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DRAINAGE IN HEAVY SOILS

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SUMMARY

Drainage of heavy land is largly governed by the fact that the hydraulic conductivity of the subsoil is generally too low to allow percolation of excess rain water to lower depth. Vertisols and associated soils occupy about 72.9 m ha areas in India. Inspite of high potential productivity of these soil and favourable climatic conditions, the soil remain under utilized due to number of problem. Most of the problem arise due to their generally low water intake rate and due to poor internal drainage.

There are several technique available for draining heavy clay soils. The solutions depends essentially on the ratio of rate of precipitation to the rate of downward flow through the soil system consisting of poorly previous layer and the presence or absence of a high perviou subsoil. The various technique of draining heavy soil currently practised in different parts of Maharashtra, Madhya Pradesh such as various surface methods, vertical drainage, pipe drainage have been reviewed. Also the use of various models for estimating field drainage from heavy land in the tropics have been presented. The various methods currently used in different parts of the world for draining heavy land such as artificial backfill, mole drainage, subsoiling, chemical methods and surface drainage have also been reported.

1.0 INTRODUCTION

Drainage of heavy land is largely governed by the fact that the hydraulic conductivity of the subsoil is generally too low to allow percolation of excess rain water to lower depth. Under these situations, the problem of water logging and accumulation of salts generally arises. The traditional drainage system on heavy clay soil is by surface drainage. Recently it has been proved that subsurface drainage can be used in situations where an underlying layer with a high hydraulic conductivity occurs (Van Hoorn, 1973).

Vertisols and associated soils (heavy soils) occupy about 72.9 m·ha areas in India. They are distributed in order of extent in the states of Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh, Karnataka, Tamil Nadu, Rajasthan, Orrissa, Bihar and Uttar Pradesh. Inspite of high potential productivity of .these soils and favourable climatic conditions the soil remain under utilised due to a number of problems. Most of the problems arise due to their generally low water intake rate and due to poor internal drainage.

1.1 Need for Drainage

The Drainage of heavy land is required in regions facing the following problems:

a) High Water Table: Due to introduction of Canal irrigation and lack of natural outlets, some lands are under high water table. Examples in black soil regions are;Barna command areas(madhya Pradesh),Tungbhadra (Karnataka) and Chambel command areas (M.P), Nira Canal areas(Maharashtra) and Ukai Kakrapur Project (Gujrat).

(b) Low Infiltrability and Poor Internal Drainage: Heavy soils are characterised with low infiltration and poor internal drainage. The soils are often inundated by rain water for a long period during Kharif season particularly in relatively flat terrains. This reduces the yield of many upland Kharif crops because of oxygen stress in the active root zone particularly during rainy days.

(c) Perched Water Table: Relatively low hydraulic conductivity of deeper soil layers in the profile furnishes ideal conditions for development of perched water tables following rains. This leads to excessive soil moisture content in the root zone unless appropriate provision is made for drainage.

(d) Salt affected Areas: The presence of high water table in the regions with semi-arid climatic conditions, use of poor quality irrigation water and accumulation of salts transported through runoff from upper catchments are associated with development of salinity problems. Vertisols and associated soils adversely affected by salts occur in Western Madhya Pradesh, Gujarat, Maharashtra, Karnataka, Tamil Nadu and Andhra Pradesh (Bhumbla, 1977).

1.2 Methods of Draining heavy Clay Soils

There are several techniques available for drainage heavy clay soils. The solutions depends essentially on the ratio of rate of precipitation to the rate of downward flow through the soil system consisting of poorly pervious layer and the presence or absence of a high pervious sub-soil. The techniques of draining heavy clay soils can be summarized as follows:

- closed gravity drains (Tile drainage).
- mole drainage
- surface drainage
- well drainage

a) Closed gravity drains (Tile drainage): Closed gravity drains are pipe system that are installed underground to collect and carry away excess ground water. They consist of pipes, porous material laid horizontally at a depth of 1 to 3 meter. Tile drainage is the most common and effective in heavy soils. Tile drainage can be particularly effective if a highly pervious layer occurs within a depth that can be reached by drainage machinery and if the rate of precipitation does not exceed the rate of downward flow through the overlying poorly pervious clay layer. Presence of such pervious layer below soil surface, say one meter below, and adopting tile drainage can lower the groundwater table, create more storage in the soil profile and in long run will improve the hydraulic conductivity of the soil thus leading to the better conditions for crop growth.

When the rate of precipitation exceeds the rate of downward flow or when there is no highly pervious layer within the reach of drainage machinary, tile drainage can still be used although tile will mainly function as covered furrows. Since most of the water will flow into the tiles through the trench that has been dug to install them, the hydraulic conductivity of the material with which the trench has been refilled will largely be responsible for performance of tile drainage system. In situations where tiles function as covered furrows and the main discharge takes place through the top layer, it is difficult to prevent the water table from rising to near the ground surface. Under such circumstances, local experience can be adopted for selecting the spacing of the tiles.

b) Mole drainage: Mole drainage is another technique that might be applied when no highly pervious layer is present within a depth that can be reached by machinary. Mole drainage are unlined underground channels, formed by a mole plough as shown in Fig. 1(a), without digging the trench. Mole drainage is particularly appropriate in dense, poorly pervious clay soils which have a certain general slope. The primary aim by this method is not to control the ground water table, but to remove excess water from the field surface from topsoil. The water reaches the mole channel mainly through the fissures and cracks that are formed when the moles are being drawn Fig.1(b). The main risk in mole drainage is the collapse of the drains due to lack of stability of the soil.

c) Surface drainage: If irrigation is practised on heavy clay soils, furrow and ditches can be used to remove excess surface water although only tile drainage will allow leaching and be able to maintain a favourable salt balance in the soil. The method have some disadvantages; as farming becomes more mechanised, it creates problem in doing various agricultural operations in the field. In spite of all this

