HGCA

PROJECT REPORT No. 64

DEVELOPMENT OF LOWER COST DRAINAGE SYSTEMS FOR HEAVY SOILS

SEPTEMBER 1992

PRICE £8.00

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DEVELOPMENT OF LOWER COST DRAINAGE SYSTEMS FOR HEAVY SOILS

by

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Final report of a three year project at Silsoe College, Silsoe, Bedford MK45 4DT, done in collaboration with ADAS Field Drainage Experimental Unit, Trumpington, Cambridge CB2 2LF. The work commenced in August 1988 and was funded by a grant of £98,133 from the Home-Grown Cereals Authority (Project No. 0090/4/87).

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INTRODUCTION

A significant proportion of the UK cereal crop is grown on lowland heavy clay soils which are very expensive to drain. This high cost together with the recent decline in the gross margin of cereal production has prompted the need to develop lower cost drainage systems. Drainage costs on moleable soils are relatively low, providing the gravel/pipe collector systems are already installed, nevertheless, any increase in mole channel life and efficiency would be very beneficial. Where no gravel/pipe system exists or where soils are unsuitable for mole drainage and hence require close spaced pipe systems with gravel backfill, new or replacement drainage systems are difficult to justify in the current economic climate. Improvement and extension of mole drainage and related practices offers a promising way forward for reducing costs in the future.

Three areas for investigation were initially identified, these being the development of techniques to increase mole channel life and efficiency, the identification of the requirements for the successful re-introduction of much cheaper moled main systems and the exploration of ways of improving the reliability of mole drainage in marginal situations. The exceptionally dry conditions over the period of the project meant that some of the mole drainage studies had to be curtailed. These studies were replaced by investigations exploring the possibility of using a low cost mole channel liner pipe for use in very marginal or non-moling soils.

OBJECTIVES

The final overall objectives of this research project were to:-

(a) Identify appropriate mole plough geometries and installation techniques to minimise permeable backfill movement and smear at the mole channel/backfill interface and hence ensure rapid water discharge from the mole into the backfill.

(b) Develop satisfactory installation techniques for successful moled main systems in moling areas, as an alternative to expensive gravel/pipe collector systems.

(c) Assess the potential for increasing mole channel life and reliability in marginal soils and at extremes of soil moisture conditions through changes to mole plough geometry and installation technique.

(d) Explore the possibility of developing a low cost mole channel liner system for use in non-moling situations.

(e) Provide guidelines for field uptake of the research results.

1. MOLE DRAINAGE SYSTEMS

In future, the achievement of effective drainage at lower cost on many of the heavier cereal growing soils will depend increasingly on the adaptation, improvement and extension of mole drainage practices. Current moling techniques are based on the use of a standard mole plough in association with gravel backfilled collector drains. Unfortunately these techniques are costly and are only reliable and satisfactory in a limited range of heavy soils and conditions. In addition, water discharge from the mole channel into the gravel backfill is sometimes impeded or blocked due to the mole plough foot forcing soil across the gravel connection and causing a seal, (Castle et al[1], Castle[2]).

New technique and equipment developments have been identified within recent mole plough/soil interaction studies funded by AFRC and MAFF, (Spoor and Ford[3], Spoor[4], Spoor et al[5]). They have potential for increasing mole drain life and reliability on a wider range of heavy soils and for reducing the mole/gravel discharge problems. Cost savings on gravel backfilled pipe collector drains could also be made by re-introducing the moled main technique, where deeper mole drains replace the pipe collectors. These possible developments have been explored and wherever possible guidelines have been developed for field uptake.

Depending on the farm situation, the potential benefits which could arise are:-

(a) where permeable backfill collector mains are already installed, more satisfactory discharge between the mole and the main, and extended moling interval and increased reliability.

(b) where permeable backfill mains are to be installed, increased spacing between main drains due to improved mole stability and narrower backfill trenches reducing the quantity of backfilled required.

(c) where permeable backfill mains are uneconomic, the use of moled mains or moling from open ditches, thus making mole drainage possible.

(d) where moling is currently marginal or unsatisfactory, the development of a low cost mole liner will make drainage possible.

Work has proceeded in 3 main areas, namely mole channel/permeable backfill connections, moled main systems and development of mole channel liners. The work is discussed in this report under these three headings.

1.1 Mole channel/permeable backfill connection

Recent work by the ADAS Field Drainage Experimental Unit (FDEU) has identified two problems influencing mole drainage efficiency which can occur at the mole channel/permeable backfill interface. These are:-

(a) significant movements of permeable backfill out of the pipe trench area, reducing the possibility of a good mole channel/permeable backfill connection at the next moling.

(b) soil being drawn into the permeable backfill area interfering with downward water flow from the mole channel into the pipe drains.

The latter problem can sometimes cause complete blockage in narrow backfill trenches under wetter conditions.

1.1.1 Materials and methods

The effect of mole plough geometry on the magnitude of these backfill problems was investigated in a collaborative study undertaken by FDEU and Silsoe College. The experimental site was on a Rowsham Series soil where the moisture content was above the plastic limit.

Mole ploughs with differing foot and expander geometry were drawn across 125 mm and 150 mm wide drain trenches and the permeable backfill and soil displacements which occurred measured.

The plough geometry variables investigated included:-

(i)	foot leading edge shape:	- standard chisel
		- vertical wedge
		- flat conical
		- conical
(ii)	expander shape:	- barrel
		- taper

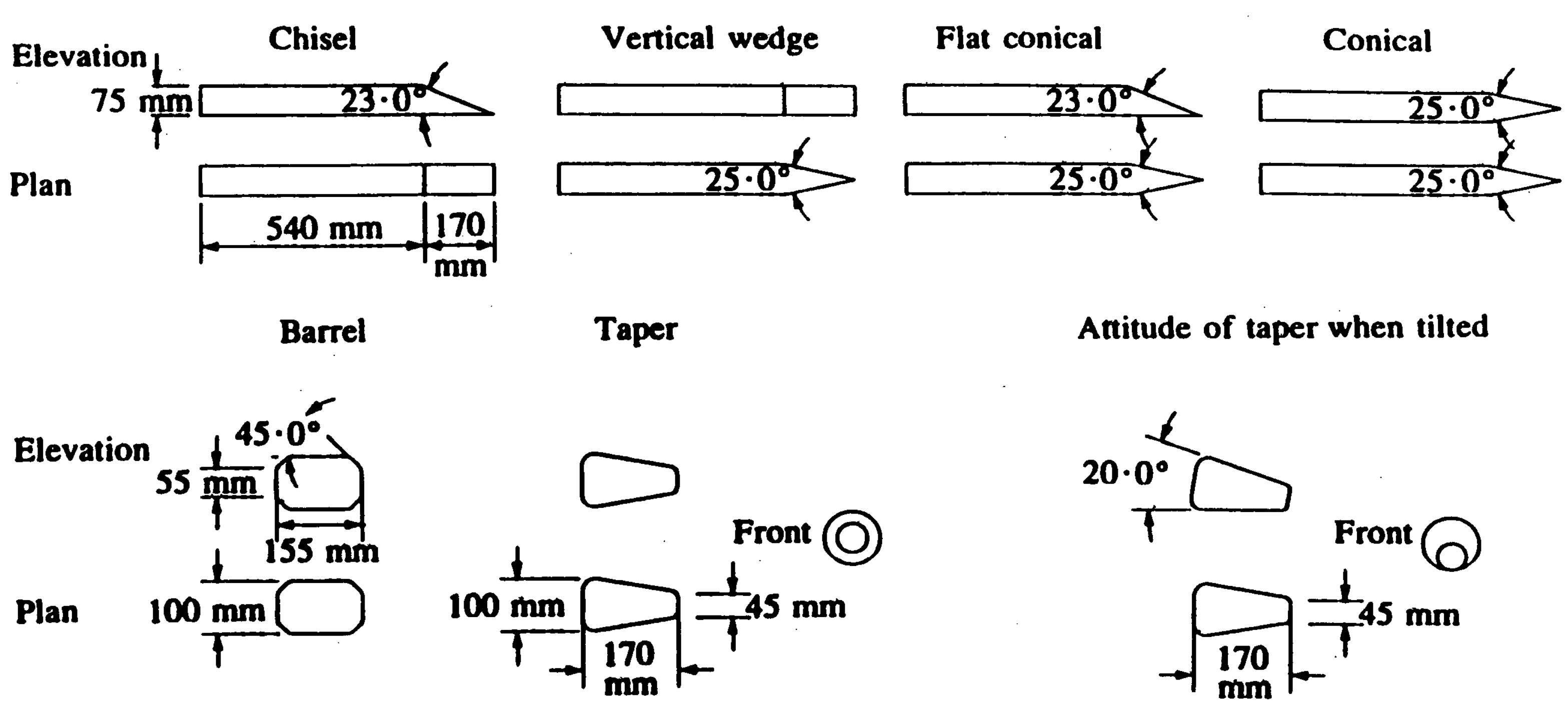
See Fig. 1a.

1.1.2 Results

Examples of the types of soil and gravel displacement monitored are shown in Figure 1b.

The conical and vertical wedge shaped leading edges of the mole foot produced less soil and gravel disturbance than the standard foot but unfortunately both had very poor penetration characteristics which more than offset this benefit.

Figure 1a. Geometry of mole plough feet (top) and expanders (bottom). 85 mm and 125 mm diameter expanders are of similar geometric shape.



The barrel shaped expander was found to cause significantly greater displacements than the taper expander. This reduced the flow rate of water from the mole channel into the permeable backfill. Flow following a barrel expander installation was only half that of the taper in the 125 mm wide trench.

Although the taper expander created less disturbance than the barrel, there was still a major risk that even this may seal off the permeable backfill connection under moist soil conditions with narrow (125 mm or less) drain trenches. Following further experimentation, it was found this sealing problem could be overcome or avoided with any expander by attaching a simple small tine 30-40 mm behind the expander, Figure 2. This tine extends approximately 10 mm below the bottom face of the expander and cuts a groove 10 mm deep and 10 mm wide in the mole channel floor. It is deep enough to hook into the backfill material in the drain trench so disturbing any soil smear which may have occurred, thereby opening up the connection without upsetting mole channel stability.

Further detail of these and other trials on this mole/backfill connection are described in Castle, Spoor, Onasanya and Ormandy (1992)[6].

1.2 Development of Moled Main Systems

Moled main systems use mole drains as collectors as opposed to the now commonly used but expensive clay or plastic pipe backfilled with gravel or other permeable material. These systems were the norm until the 1950s when improved agricultural profitability and drainage subsidies made the use of the gravel systems possible. Whilst the gravel systems are more reliable, this is only a benefit providing they are economically viable, which is currently rarely the case.

Information concerning the installation of moled main systems was collected from experienced UK drainage contractors and this together with information from New Zealand studies (Hudson et al[7]) was used as a basis for the investigation.

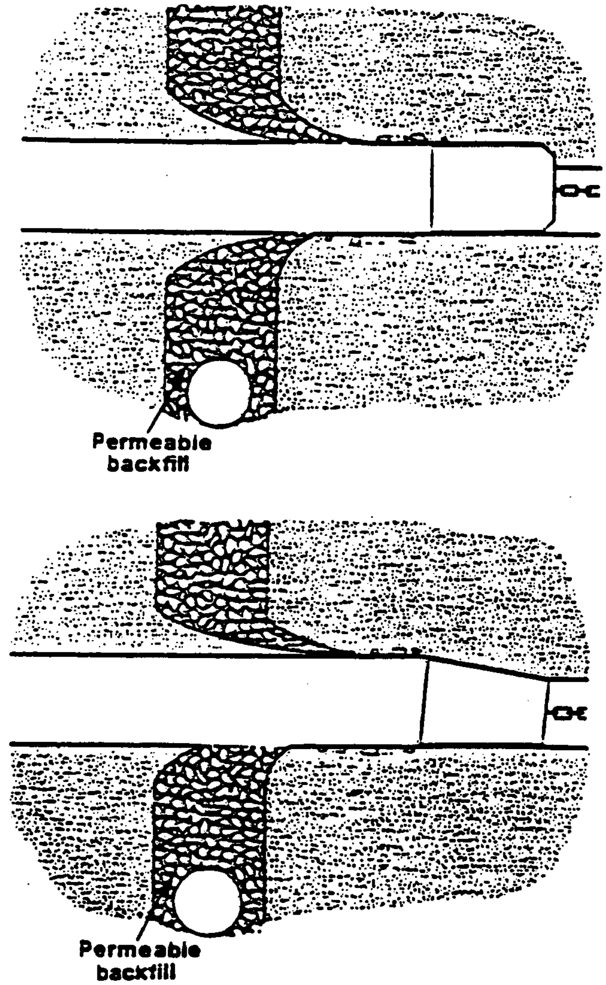


Figure 1b. Movement of soil into, and gravel out of, backfill trench with barrel (above) and taper (below) expanders.

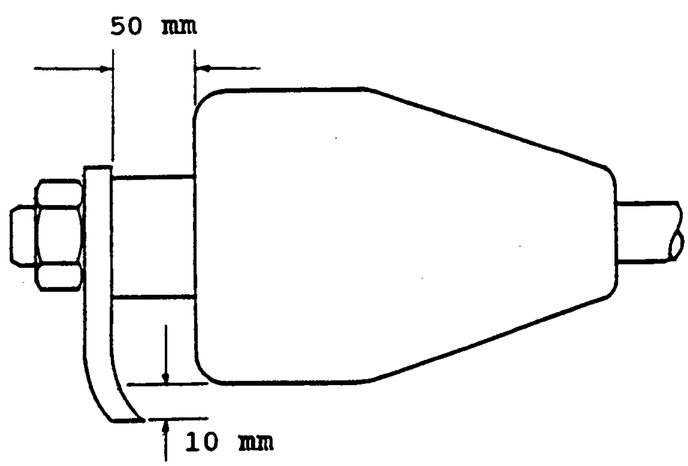


Figure 2. Expander with shallow working tine.

1.2.1 Installation techniques

1.2.1.1 Materials and methods

The critical areas influencing the success of moled main systems are channel stability at the connection between the mole and the moled main and the effectiveness of this connection in allowing water flow between the two. In the past a connection was often created by spearing a hole between the upper and lower mole channels using a hand held rod, in other cases this appeared to be unnecessary. The conditions where it was or was not necessary to spear this connection needed defining.

A series of trials were conducted to collect basic information and to check and expand some previous New Zealand work (Hudson et al[7]) in this area, prior to developing a moled main installation technique suited to current needs and to assessing its performance on a larger field scale. Investigations concentrated on examining the effect of the position of the two channels relative to each other both in terms of height difference and angle of intersection on mole channel stability and junction permeability. These are of particular interest because the relative position of the channels is likely to vary during field installation.

Two basic experiments were carried out:-

(a) A series of moled main connections were installed on 2 sites (both on Evesham Series clay soil). They were then carefully excavated and the soil disturbance, channel stability and the permeability at the intersection examined.

The types of connection investigated were as follows:-

(i) both mole channels pulled at the same depth, a technique which, if successful, would avoid the need for spearing. There was particular interest in channels intersecting at approximately 30°, since this had shown promise in New Zealand experiments

(ii) moled main channel installed after and below minor channel

(iii) moled main channel installed first. The minor channel installed afterwards and above. This was the standard UK technique in the past.

(b) Moled main systems were installed in November 1988 on 2 sites (Rowsham and Evesham series soil) to study the long term behaviour and effectiveness of the connections.

These connections were monitored to assess channel collapse using a non-destructive technique developed at Silsoe College (Leeds-Harrison et al[8]) which uses a borescope (periscope).

1.2.1.2 Results

A brief summary of the results of the detailed examination of connections is as follows:-

(i) Both mole channels pulled at same depth

In all cases when the second mole channel was installed clay was forced into the first channel, tending to close the exit. When the channels crossed at right angles, two approximately equal sized plugs of soil (A and B) were produced, see Figure 3, closing the connection in both directions.

