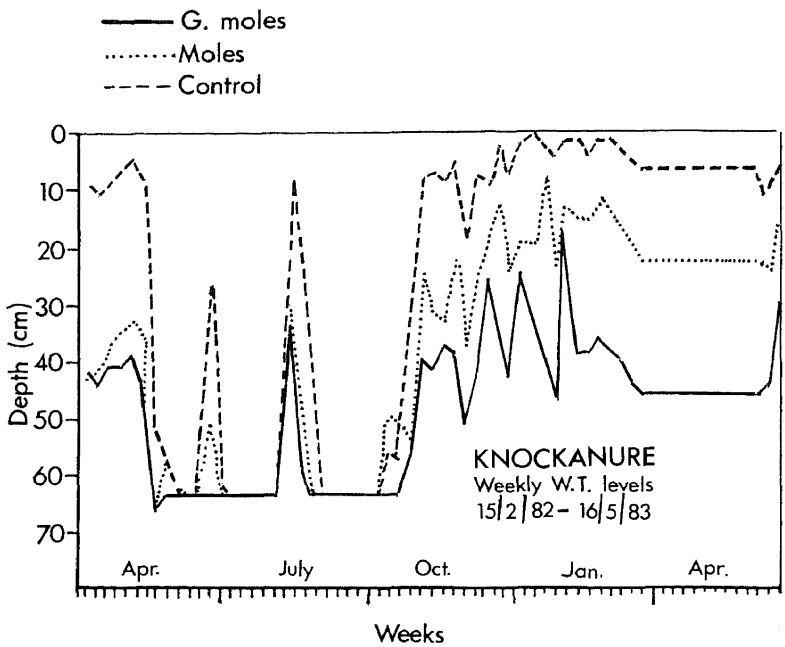

Fig. 6: Water level fluctuations at Knockanure

moisture deficit on that date was about 9 mm. Although the surface was dry and no traction or trafficability problems arose during installation, the drainage response to all treatments is unsatisfactory.

The ground scoring shows that the average score for all the drained plots was very high (between 5.2 and 5.4) during the October-May period. This is the highest average score recorded at any site. The water levels are also generally higher than those recorded at the other sites and the median value of the maximum water level on all plots (including control) of 4 cm is indicative of the ineffectiveness of the drainage treatments in controlling the water level. In 1982, site excavations showed that the mole drains were in reasonably good condition, although occasional partial blockages were observed. Polyurethane castings (8) of the moles were taken. These had dimensions of the order of 70 mm × 50 mm. However, the rip tracks had deteriorated to such an extent that it was not possible to take castings. Further excavations in 1983 showed that the rip tracks were completely filled up and scarcely distinguishable. The moles had deteriorated substantially in places but it was still possible to obtain castings. The gravel moles were in good condition.

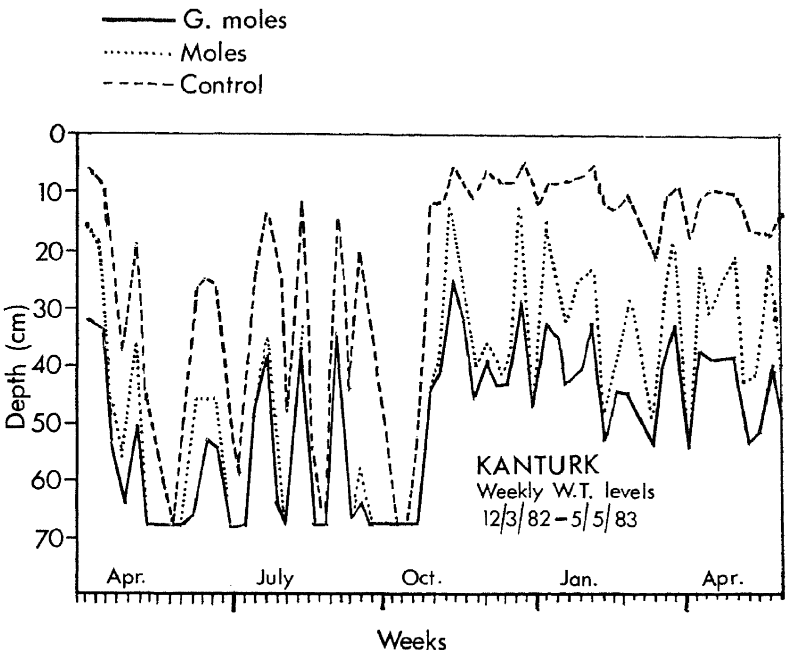

Fig. 7: Water level fluctuations at Kanturk

TABLE 4: Water-level depths (median and range) on the experimental sites from October 1982 to early May 1983 (cm)

Drainage treatment		Ballinamore	Drumcoura	Kilmaley	Cree	Knockanure	Kanturk
Gravel	Median	23	29	31	43	39	42
moles	Range	5-44	13-44	20-52	27-68	13-52	26-56
Gravel moles	Median	22	29	29	37	31	40
+ ripping	Range	3-46	14-43	21-49	20-68	14-58	24-55
Moles	Median	20	26	23	30	20	32
	Range	3-43	13-44	10-45	16-68	8-38	13-54
Ripping	Median	-	32	27	30	31	-
	Range		8-48	17-42	12-66	12-53	
Control	Median	14	24	6	16	5	10
	Range	4-34	7-47	3-20	3-54	1-19	5-22