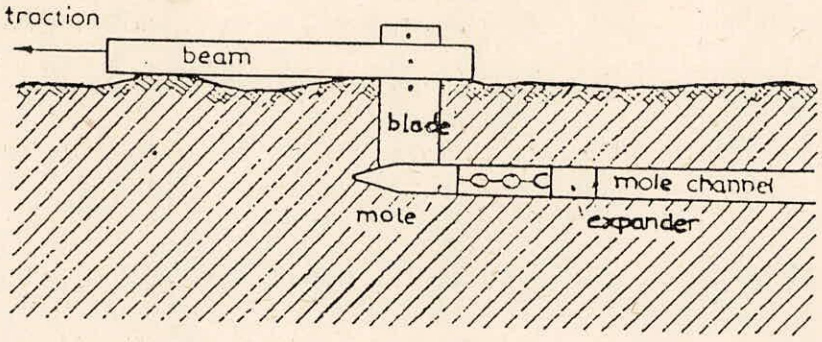

Fig. 1(a) : Mole Plough

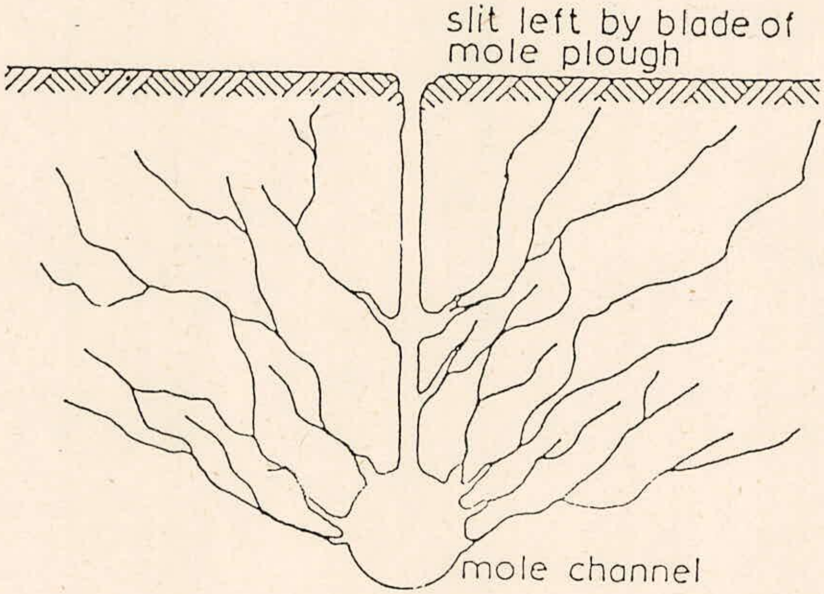

Fig.1(b) : Cracking and Fissuring of heavy Soil
as a result of mole drainage.

furrow drainage is a low cost method and still has its uses.

d) Well drainage: Drainage wells are groundwater wells designed to control an existing high water table. Drainage occurs only within the influence of the cone of depression. Most drainage well installation consist of a group of wells so spaced that their individual cones of depression overlap sufficiently to lower the water table level at all points in the well field.

2.0 HEAVY SOILS IN INDIA AND THEIR CHARACTERISTICS

Heavy soils and associated soils(Block Soils) occur in peninsular India, particularly in the Deccan Plateau of India, covering an area of about 72.9 million hectares. This area roughly consititute 22.2 percent of the total geographical area of the country. These soils are distributed in the states of Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh, Karnataka, Tamil Nadu, Rajasthan, Orrissa and Bihar. The extent of black soil region in each state is given in Table 1.

TABLE : 1 DISTRIBUTION OF BLACK SOILS IN INDIA

State	Area (m ha)	Percent of total black soil area of country	Percent of total geographical area of country
Maharashtra	29.9	35.5	7.9
Madhya Pradesh	16.7	23.0	5.1
Gujarat	8.2	11.9	2.6
Andhra Pradesh	7.2	10.0	2.2
Karnataka	6.9	9.4	2.1
Tamil Nadu	3.2	4.2	1.0
Rajasthan	2.3	3.0	0.7
Orrissa	1.3	2.0	0.4
Bihar	0.7	1.0	0.2
Uttar Pradesh	0.0	-	-

(Murthy et al 1982)

2.1 Soil Physical Characteristics

2.1.1 Depth of soil

The vertisols in the states of Maharashtra, Madhya Pradesh, Andhra Pradesh, Gujarat, Karnataka have been characterized as very deep (more than 90 cm in depth). In some of the command areas like Jayakwadi and Purna(Maharashtra State) have vertisols more than 2.5 m depth.

2.1.2 Soil texture:

The clay content of vertisols of deccan plateau varies from 52 to 73 percent. The soil textural classes observed are clayed, silty clay and clay loam. The clay content has been observed to be gradually increased with respect is depth in typical vertisols profiles.

2.1.3 Soil structure

Deep black soils are generally characterisezed by sub-angular blocky to angular blocky structure. These soils exhibit swelling and shrinkage properties with variation in soil moisture.

2.1.4 Available water capacity

Vertisols have a relatively high water storage capacity in the root zone because of high clay content and deep soil profile. It is observed that deep black soil have available water capacity ranging from 20 to 25 cm/90 cm depth. The value of soil moisture content at field capacity and permanent soil wilting point varies from 35 to 40 percent (gravimatric) and 18 to 20 percent (gravimatric) respectively. Vertisols from Maharashtra have slightly higher values of available, water capacity than vertisols from other states.

2.1.5 Bulk density

The bulk density of vertisols varies from 1.18 to 2.05 gm/cm^3 and generally tends to increase with increase in profile depth due to compression caused by overburden weight. A typical example for a vertisol profile from Madhya Pradesh is given in Table 2.

TABLE 2 : VARIATION OF BULK DENSITY WITH DEPTH FOR A VERTISOL PROFILE FROM JABALPUR, MADHYA PRADESH

Depth	Bulk density* (gm/cm^3)	Texture	Remarks
0-10	1.30	Clay	
10-20	1.45	Clay	
20-30	1.56	Clay	
30-40	1.59	Clay	
40-50	1.62	Clay	
50-60	1.62	Clay	Clay varies from 53 to 61 percent.
60-70	1.65	Clay	
70-80	1.69	Clay	
80-110	1.67	Clay	
110-150	1.70	Clay	

* Average of 12 sample and determined by core sampling.

2.1.6 Infiltration

The heavy soils are having very high infiltration rate due to the presence of wide and deep cracks in dry soil. Once the cracks have been sealed and the profile is wet throughly, the infiltration rate becomes low. The average values of infiltration rate for vertisol from Maharashtra, Madhya Pradesh, Andhra Pradesh varies from 12-43 mm/hr, 4-13 mm/hr and 0.2 mm/hr respectively. The difference is due to calcareous nature of vertisols.

2.1.7 Hydraulic conductivity

The hydraulic conductivity value of some vertisols are given in Table 3.

TABLE 3 : HYDRAULIC CONDUCTIVITY OF SOME VERTISOLS

Location	Rate mm/hr
Indore (M.P)	12.60
Jabalpur (M.P)	4.70
Hyderabad (A.P)	0.21
Rahuri (M.S)	6.4
Satna (M.P)	4.0
Parbhani (M.S)	7.0
Sundra Series (M.P)	5.0

2.2 Soil Chemical Characteristics

2.2.1 Soil pH

The normal profiles of vertisols of the Deccan plateau have soil pH ranging from 7.2 to 9.3. The pH values generally increases with increase in profile depth.

2.2.2 Soil salinity

Seven million hectares of land in the country is estimated to have salt affected soils in the arid and semi arid regions of the country. About 20 percent (1.42 million ha) of the salt affected lands having deep black and medium deep black soils are in the states of Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh, Karnataka, Tamil Nadu and Rajasthan. The main contributing factor of soil salinization in the black soil regions are; aridity of the climate, basic parent material, saline groundwater, improper water management and impermeable nature of black soils.

2.2.3 Soil sodicity

It is measured by exchangeable sodium percent (ESP) values of the profile layers. In the normal vertisols profiles, the ESP values upto 1 m soil depth are observed as 1-2 for Maharashtra, 7-9 for Madhya Pradesh, 4-17 for Karnataka and 2-13 for Andhra Pradesh.

2.2.4 Calcium carbonate content

The Calcium Carbonate content in vertisols varies from 1 to 16 percent. The distribution may be uniform throughout the profile or may increase in the lower horizons.

2.2.5 Electrical Conductivity

The non saline soils has electrical conductivity value less than 4 mmhos/cm. The saline vertisols profile have electrical conductivity value as 6-24 mmhos/cm in Karnataka and 4-16 mmhos/cm in Maharashtra.

2.3 Drainage Solution for Heavy Clay Soils

The drainage problem particularly in irrigated heavy soils is caused by over irrigation or by surface runoff resulting from excess rainfall. The solution depends essentially upon the ratio of the rate of precipitation to the rate of downward flow through the poorly pervious layer and the presence or absence of a highly pervious subsoil. The heavy clay soils are often unsuitable for high value cropping. The investment that can be made in draining and improving such soils will, therefore, be less than the other productive soils.