Reducing the angle of approach caused a reduction in the thickness of plug A. At an angle of approximately 30^{o} there was often a small hole approximately 20 mm wide by 30 mm high providing a connection between the two channels in one direction; Figure 4. Providing the moled main was pulled last and the opening on the minor mole was on the discharge side, this connection could be adequate for water discharge into the main.

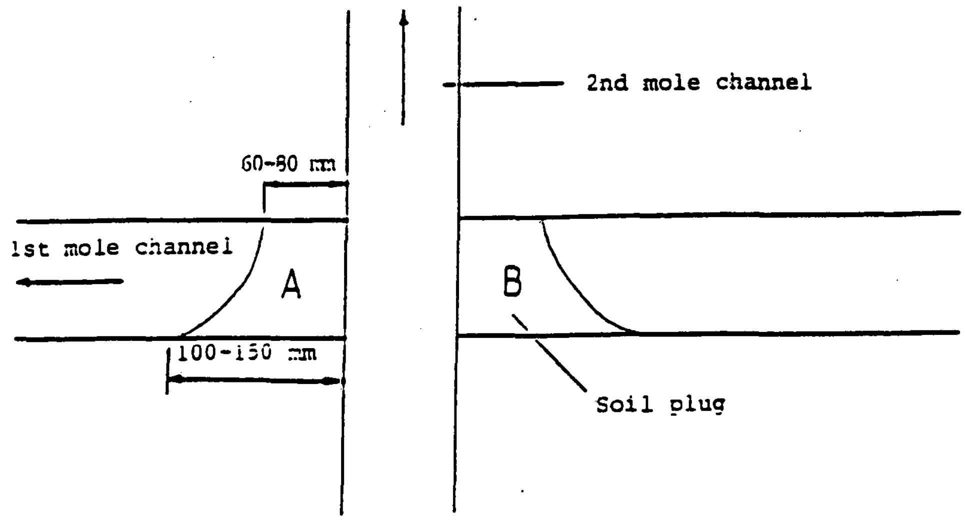
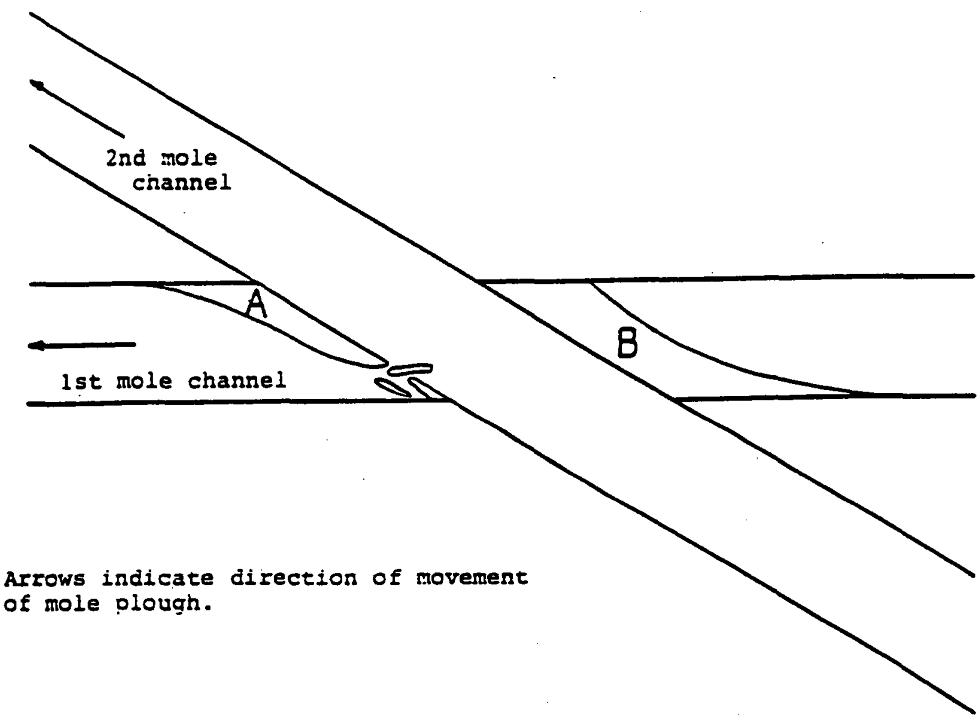


Figure 3. Intersection of mole channels at the same depth and 90°



Arrows indicate direction of movement of mole plough.

Figure 4. Intersection of mole channels at the same depth and 30°

At these small angles, however, the vertical soil fissures generated by the mole plough leg joined together near the connection to produce large soil wedges approximately 600 mm long. These wedges were moved by the advancing leg tending to seal off the leg slot of the first installed mole and also leaving a weakened area at the mole channel intersection, prone to collapse.

(ii) Main mole channel installed after and below minor channel

In all cases when the moled main (major) was installed last and below the minor channel floor, soil heave occurred into the upper channel over a distance of approximately 150 mm either side of the leg slot. This heave closed off the connection between the two channels and also left a very weak area in the roof of the major mole, prone to collapse.

(iii) Main mole channel installed first, minor channel installed afterwards and above.

When the bottom of the minor mole channel just clipped the roof of the main channel, clay was forced into the latter for a distance of approximately 120 mm either side of the leg slot. Although the main channel was completely filled with debris, water flowed fairly easily into it from the minor mole.

Increasing the vertical distance between the two mole channels caused a decrease in the disturbance of the main channel. When the two channels were separated by a distance of 75 mm there was very little visual distortion of the lower channel and water was still able to flow easily from the upper to the lower channel in this particular soil.

In practice it was difficult, due to minor surface undulations, to achieve the desired distance between the upper and lower mole channels. Errors of up to 50 mm were common. Obviously any commercial system must be able to tolerate such differences and still provide a satisfactory stable connection.

(iv) Stability of connections.

The longer term condition of the mole channel connections was studied in the moled main field sites. Collapse occurred very rapidly in the installations where the moled main was installed last and below the moles and where both channels intersected at the same depth, regardless of angle of intersection.

The connections where the moled main was installed first with the minor moles installed afterwards and above proved to be much more stable. Whilst the connections of those installed with the greatest vertical distance between the channels proved to be the most stable, the differences were not too great on this good moling soil. On poorer moling soils or when soil moisture conditions are more marginal, it is anticipated a greater vertical distance would be more stable. Due to surface undulation effects, it would be inadvisable to attempt to just clip the top of the moled main with the second mole , since this would increase the risk on occasions of both moles being almost at the same depth.

1.2.2 The efficiency of the hydraulic connection between the moles and the collector moled mains.

1.2.2.1 Materials and methods

The hydraulic efficiency of the mole/moled main connections was assessed in spring, 7 months after installation. This was achieved by introducing water into the upper channels and measuring the maximum (threshold) flow rate that each junction could sustain. The channels were installed at different angles and vertical distances to each other in soils of moderate to good structure. Little drain flow had occurred between installation and the time of testing due to the dry winter.

1.2.2.2 Results

The hydraulic test, together with careful examination and the casting of plaster of paris moulds, revealed that in general, the water flowed from the mole lateral to the collector channel by one of two routes:

(a) indirectly through both fissures developed by the mole plough leg at installation and soil structural fissures. The water flow rates tended to be low (of the order 0.05l/s),

(b) through a direct connection between the two channels - when flow rates tended to be 0.4l/s or more.

On a number of occasions during the hydraulic test, the flow rate in the collector channel was observed to increase suddenly from a low value to a relatively high threshold flow rate, typically greater than 0.3l/s. This increase was caused by erosion within one or more of the fissures enlarging the fissure diameter until a direct connection between the channels was formed (flow regime b). Direct connections are more likely to form in situations where the distance between channels is relatively small and there is reasonably good soil structure and fissure development at the time of installation.

The indirect flow regime described in (a) with subsequent fissure enlargement through erosion is likely to be adequate for water discharge in well structured soils with numerous relatively large fissures. On poorly structured less stable soils of lower fissure permeability, discharge is likely to be extremely slow with little erosion. In these circumstances a spearing operation will be necessary to provide a direct connection between the two channels. This speared connection has been found to erode and enlarge with time to provide an excellent connecting channel up to 30 mm in diameter.

1.2.3 Large scale field moled main sites

The prime aim of these trials was to test, on a larger scale, the findings of the more detailed studies. In addition, two existing moled main sites were located in Suffolk and Essex and drain discharges were to be monitored on these. Unfortunately, due to the two exceptionally dry winters, no drain flows were recorded at either the Suffolk or Essex sites.

1.2.3.1 Materials and methods

The aim initially was to establish two moled main sites during the summer/autumn of 1989, based on the results of the winter 1988 trials, and to monitor winter flows. Six potential sites were investigated, but all proved to be unsuitable due to exceptionally low moisture contents at depth. Site installation was therefore postponed until spring 1990.

The following two sites were installed:-

(a) on a non calcareous micaceous clay soil (Dale series) in Staffordshire (March 1990),

(b) on a calcareous smectitic clay soil (Evesham series) in Bedfordshire (April 1990).

The Staffordshire site was a single treatment comprising 17 laterals pulled over twin collectors spaced 2 m apart. A nominal clearance of approximately 75 mm was chosen between the top (soffit) of the collector and the bottom (invert) of the minor mole. The soil had a poor structure with few fissures and little fissuring occurred at installation due to the wet conditions. The connections between the moles were therefore speared with a 10 mm diameter rod immediately after installation. Provision was made to allow visual examination of the junctions using a borescope. A plan of this site is given in Figure 5.

The Bedfordshire site was divided into three treatments, chosen to assess the performance of different minor mole/moled main junctions. These were:-

(a) a 65 mm clearance between lateral and collector channels with the junction speared,

(b) a 65 mm clearance between lateral and collector channels - no spearing,

(c) a 15 mm clearance between lateral and collector channels - no spearing.

Automatic flow recorders were calibrated and installed at the collector outfalls - see Figure 6.

The site was a well structured Evesham Series clay soil well fissured at the time of mole installation. Due to lack of rain the site was irrigated regularly to provide drain flows.

1.3.3.2 Results

Drain flows following rainfall did occur on the Staffordshire site and although some mole channel collapse occurred on this marginal moling soil, rapid discharge from the moled mains occurred after rain. Some of the minor mole/moled main junctions were excavated approximately 15 months after installation and observations clearly identified the need for spearing in such situations. Where the spear had failed to pierce the two channels there was zero connection, the water in the mole flowing passed the collector main to a dead end. Where a spear connection had been made, the water flow had enlarged the 10 mm diameter hole into a stable cavity varying from 30-40 mm in diameter.

The Bedfordshire site was irrigated regularly from shortly after installation in April through to the end of July 1990. Discharges from the collector outfalls were monitored from the beginning of June. Data following two irrigations and one natural rainfall event characterize the drainage performance of the plots and are given in Table 1.

Throughout June, drain flow hydrographs generated following irrigation, showed that all plots were performing efficiently, however, greater peak flow rates were obtained from the 15 mm clearance plot, followed by 65 mm (speared) with the 65 mm (unspeared) plot producing the lowest peak discharges.

Figure 5. Plan of large-scale moled main site in staffordshire.

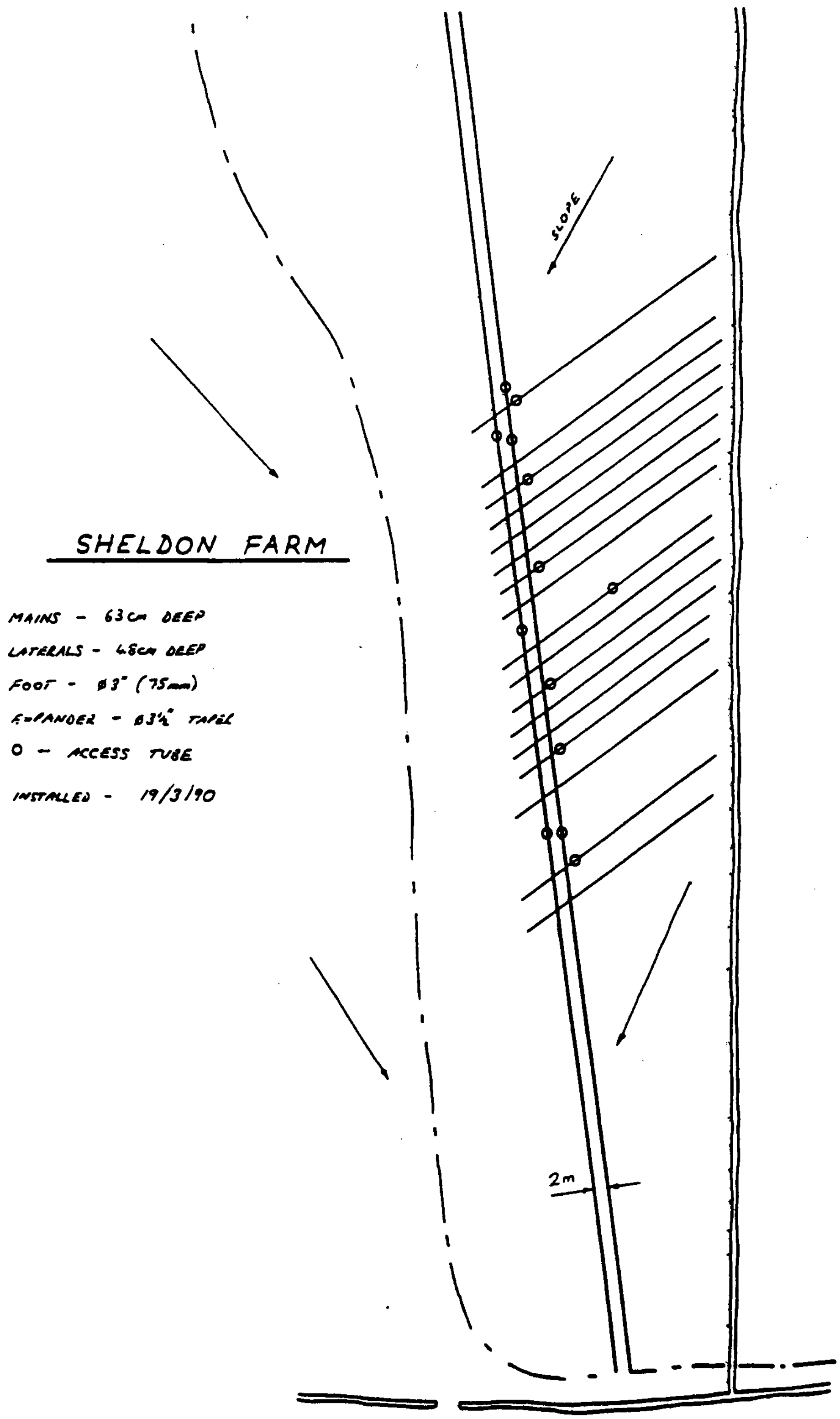


Figure 6. Plan of large-scale moled main site in Bedfordshire.