The mole channels on this site are in better condition than those at any other site. This is due mainly to the higher clay content and clay/silt ratio of the subsoil (Table 3). Despite this however, the drainage effectiveness of all treatments is inferior. This is probably due to the fact that the lateral disruption and cracking achieved during installation was limited. During the site excavations, no subsoil cracking was apparent in the vicinity of any disruption channel although some topsoil cracking was observed. It would appear that most of the drainage water reaches the disruption channels through the leg cracks. That these are still functioning is borne out by the fact that the discharge hydrograph peaks correspond quite closely with the rainfall peaks. However, the infiltration on all plots is insufficient and the drainage plots were therefore completely disrupted to a depth of 30 cm using a winged subsoiler, in July 1983.

Drumcoura

This site had been mole drained in 1978 but had deteriorated substantially by 1981 although the drains continued to discharge some water. The calculated moisture def-

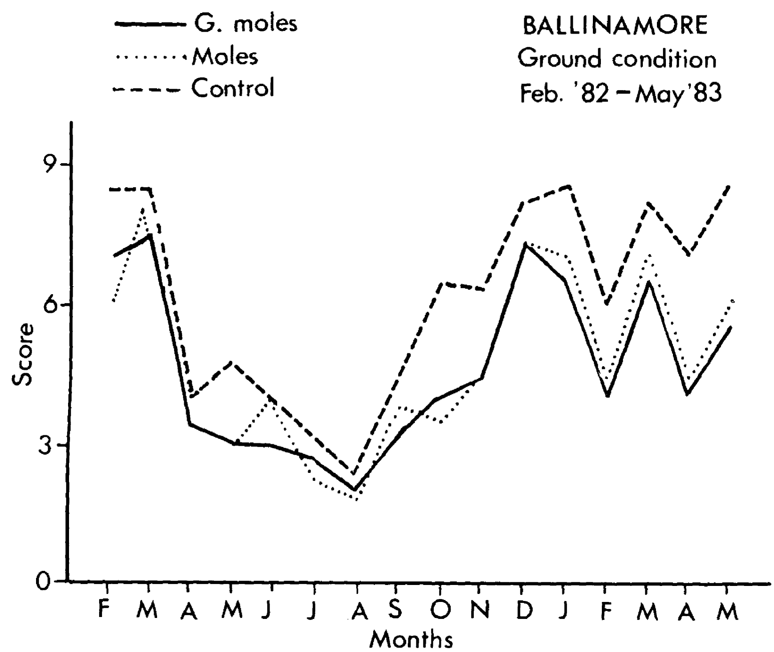

Fig. 8: Ground condition scoring at Ballinamore

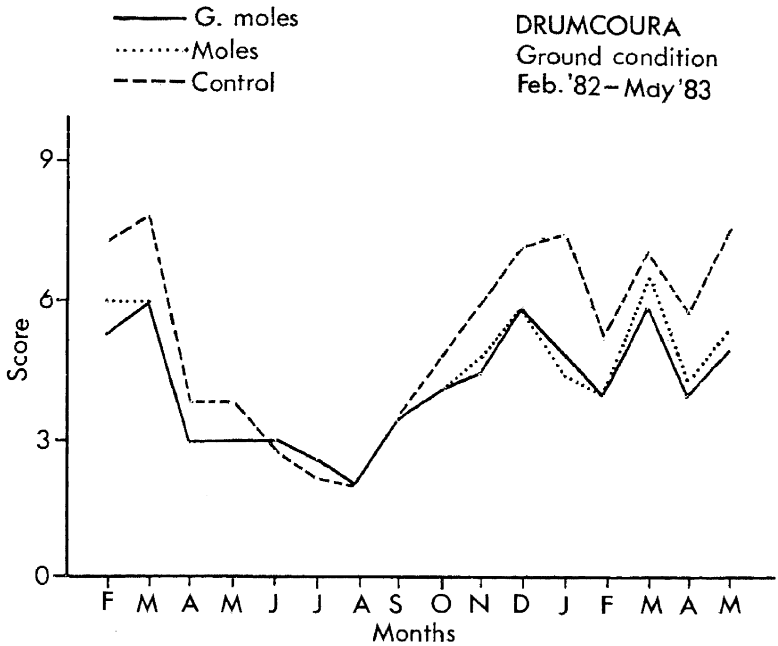

Fig. 9: Ground condition scoring at Drumcoura

icit on the date of disruption (12 August, 1981) was about 9 mm. The soil surface however appeared to be reasonably dry and solid. This may be influenced to some extent by the 1978 mole drainage and also by a cherty layer which lies below the topsoil over most of the site.