The techniques which are currently used in various drainage projects in India under heavy soils are reviewed and presented.

2.3.1 Surface drainage systems

a) Raised bed-sunken bed system : This system consists of an array of raised and sunken beds running parallel to each other. The runoff from raised beds planted to an upland crop drains into and collected in sunken beds supporting the crop. The elevation between sunken and raised bed is kept 20-30 cm. In high rainfall areas (1500 mm), 3 m wide beds with 20 cm elevation difference or 6 m wide beds with 30-35 cm elevation difference have been found to yield good results (Gupta et al, 1978). However, the specifications can be modified according to the soil depth and rainfall pattern of the region. About 33 percent high grain yield can be recorded on raised beds then on conventionally prepared flat beds, as shown in figure 2. The field should be ploughed along with general slope and should be shaped into 20 cm high and 20 cm long upland strips of about 6 m width. The beds should be constructed along the general slope. This is done by shifting 10-15 cm surface soil from 6 m wide strips referred to as sunken bed to make raised beds on either side. Each sunken bed serves as a mini water reservoir with two sides formed by raised beds running parallel to each other. Sunken beds are interconnected through 10 cm wide tiles placed such that the level of water in sunken beds is always at least 10 cm below the surface of raised beds and the excess water can drain into a cross drain provided at the tail end of the field. The land configuration once created is more or less permanent and can be cultivated with bullock drawn implements. The preparation of this type

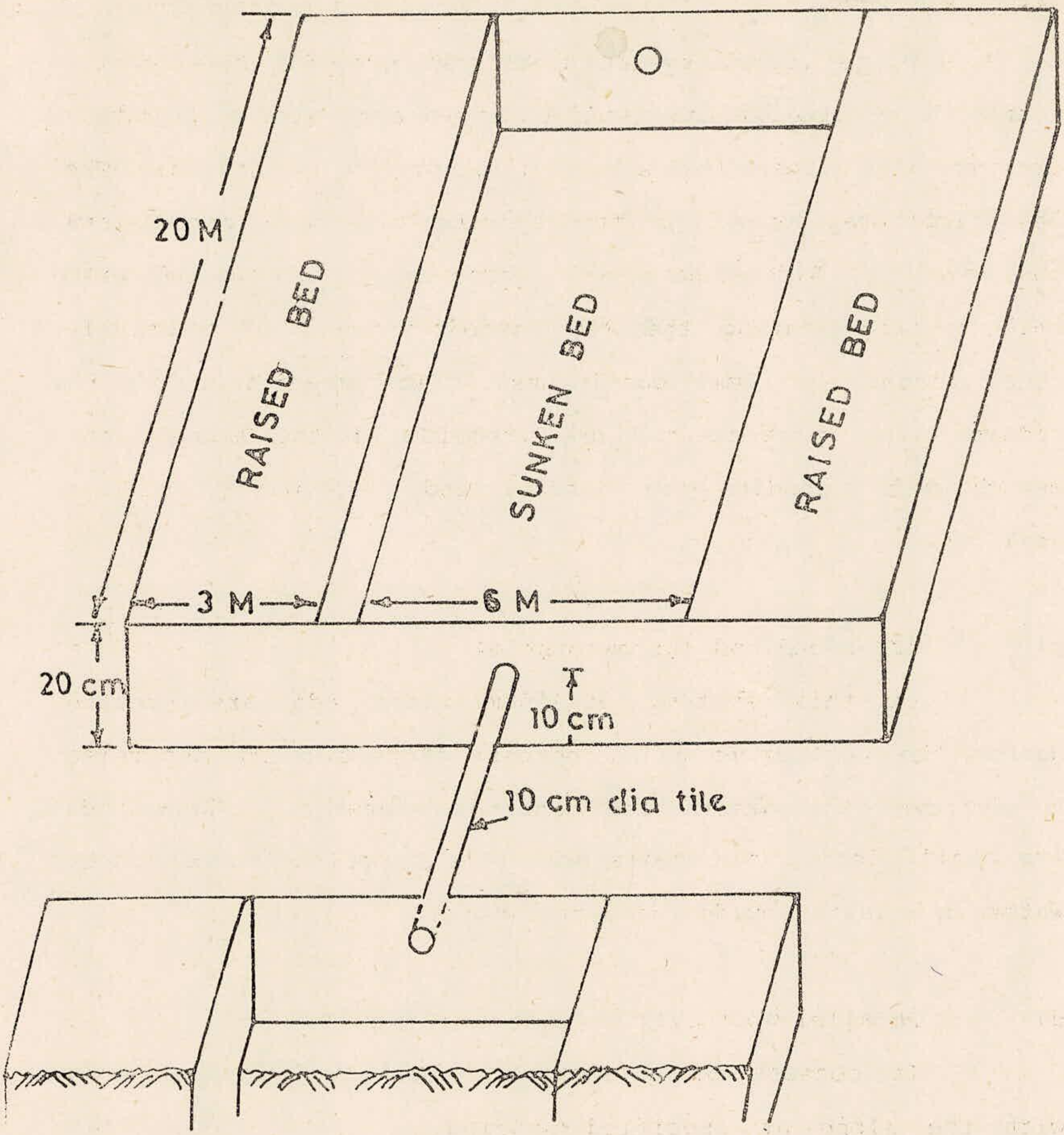

Fig. 2: Raised bed - Sunken bed drainage system

of drainage system involves earth work, costing Rs.6000/ha approximately.

b) Ridge furrow system : Furrows provide an effective means of surface drainage and convey excess water into cutoff drains, dug across the slope at about 20 m interval. The specifications depend on the spacing of the cropped rows and rainfall. Ridges have been observed to provide adequate soil aeration during the wet period even under relatively high rainfall (1500mm) conditions. The orientation of the ridges with reference to the direction of the slopes can be changed depending on rainfall and erodibility of the soil.

c) Broad bed and furrow system:

In this system, 90-150cm wide beds are created across the contour to a 0.6 percent slope and are separated by furrows that drain into grassed waterways. These beds are stable for 2 to 4 years and permits collection of runoff water in a tank provided down the slope.

d) Parallel open ditch system:

It consist of a series of parallel ditches along with the slope at specified spacing. These ditches take care of excess runoff water and carry it to a collector drain and finally to the outlet. This system is adopted to poorly drained, relatively flat soil in which there are numerous shallow depressions. The size of the ditch varies with drainage area.

2.3.5 Vertical drainage

Vertical drainage or well drainage is comparatively a recent development as compared to the traditional methods of gravity drainage. The number of projects where well drainage is being used is very limited. Earliest examples are found in California where some projects based on vertical drainage were taken up as early as 1918 (Peterson, 1957). In the Ararat plain in USSR some 2000 hectares were drained by using 25 wells (Ananian et al, 1969). In the Indus plain in Pakistan, an intensive network of shallow multiple well systems called by skimming wells have been installed for water table and salinity control. The design and operation criteria for such system have been evolved by Sahani (1972,73) Chandia and Larock (1984). In a drainage research project in Mundlana village of district Sonepat of Haryana, a vertical drainage system consisting of 5 cavity tubewells of 10 cm diameter installed at 150 meter in spacing in the form of Pantagon with depth varying from 10 to 20 m (Mishra et al, 1986).