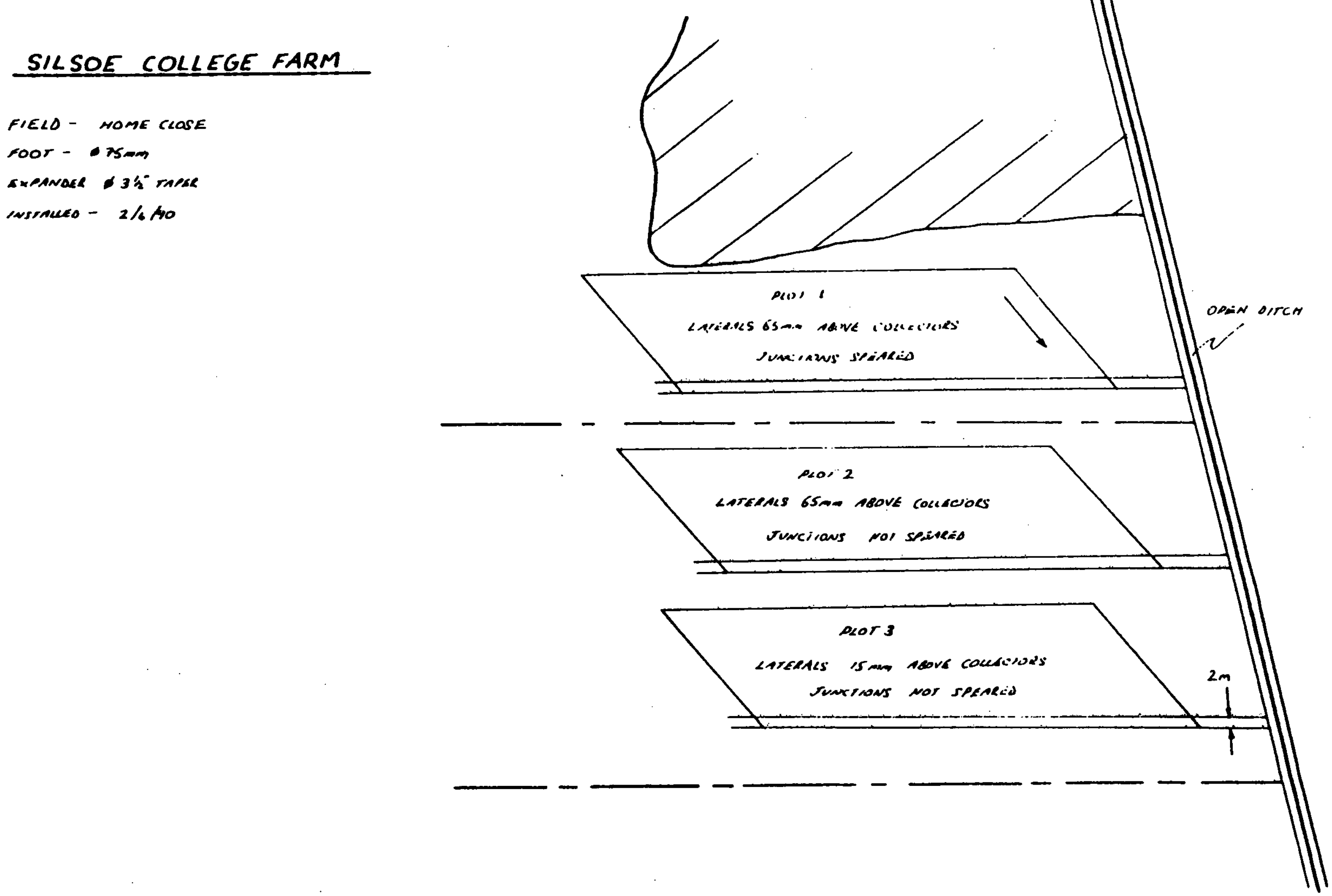


Table 1: Collector drain discharges for the Bedfordshire moled main site (l/s)

		3/6/90 3.8 mm RAIN	26/6/90 18 mm IRRIGATION	17/7/90 27 mm IRRIGATION
15 mm clearance,	near main	0.33	0.140	0.036
	further main	0.40	0.120	0.040
65 mm clearance,	near main	0.07	0.015	0.050
	further main	0.04	0.020	0.040
65 mm speared,	near main	0.24	0.022	0.030
	further main	0.17	0.040	0.050

By mid-July similar peak discharges were observed for all three plots and irrigation was stopped to allow the land to dry prior to harvesting. On all three plots both moled collectors carried approximately equal quantities of water during drain flow.

Drain flows were monitored again one year later, however, the condition of the mole channels had deteriorated so much during exceptionally dry weather that the site was abandoned.

The results obtained from this site indicate that where soil structure is good and numerous well developed fissures exist, spearing is unnecessary where the vertical distance between the two drains is approximately 15 mm. There may be some advantage to be gained by spearing for larger distances, particularly for the rapid discharge of the first drain flows.

1.3 Improvements to mole channel stability

Two major causes of mole drainage failure following installation on marginal soils or under marginal soil moisture conditions are:-

(a) slurry formation through excessive swelling of loose soil and in the channel wall, due to wetting soon after installation followed by subsequent prolonged wetting,

(b) roof collapse in the mole channel as a result of shrinkage and swelling and expander action, following installation under drier conditions.

Experimental field sites were set up on three different soil series to explore ways of minimising these risks.

1.3.1 Reducing slurry formation and wall swelling

1.3.1.1 Materials and methods

Eight experimental mole plough foot shapes were fabricated which, it was hoped, would form a sacrificial channel directly below the standard channel. The hypothesis was that if significant wetting and drain flow occurred soon after channel installation then the lower sacrificial channel would take the bulk of the water allowing the upper channel a prolonged drier period for maturation, beneficial for producing a stable mole channel, (Spoor and Ford[3], Spoor[4]).

A preliminary trial, using the eight feet, was carried out on a stable Evesham series clay soil. Each run was excavated both longitudinally and in section to examine the type of channel formed. From these initial trials, five of the feet, see Figure 7, were selected for longer term experimentation in more marginal, less stable, micaceous clay soils.

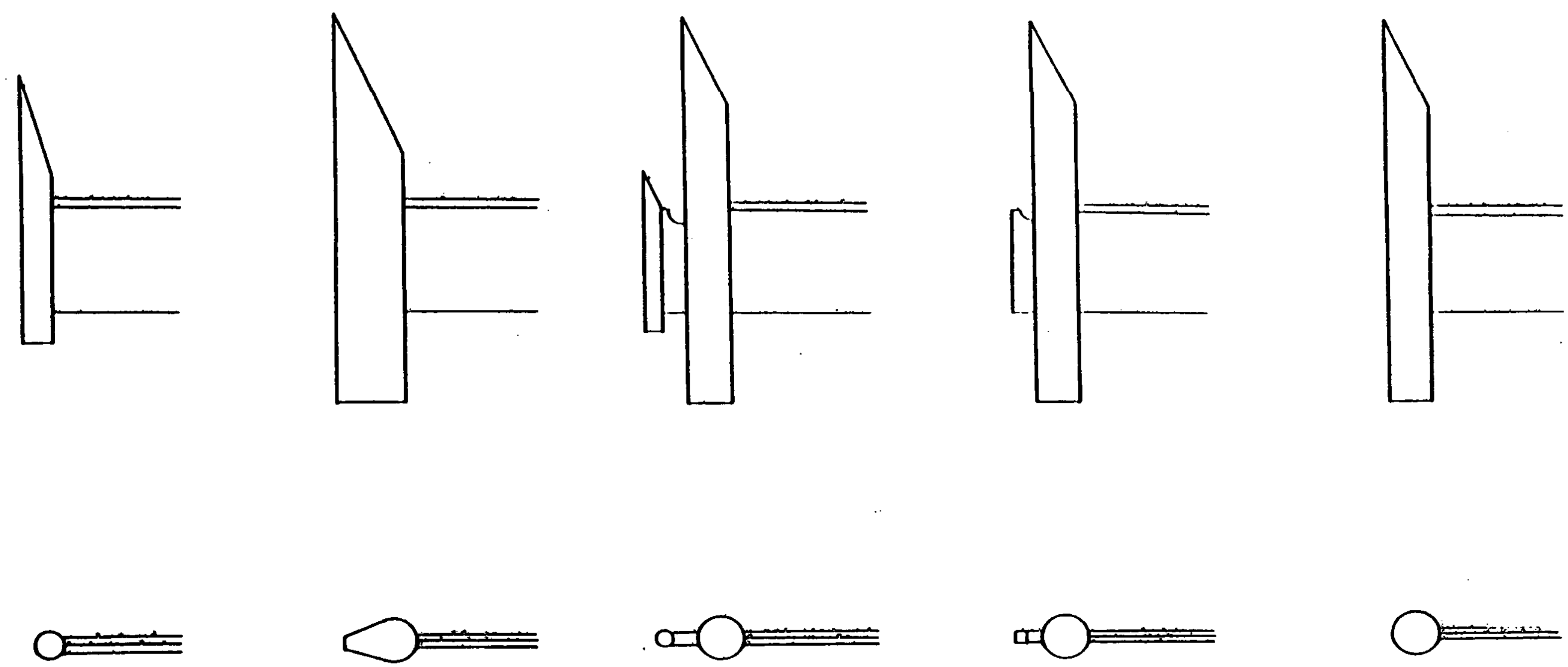
Two suitable micaceous clay field sites were identified, on Dale and Brickfield (less stable) soil series. The mole drains were installed in November 1989, with three replicates of each foot configuration. The mole runs crossed gravel backfilled collector drains at 90^{o}. Soil conditions at the time of installation were moist and satisfactory for moling and the drains carried considerable quantities of water later.

1.3.1.2 Results

Unfortunately the Brickfield series site was plagued with moles (the animals) which chose to integrate the experimental channels into their own channel system. The result of this was to destroy the experiment.

The Dale series site continued to function effectively through to February 1991 when monitoring ceased.

Figure 7. Variations in mole plough foot geometry used in the mole channel stability trials.



The conclusion from this work is that there is some advantage in producing a sacrificial channel below a mole channel, but the benefit is a function of enlarging the overall cross sectional area of the drain and a similar effect may be gained by simply using a larger conventional foot and/or expander. Enlarging the channel size reduces the depth of water in the channel and the wall area wetted for any given flow. This reduces the swelling in the walls and particularly in the upper part of the channel which is the most vulnerable to collapse.

The dry soil conditions precluded the extension to the field of laboratory work investigating the use of calcium oxide (quicklime) to dry out the mole channel wall immediately after channel formation. The lime increases the wall strength and reduces the soil swelling potential. The laboratory tests showed promise and the work is being continued and being extended to other chemicals such as sulphuric acid.

1.3.2 Reducing risk of roof collapse

Roof collapse tends to occur after moling under drier conditions through a lack of strong soil bonding in the roof of the channel. Under drier conditions the soil is less plastic and hence it does not mould together so well when worked by the mole foot and expander.

1.3.2.1 Materials and methods

The exceptionally dry conditions in autumn 1989 enabled trials to be set up on an Evesham series soil, to study the effect of expander size and the use of an expander on the stability of mole channels installed under dry conditions.

Fourteen 20 m long mole runs were pulled directly from an open ditch and provision was made for subsequent visual assessment of the channels using the borescope technique. Table 2 below lists the expander treatments and moling depths. A standard 75 mm diameter foot was used throughout the trial and all the expanders were taper rather than barrel shaped. Taper expanders have proved in other experiments to be more satisfactory than barrel expanders in increasing roof strength.

Table 2: Expander treatments and moling depths for the mole channel roof stability tiials

Expander diameter (mm)	Channel depth (mm)
NONE	720
NONE	670
NONE	620
90	620
100	620
125	620

1.3.2.2 Results

The site was monitored through to March 1990 and the following conclusions were draw from this work:-

(a) where no expander was used, the channels formed in drier soil (friable) were prone to rapid collapse when wetted. The main mode of failure was side wall collapse which subsequently triggered off roof collapse.

(b) channels were more prone to failure when the relatively large diameter expanders (100 or 125 mm) were used rather than the 90 mm expander.

(c) Channel roofs were more stable when formed using a small 90 mm expander as compared with no expander at all.

The general conclusion is that when moling under marginally dry conditions at moling depth. The expander should only be slightly larger in diameter than the foot to smooth out the walls and roof of the channel, without causing significant soil displacement in the roof area.

1.4 Discussion

The mole channel/permeable backfill connection work has clearly demonstrated the benefits of adding a small tine to the rear of the expander to relieve any sealing problems arising at the backfill in narrow drain trenches.

The examination of moled main connections indicates that where the lower channel is installed after the upper one using the equipment currently available, it is unlikely that the system will function satisfactorily.

When two mole channels intersect at the same depth and at an angle approaching 90^{0} there is no connection between them - the first drain being sealed with two equal sized clay plugs.

At considerably smaller angles of intersection an opening is left in one side of the first channel. If sufficient water flows through this type of connection the opening may well be enlarged. On the other hand the initial high resistance to flow may encourage a rapid and large build-up of water soon after installation which could lead to premature channel collapse.

The installation of the upper mole channel after the main appears to be the most successful installation technique. When there is a small vertical distance between the two, some debris tends to enter the main channel at the point where they cross. Increasing the distance to 65 mm decreases the amount of soil disturbance but in stable well structured soils soil fissures still provide good paths for water flow. In less stable micaceous soils spearing of the junctions during installation is necessary.

The penalty of an increased vertical distance is an increase in draught force.

Attempts could be made to develop machinery to either spear the mole connections or remove the clay plugs. The complexity and hence cost of this machinery would need to be carefully considered.

The moled main hydraulic efficiency work suggests that water flows from the minor mole to the collector through one of two routes:-

(a) indirect structural fissure flow - low flow rates,

(b) direct connection - high flow rates.

The results suggest that under certain conditions the water flowing indirectly down from the upper channel enlarges the fissures, increasing the flow into the collector channel. This leads to accelerated erosion until eventually a large hole is formed, making a direct connection.

Where mole channels are installed in wet soil conditions, there may be some advantage to be gained by increasing the foot cross sectional area. This appears to prolong the functional life of the drain through the provision of a large initial channel section which takes longer to clog-up, rather than to contribute directly to wall stability.

Where mole channel installations are to be carried out under relatively dry soil conditions, expander studies indicate that better channel stability may be gained by using smaller expanders, rather than larger diameter taper expanders or no expander at all.

2. MOLE CHANNEL LINER SYSTEMS

The three major cost components in a drainage installation are the pipe, gravel and installation costs. Costs can therefore be reduced by developing a cheaper pipe, avoiding the need for gravel and developing low-cost installation equipment which could be used by the farmer himself during non-peak work periods.

The approach taken within the project was to examine possibilities for reducing pipe cost by reducing wall thickness and for replacing gravel with well-developed soil fissures to promote rapid water flow to the drain. This required the development of a new installation technique and associated equipment to generate the necessary soil fissures at installation and to ensure the new much weaker pipe was positioned where it would not be subjected to excessive crushing loads. The installation technique investigated was to place the weak pipe into the equivalent of a mole channel where the pipe would act both as a conduit and liner to remove water and to prevent soil falling in or swelling to block the channel respectively. The strong undisturbed soil around the liner would carry all the loads, thus protecting the weak pipe and the soil fissures generated by the vertical leg of the equipment at installation, which would allow rapid water entry into the drain.

Four aspects were investigated:-

(a) determination of pipe strength requirements,

(b) identification of potential drainage system layouts,

(c) development of installation technique and equipment,

(d) site trials.