The median water level over the October-April period was 29 cm for both gravel-moled plots, 26 cm for the moles, 32 cm for ripping and 24 cm on the control. The median value for the maximum water level was 10 cm for the gravel-moled and moled plots, 7 cm on the ripped plot and 6 cm on the control. The average ground scoring value for the drained plots lies between 4.6 and 4.9 and is 6.2 for the control. The flow hydrogaphs indicate that the peak flows correspond very closely to the rainfall peaks. There are distinctive high peak discharges from both gravel-moled and the moled plots with much lower peaks on the ripped and control plots. The surprising aspect of these records is the relatively good water-level control and drain flow achieved on the control plot. This seems to indicate that the 1978 moles are still influencing the drainage.

The site excavations showed that the visible crack structure adjacent to all disruption channels is very limited. The gravel moles are in good condition but the moles and rip tracks were substantially silted up when examined in 1982. In 1983, the mole channels were practically indistinguishable from the surrounding soil, all of which was solid. The ripping tracks were also solidly packed with subsoil. In all trial holes examined the only soft sections found were directly over the disruption channels. The remaining subsoil was very hard and compact. Topsoil had worked its way into the leg cracks over some of the disruption channels. This tends to improve the permeability of the leg cracks and contributes to the infiltration and discharge capacities. It would appear, at this stage, that the moles and ripping tracks have deteriorated substantially. In the circumstances, the flow and water-level hydrographs on these plots over the next year should prove quite interesting.

Kilmaley

It was apparent during the installation of the disruption treatments on this site in August 1981 that the surface soil was too wet for optimum shatter. This is borne out by an examination of Table 2. In the circumstances, an attempt was made to improve the shatter by shallow moling along the centre lines between adjacent disruption channels on all plots at the end of April 1982. The piezometer installations were however by-passed during this operation.