The success of vertical drainage system largely depends on the availability of sufficient gradient and clear outfall in the junction of carrier drains and the main drains. If such condition is not existing, the only effective way to lower water table is to pump the water out.

An extensive review of various drainage schemes in the Maharashtra State has been given in a recent report of Abhange (1986). Some of the worst affected projects are given in Table 4.

TABLE 4 : EXTENT OF DRAINAGE PROBLEMS IN SELECTED IRRIGATION PROJECTS IN MAHARASHTRA STATE

Sl.No.	Name of Canal	Irrigated command Area (ha)	Percentage damaged area (1984-85)
1.	Nira left Bank Canal	60632	6.52
2.	Nira Right Bank Canal	77308	7.44
3.	Krishna Canal	10706	32.35
4.	New Mutha Right Bank Canal	61556	6.37
5.	Ghode Left Bank Canal	24602	11.36
6.	Gode Right Bank Canal	11019	9.80

The data on 34 completed drainage scheme in deep Black Cotton Soils (Abhange, 1986) shows that most of the drains are of open ditch type. The cost of open drains worked out to be Rs. 242,000 per km. In some drainage schemes closed drains are also have been installed and the cost estimated to be Rs. 201,000 per km.

In areas with deep Black Cotton Soils underline by murum artesian pressures may often to be present. In such soils pumping groundwater from the Murum and other permeable sub-strata may lower the peizometric surface below the water table creating a vertical downward flow from the upper layers. In areas where the water table is quite shallow, lowering of the water table to deeper layers with the help of vertical drainage will help in getting additional induced recharge to groundwater in rainy season.

One of the major limitations of vertical drainage is the additional cost of energy required for operating a multiple well system. Vertical drainage system is also more expensive to construct as compared to pipe drainage system. However, the cost of well drainage can be reduced by constructing radial horizontal bores in deeper and more permeable layers through the vertical wells.

Well drainage offers the following advantages:

i) It can be applied on undulating land, limiting earthmoving and levelling to the installation of pipelines or main drain channels to interconnect the wells.

ii) It diminishes maintenance costs because of the smaller network of canals/drains that are necessary.

iii) The groundwater table can be drawn down to a much greater depth, reducing the risk of salinization of the soils in arid and semi-arid regions.

iv) It diminishes artesian pressure of aquifers underlying the top layers so that downward percolation of irrigation water becomes possible.

v) If the water in the pumped aquifer is of good quality it can be used for irrigation. The drainage water then has an economic value and this fact may contribute considerably to the economic feasibility of the project.

2.3.3 Pipe drainage system

In this system a series of parallel drains are laid out in the direction of the slope of the land and that feed into a collector drain which is slightly inclined to the direction of the contour. The key parameter to be selected are the depth and the lateral spacing of the drain. The maximum depth of the drains may be limited by the trenching and pipe laying equipment available. Once the depth of the drains has been selected, it is necessary to select the depth of the peak of the curved water table surface midway between the drains. This is usually made equal to the depth of the root zone of the deepest plants in the crop rotation.

A buried rubble drain was constructed near Telgaon in Purna command area of Maharashtra. It was laid at a depth of about 2 m below ground, the following procedure were adopted for constructing the burid pipe drains:

i) a contour map of the affected area with a contour interval of 1 m was prepared.

ii) a number of piezometers were installed at selected location to ascertain the ground water profile.

iii) the alignment of the drain is decided with the depth of murum level and also the outfall level of the drain which would be 0.5 metre above the nalla bed.

iv) after alignment has been decided, a trench was excavated upto 2 m depth; where murum was encountered. The main drain is PVC perforated pipe with 5 percent perforated area and covered by 10 cm metal. The pipe trench had a gradient of 1 in 500. The trench then backfilled with the excavated stuff.

v) manholes are provided at suitable locations.

vi) the outfall of the buried pipe drain was taken into the nearby Katneshwar distributory.

The above drainage work was completed in May 1986. In the low lying areas of purna command, an experimental scheme was taken for design of buried pipe system. A contour map of the water logged area is prepared with a contour interval of 0.3 meter. Groundwater profile was prepared with the help piezometers. The soil samples were collected, with the help of Auger holes at 100 m interval to study the soil profile. The alignment of the drain was decided depending on the groundwater profile. A 2 m trench was excavated and the construction of the drain was similar to the Katneshwar drain.

The main advantage of buried pipe drainage system is that it does not involve loss of curtivable land. In the case of an open drain particularly in deep soils a large chunk of area is lost for cultivation and therefore the land owners are reluctant to make the land available for the drainage scheme. Also the maintenance cost of pipe drainage system is much less as compared to the conventional open trench drain.

The cost of drainage scheme can also be described in the form of cost per ha of land protected or cost per ha of land reclaimed. Table 5 gives the comparison of the cost of buried pipe drain with the cost of a conventional open type drain and the cost of a closed rubble drain in the state of Maharashtra.

TABLE 5 : COST OF VARIOUS DRAINAGE SYSTEM IN TERM OF COST PER HECTARE OF LAND RECLAIMED

Sl.No.	Type of drain	Cost per ha. of land reclaimed (Rs.)
1.	Conventional open trench drain	2400
2.	Buried rubble drain	3100
3.	Buried pipe drain	1100

2.4 Performance of Drainage Systems in Waterlogged Saline Soils

One of the major functions of a drainage system is to establish and control the water table at a desirable depth. The effect of drainage on water table was studied during monsoon month (Gupta, 1985) when pumping was resorted to once the water table came within 1 m of the soil surface. The observations at the research farm of Central Soil Salinity Research Institute, Karnal at sampla indicated that with constant pumping, the water level in the drained area can be brought down. Once the pumping is stopped the water table in the drained plots starts rising due to seepage of water from the undrained area. In the initial year of operation, a difference of 30-50 cm continued to exist between drained and undrained plots. However, this lowering of water table atleast when the water table was above 1 m made significant differences in the leaching of salts and hence salinity status of the soil profile. Subsequent, higner yields of the crop can be attributed to these difference in soil salinity.

To lower the water table through natural drainage from surface to 1 m below the soil surface; it may take nearly 50-55 days but the period could be reduced to around 15 days even with limited pumping when drainage rate can be as high as 6 cm/day. In case of a large scale reclamation and cropping, it is likely that natural drainage may get further reduced and in that event drainage of saline soils in these regions may become still more important.

2.4.1 Changes in ground water quality

The ground water salinity varies from season to season. In fact the ground water salinity is related with depth of ground water below the soil surface. Considering the quantitative differnces in ground water quality due to drainage at Sampla, a long term reduction in ground water salinity was noticed in the drained area whereas in the undrained it was comparatively much less and was none in the unreclaimed area. The experiment indicated that though drainage water salinity in the newly installed drainage system is less than the salinity of drainage water in the initial year of drainage but is much higher compared to firth year of reclamation. The trend of decreasing salinity with each year of reclamation was observed except in year 1982 when rainfall was less. Thus the ground water salinity in the drained area may improve with time which is beneficial and desirable.

2.4.2 Effect on soil salinity

The installation of drainage system brings out significant changes in the salinity status of the soil profile. Compared to the undrained fields placed under similar management, at sampla, it was observed that the salinity in the drained plots was always lower than the salinity achieved in the undrained areas. The salts are also leached to greater depth.