FIG. 8. MOLE LINER WALL THICKNESS REQUIREMENTS FOR STABLE INSTALLATION (AFTER SCHWAB')

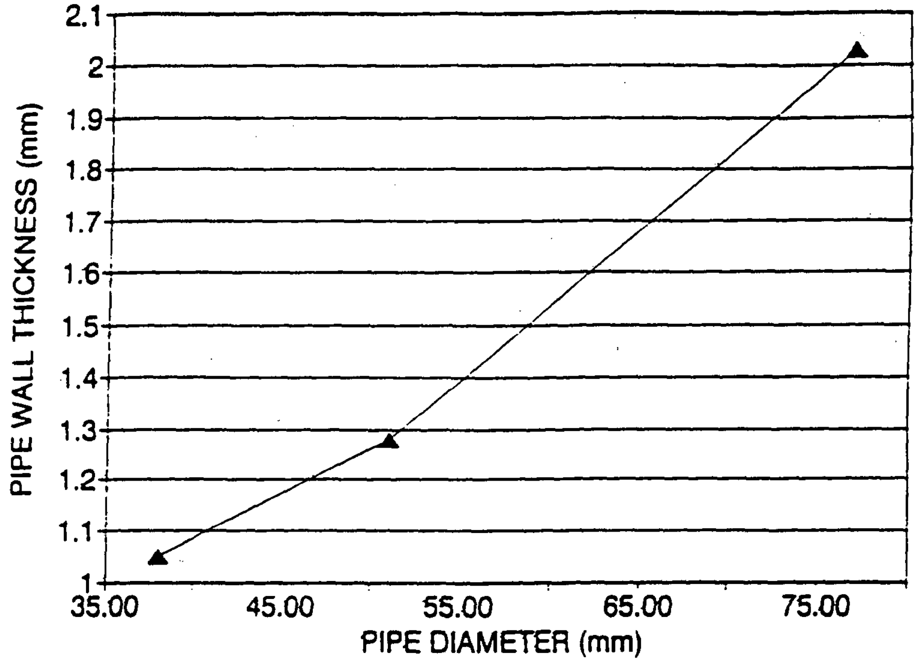
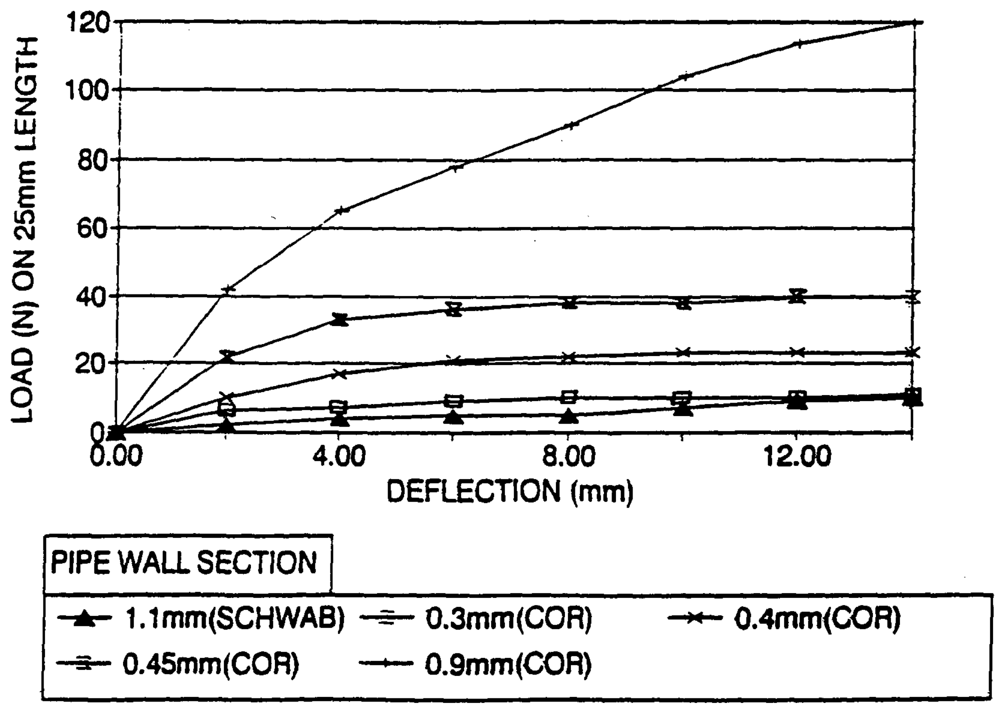


FIG. 9. LOAD/DEFLECTION CHARACTERISTICS OF 35 mm DIAMETER SMOOTH (SCHWAB) AND CORRUGATED PIPES



2.1 Pipe strength requirements

The two major loadings on a pipe within a mole channel are likely to result from channel roof collapse and/or soil swelling in clayey soils. Schwab[9] in the 1950's conducted trials using plastic pipes of various wall thicknesses installed into mole channels to assess their deformation characteristics. He conducted a 4 year trial and determined the minimum required pipe wall thickness necessary to ensure sufficient pipe strength to avoid collapse. A summary of his results is presented in Figure 8. This work was done during the early stages of plastic drainage pipe development using smooth walled low density polyethylene pipe. For his results to be meaningfully applied to present day pipes (corrugated walled polypropylene) strength comparison tests were necessary for both short and long term strength.

To ascertain the comparative initial strengths of the pipe used by Schwab and present day corrugated pipes, the pipes were loaded when held between two flat plates and the load/deformation relationships determined. The pipes used were samples of 35 mm diameter smooth walled pipe (made from low density polyethylene to the dimensions of the stable pipe implied from Schwab's results) and similar diameter corrugated polypropylene samples extruded with different wall thicknesses. The results are shown graphically in Figure 9. The deformation characteristics of Schwab's pipe represents the minimum strength or stiffness required by a 35 mm pipe to resist compression when installed in a mole channel. It can be seen that this roughly corresponds to the deformation characteristic of the corrugated pipe sample with a wall thickness of 0.3 mm. The wall thickness of pipe currently being produced with extrusion machinery and marketed as conforming to BS4962 (the drainage pipe standard) is 1.2 mm. In terms of initial strength, therefore, the wall thickness of current standard pipe can be significantly reduced and yet still be sufficiently strong for a mole channel installation.

From a pipe production viewpoint, consultations with D.W. Clark of Aquapipes, the pipe manufacturer, revealed that problems would arise in the extrusion process if the wall thickness was reduced below 0.45 mm. In addition there was a hole cutting problem with the 0.45 mm pipe, which was overcome at a wall thickness of 0.6 mm. All further work was, therefore, carried out on 0.6 mm wall thickness pipe, which could be produced at approximately 50% of the cost of standard pipe and which had a good margin of safety in strength terms. It is anticipated that with a different hole design and appropriate tooling changes, satisfactory holes could be produced in the 0.45 mm wall thickness pipe.

A good indicator of the comparative long term stability of Schwab's low density polyethylene pipe and the proposed thin walled polypropylene pipe can be obtained by comparing the relaxation or creep characteristics of the two materials. These are defined by Baer[10]. Low density polyethylene shows 2.7 times greater relaxation than polypropylene when compared at the same temperature and over the same period. The polypropylene pipe will, therefore, be more stable than the polyethylene pipe in the long term.

A swelling pressure test on 0.3 and 0.9 mm wall thickness pipe was also conducted using an Evesham Series clay soil and measurements made of pipe deformation over a 3 month period. Dry soil was packed around the pipe as shown in Figure 10 and the whole wetted and allowed to swell. No significant reductions in pipe diameter were measured, nor was there evidence of clay moving into the holes in the pipe. These thin walled pipes should, therefore, be capable of withstanding any likely field swelling pressures.

On a basis, therefore, of past field experience, 35 mm diameter good quality corrugated polypropylene pipe should prove to be a stable mole channel liner, providing its wall thickness is equal to or greater than 0.45 mm. A poorer quality polymer would require a thicker wall.

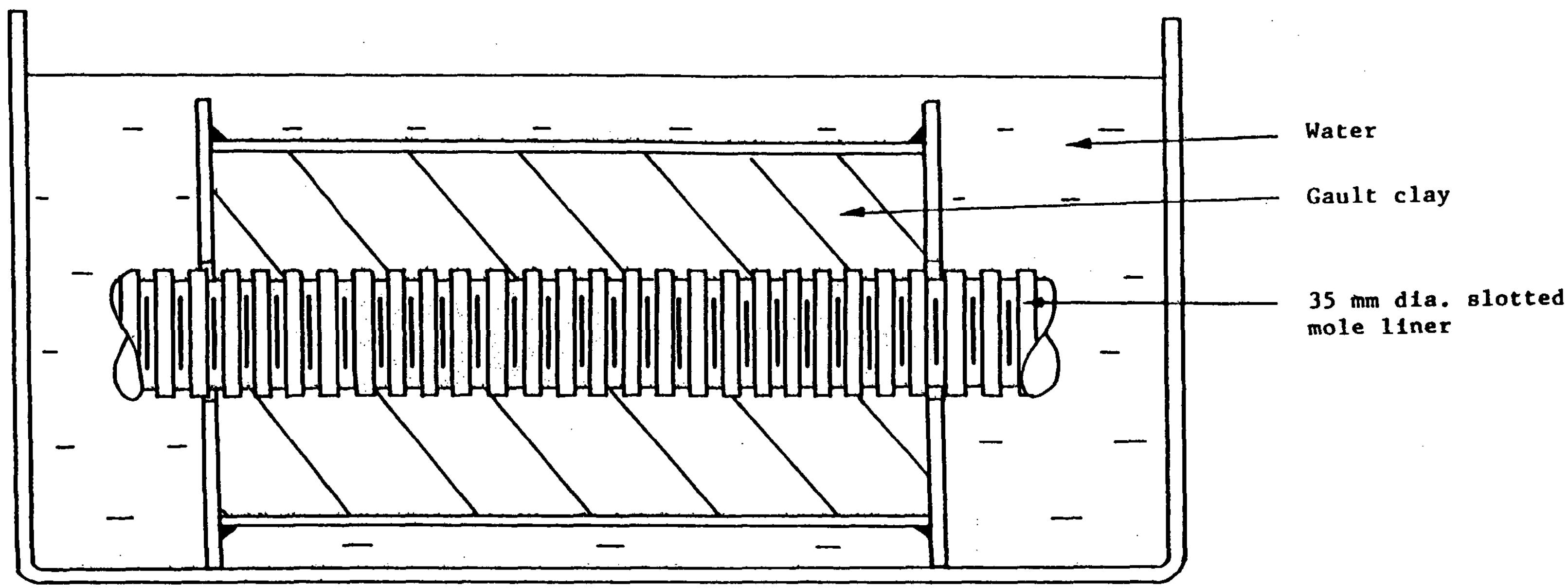
2.2 Potential drainage system layouts

A range of possible pipe system layouts were reviewed to determine those likely to be most cost-effective. Consideration was given to pipe flow requirements and hence pipe size as influenced by likely spacings, run length and climate and also to the method of connection between mole liner and collector.

2.2.1 Pipe size

The two most suitable sizes of pipe available for a mole liner from currently marketed ranges are 35 and 60 mm outside diameter. The constraints on pipe run length for these sizes in terms of internal flow capacity for a 7 mm/day discharge (common discharge requirements in eastern UK), are shown in Figures 11 and 12 respectively. It can be seen that even at low gradients of 0.1% and spacings of 7 m, runs of at least 320 m can be accommodated using 35 mm diameter pipe. Castle et al[11] have identified that in 95% of drainage systems in UK run lengths do not exceed 300 m.

Fig.10. Swelling pressure test equipment



Pipe compression rig

It is, therefore, unlikely that internal flow capacity will impose constraints on pipe run length even using the smaller sized 35 mm pipe. This suggests that the smaller sized option is more suitable for installation at spacings up to approximately 10 m, as in most cases the 60 mm pipe will give excess capacity with associated cost penalties.

If the 60 mm pipe had sufficient capacity it could be used as a main (collector) drain but examination of Figure 12 shows this not to be the case (At 100 m spacing, pipe run length on a low gradient of 0.1% corresponds to a run length of only 50 m). The 60 mm pipe is, therefore, not a viable option, having over-capacity as a close spaced 'in field' liner, but under-capacity to act as a useful collector drain. A lined mole used as a collector drain, would also create lateral connection difficulties.

2.2.2 Pipe layout and relative costs

To compare relative costs of the various possible drainage system layouts and installation methods available, a 'standard' field of approximately 10 ha (320 x 320 m) was considered. It was assumed that the topography is such that either one or two main collector drains are necessary at the side of the field. The layout is a simplified representation of actual field layouts but does give a reasonable basis for cost comparisons. Costs were based on data from Nix[12] as well as on information provided by drainage installation specialists.

It was assumed that the cost of running a modified mole plough to install the low-cost mole liner would fall midway between the cost of traditional mole ploughing and running a trenchless drainer.

It was also assumed that the main side drain would be installed by a hydraulic backacter. This avoids the disproportionately large transport cost component associated with moving a trenching machine to a site where it is to be little used (the majority of the pipe system would be installed by the mole plough liner installation tool).

FIG. 11. MAXIMUM LENGTH OF PIPE . /SPACING RELATIONSHIPS (35 mm DIAMETER CORRUGATED PIPE, 7mm/DAY DRAINAGE COEFFICIENT)

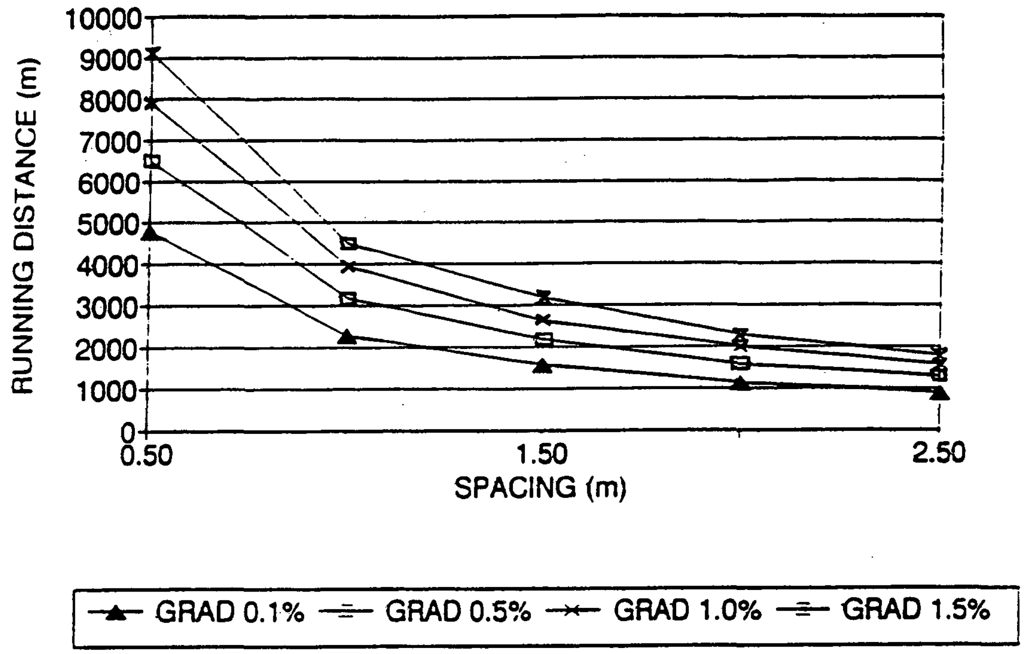
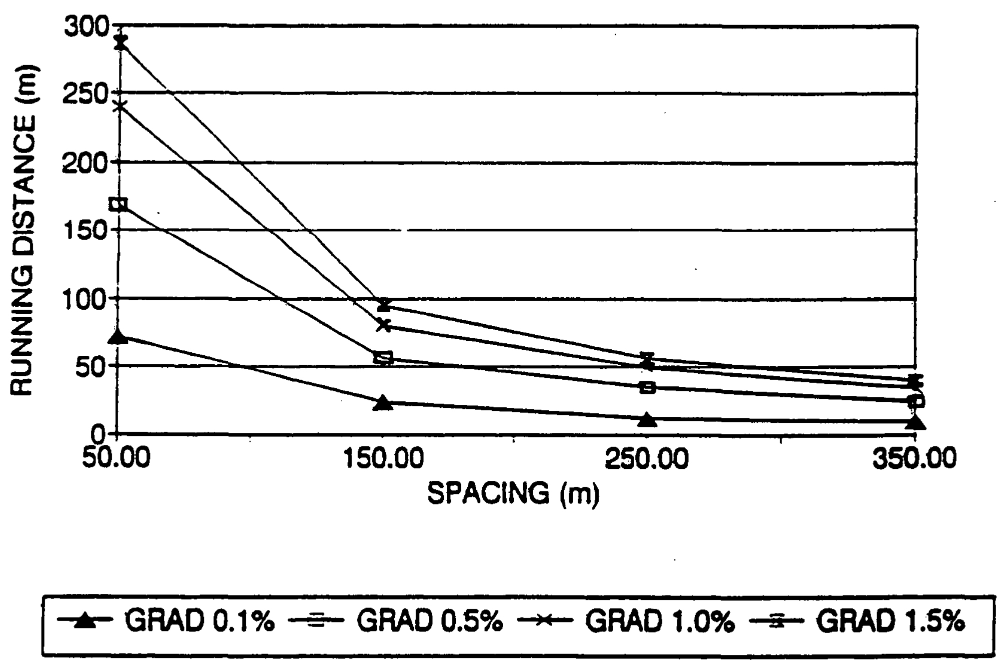


FIG. 12. MAXIMUM LENGTH OF PIPE RUN/SPACING RELATIONSHIPS (60 mm DIAMETER CORRUGATED PIPE, 7mm/DAY DRAINAGE COEFFICIENT)



The data used in the cost estimates are presented in Appendix 1. Four different drainage systems have been analysed as follows.

a. *System 1. Standard mole system. 1 side drain. See Fig. 13*

Costs are analysed with backfill on laterals for different lateral spacings and different installation methods. The results are shown graphically in Figure 14. Costing for this system installed by contractor is approximately £1100/ha.

b. *System 2. Lined mole system pipes running straight to single collector drain. See Fig. 15*

Costs are analysed for farmer and contractor mole liner installation, with a contractor installing the collector drain. The labour cost associated with this operation when completed by the farmer is not accounted for, as it is assumed that the installation takes place during a slack period, so that no significant variable cost is incurred. The cost of the mole liner is assumed to be 11 p/m. Results of the cost analysis are shown in Figure 16. It can be seen that if a contractor installs the system with 3 m mole liner spacings, the cost is similar to that of a standard mole system i.e. £1000/ha. The lowest cost realistic option (£300/ha) is mole liners (installed by farmer) at 8 m spacings and one collector drain (installed by contractor using backacter) with backfill.

c. *System 3. Standard moles running across wide spaced lined moles discharging to single main drain. See Fig. 17*

This is equivalent to the pre - 1950's standard moled main system, only in this case the moled main is stabilised using a pipe liner. Costs are analysed for different spacings and contractor and farmer installations - see Figure 18. Again, farm labour costs are not included in the farmer installation being assumed to be part of fixed costs. It can be seen that where 30 m spaced lined moles are acceptable, the variable costs are £140/ha if the farmer installs the liners and moles himself.