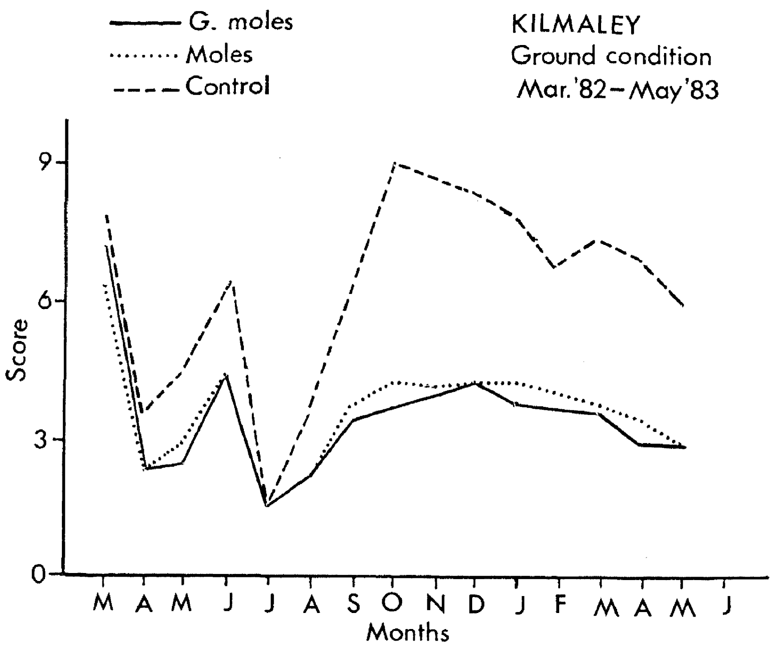

Fig. 10: Ground condition scoring at Kilmaley

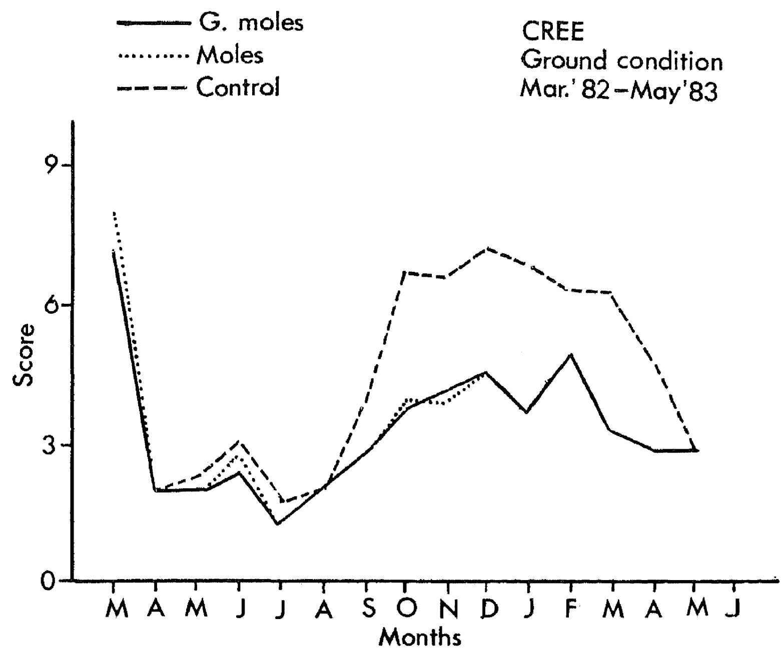

Fig. 11: Ground condition scoring at Cree

The water-level records (Table 4) show that the median over the October-April period averaged 30 cm for the gravel-moled plots, as against 23 cm for the moled plot, 27 cm on the ripped plot and 6 cm on the control. The median of the maximum water levels (Table 5) averaged 20 cm for the gravel-moled plots, was 9 cm for the moled plot, 15 cm for the ripped plot and 4 cm on the control. These figures indicate that the shallow moles combined with the original disruption are providing reasonable water control (see Fig. 4). The ground scoring averages and range (Table 6) confirm this. The discharge hydrographs show that all drainage treatments respond well to rainfall events but the discharge from the control plot is practically negligible. Peak discharges on all drained plots correspond with the rainfall peaks and it is obvious that there is a substantial element of direct access of rainfall to the disruption channels, particularly to the shallow moles.

Site excavations at various periods between August 1981 and July 1983 showed that the moles and the base of the ripped channels had silted up at an early stage (during the first winter). The shallow moles installed in April 1982, however, were still in good condition and discharging substantial quantities of water up to July 1983 when they were disrupted. Radial cracking and fissuring in the immediate

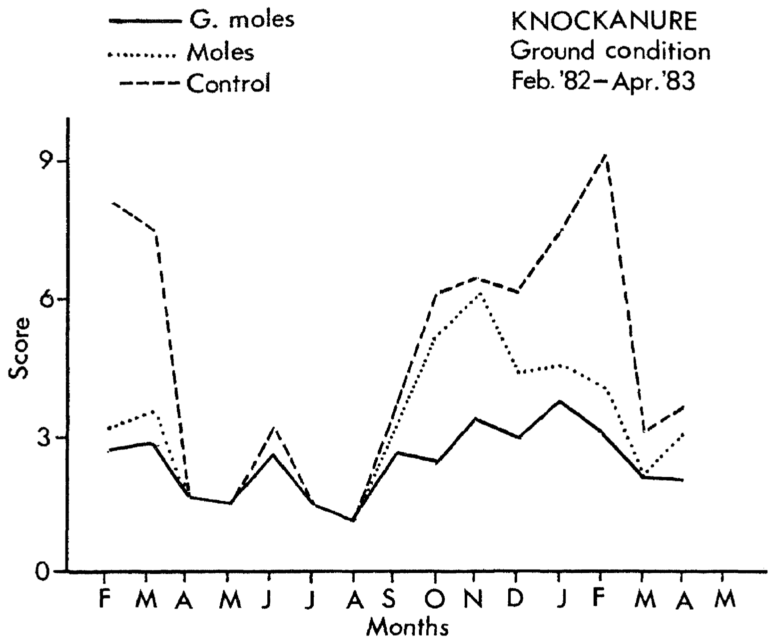

Fig. 12: Ground condition scoring at Knockanure

TABLE 5: Maximum water-level depths (median and range) recorded weekly on the experimental sites from October 1982 to early May 1983 (cm)

Drainage treatment		Ballinamore	Drumcoura	Kilmaley	Cree	Knockanure	Kanturk
Gravel moles	Median	4	10	19	27	22	24
	Range	2-33	4-37	13-44	12-62	13-37	14-49
Gravel moles + ripping	Median	4	10	21	18	14	19
	Range	2-30	2-37	11-40	10-66	6-39	5-45
Moles	Median	4	10	9	17	11	11
	Range	2-26	2-35	3-37	8-53	5-23	5-38
Ripping	Median		7	15	11	16	
	Range		3-42	8-35	5-49	8-37	
Control	Median	4	6	4	4	2	4
	Range	2-16	3-25	2-14	2-36	1-5	2-13

TABLE 6: Ground scoring (overall average and range) from October 1982 to early May 1983

Drainage treatment		Ballinamore	Drumcoura	Kilmaley	Cree	Knockanure	Kanturk
Gravel moles	Average	5.2	4.8	3.7	4.0	2.7	3.2
	Range	3-9	3-8	2-5	2-6	2-5	3-5
Gravel moles + ripping	Average	5.3	4.6	3.9	4.1	3.2	3.2
	Range	3-9	3-8	2-6	2-6	2-6	3-5
Moles	Average	5.4	4.9	4.1	4.0	4.1	4.3
	Range	3-9	3-8	3-5	2-5	2-7	3-6
Ripping	Average		4.9	4.0	4.3	2.7	
	Range		3-8	3-5	2-8	2-5	
Control	Average	7.2	6.2	7.8	6.5	5.9	7.5
	Range	5-9	3-9	5-9	3-8	2-9	5-9