2.4.3 Effect on crop yields

The factors affecting crop yields are depth of water table, its quality, and soil salinity.The observations of three crops i.e. Wheat, Bajra and Barley at Sampla farm is as follows:

a) crop yields vary widely and in general improvements occur with number of years after reclamation, which shows successive improvement in soil salinity status.

b) artificial leaching may be desirable to maintain the salinity and yield levels during below normal monsoon rainfall years.

c) to obtain continuous and sustained yields of crops, provision of subsurface drainage may be essential unless sufficient leaching water is available. Even if the leaching water is available, its use may be restricted because its use on wide scale may aggravate the water logging problem of the region.

d) drainage play an important role in reducing the leaching requirement of these soils and is beneficial because to provide leaching each time a crop is sown is difficult in view of the limited fresh water resources of the region.

2.4.4 Cost of drainage

The cost depends on the type of drainage system. It is less in case of open drainage system as compared to tile drainage system. The cost of tile system at Sampla farm is found double that of an open system and it is worked out to be Rs. 20 per meter length of the tile drain. The collector drain costs abot Rs. 22 per meter length.

Effect of drain type and spacing on cost of sub-surface drainage system at sampla suggest that if finance is not constraints one may go for tile drainage system (Table 6) It will also save an annual maintenance cost which may be a considerable sum in case of open drains. It may, however, be a useful proposition to go in for open drains initially at a lesser spacing and then converting the area into a tile drained land, by tiling and refilling the alternate row.

TABLE 6 : EFFECT OF DRAIN TYPE AND SPACING ON COST OF SUB-SURFACE DRAINAGE SYSTEM AT SAMPLA

Type of drain	*Cost/ha with spacing		Area lost as % of the area drained with spacing	
	20 m	50 m	20 m	50 m
Open drain with covered collector	Rs. 7400	Rs. 4400	14.6%	6.2%
Tile drains with covered collector	Rs. 12600	Rs. 6600	-	-

* at 1979 prices.

2.5 Estimation of Field Drainage from Heavy Land in the Tropics

Smedema (1984) evaluated field drainage discharge from heavy land in the tropical lands. Drainage discharges were measured in a sugarcane field in Tanzania. Most of the tropical land being classified as heavy land, having a profile consist of shallow, well structured and well permeable subsoil.

The sugarcane field of size 500 x 500 m was considered for drainage system design. The cane crop was planted on 20-25 cm high ridges, spaced 75 cm, leaving a distinct furrow in between. The ridges are periodically 'uphilled'. The furrows run in the direction of the slope. At every 30 m, the drainage flow was intercepted by a cross-drain. These cross drain run parallel with the contours and may discharge either way to the field drains which extended over the length of the field. The field drains discharged into the border ditch which runs along the lower side of the field.

The soil generally consisted of a loam to clay loam in upper layer of 30-40 cm depth, having a hydraulic conductivity of 0.40 m/day, and overlies a poorly permeable clay loam subsoil having hydraulic conductivity less than 0.10 m per day. Two discharge measurement stations were established in the border ditch into which all field drains discharged. Flow measurements of the stations were made at several instances by the calibrated float method, covering the entire range of observed discharges.

Three different rainfall - discharge models were used for the analysis of the observed discharge.

2.5.1 Linear reaction model

According to this model the drainage discharge at any time t, q_t, was lineary dependent on the dynamic storage

$$q_t = \alpha \ St$$

where, α= reaction factor (in hr^{-1} when q in mm hr^{-1} and S in mm). From this equation it may be derived that:

$$\frac{dq}{dt} = \alpha \left(\frac{ds}{dt} \right) = \alpha(R-q)$$

where R = excess rainfall (mm hr^{-1})

Integrating .

$$\int_{qt-1}^{qt} dq/(R-q) = \alpha \int_{t-1}^{t} dt$$

for time interval Δt from (t-1) → t gives :

$$q_t = q_{t-1} \exp(-\alpha\Delta t) + R\Delta t \ (1 - \exp(-\alpha\Delta t))$$

This value of α may be determined from the recession part of the discharge curve (when rain has stoped, R=0), since for this situation it holds that

$$= (\ln q_{t-1} - \ln q_t)/\Delta t = 2.3 (\log q_{t-1} - \log q_t)/\Delta t$$

Using this method the value of Δ was calculated.

2.5.2 Travelling time model

According to this model, the drainage discharge rate q_t = CR when the storm duration t exceeded tc, the time of concentration of the basin. For t < t_c only a part of the basin contributed to the discharge expressed by:

$$q_t = CR(A_t/A)$$

Where

A_t = contributing basin area at time $t(t\ t_c)$

A = entire basin area

C = discharge coefficient; and

R = excess rainfall.

For a variable rainfall made up by a series of short uniform rainfall intensity periods, it holds that:

$$q_t = CR_1(A_t/A) + C(R_2-R_1)(A_{t-t_1}/A) + C(R_3-R_2)(A_{t-t_2})+\ldots + C(R_n-R_{n-1})(A_{t-t_{n-1}}/A)$$

Where R_1, R_2, R_3......... and R_n are rainfall intensities during the periods from 0 to t_1, from t_1 to t_2, from t_2 to t_3 and from t_{n-1} to t, respectively and A_t, A_{t-t_1}............., $A_{t-t_{n-1}}$ are contributing areas at time t, $t-t_1$....... and $t-t_{n-1}$ respectively.

The model assumes that the coefficient C and the velocity at which the drainage water discharge from the field remain constant, depending on the physiographic characteristics of the basin.

2.5.3 SCS - UH model

This empirically established unit hydrograph (UH) model transforms the excess rainfall into drainage discharge; the excess rain is derived from the recorded rainfall by means of the curve number (CN) graph. The method requires the time to peak to be known (t_p i.e time elapsing between the beginning of the discharge and the moment at which it reached its peak value). The t_p value depends on the generating rainfall. Recorded rainfalls and storms were converted into drainage discharge hydrographs by each of the discussed rainfall-discharge models.

The linear reaction model describes the observed hydrograph quite well. The value of α is determined and varies from 0.10 to 0.15. The close fittness of the linear reaction model could not prove the validity of the underlying drainage flow conception. The theory does not predict the discharge rate to be linearly dependent on the storage for the drainage processes under consideration. Interflow obeyed the linear relationship but as it was deducted as baseflow, the remainder being overland flow. The flow through the furrows could be of laminar type at very low discharges. For such type of flow

$$q = (\beta g I/3v)d^2$$

where,

q = rate of discharge,

g = gravitational acceleration,

I = bed slope,

d = water depth,

v = kinematic viscosity and

β = dimension factor.

At higher discharge, when the flow becomes turbulent, the Chezy channel flow formula could be used:

$$q = \beta C A R^{1/2} I^{1/2}$$

where,

q = rate of discharge,

C = Chezy roughness coefficient,

A = wet cross-section,

R = hydraulic radius,

I = bed slope and,

β = dimension factor.

From the above equation, the relationship between q and dynamic storage S was calculated. This relation was nearly linear.

The travelling time and SCS-UH models describes the observed discharge with less precision then the linear reaction model. The deviation on the vertical scale relate to the value choosen for coefficient C(travelling time model) and for the CN number (SCS-UH Model), whereas the deviation on horizontal scales ralates to the time parameter used in the model.

Smedema concluded that Travelling time and SCS-UH Models gave inferior results in comparison with linear reaction model because they do not adequately capture the influence of dynamic storage on the discharge process.