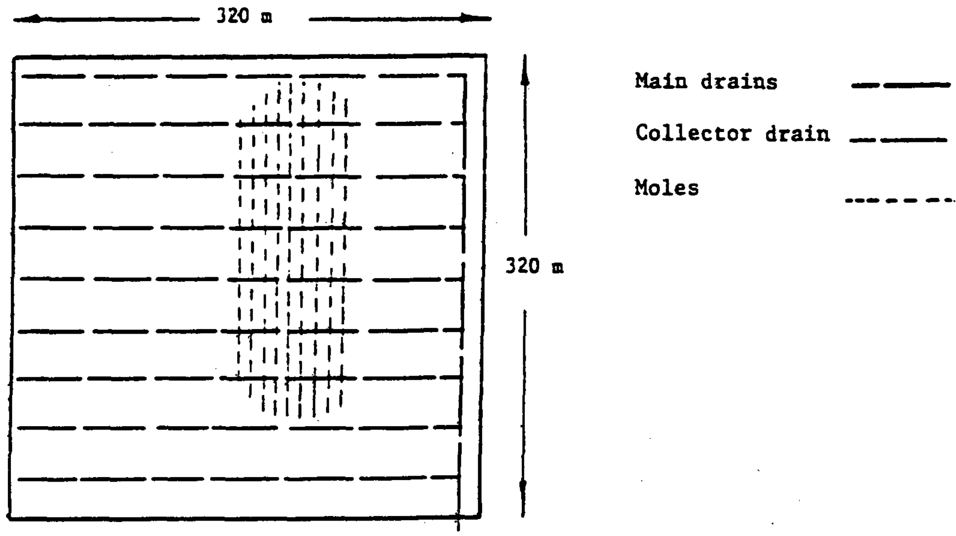
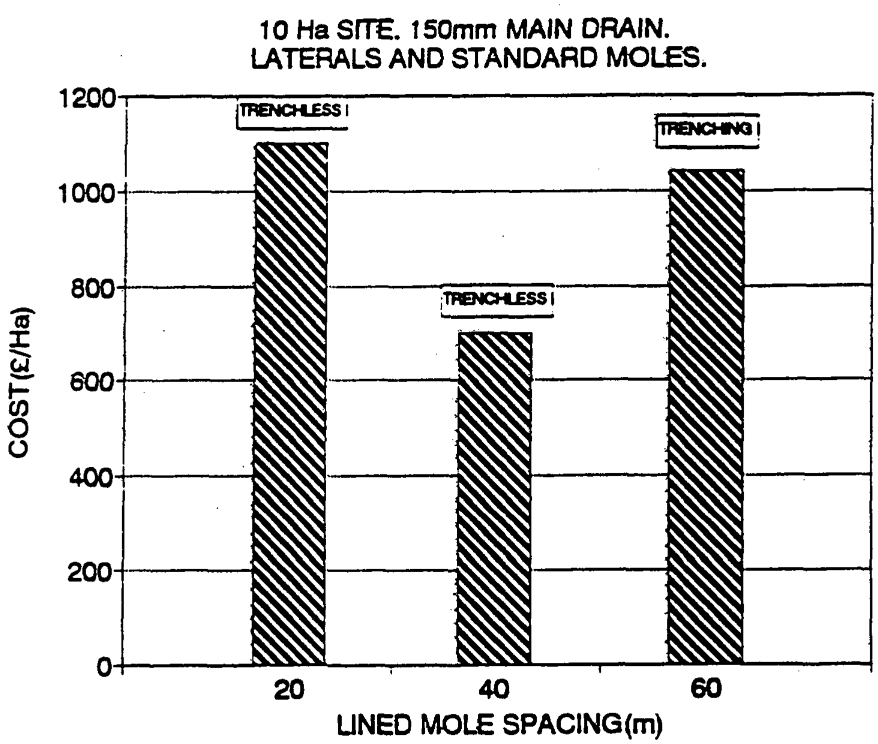


Fig. 13. Drainage system 1. Standard mole system with lateral collectors and one main drain



Laterals.	Spacing (m)	Pipe dia. (mm)		Installation method
	20	45	-	Trenchless
	40	60	-	Trenchless
	60	100	-	Trenching

Fig. 14. Costing for drainage system 1

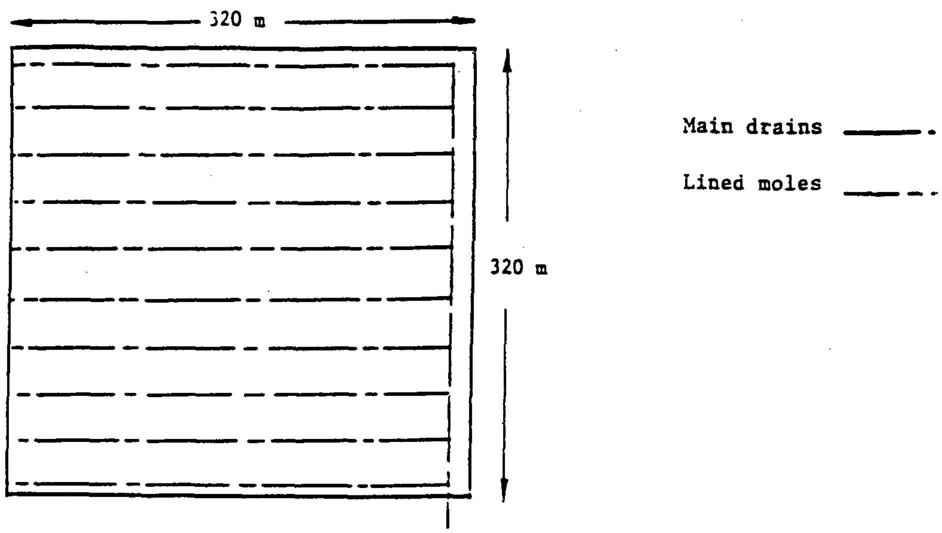
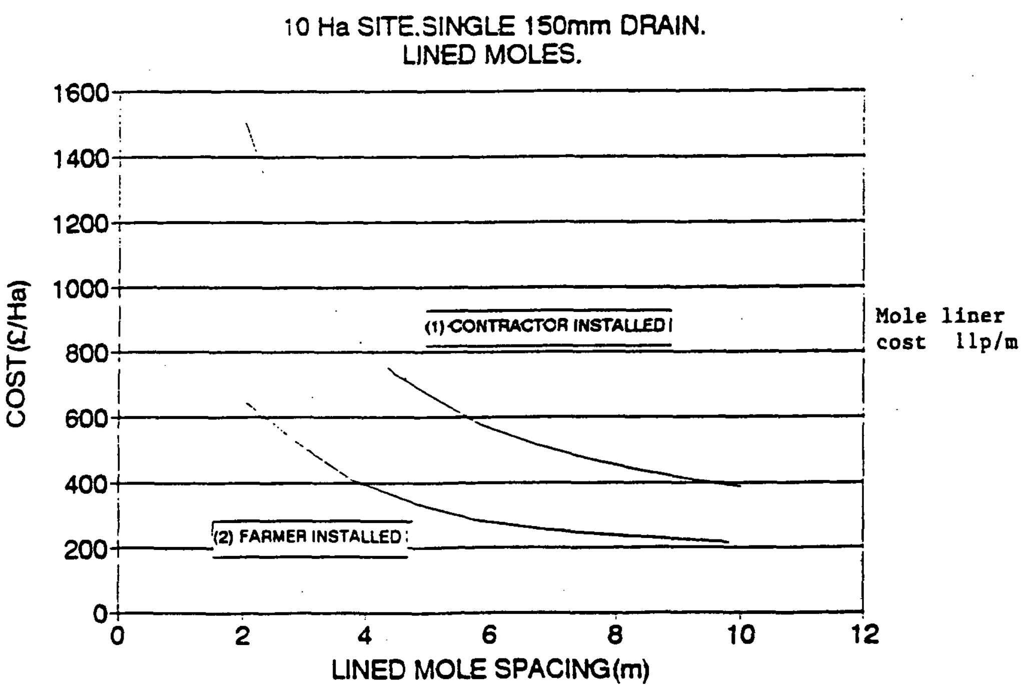


Fig. 15. Drainage system 2. Lined moles with one collector drain.



SERIES	PIPE SYSTEM	BACKFILL	INST. BY	USING
1	Mole liner (35 mm)	No	Cont.	'Moler'
	Single drain (150 mm)	No	"	Backacter
2	Mole liner (35 mm)	No	Farmer	'Moler'
	Single drain (150 mm)	No	Cont.	Backacter

Fig. 16. Costing for drainage system 2.

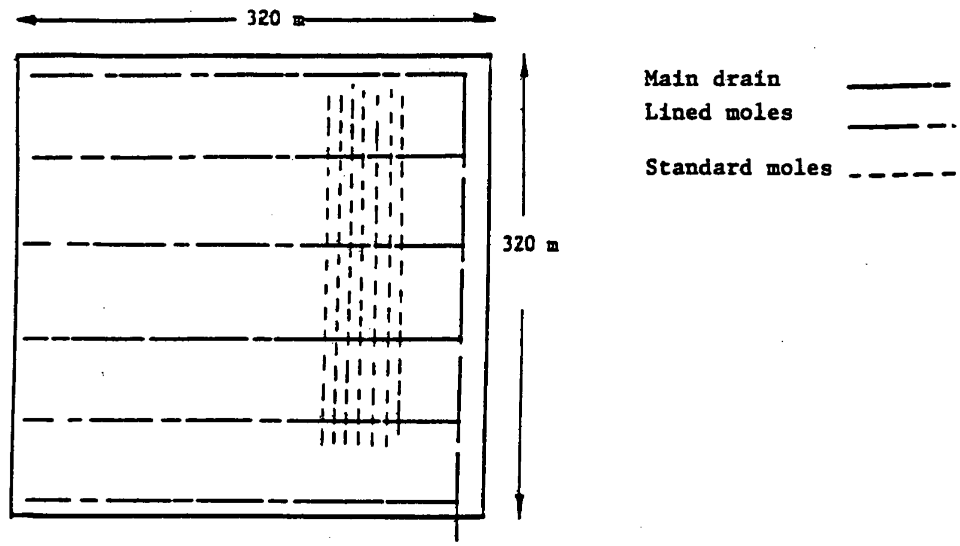
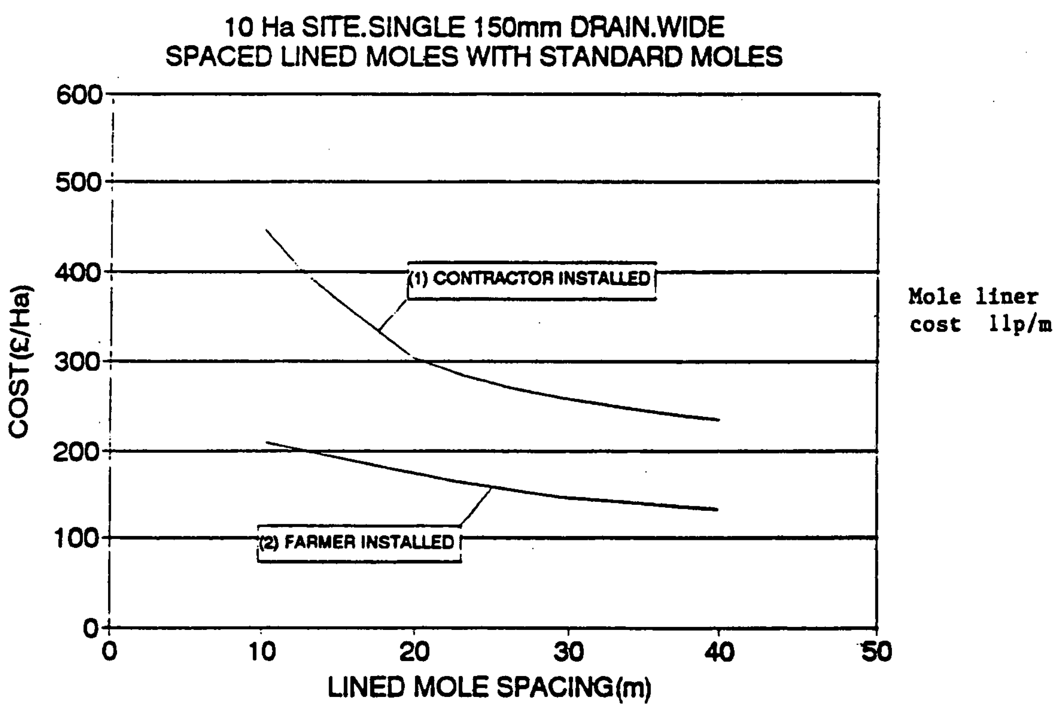


Fig. 17. Drainage system 3. Standard moles across wide spaced lined moles discharging into single main drain.



SERIES	PIPE SYSTEM	BACKFILL	INST. BY	USING
1	Mole liner	No	Cont.	Moler
	Moles	No	Cont.	Mole plough
	Single drain (150 mm)	No	Cont.	Backacter
2	Mole liner	No	Farmer	Moler
	Moles	No	Farmer	Mole plough
	Single drain	No	Cont.	Backacter

Fig. 18. Costing for drainage system 3.

d. *<u>System 4</u>. As system 3 but assuming the lined moles discharge direct into an existing ditch. See Fig. 19*

This is obviously the cheapest option and results show (Figure 20) that even if the system is installed totally by contractors at 30 m spacing with lined moles, the cost is £150/ha.

These trial costings clearly show the significant cost benefits which could arise from the use of the lower cost mole liner pipe, particularly with farmer installation.