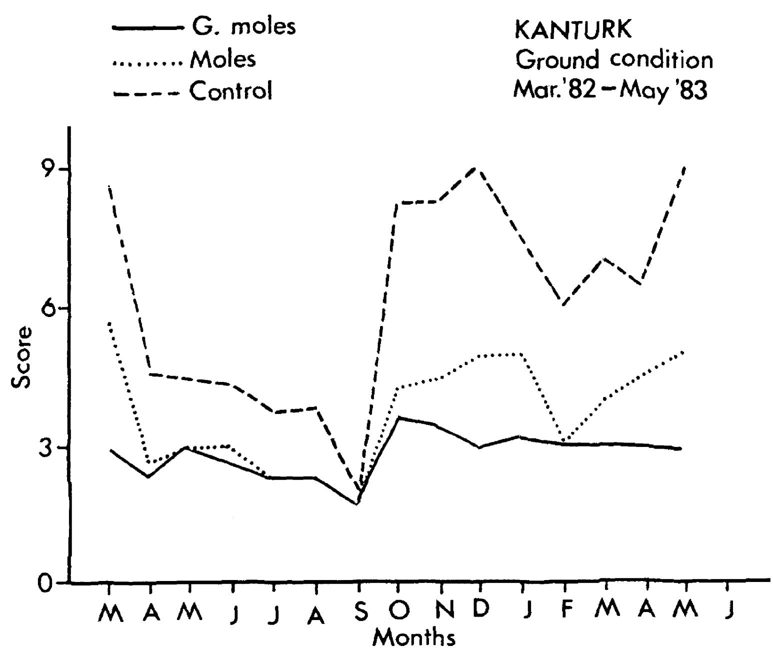

Fig. 13: Ground condition scoring at Kanturk

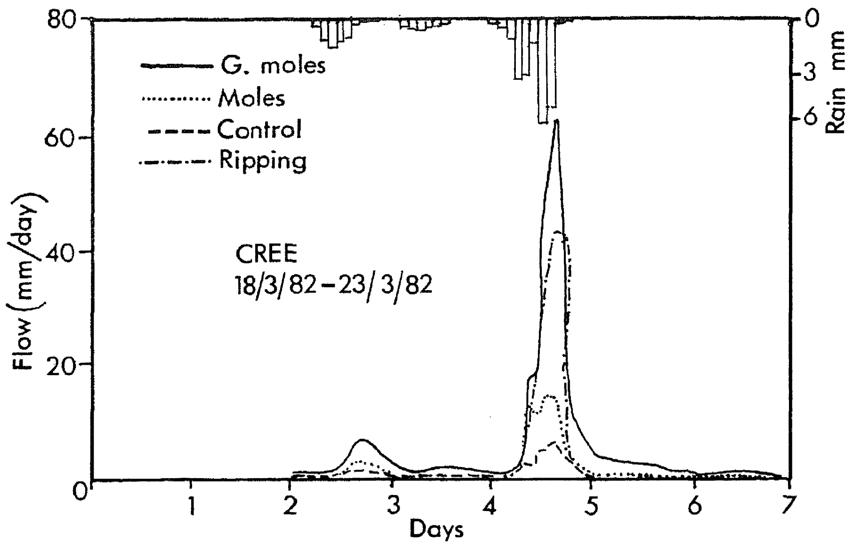

Fig. 14: Discharge hydrographs for Cree

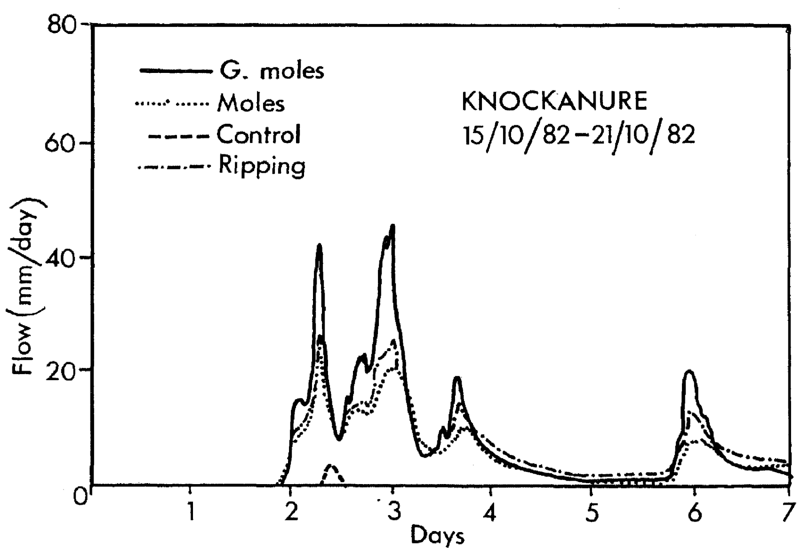

Fig. 15: Discharge hydrographs for Knockanure

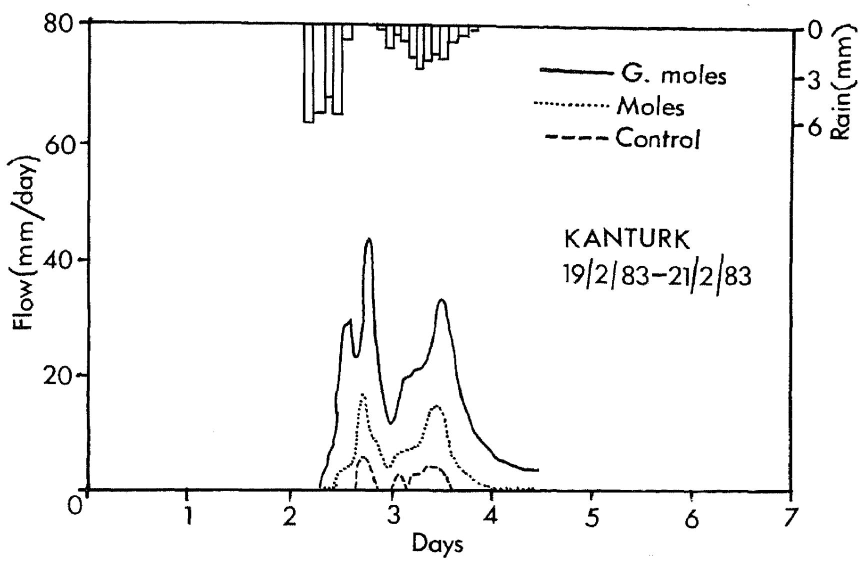

Fig. 16: Discharge hydrographs for Kanturk

vicinity of all disruption channels is very limited. However, clods of soil and small sods had fallen into the wider (up to 90 mm) leg slots formed by the gravel mole machine which had also been used for ripping (without feeding gravel) on this site. These tended to form crude drainage channels within the slots. This was particularly evident in the ripped plot and during excavations undertaken immediately after heavy rain, appreciable discharge was found in some ripped channels at a depth of approx. 30-35 cm. The flow in the deep moles was however very limited.

Cree

This site had been previously drained and ripped under very good conditions in August 1977. The ripping gradually deteriorated and finally broke down badly in autumn 1980. At that stage the soil surface suffered severe damage (4) and further surface damage occurred during the installation of the experimental catchment drains in June 1981. The calculated accumulated moisture deficit (Table 2) on the date of disruption (1 September, 1981) was 41 mm but the topsoil had not dried out sufficiently at that stage. In the circumstances the lateral disruption achieved was minimal and this site was also shallow-moled in April 1982.

The water levels (Table 4) show that there is reasonably good control on all drainage plots (Fig. 5) and especially on gravel-moled and gravel-moled + ripped plots. The maximum water levels (Table 5) show that the gravel moles were most effective in controlling the water-level rise. The ground scoring on all plots however shows that the severe surface damage, already referred to, is still affecting the infiltration characteristics of the topsoil.

Site investigations in May 1982 showed that the moles were almost totally silted up and the base of the rip tracks fully silted. By June 1983, the silting of moles and rip tracks was complete. However, in both cases part of the siltation was caused by topsoil which either fell or was washed down through the leg cracks and deposited in the mole channels and rip tracks. Fig. 17 shows an excavated section of subsoil surrounding a rip track. The rip track is solidly filled with black peaty topsoil but there is no evidence of topsoil in the leg crack, which is completely