2.6 Drainage Practices Adopted in Heavy Soils in Different Countries.

Food and Agriculture Organisation (1971) has summarized the various practices adopted in heavy soils in different countries. Table 7 gives the summary of practices used in different countries under heavy soils.

2.6.1 Surface method

Food and Agriculture Organisation observed that surface drainage methods, such as land bedding, made the use of modern techniques more difficult, several members countries pointed out that these low cost drainage techniques still had a useful place. In Isreal land bedding had been successfully used for orchards but to a lesser extent with annual crops. The details of surface drainage method used in different countries is shown in Table 8.

2.6.2 Artificial backfill

Somewhat conflicting experiences were reported on the value of artificial backfill. In the Federal Republic of Germany artificial backfill is widely used with successful results, whilst in Spain problem had arisen with Cementation of backfill. Mention was made of the various materials in use and of the possibility of plastic material, such as Polystyrene, but gravel, sand and similar naturally occurring materials appeared to be used most common use. Table 9 gives the details of artificial backfill used in different countries.

2.6.3 Mole drainage

Several countries including Australia and the U.K. reported successful use of mole drainage system. On the question of maximum gradient it was pointed out that this could not be rigidly fixed as it depends on the length of mole between mains and the expected life of the moles. It was concluded that in suitable soils and non-watertable conditions, mole drainage offered a cheap and effective system of draining heavy soils. Table 10 gives the details of mole draining used in different countries.

2.6.4 Subsoiling

Spain and several other countries reported on the very successful use of subsoiling as a means of improving conditions in the subsoil and hence the water movement. It was reported that subsoiling was a very effective technique and enabled economic drain spacing to be used, but more research work was needed into the degree of extra spacing which subsoiling would allow. Table 11 shows the details of subsoiling method used in different countries.

2.6.5 Chemical methods

The use of Bitumen as a soil conditioner and use of Polystyrene or Peat or other naturally bulky materials have been reported. The benefits of using gypsum were reported but it was suggested that this would only have marked benefit on soils with high level of sodium. Table 12 gives the details of chemical method used in different countries.

2.6.6 Drainage practices and their performance in heavy soils in different countries.

a) Ireland: In Ireland mostly mineral soils are in the heavy clay category. The extent of clay land is nearly 750,000 ha. Surface drainage methods are not used for draining heavy soil because it is observed that surface drainage hinders mechanisation. Artificial backfills are almost invariably used. Mole drainage is a common method of draining heavy clays. The depth of mole varies from 0.4 to 0.5m, bullet diameter of mole 0.75 to 100mm. Spacing between the moles being 1.4 to 1.8m, the main drains used are gravel filled. Subsoiling is done to allow surface water to reach more quickly the permeable subsoil layer, the depth being 45-51 cm. and the spacing 1.3 to 1.5m. No chemical methods are employed to drain heavy lands.

b) Netherland: In Netherland large areas of heavy clay soils are found, comprising river clays as well as Marin clay segments. Nearly 59% of the total agricultural land is clay land.

The traditional drainage system is surface drainage with parallel furrows or shallow ditches. Land bedding is only used on soils which cannot be under drained economically. A surface system of furrows is applied, with a spacing of 15-25m, depending on the hydrological properties of the top horizon and the underlying layers. A height of the beds of about 20cm is normal; the slope facilitates the movement of surface water. In present days also surface drainage is playing a predominant role. Artificial backfills are used to a very limited extent. Sea shells and gravel is type of material used. Until now, mole drains have been used only to a very limited extent. This is due to the often short life span of the mole channels and the difficulty in some years of carrying out the moling work under suitable conditions.

c) Austria: In Austria, the percentage of soils with low permeability out of the total agricultural land is 10%, so nearly 1/3rd of the total agricultural land is to be drained. Surface drainage methods were formerly used but they are being removed. Special ploughing techniques or other methods are not applied. The backfill material for drainage is Sea gravel. It is mainly used in mole drainage systems. Moreover it is used to create a permeable zone above the drain in order to drain off stagnant surface water, the depth 60-80 cm layers.

Since 1950 mole drainage is used. Mole drains are only installed when combined with pipe drains. They are placed at a depth of 0.5 to 0.6 m, the diameter being 10cm and the spacing between moles varying between 2 and 4 m. The spacing of pipe drains varies from 25 to 60 m according to the gradient of the slope. The size of pipe drains ranges from 8 to 13 cm. Subsoiling without any drainage system is rather rarely done, the depth is 60-80 cm, and the spacing being 1.0 m approximately. Chemical methods are very rarely used in Austria for reclaiming heavy soil. Only in some part liming is done.

(d) Belgium: In Belgium, out of the 1.5 million ha agricultural land, the 7-9% of land is clay land. Surface drainage methods were used in the past but presently they are not in much use. Previously adopted system of surface furrows is being replaced by drain pipes. Artificial backfills are also used to improve drainage of heavy soils. But here the type of material is topsoil peat, peat bond and flox band, gravel, broken stone or permeable band are not used as used in other countries because they proved to be too expensive. The thickness of the band is about 20 cm.

Mole drainage has negligible application in Belgium. Hence, subsoilding also is done only when an impermeable layer is situated at low depth.

e) United Kingdom: In U.K. nearly 25 percent of the agricultural land is in the clay category. Surface drainage methods were applied in the past but now the only use of these methods is the surface grippling which is used on low value grazing lands. Artificial backfill is used to provide an entry route for either surface water or water from more permeable layers. Gravel is used as backfill on about 60% of work on clay. Nearly 10% of the total drainage is Mole. The mole drainage work is done in conjunction with piped mains covered with artificial backfill to provide a connection between moles and pipe. Attempts have been made to link the effective life of mole drainage channels with the soil type.

Subsoiling is used depending on climate. The type of subsoil varies from soil to soil. Comparative observations on the effect of mole draining and sub-soiling seems to suggest that sub-soiling might be preferable provided the spacing between drains is such that the secondary work is just a permeability aid whereas once the drain spacing is such that real channels are needed to carry the water to the pipes, then the secondary operation should be moling.

No chemical methods of improving the drainage of clay land are in widespread use. Only Gypsum is used to improve the soil structure in normal clay land.

f) Spain : In Spain of the 20.7 million ha agricultural land, nearly 5 million ha is the clay land. Much of the land is in the flood plain of the Guadalquivir river and salinity is the major problem. Surface drainage methods were neither adopted in past nor in present. Land being practically flat, only bedding work is considered. The purpose is to allow most of it to percolate down through the soil profile and thus leach out the salts to the drainage pipes.

Artificial backfills were used experimentally. This included covering up of the drainage pipes. Experiments are being also conducted to find better means of drainage by mole drainage. Drainage pipes are laid at a depth of 0.7 m with bullet diameter 80 mm.

Subsoiling has been very successful, this method combined with trenches and drainage pipes has shown effective results, the depth is about 80 cm and the spacing 0.9 m. No soil amendments are used, the only work being physical ploughing.

Chemical methods are also used. Gypsum is being used in conjunction with subsoiling and also mixtures of Sand and lakeshores soils have been used with good results.

g) Hungary : The basic problem of draining heavy soils in Hungary is their exceeding low permeability and high precipitation. Keeping in view, all the soil problems and contradictions, it is seen that it can be achieved by combined procedures i.e. drainage, deep losening, and chemical, mechanical and biological soil amelioration jointly.