2.3 Installation

The above discussion and cost analyses indicate that the most likely mole liner system to be taken up would be one that uses lower cost pipe installed with low cost equipment. To function satisfactorily any pipe installation technique must ensure that no pipe crushing takes place, that the pipe does not fill with sediment, that water can enter rapidly and that no serious pipe undulations occur which could cause ponding. To achieve these requirements a floating beam mole plough was modified for pipe installation as shown in Figs. 21, 22 and 23. The functional requirements of the installation device were achieved as follows:-

2.3.1 Avoidance of pipe crushing

As discussed earlier, it is essential that the pipe is installed with a below critical depth moling type soil failure. To achieve this at depths of 400 mm or more, the width of the leg is limited to 50 mm, to satisfy the critical depth/tine width ratio requirement of 7.0 (Spoor and Fry[13]). Trials where pipe was installed at 550-600 mm depth, confirmed that the desired type of soil failure was being achieved, protecting the pipe from surface loadings. It is noteworthy that 50 mm is also the narrowest leg that can be used to install 35 mm pipes. It is also the widest leg that can be pulled using generally available 120-130 HP, 4-wheel drive conventional wheeled tractors. A greater leg width such as would be required for 60 mm pipe installation would require a tracked vehicle and would also be likely to produce at similar drain depths an unsatisfactory lifting type of soil failure, with subsequently associated crushing loadings on the pipe.

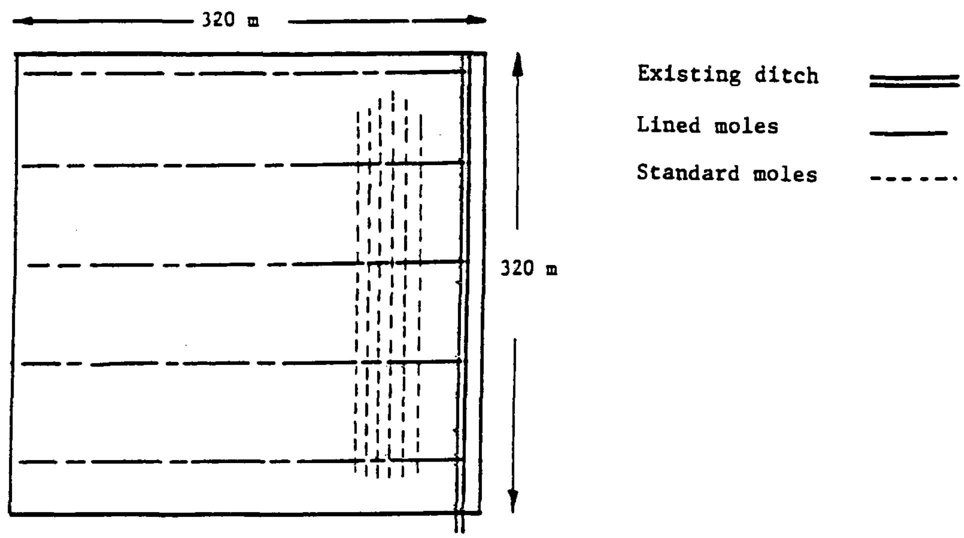
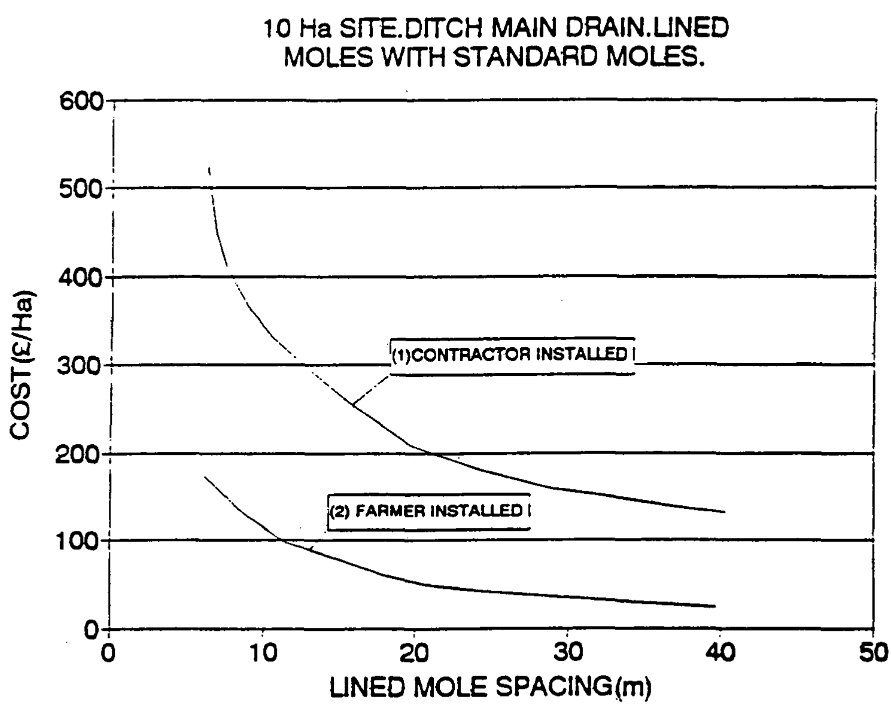


Fig. 19. Drainage system 4. Standard moles across wide spaced lined moles discharging directly into an open ditch.



SERIES	DRAINAGE SYSTEM	INST. BY	USING
1	Mole liners	Cont.	Moler
	Moles	"	Mole plough
2	Mole liners	Farmer	Moler
	Moles	Farmer	Mole plough

Fig. 20. Costings for drainage system 4.

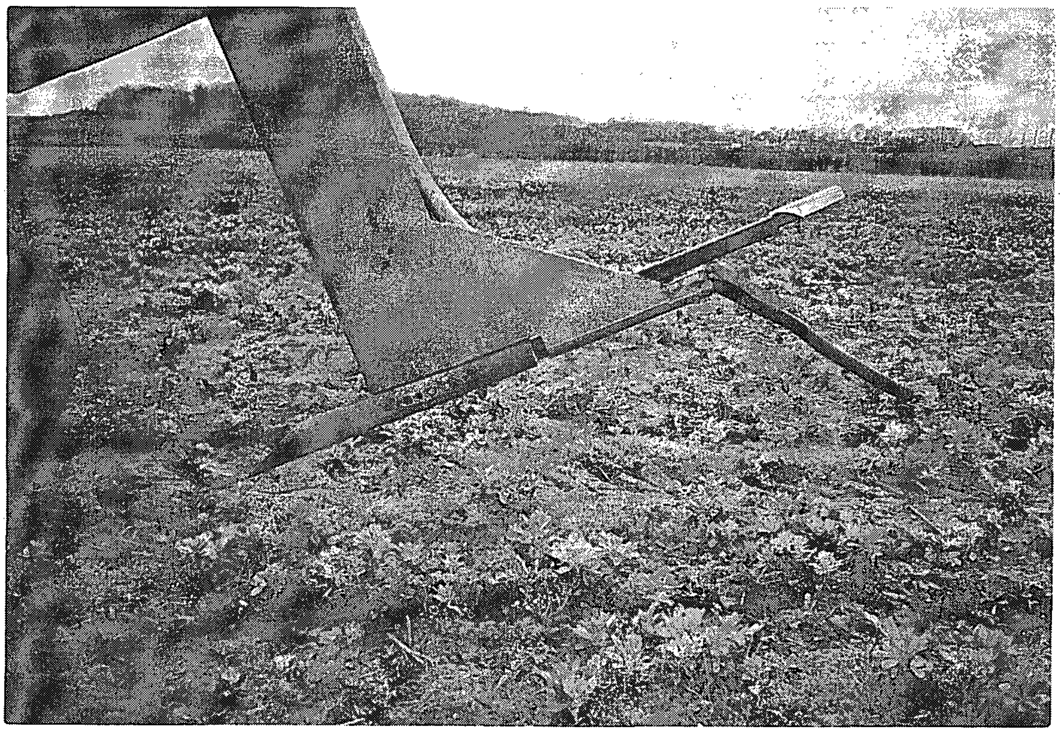


Fig. 21. Mole liner installation equipment

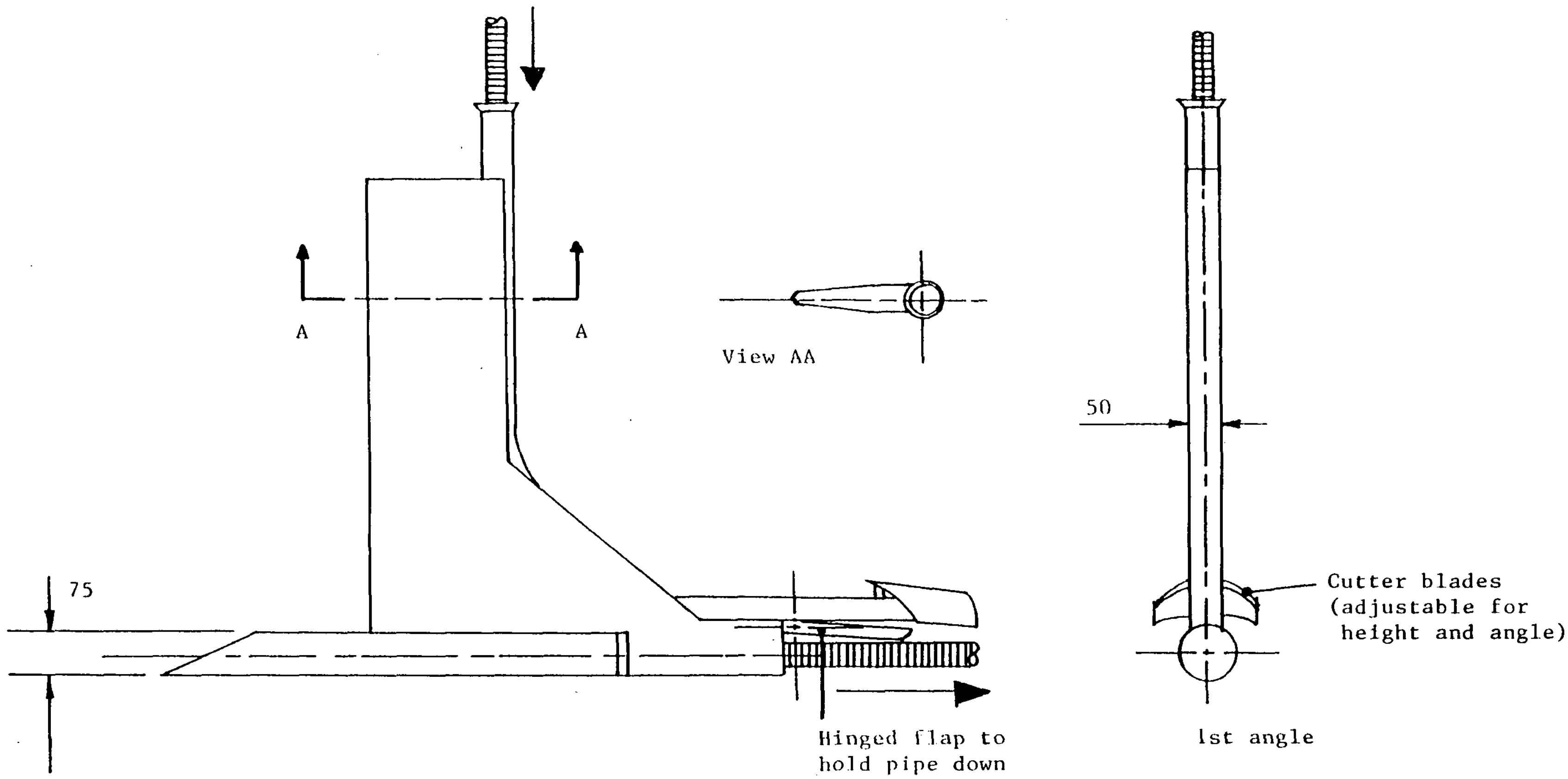


Fig. 22. Mole liner installation device

Fig. 23. Complete mole liner installation equipment including smoother device

The other possible problem area relating to pipe crushing is soil swelling. Although field data are not available concerning the swelling pressures likely to be exerted on the pipe, Yong and Warkentin[14] suggest that soil properties are such that provided there is some allowance for soil movement or free volume at the onset of swelling, the pressures involved will be very low. The installation tool was fitted with a 75 mm diameter mole foot which leaves a mole channel of approximately 60 mm diameter in most soils after soil recovery. The mole liner is therefore a loose fit in the channel (approx. 25 mm diametric clearance) ensuring free space for soil expansion and the avoidance of pressure build up. Obviously the results of long term trials will be needed to validate this hypothesis, but the risks of problems arising are very small.

2.3.2 Avoidance of pipe filling with soil sediment

The pipe perforations in the mole liner are exactly the same as those used in normal thickness 35 mm pipes, and which have proved satisfactory in the past. Hence their performance can be expected to be satisfactory in terms of minimal sedimentation ingress under most field conditions. Care must be taken, however, as with any pipe, not to install under very wet conditions, otherwise sedimentation and slurrying problems could be severe.

2.3.3 Ensuring water entry to pipe

Two essential requirements at installation to permit rapid water entry, are the generation of major fissures in the soil and overcoming any significant smear or soil compaction in the immediate vicinity of the pipe. The mole plough leg is responsible for the fissure generation and the foot for any smear or compaction.

The mole plough leg dimensions, 50 mm width and 200 mm side length, were chosen to provide the desired fissuring, shown in Figs. 24 and 25 and schematically in Fig. 26. These vertical fissures extend from the surface to the drain allowing rapid downward water movement.

To remove local smear and compaction around the pipe, cutting blades are fitted behind the foot to partially cut and partially fail the soil in the channel roof and side area, see Fig. 22, 25 and 26. The failed soil falls on top of the pipe holding it in position in the bottom of the channel. This technique, although not entirely satisfactory in situations where groundwater (bottom water) control is the problem, is quite satisfactory on the heavier soils, with their top water control problems.