sealed up in this case. However, in many of the excavations carried out on the ripped plot, topsoil and soil clods were found in the leg cracks at depths of about 30-35 cm, resulting in a series of cracks and fissures through which drainage water is discharged. This is borne out by the discharge hydrographs (Fig. 14). These show that the discharge from the ripped plot is very rapid with a peak flow almost three times that of the moled plot. However, the water-level data (Tables 4 and 5) show that the water-level control on both plots is somewhat similar. The shallow moles on both plots would be expected to discharge approximately equal quantities of water under intensive rainfall. The indications are therefore that the wide leg slots formed by the ripper and in which a cracked structure is maintained by topsoil and small sod deposits are discharging relatively large quantities of rainfall. In contrast, the narrow leg slots formed in the moling operation have practically disappeared and their contribution to discharge is minimal at this stage.

Knockanure

The disruption achieved at this site was superior to that at all sites except Kanturk. This is partly due to the soil type (Table 3) but the soil moisture status on the date of disruption (20 August 1981) was a major factor. Table 2 shows that the accumulated moisture deficits calculated for Knockanure (37 mm at the end of July and 78 mm at the end of August) are less than those obtaining at Kanturk but much greater than at any other site.

The water-level records (Fig. 6) at this site indicate that there is reasonably good control on the drained plots. There was however a break in the readings in March/April 1983. The data for the period October to February (Table 4) show median water levels of 39 cm for gravel moles, 31 cm for the ripping and gravel moles + ripping, 20 cm for moles and 5 cm for the control. The maximum water levels (Table 5) display a similar pattern, having median values approximately half those shown in Table 4. The ground scoring data are very good on all drainage plots except the moled plot.

The discharge hydrographs show that the highest peaks are attained on the gravel-moled plot. The corresponding discharge peaks on the moled and ripped plots are

Fig. 17: Rip track filled with topsoil

approx. half the gravel moled peaks (Fig. 15). The gravel mole + ripping peak is about 20% higher than the mole drainage peak. These hydrographs display the typical peaks associated with surface flow or the access of surface water through cracks to the disruption channels.

