

OPTIMIZATION OF PHYSICAL PARAMETERS OF SUB - SURFACE CLAY TILE DRAINS USED IN AGRICULTURE

A THESIS

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in the Faculty of Engineering - Civil
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By

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D E C L A R A T I O N

I hereby declare that the matter embodied in this thesis is the result of investigation carried out by me in the Department of Civil Engineering (Soil and Water Conservation), U.V.C.E, Bangalore University, Bangalore, under the supervision of Dr.K. Ranga, Professor of Civil Engineering and it has not been submitted for the award of any degree, diploma, associateship, fellowship etc., of any University or Institute.


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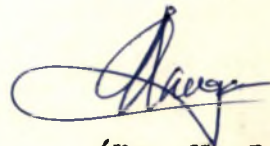
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C E R T I F I C A T E

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(REDDIHALLI RAMAIAH)

ABSTRACT

The effects of excess irrigation water are of many fold; water in excess of field capacity remain unavailable for plants. This excess water not only blocks aeration space of root zone of plants, but also influences the accumulation of salts at root zone, which in turn creates toxicity in the soil.

Wherever topography of sub-soil conditions obstruct the natural movement of water from the root zone, artificial sub-surface drainage becomes inevitable to maintain high productivity of soil. In sub-surface drainage, drain tiles and envelope materials play important role in keeping the drainage system efficient.

In irrigated command areas of Karnataka the tile drains of 10 cm (diameter) by 60 cm (long) are being used. These tiles have been provided with perforations of slits on the body for entry of drainage water. The sub-surface drainage systems with these clay tiles have failed most often. It has been seen from investigations that there was an inadequate technology for such tiles. The main deficiencies noticed in technology were lack of knowledge on number and size of perforations for tiles, proper method of placement of tiles in trenches and type of envelope materials required for tile drains. In order to understand the above said information of perforated tiles, four field experiments were conducted in soils which were amenable for free flow of water.

In Chapter two, the details of review of literature on previous studies connected with the present investigation have been summarised under the following headings, (1) drain tube materials and installation, (2) water entry area of tiles and its relation to tile out-flow, (3) surface area of perforations and load bearing strength of tiles, (4) orientation of tile perforations, (5) envelope materials for sub-surface drainage, and (6) salts washed out in drainage water. From the literature it was found that for 60 cm long bell-mouth jointed tiles, there was no specific information regarding the size and number of perforations required for higher hydraulic efficiency and for long life. The reliable information was also not available to guide the manufacturers regarding the size and number of perforation per tile in relation to bearing strength of tiles. Even though the bottom orientation of perforations tiles was known through the literature, but it was very vague to adopt for the tiles used in irrigated areas of Karnataka State. Also from the existing literature, it was not possible to identify the critical use of each one of the envelope materials locally available for adoption to tile drains. Hence the study had been undertaken to investigate the problems of tile drainage in irrigated soil.

In Chapter III on Methods and Materials, the experimental techniques and details of four experiments have been described. The first experiment was on identification of optimum size of circumferential perforations for clay tiles of 60 cm (long) by 10 cm (dia). The main treatments were clay tiles with

0.50, 0.75, 1.00, 1.25, 1.50 cm dia perforations and plain drain without tile perforations. The sub-treatments were four depths of irrigation, namely 8, 10, 12 and 14 cm above field capacity of soil profile to a depth of 90 cm. The second experiment was on optimum number of perforations per tile. The main treatments adopted were 6, 12, 24, 36, 48, 60 perforations per tile and a plain drain without tile perforations and sub-treatments were 2.5, 5.00, 7.5 and 10 cm depth of irrigation above field capacity. The third experiment was an appraisal to find out the suitable orientation of perforated face of tiles as drains for easy entry of drainage water. The main treatments were top, lateral and bottom orientation of perforated face in the trenches and sub-treatments were 5, 10, 15 and 20 cm depth of irrigation above field capacity. The fourth experiment was to identify the suitable envelope materials for perforated clay tile drains in the irrigated soils of Karnataka State. The main treatments were top-soil, coconut fiber, saw-dust, corn-cobs and graded gravel and sub-treatments were 2.5, 5.00, 7.50 and 10.0 cm depth of irrigation above field capacity.