At places where the location of groundwater is deep, two kinds of combined drainage methods are applied. The first method being Mole draining. In this system the Mole drains acts as suction lines. The collectors are laid in a sandy gravel filtering bed. The top level of the filter correspondence to the depth of the deep loosening. The task of the filter is to pass on easily and quickly into the collector the water accumulated by the Mole drains. While in the second method instead of sandy gravel used for filtering material, 4-5 kg of Cao/m mixed with soil poured back into trunch is used as filtering material.

In Hungary the problem of land drainage is often aggrevated by the high level of underground water as well as by high salt concentration. In such cases, the traditional drainage method must be combined with deep draining but the problem of designing deep draining, as well as the question of its economic efficiency has not yet been worked out.

i) Portugal: In Portugal, there is heavy soils with an A_p horizon with good structure and high permeability but there is water logging due to the lower horizon being compact and with low permeability. Nearly 8% of the total land is clay. For drainage, land bedding method and chemical methods are being used.

j) Yugoslavia: The problem of draining heavy clay soils in Yugoslavia is more complicated because some other types of soils exist with B horizon of low permeability.

The following drainage methods are mostly applied in Yugoslavia:

a) narrow bedding with dead furrows,

b) wide bedding with dead furrows,

c) seasonal shallow parallel ditch system,

d) mole drainage,

e) cross drainage system,

f) tile drainage,

g) random system

Narrow bedding with dead furrows is the oldest surface drainage method but it is not used because of decreased yield in the immediate vicinity of the dead furrows. This method was replaced by wide bedding with dead furrows which also could not give satisfactory solution for regulating the air-water regime of the soils.

The seasonal shallow parallel ditch system has recently been applied more frequently. The advantages are good in comparison to previous methods but however this method can not be recommended in all cases because of the poor hydro-physical properties of soils, the frequent high groundwater level, and the shallow ditches in the above system, it is impossible to drain off the surface water.

The Mole drainage started to be applied after 1950; since then this method appears to be successful. The estimation of physical soil properties is one of the most important tasks when deciding on the application of the method.

Combined drainage system was chosen for the purpose of replacing costly tile drains by cheaper and more suitable drainage. This is applied on heavy hydromorphic soils. It is a combination of collector drains and mole drains.

The regulation of the air-water regime of heavy soils by means of tile drainage has been applied on Pseudogley and mineral heavy black soils.

To avoid high costs for planning the soil management of heavy clay soils with developed micro-relief, agrotechnical measures are applied. In these conditions shallow drains are laid in the lowest parts of a field according to the Random System. It has shown good results, particularly from the point of view of simultaneous soil tillage.

TABLE 7: SUMMARY OF DRAINAGE PRACTICE ADOPTED IN HEAVY SOILS IN DIFFERENT COUNTRIES

Country	Extent of agricultural land-ha	Extent of clay land ha	Clay as % of total land	Surface drainage methods	Artificial backfills	Mole drainage	Subsoiling	Chemical methods	Other remarks
1.	2.	3.	4.	5.	6.	7.	8.	9.	10
Luxemburg	134,000	4,000 - 8,000	5% approx.	No land smoothing, ploughing often arranged to provide drainage	Gravel used mainly as a filter	Not used	Very limited	Very limited	
Spain	20.7 million	5 million	25%	Land bedding being considered	Experimental use of limestone gravel, reeds	Experiments only	Used successfully	Gypsum used experimentally	
Greece	39,034000	360,000	10%	Land beding 5-20 m	Experimental only	Experiments only	Used with open ditches or to break pans.	Gypsum	
Ireland	5 million	750,000	15%	Not used	Almost invariably used	Commonly used	Used in preference to closely spaced drains	None	

1.	2.	3.	4.	5.	6.	7.	8.	9.	10
Fedral Repub-lic of Germany	13.85 million	700,000	5% approx.	Not often used	Used on 60% of work, Gravel, Slags, peat & synthetic materials	Increa-sing use but still limited	Large scale use in the last 5 years	Liming and ferti-lizing	
Hungary	about 10 million	several 100,000	13%	Commonly used in the past & Present	Gravel used	Used often com-bined with sub-soiling	Used both with drains & with mo - ling	Gypsum used to stabilise trench fill	
UK	11.4 million	3-3.8 million	25% app-rox.	Common in the past, little new work	Gravel used on about 60% of work on clay	10% of all drainage is mole; 4,700-5,700 ha p.a	10,000 ha of new work p.a. Also renewal work	Limited use of gypsum experi-ments with other chemicals	
Portugal	4.8 million	300,000-400,000	8% approx.	Land bedd-ing used	Rarely used	Not used	Very limited use	Liming and gypsum	
Yugosla-via	3.7 million	3 million	about 50%	Used in the past but limi-ted use now	Gravel	Used since 1950	Used in prefer-ence to closely spaced drains	Very limited	

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Austria	3.9 million	400,000	10%	Formerly used now tending to be replaced	Gravel used with moling	Used since 1950	Used often to revive old drains	Liming only	
Nether-lands	2,230,000	1.3 million	59%	Used on very impermeable clays	Rarely used	Very limited use	-	-	
Belgium	1.5 million	100,000-120,000	7-8%	Used in the past not used now.	Topsoil peat, peat band & flax band on drainpipes	Very limited use	Very limited use	Bitumen used perimen-tally	No gravel is used an back-fill on agricul-tural lands. Also drain-pipes are placed without filter materials

TABLE 8 : SUMMARY OF SURFACE DRAINAGE METHODS USED IN HEAVY SOILS IN DIFFERENT COUNTRIES

Country	Surface methods		Land bedding used	Special ploughing techniques used	General remarks
	Past	Present			
1.	2.		3.	4.	5.
Luxemburg	Yes	No	not used	furrows on slope to assist drainage	Pointmade that surface drainage methods hinder mechanisation
Spain	no	no	land is already level, bedding work being considered	no	Much of the land is in the flood plain of the Guadalquivir river and salinity is a major problem
Greece	Yes	Yes	land levelling used with irrigation; bedding used	furrows on slope used	spacing between ridges on bedded land is 5-20 metres
Ireland	yes	no	not used	no	point made that surface drainage hinders mechanisation
Fed. Rep. of Germany	yes	no	land levelled for vineyards but not on clay		Similar remark to above remechanisation
Hungary	Yes	no	not used	deep cultivation and periodical ditches	Hungarian drained lands are mostly on the flood plain of the Tidra river

1.	2.		3.	4.	5.
UK	yes	limited	moorland gripping only	furrows on slope to assist drainage	Major use of surface methods is now on moorland of low value. Large tractor and plough cut grips 10-40 m apart.
Portugal	yes	limited	yes	furrows on flope	Details of a laboratory study of heavy soils are available
Yugoslavia	yes	yes	used	furrows on slope to assist drainage	Land bedding upto 16 m wide is used with a cross fall of 1-2%. However, with mechanisation this is giving rise to problem A very wide range of treatments are being tested experimentally. Evidence of improved pipe performance when bedding also used.
Austria	yes	no	no	no	Old surface furrows tending to be replaced by surface drains
Netherlands	yes	yes	only on soils which cannot be under drained economically		Furrows 15-25 metres wide 20 cm high are normal
Belgium	yes	no	no	no	The system of surface furrows is replaced by drainpipes.