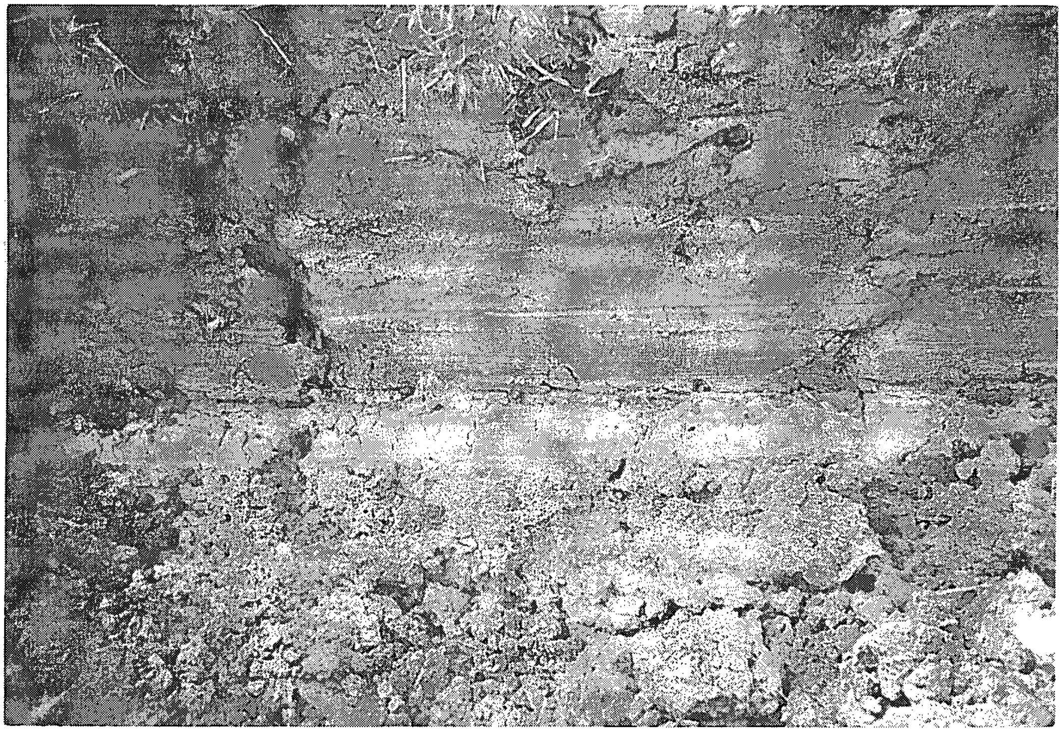


Fig. 24. Soil failure produced by mole leg installation device

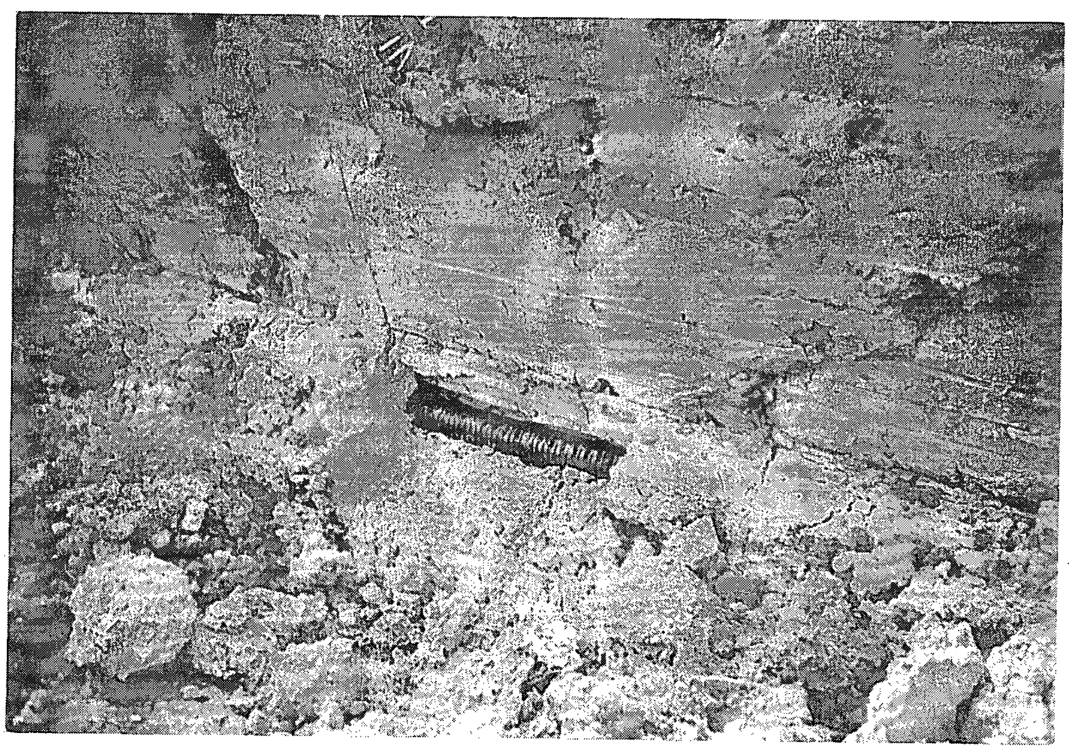
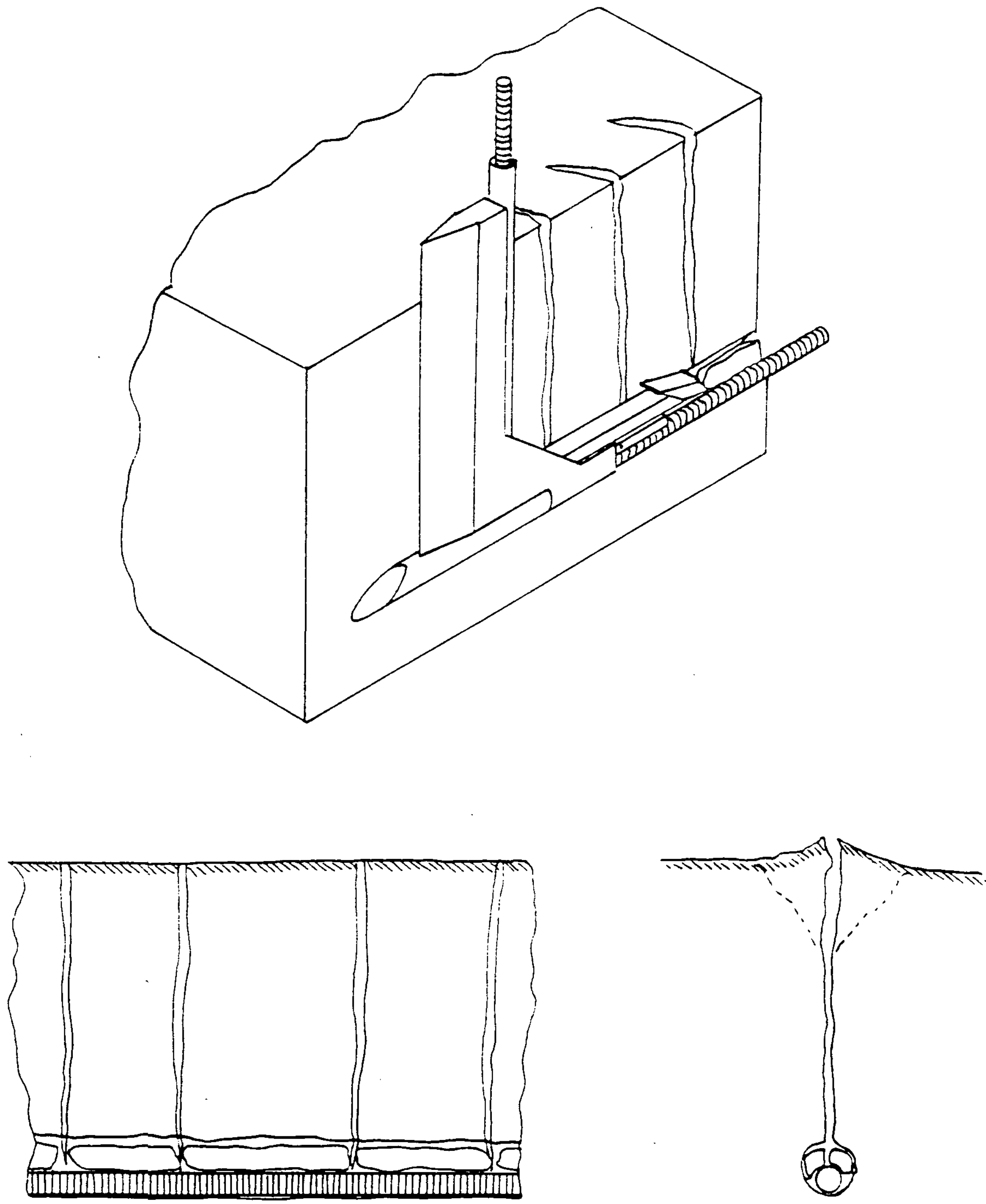


Fig. 25. Pipe installation



Side view of pipe installation

End view of pipe installation

Fig. 26. Soil failure produced by mole liner installation device

2.3.4 Avoiding pipe undulations

Significant pipe undulations must be avoided or air locks may restrict water flow along the pipe. Ponding at low points also causes prolonged soil saturation, increasing the likelihood of soil slurrying and mole leg crack closure. Two causes of pipe undulation are possible, firstly lack of control over mole channel grade and secondly pipe undulations within the mole channel itself. The former possibility can be avoided by using suitable grade control machinery, whose required level of complexity is dependent on ground topography. Ground with a fairly regular slope will require only a simple floating beam type mole plough grade control system, whereas flattish ground with surface undulations may require a full laser datum grading system. Details of an experiment using laser grading are given in the next section. To avoid the second possibility, the plastic pipe must be held onto the bottom of the mole channel. The mole plough installation tool (Figure 22) has a hinged flap/weight at the rear that pushes downwards on the pipe ensuring it is bedded on the bottom of the mole channel. This weight holds the pipe on grade until the following blade collapses soil on top, to ensure that the pipe is held firmly in the base of the mole channel. As already mentioned, this roof failure also aids water permeability. Excavation of a lined mole shows (Figure 25) that the plastic pipe does lie at the bottom of the mole channel even when after the pipe has been stored for several months in coiled form prior to installation.

2.3.5 Laser grade control

The gradient of the mole channel following a floating beam mole plough installation follows very closely the gradient of the hitch point where the mole plough is connected to the smoother (see Figure 27). Control over mole channel and hence pipe grade can, therefore, be achieved by controlling hitch point grade. Experiments to assess the potential improvement in pipe grade control using laser control were carried out on undulating surfaces. The laser receiver was mounted immediately above the hitch point and hitch point elevation in work was controlled through an electro-hydraulic ram.

The field tests results (Figure 28) show that for closed spaced undulations (horizontal peak to peak distance of 7 m) no significant improvement in performance was achieved with the laser over the floating beam/smoother system. The peak to trough distance of the ground profile was 18 cm, and the corresponding mole channel variation was 8 cm with or without the laser control system operating. For wider spaced undulations (horizontal peak to peak distance of 20 m) the results (Figure 29) show an improvement in grade control when the laser system was operating. Again the peak to trough distance

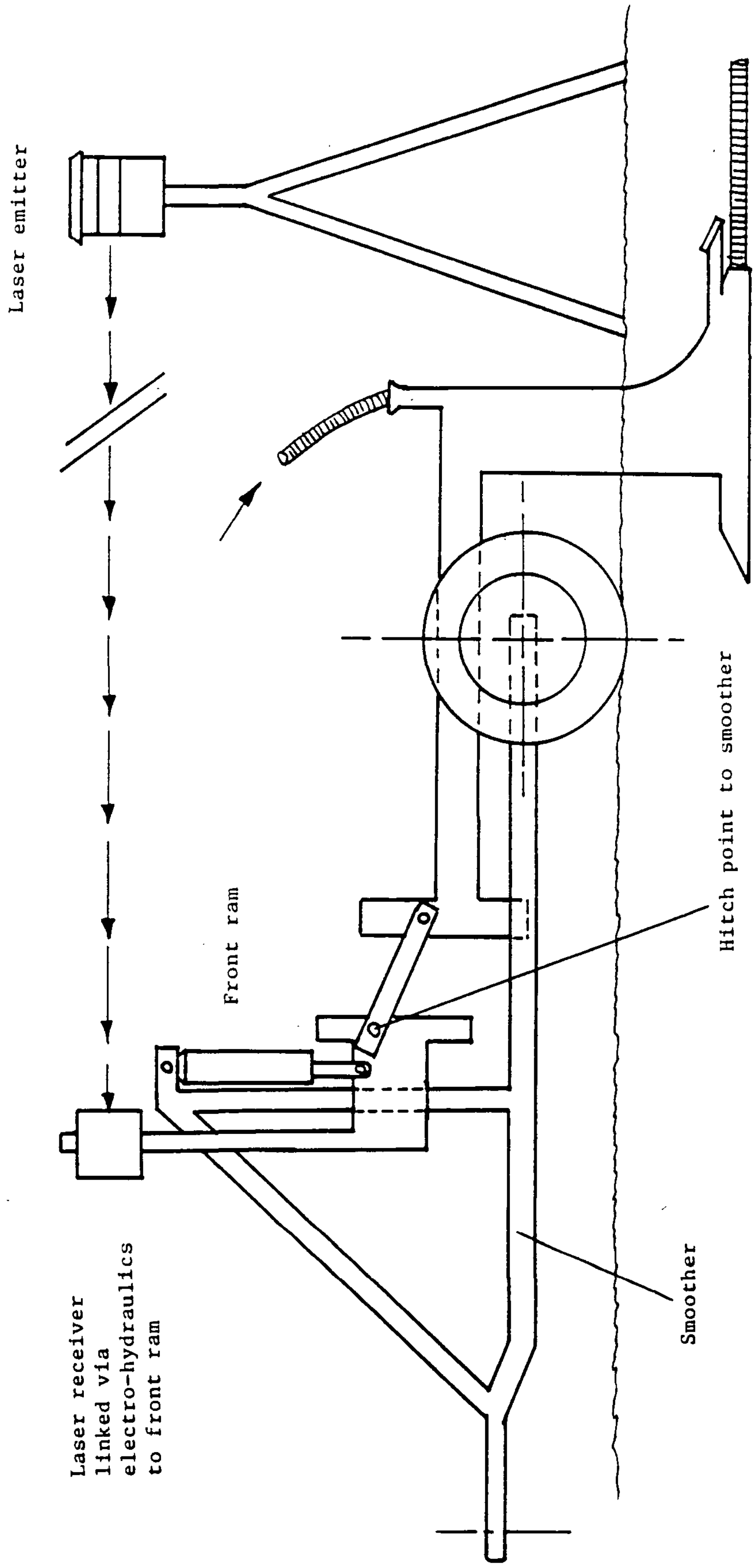


Fig. 27. Mole plough laser control system

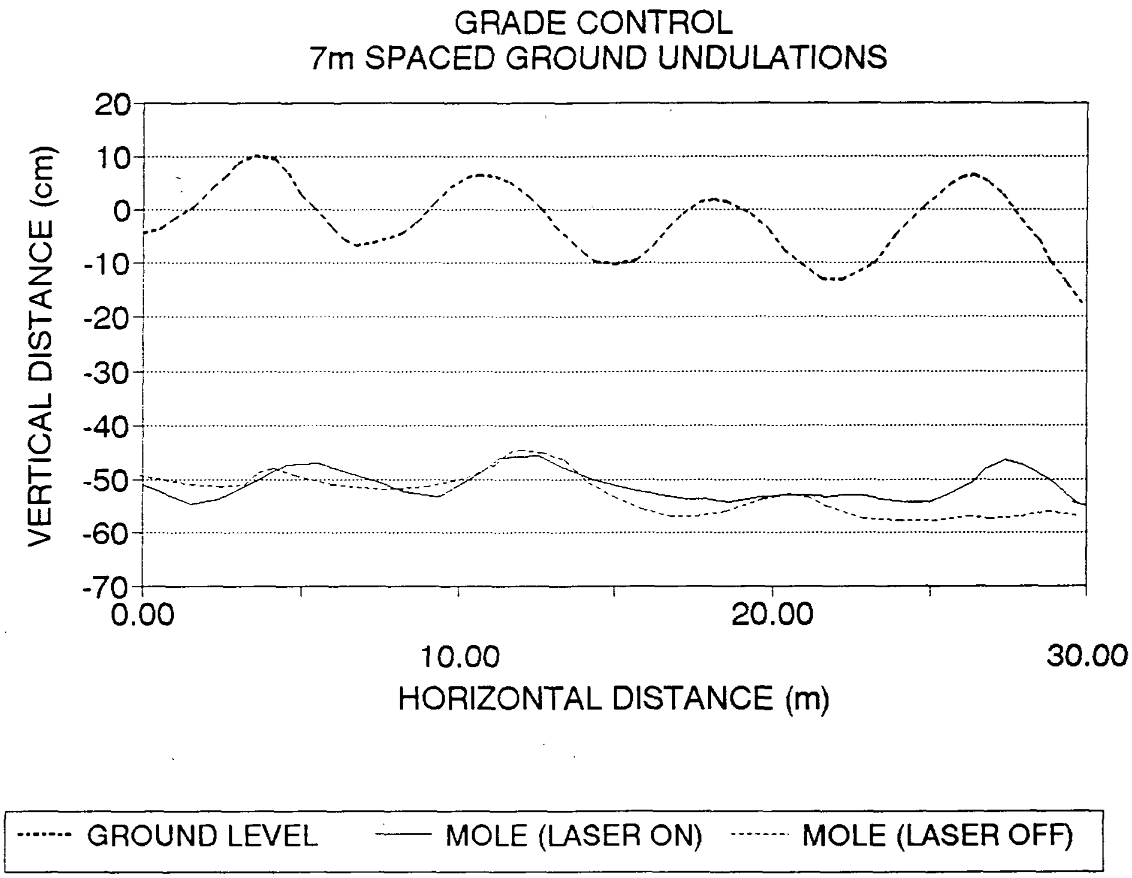


Fig. 28. Comparison of grade variations between soil surface and mole drain with and without laser control (closer spaced undulations).