The Chapter IV, illustrates the results of all the four experiments in relation to total drain out-flow, rate tile drain out-flow, rate of silt discharged and silt accumulated in tile drains and also bearing strength of tiles under varied conditions of perforations.

In the experiment on size of perforation, the mean total tile drain out-flows were 263.00, 505.00, 576.00, 686.00, 716.00 and 750.00 litres respectively, in tile drains with 0, 1.50, 1.25, 1.00, 0.75, 0.50 cm dia size of perforations. The corresponding rate of tile drain out-flow and rate of silt discharges were 0.033, 0.063, 0.098, 0.132, 0.152, 0.165 litres per minute and 0.270, 2.02, 1.37, 0.96, 0.69, 0.46 grams per litres. The accumulated silt and bearing strength of tiles in the same order were 2.65, 7.85, 6.53, 6.00, 5.61, 5.04 grams and 12.13, 9.86, 9.25, 8.67, 6.75, 5.68 kg/cm².

In the experiment on number of perforations per tile, the mean tile drain outflows were 105.85, 155.13, 183.63, 248.87, 308.38, 336.25 and 356.58 litres in tiles with 0, 6, 12, 24, 36, 48 and 60 perforation per tile respectively. The corresponding mean rate of tile drain out-flow and silt discharges were 0.071, 0.108, 0.128, 0.173, 0.213, 0.238, 0.247 litres per minute and 0.586, 0.744, 0.925, 1.184, 1.562, 2.124, 2.863 grams per litre. The accumulated silt in tile drains and bearing strength of tiles in the same order were 5.68, 8.76, 10.46, 12.23, 16.65, 20.54, 25.00 grams and 12.15, 10.68, 9.50, 8.67, 7.28, 6.12, 5.03 kg/cm².

In the experiment to find out proper placement of perforated face of tiles in trenches, the top, lateral and bottom orientations were adopted. The mean tile drain out-flows were 211.24, 247.34 and 428.48 litres in lateral, top and bottom orientations

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In the experiment on the envelope materials, coconut fiber, corn-cobs, saw-dust, graded gravel and saw-dust were evaluated. The mean tile drain out-flows of 183.30, 222.10, 244.80, 282.00 and 319.00 litres were recorded in tile drains with envelope materials, coconut fibre, corn-cobs, back-fill soil, saw-dust and graded gravel. The corresponding rate of tile drain out-flows and silt discharges were 0.443, 0.522, 0.564, 0.570, 0.620 litres per minute and 0.938, 1.483, 1.570, 0.690, 0.825 grams per litre. The corresponding silt accumulation in tile drains were 2.84, 4.64, 2.18, 1.20 and 6.84 grams.

In Chapter V, the results of experiments were critically discussed and compared with earlier studies to draw systematic conclusions. The results of experiment were tabulated and statistically analysed using F and T tests and their significance at 5 per cent level were used for drawing conclusion. The intra and inter parameter variations were found-out by preparing tables of total and relative variations. Wherever, needed these variation were expressed in quantities as well as in percentages. The parameters involved in all the four experiments were total

tile drain out-flow, rate of tile drain out-flow, rate of silt discharged in tile drains, silt accumulated in tile drains and bearing strength of tiles. The discussion on the results of experiment on size of perforations based on hydraulic performance, silt discharged and silt accumulated in tile drains and bearing strength of tiles, perforations of 1 cm dia was more ideal for clay tiles of 60 cm (long) by 10 cm (dia). The discussion on the number of perforations of 1 cm dia per tile gave that the tiles with 24 perforations of 1 cm dia gave higher hydraulic performance, less silt discharged and silt accumulation, and optimum bearing strength of tiles. Based on the increased hydrologic performance, decreased silt discharge and silt accumulation in tile drains, the bottom orientation of perforated face of tiles were more efficient than lateral and top orientation of tiles in trenches. The discussion of results of experiment on envelope materials based on hydrologic performance and silt discharge and silt accumulation in tile drains, the envelope materials were rated in order of merit as graded gravel, saw-dust, coconut fibre and corn-cobs.