Site excavations in May 1982 showed that the moles and the rip tracks had collapsed to some extent. This was borne out by further investigation in June when castings were taken from both plots. In 1983 the site was again examined. At this stage it was difficult to find continuous channels at moling or ripping depth and castings could not be taken. However, the crack structure in the vicinity of the disruption channels is better on this site than on any of those previously discussed. The typical vertical cracks, angled at approx. 45° to the direction of travel of the leg of the disruption tine, were visible on all plots. In the gravel-moled and ripped plots these cracks were about 6 mm wide, up to 30 cm long, and extended from about 7 cm below the surface to the depth of the original channel. The cracks on the moled plot were smaller and in some cases had practically closed up again.

The same pattern was observed in relation to the cracking above the disruption channels. In the ripped and gravel-moled plots these were wide and in some cases the soil movements had resulted in the formation of a series of holes along the leg slots. The cracks developed by the narrower leg of the mole drainer (approx. 25 mm wide) were much smaller and the actual leg slot had sealed itself in some places. At this site therefore the effectiveness of the disruption treatments is due to the development of the vertical angled cracks and to the good crack structure that has developed within the leg slots. Furthermore, even though there has been some collapse in the moled and ripped plots, it would appear that there is still a system of continuous channels available for transporting water to the catchment drains.

Kanturk

The drainage effectiveness of all plots on the Kanturk site is better than for comparable drainage plots at any of the other sites. This may be due to a number of causes but the soil moisture status on the date of disruption (18 August, 1981) is a major factor. Table 2 shows that the accumulated moisture deficits calculated for Kanturk (92 mm at the end of July and 150 mm at the end of August) are substantially greater than those obtaining at all the other sites.

The water-level control on all plots (Table 4 and Fig. 7) right through the October-April period is excellent. The control of maximum water levels (Table 5) is also quite good. The ground scoring which averaged 3.2 on the gravel-moled plots, 4.3 on the moled plot and 7.5 on the control is also indicative of reasonably effective drainage. The flow hydrographs (Fig. 16) follow a similar pattern. Good discharge is a feature of all treatments but the effectiveness of the gravel moles is obviously superior to that of the mole drains. The water-level control and drain flow on the control plot are very poor.

Excavations were carried out on this site in June 1982. At that stage the moles and rip tracks were almost fully silted up but the material was loose and water tended to seep through it. It was however impossible to take a casting. Further excavation in 1983 showed that the soft material in the disruption channels had become much more compact.

Vertical radial leg-induced cracks were found on the gravel-moled and gravel-moled + ripped plots. Narrower versions of these cracks may also have existed in the moled plot but these were not discernible in the trial holes excavated. No topsoil infill was found along the leg slots over the mole drains. However, substantial quantities of topsoil were found over the gravel moles and rip tracks. In the latter the channel formed by these lumps of topsoil was probably contributing to water removal at a relatively shallow depth. The mole drains appear to be on the verge of failure on this site and measurements over the next few years should provide useful data.

CONCLUSIONS

Although the project is still at an early stage, the initial analyses and observations indicate that the effectiveness of drainage varies from poor (at Ballinamore) to very good (at Kanturk). The variation in effectiveness is related to the stability of the disruption channels installed and especially to the crack structure developed during disruption at the different sites. This is a function of the soil-moisture status on the date of disruption, the soil characteristics and also of the width of the leg on which the disruption tine is mounted. The wider leg of the gravel-mole machine (up to 90 mm) which was used for gravel-moling and ripping produced much better cracking than the 25-mm wide leg of the mole plough. This is particularly evident at Knockanure and Kanturk. At these sites the wider leg produced vertical cracks, angled at approx. 45° to the direction of travel and extending from beneath the surface to the disruption channel. These are wider and extend further than those produced by the mole plough. The production of these wide vertical cracks is very important for the drainage of impermeable soils subject to creep failure in the wetter regions of the country. However, the use of a wider leg on mole-drainage machines obviously calls for re-design and further investigation in order to reconcile the conflicting demands of wider cracking and mole stability.

Another major advantage of using the wide leg is that much wider slots are formed directly over the disruption channels. At some sites clods of soil and small sods fell into these slots, resulting in the formation of crude drainage channels. This led to a substantial improvement in water access to the main disruption channels. Furthermore, when the main disruption channels collapsed on the ripped plots, the crude drainage channels formed in the wide leg slots continued to provide drainage from the site. Water-table control was limited because of the relatively shallow (30-35 cm) depth at which the crude channels were formed and there is a possibility of their eventual collapse in very unstable soils. However, where the main disruption channels continue to function, the crude leg-slot channels are unlikely to collapse and should continue to enhance the rapid removal of drainage water. The use of wide legs for soil disruption is therefore advantageous on two scores: improved fissuring between adjacent disruption channels, and better crack formation directly above them.

With regard to the former, some preliminary soil bin studies, carried out at Silsoe College (9) using vertical tines of differing widths in an artificial clay soil, showed that the size of the cracks associated with the leg slot increased as the width of the leg increased. Increasing the roughness of the leg by glueing coarse sand to both its side faces gave an increase in crack volume. 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.