TABLE 9 : ARTIFICIAL BACKFILL

Country	Are they used	Type of material	Depth cm	Cost m^3	Cost/m of drain	Remarks
1.	2.	3.	4.	5.	6.	7.
Luxemburg	To a very limited extent	Gravel stones slag	20 cm layer	Fr.L. 140-200		Reply states main use to be an filters.
Spain	Experimentally	Limestone sand & gravel rice(husks) reeds				Touble with mineral materials cementing. Make point that driving trailers on the land to transport backfill is difficult. Soils problems can be avoided by use of fill. No special backfill material is actually used with the corrugated plastic drains.
Greece	Experimentally	Gravel	20 cm layer	107 dr		
Irreland	Almost	Broken stone 600 mm gravel	20 cm layer	£1	£0.125	Backfill usually hand placed but special trailers are now being developed
Federal Republic of Germany	Yes on 60% of work in North of Germany on clay	Permeable soil gravel stones slag	15-25 layer	8-12 DM 5-8 DM	3.0DM	Most material is placed by hand. The situation described as 'ditch filter' and 'complete filter' are primarily 'connector'.

1.	2.	3.	4.	5.	6.	7.
UK	Not common 5% of schemes	Gravel crushed stone	15 cm layer	£2.6-3.0	£0.6	Most UK use is as a connector and is used with mole draining or subsoiling
Portugal	Experiments with topsoil only	Topsoil	Surface to drain			Experimental use of topsoil to take water land bedding to drains
Yugoslavia	Experimentally	Gravel	20-50 cm	20 Din.	2.5 Din.	Backfill usually hand placed. Used mainly in conjunction with mole drainage.
Austria	Yes	Sea gravel	60-80 cm layer	40-100 AS	6-14 AS	Used mainly in conjunction with mole drainage
Netherlands	To a very limited extent	Seal shells gravel				Lack of natural stone in Netherlands
Belgium	Yes	Topsoil peat, peatband and flaxband	The band has a thickness of about 20 cm.		4-6 BF	No gravel, broken stone or permeable sand is used on agricultural land because it is too expensive.

TABLE 10 : MOLE DRAINING

Country	Technique used	Depth- m	Bullet diameter mm	Cost ha	Spacing m	Average life of mole-yrs.	Remarks
1.	2.	3.	4.	5.	6.	7.	8.
Luxemburg	Not used						
Spain	Experimental use	0.7	80	14,000 pesetas	around 2	This procedure has been abandoned	Mention of laying pipes, therefore, some doubt as to whether true moling is indicated. Point made that at 70 cm soil is often wet and smears.
Greece	Experimental use	0.7	115	400 dr.	2.5-5	3-5	Experimental moles outfall to ditch
Ireland	Yes	0.4-0.5	75-100	£10-12	1.4-1.8	8-10	Main drains used gravel filled
Federal Republic of Germany	Yes post 1965	0.5-0.8	80-100	300 DM	2-3 (5 max)	8-15	Normally used with gravel filled mains 30-80 m apart. Outfalls to ditch used only where there is a risk of ochre. Costly
Hungary	Yes	0.65-0.7	70	Ft. 1400	2.5-3	5-6	Used with plastic lined outlets to ditch or over gravel filled mains. Also used in conjunction with subsoiling.

1.	2.	3.	4.	5.	6.	7.	8.
UK	Yes 8-10% of total work	0.5-0.7	75-100	£9-12.5	2.5-3	7-10 rarely upto 15	Usually used with gravel filled mains 20-100m apart. Overall costs £ 50-200/ha.
Portugal	Not used						
Yugoslavia	Yes post 1950	0.6-0.7	70-100	£50	2-4	5 years 2 years shallow	Shallower moles used on grass-land. Min. gradient on all moles 0.5%, best result 1-3%. Lengths of 50-150 m between gravel filled drains.
Austria	Yes post 1950	0.5-0.6	100	4,000-8,000 AS	2-4	5-10	Spacing of pipe mains 25-60 m according to slope. Pipe diameter 8-13 cm.
Netherlands	Very limited use						Some experimental work has had a very short life.
Belgium	very limited use.						

TABLE 11 : SUBSOILING

Country	Is subsoiling used ?	Depth cm	Spacing m	Cost ha	Life years	Used to improve working of drains	Remarks
1.	2.	3.	4.	5.	6.	7.	8.
Luxemburg	Very limited use	60-80	Details 0.7-1.0	FrL7, 000-10,000	10	Yes	
Spain	Yes, Very successfully	80	0.9	1,400 pts	8	Yes	Mounted subsoilers on 125 hp tractors used.
Greece	Yes	40	0.7-1.0	400 dr	7-8	No	D6 caterpillars used. Subsoiling used on its own or with open ditches
Ireland	Yes	45-51	1.3-1.5	£8-10	15-18	Yes	Trailer type machines drawn by powerful crawler. Subsoiling plus.
Federal Republic of Germany.	Yes, in last 5 yhears	80	0.7	DM 600-1,000	15	Yes	Germans describe process an deep ploughing techniques also described. If rainfall is 600 mm no drains are thought to be needed.
Hungary	Yes	50	0.7	Ft10,000-15,000	3-4	Yes	Combined method: Subsoiling, together with mole drains, deep cultivation and liming.

1.	2.	3.	4.	5.	6.	7.	8.
UK	Yes	50-60	1.0-1.5	£12-18	Very limited	Yes	Mounted implements on powerful crawlers.
Portugal	Very limited use					No	
Yugoslavia	Yes	50	0.7	400-600 Din.	3-5	Yes	100 hp tractors used
Austria	Yes	60-80	approx. 1.0	ASI 1,500	Very varied	Yes	Subsoiling rarely used without drainage
Belgium	Very limited use						Only when an impermeable layer is situated at low depth.

TABLE 12 : CHEMICAL METHODS

Country	Are chemical methods used ?	Remarks
Luxemburg	Very limited use	No details available
Spain	Yes	Gypsum being used in conjunction with subsoiling. Sand used on gardens
Greece	Yes	Gypsum used on saline soils 5000-20,000 kg/ha used. Hyproduct of phosphate fertilizer now available.
Ireland	No	
Federal Republic of Germany	Yes	Lime and fertilizer used - typical use N 200 kg/ha, P 300kg/ha, L(K) 300 kg/ha.
Hungary	Yes	CaO used in trench fill to stabilise it. Beneficial to ochre problem.
UK	Very limited use	Use largely experimental only.
Portugal	Yes	Lime used on acid soils. Gypsum used on saline-alkali soils.
Yugoslavia	Very limited use	Lime is only material used, for experimental purposes only.
Belgium	Experimental use	Bitumen soil condition has been used experimentally. Details are available.
Austria	Very limited use	Lime is only material used.

3.0 CONCLUSIONS

The drainage problem particularly in irrigated heavy soils is caused by over irrigation or by surface runoff resulting from excess rainfall. The drainage of heavy land is required under the high water table condition, perched water table condition and due to the low infiltration and poor internal drainage characteristics of the subsoil. The solution depend essentially on the ratio of rate of precipitation to the rate of downward flow through the soil system consisting of poorly pervious layer and the presence or absence of a highly pervious subsoil. The various technique of draining heavy soil such as surface method, vertical drainage system, pipe drainage system have been reviewed in this note. The use of linear reaction model, travelling time model and SCS-UH model for estimating field drainage from heavy land in the tropics have been reported.

The various drainage practices such as surface drainage method, artificial backfill, mole drainage, subsoiling and chemical methods used in different countries under heavy soil has been presented in the tabular form.

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