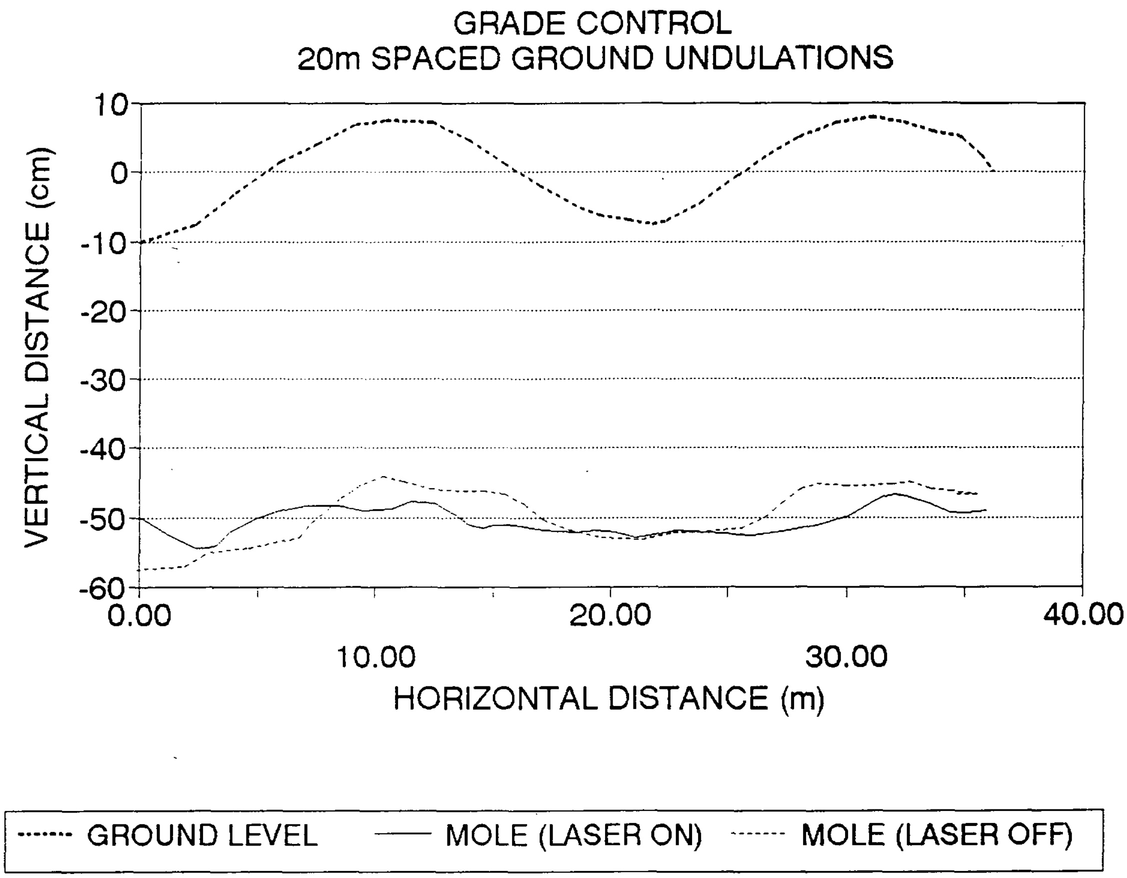


Fig. 29. Comparison of grade variations between soil surface and mole drain with and without laser control (wider spaced undulations).

of the ground profile was 18 cm, but the corresponding mole channel variations were 10 cm without laser control and 6 cm with laser control, representing a 40% improvement in grade control.

The fact that the laser control system shows no advantage when used on ground with close spaced undulations is to be expected as the geometry of the floating beam mole plough was designed and developed to minimise mole grade variations resulting from localised surface undulations. This smoothing effect, however, does not occur with longer ground undulations and therefore the laser control is able to reduce the mole channel deviation from grade in these situations.

The use of a laser control system with associated expense and complication is therefore only justified when pipes need to be laid in ground that either has a very low overall gradient or has low overall gradient and widely spaced undulations.

2.3.6 Overall Grade Performance

The overall grade performance of the installation equipment on undulating surfaces is not as good as would be expected with a floating beam mole plough. Development work is continuing with the installation equipment to improve its grading performance further.

2.4 Site Trial

The real test of any proposed new development in drainage is how well it performs over time and this has been very limited in this investigation.

A trial system was installed at Lower Farm, Kingswestern, Somerton, Somerset, on 19 September 1991. Due to the topography and soil types present three types of drainage system were installed, unlined moles running directly into a ditch, a moled main system running to a gravel covered main and lined moles (35 mm pipe) running directly to a ditch. (See Figure 30). The lined moles had an average run of 220 m and were aligned to a 2% grade. The soil was a stable mainly stoneless clay with large flat limestone plates at depths below 60 cm. Mole liner installation proved very feasible on this field scale, once the installation equipment had been strengthened to suit the conditions. Performance to date (July 1992) is very satisfactory.

The trial site will be monitored during future years.

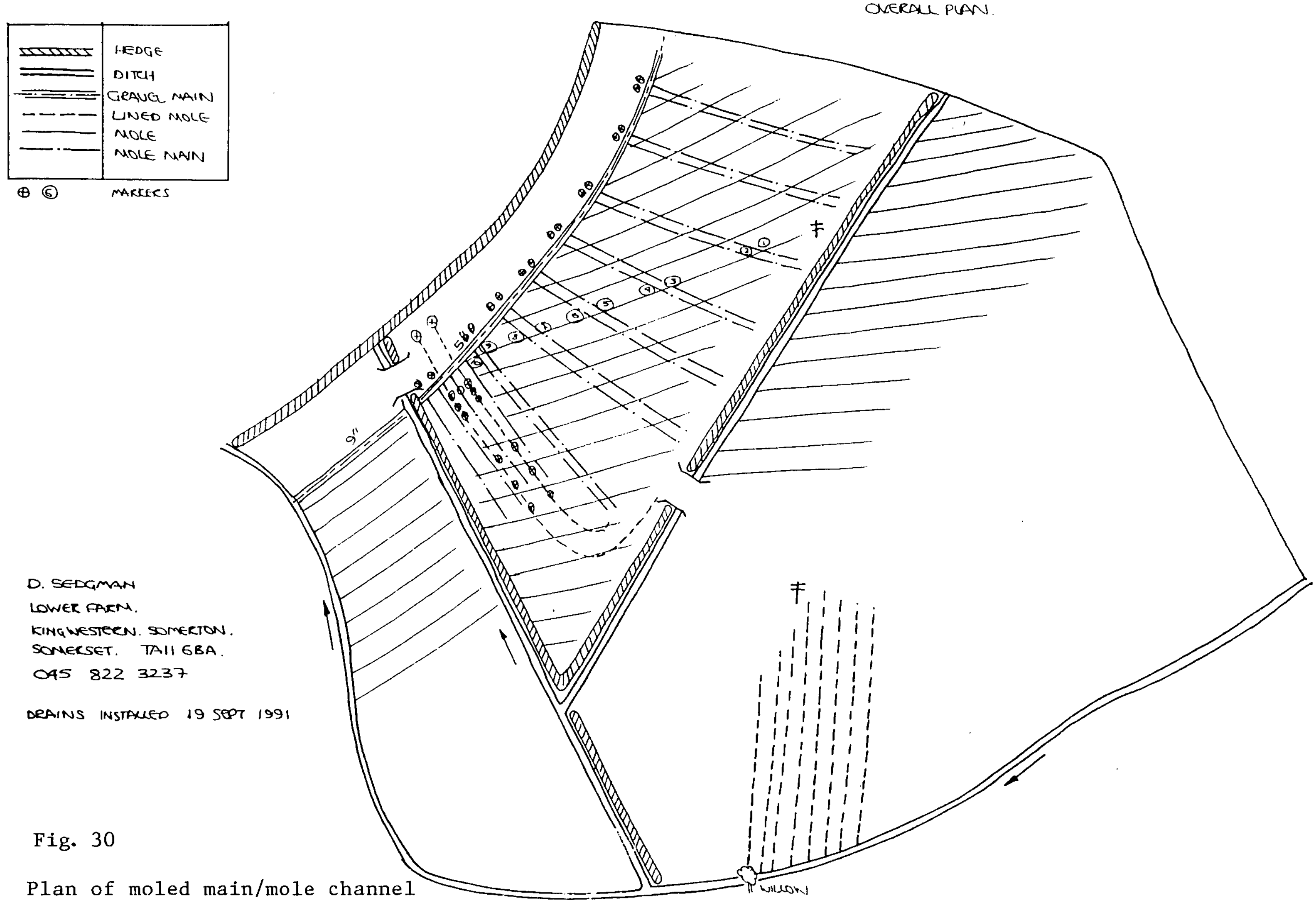


Fig. 30

Plan of moled main/mole channel liner site in Somerset

3. SUMMARY AND CONCLUSIONS

Four potential ways have been identified and investigated for reducing drainage costs on heavy soils without reducing drainage efficiency. All involve the extension and development of mole drainage and related practices. The four methods are as follows:

1. Improving the effectiveness of narrow bands of permeable backfill in discharging water from mole drains.

2. Installing moled main systems instead of permeable backfill systems on suitable moling soils.

3. Increasing mole channel stability to extend mole channel life and collector spacings.

4. Replacing standard pipe and permeable backfill systems with lower cost mole drain liners in non-moling soils.

Effective mole drainage into narrow bands of permeable backfill

Soil drawn into the permeable backfill zone by the mole plough foot and expander at installation can in certain circumstances, impede or prevent water discharge from the mole into the backfill. Equally, backfill material moved out of the trench area by the mole plough will reduce the effective life of the backfill zone for future mole drainage. The risk of these problems developing increases with narrow backfill bands and larger diameter expanders. These problems can be avoided by adopting the following installation procedures:

1. Maintain a sharp leading edge on the mole foot, keeping expander size to the acceptable minimum.

2. Use a taper rather than a barrel expander if possible.

3. Use a tine behind the expander when moling across newly installed permeable backfill over a pipe drain, particularly at high soil moisture contents.

4. Use a tine behind the expander when moling across trench widths of 100 mm or less. This is also advisable with trench widths of 125 mm if moisture contents are high and soils are soft or low density.

5. Avoid installing narrow zones of permeable backfill in wide trenches, the safest method of achieving an effective narrow backfill band is to use a narrow trench.

6. Narrow zones of permeable backfill, with their associated cost savings, can provide very satisfactory discharge connections for mole drains, provided that a tine is used behind the expander under high risk conditions.

Moled main systems

On potential moling soils, where no collector systems exist or the current system is inadequate, the use of a moled main system offers great opportunities for very low cost drainage. Obviously the risk of failure is greater than with permeable backfill systems, but even if moling has to be carried out more frequently, the cost savings are still considerable. The recommended procedure for installing moled main systems is as follows:

1. Identify the most appropriate location for the moled mains giving them ready discharge into an open ditch or pipe system. Their position must allow adequate distance for the mole plough installing the field mole system to penetrate to the required working depth before crossing the first moled main and to be lifted out after crossing the last main.

2. Install the mains first, pulling two runs at approximately 2-3 m apart. The depth of these mains should be the expander diameter plus approximately 30 - 40 mm greater than the required depth for the field moles (minor moles).

3. Pipe the moled main outfalls to the open ditch or pipe system for protection.

4. Draw the minor moles on an appropriate grade across the moled mains so that there is approximately 30 - 40 mm clearance between the two sets of drains.

5. Foot and expander sizes can be the same for both minors and mains, although sometimes a slightly larger expander may be used for the main if a large area is to be drained.

6. If spearing is required to make a direct connection between the minor moles and mains, this should be done as soon as possible after the laterals are installed. The need for spearing will be dependant upon the soil type and the moisture conditions as follows:

   a. spearing will be unnecessary on well structured soils with relatively open fissures, i.e. the soil structural units in subsoil fall apart quite readily.

   b. poorly structured soils with tight fissures, i.e. soil structural units difficult to force apart, particularly if wet, will require spearing.

   If there is some doubt as to whether or not a soil requires spearing, the recommendation is to carry out spearing.

7. Spearing should be carried out using a rod of approximately 10 mm diameter. The technique is to insert the rod almost vertically downwards from the intersection of the main and the minor leg slot following a path of least resistance. The path of the spear is not quite vertical because soil, at the intersections, is displaced by a few centimetres near the surface when the mole plough leg passes through it. Some patience is required for effective spearing when practiced for the first time. Experience, however, is quickly gained and the operation takes very little time.

Increasing mole channel stability

Accelerated mole channel deterioration tends to occur if the moles are wetted very soon after installation and the wetting continues for some time afterwards, and if soil conditions are rather dry at installation.

No positive solution has yet been found for the first problem when slurry conditions develop and the only action that can be taken is to plan on having to re-mole earlier if necessary.

Where installations are to be carried out under marginally dry conditions, i.e., the soil at moling depth is barely mouldable, greater channel stability can be achieved by paying attention to expander size. Greatest channel stability can be achieved in these marginal circumstances by fitting an expander which is only slightly larger in diameter than the mole plough foot. This smoothes out the wall of the channel without deforming the soil significantly in the roof area. A tapered expander is also much more satisfactory than a barrel expander in these circumstances.

Use of mole channel liners

Mole channel liners offer considerable potential for reducing drainage costs on very marginal and non-moling soils. Providing the installing equipment disturbs the soil in a similar way to a mole plough, a very thin walled pipe or liner inserted into the cavity is all that is required to prevent cavity collapse. With this type of soil disturbance, the soil itself is able to carry all the surface loads, allowing a very weak pipe to be used with minimal risk of collapse. It is essential that this moling rather than a loosening or subsoiling type of disturbance occurs.

In the trials to-date, it has been possible to reduce the pipe wall thickness of corrugated polypropylene pipe by approximately 50% thus roughly halving its cost. Further reductions in wall thickness should be possible in future following modifications to pipe slotting equipment. Possibilities also exist for substituting a much lower grade polymer without compromising strength, with further cost reductions.

Farmer installed field drainage installations utilising 35 mm diameter pipe offer the greatest potential for very significant cost savings. Cost could fall, at 1992 prices, to between £150 - 200/ha depending on soil, where the mole channel liners can discharge directly into an open ditch system and farm labour costs are not charged. A relatively simple low cost (£4000 approx.) modified floating beam mole plough system has been developed for pipe installation, requiring a 120 - 130 HP minimum 4-wheel drive tractor for work in most situations.

The floating beam system alone provides satisfactory pipe grading on sloping areas with minor local undulations. A laser control system can be fitted for work on fairly flat areas with local undulations. Development work is continuing to improve grading performance further.

Whilst the longer term performance of these lined moles is unknown, past experience in the 1950s (in the early days of plastic pipe) is, however, very encouraging. One trial site has been established and monitoring will continue in the future.

This lower cost drainage technique shows great promise for the control of surface or top water problems commonly found on the heavier soils, providing drain installations are executed under reasonable moisture conditions. It is currently not recommended for ground or bottom water problem situations.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to Aquapipes Ltd for providing pipes, David Sedgeman for cooperating and assisting with trial plots and Laser Alignment for loaning laser equipment. We would also like to thank the following farmers, for their invaluable help in carrying out field trials:

Mr Alcock, Sheldon Farm, Ford, Ashbourne, Staffs.

Mr Course, Silsoe College Farm, Silsoe, Beds.

Mr Egdecox, New Mixon Hay, Onecote, Staffs.

Mr MacMillan, Gowers Farm, Stisted, Essex.

Mr & Mrs Yapp, Taylors Barn Farm, Horton, Leek, Staffs.

Mr H Chandler, Great Ion Farm, Lower Gravenhurst, Beds.

Mr Boston, Vicarage Farm, Wilstead, Bedford.

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APPENDIX 1

SUMMARY OF COST DATA

Pipe costs	
35 mm mole liner	11p/m
160 mm drainage pipe	1.57/m
Installation costs	
Moling	60/ha
Mole liner	17p/m
160 mm drain (backacter)	1.87/m
Gravel fill	
160 mm drain	2.00/m