For the drainage of impermeable soils, the disruption method that produces a system of vertical cracks is far superior to that which produces a general soil loosening. The vertical cracks provide ready access for drainage water to the disruption channels and are less liable to subsequent re-compaction. Further investigations are however required into equipment design and installation procedure to maximise on the production of vertical cracking.

Good drainage at a relatively shallow (approx. 30 cm) depth was provided at Kilmaley and Cree by the installation of shallow moles at the end of April 1982. Because of the shallow moling depth, and as both soils were deemed to be unstable for mole drainage, it was envisaged that the mole channels would collapse very rapidly. However, at both sites, the shallow moles, though reduced in size, were still operating satisfactorily in July 1983 (14 months later) and their condition at that stage was superior to that of the original moles over the same time period. The shallow moles were however installed on plots that had already been drained (to varying degrees, depending on the disruption technique used) whereas the original moles had been installed in undrained soil. There may be a case, in wetter regions, for installing sacrificial moles at the standard depth when the piped catchments are installed and re-moling during the following summer. Shallow moling at intervals of 2 to 3 years could also be advantageous. The surface cracking and topsod disturbance caused by their installation can lead to the rapid removal of drainage water.

The mole drains installed at Kanturk appear to be completely silted up and no discernible cracks were found in their vicinity during the 1983 site excavations. In the circumstances, the drainage performance, as assessed from the water-table and discharge data (Figs 7 and 16), is surprisingly good. Likewise, there is evidence of some drainage on the control plot (Tables 4 and 6) at the Drumcoura site, which was mole drained in 1978 and considered a failure by 1980. It would appear that on these plots there is a continuous system of mini-cracks and planes of weakness through which drainage water continues to percolate slowly to the catchment drains. The experience on some of the pilot trials was similar. The ripped and mole-drained plots on these trials continued to provide some drainage control even after the disruption channels and cracking appeared to have silted up. The drain flow was however reduced considerably, and the soil surface was saturated for much longer periods than the corresponding gravel-moled plots. During the wet summer and autumn of 1980, when the Cree pilot trial was subjected to intensive traffic under wet conditions, the ripped and mole-drained plots suffered very severe surface damage and became practically impassable (4). The surface of the gravel-moled plots was not damaged.

Experimental sites, especially those that are extensively instrumented, are not usually subjected to the same intensity and frequency of animal and vehicular traffic as farmland. In the circumstances, the potential is reduced for surface damage, under intensive grazing and silage harvesting, under wet conditions. As a result the less-efficient drainage treatments on experimental sites are less liable to severe surface damage and accelerated drainage breakdown than corresponding treatments on commercial farmland.

The soil moisture status at the time of disruption is a major factor in determining drainage success. The good cracking that was achieved at Kanturk and Knockanure as compared with the other sites bears this out. In the light of this and of the other factors, already discussed, there is a need to provide a code of practice for drainage contractors, engaged in soil disruption, to enable them to maximise on the effectiveness of the drainage installations.

ACKNOWLEDGMENTS

The author acknowledges the assistance of: M. O'Herlihy and P. Healy for field installations, recorder assembly and calibration; P. McCormack for recorder construction; W. Burke, P. Maloney, D. Rawle, B. Corr, L. Foley and J. Grant, Kinsealy; P. Butler, B. Kilkenny and M. Cawdrey, Ballinamore; F. Kelly, T. Cullinan and J. Kiely, Kilmaley; E. Walsh, J. O'Donovan and T. Weldon, ACOT, Kanturk; and thanks the landowners on whose farms the experimental sites are located for their co-operation and help.

The project is part-funded by the EEC under contract No. 0582. The assistance of the Commission is gratefully acknowledged.

REFERENCES

1. Keane, T. and Fitzgerald, D. Meteorological data, personal communications, 1983.
2. Galvin, L. F. The drainage of impermeable soils. In "Land Drainage, Proc. EEC land drainage seminar, Cambridge, July 1981", A. A. Balkema, Rotterdam: p. 85, 1982.
3. Galvin, L. F. and MacGrath, M. Joint project on land reclamation. *Fm Fd Res.* **8:** 22, 1977.
4. Galvin, L. F. Gravel-mole drains are the most suitable system for many impermeable soils. *Fm Fd Res.* **13:** 103, 1982.
5. Talman, A. J. Simple flow meters and water table meters for drainage experiments. Tech. Report 79 (1), FDEU, Cambridge: 1979.
6. Davies, B. Maximum piezometer water level indicator. Ann. Report, FDEU, Cambridge: 29, 1969.
7. Leeds-Harrison, P., Spoor, G. and Godwin, R. J. Water flow to mole drains. *J. agric. Engng Res.* **27:** 81, 1982.
8. Thorburn, A. A. Materials for mole channel casting: polyurethane foam as an alternative to plaster of paris. Land Drainage Service (R. & D.), ADAS, Report No. 1, March 1980.
9. Spoor, G. Personal communication, 1983.

Received October 10, 1983