In Chapter VI, the specific conclusion are stated, based on the results and discussion given in earlier Chapters. Suggestions are also indicated for future line of research work.

In Chapter VII, a brief summary of the introduction, review of literature, experimental procedure, results of experiments, discussion of results and conclusion are stated.

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NOTATIONS

A	=	Cross-Sectional area of the pipe
A	=	Cross-sectional area of water flowing in channels
C	=	Involved constant in Kirkham equation (1950)
C	=	One half of crack width in cm.
G	=	Junction end-loss coefficient
H	=	Hydraulic head between equipotential
K	=	Hydraulic conductivity (cm/ha)
L	=	Length of tube in Mohammad and Skeggs(1983) equation
Q	=	Flow rate or Discharge (cm ³ /hr)
Q	=	Flow per cm length of tile (cm ³ /hr)
S	=	One half the tile length plus one half the crack width
B _o	=	Outside diameter of the conduit
B _d	=	Width of ditch at top of conduit
B _{d1}	=	Bulk density of i th layer of soil profile
C _c	=	Coefficient of vena contracta in Walker and Armstrong (1980) equation.
C _d /C _c	=	Load Coefficients in Marston equation(1980)
D _i	=	Depth of i th layer of soil profile
K _{ce}	=	Loss coefficient for contraction and expansion
M _{b1}	=	Moisture content before irrigation of i th layer in per cent
M _{fc1}	=	Field capacity of i th layer in per cent
W _o	=	Total Load on pipe drains
b	=	Lateral or branch tile drains

Continued

- d = Depth of water applied
 d = Subscript denoting the down stream main
 l = Length^{of}/tile drain or tube
 n = Number of soil layers in a profile
 q = Rate of flow of water (partly)
 r = Out-side radius of tile
 S_1
 and S_2 = Summation terms as defined by Kirkham (1950)
 t = Time in seconds
 t = Height of ponded water on soil surface
 u = Subscript denoting the upstream main
 w = Unit weight of materials under study
 y = Rise of water in time t in cms
 θ = Angle between the lateral and the upstream main
 h_s = Hydraulic head of cylindrical source (cm)
 h_t = Hydraulic head inside drain (cm)
 q_0 = Rate of flow of water
 r_e = Effective radius
 r_s = Radius of source or outer equipotential
-

CHAPTER 1

INTRODUCTION

CHAPTER I

INTRODUCTION

The value of soils for crop production is determined by how well it can supply plant roots with water, air, and nutrients. The solid, liquid and gaseous materials form the soil skeleton and provides the structural pattern of pore space. For an average cultivated soil, the pore space is about half of the total soil volume. Depending on the shape of the skeleton, the pore space is divided into a complicated system of channels and cavities; the pore system below a water table is completely filled with water. If the water table drops, the pores are progressively emptied of water, and air fills the pores.

The concept of soil structure includes every thing that deals with the fabric of soils, i.e. the manner in which individual particles are arranged and joined to form aggregates. The cementing agent is primarily clay particles and soil organic matter. As these particles are mutually cemented, they also bind together the large silt and coarse-textured particles. An aggregated clay soil provides for movement of water and air in the macropores likewise, the root system can spread out in the sub-soils network of cracks and channels. Therefore, the root system can reach and effectively penetrate large volume of the sub-soil, and thus assure water availability during prolonged dry periods.

Coarse-textured soils lack cementing substance and ability to form a macrostructure, with creeks and channels. In these types of soil, root penetration is halted immediately below the top soil because of various reasons such as mechanical resistance, a dry zone, lack of nutrients, or low aeration. Therefore, in this case the sub-soil is not available for root growth; however, a portion of any stored sub-soil water may be transported by capillary action to the root zone. It is, therefore, necessary in single grain soils the top soil structure provides for good root development and consequently for good root contact with sub-soil.

The total irrigated area in the world has expanded rapidly from 194 million hectares in 1964 to 226 million hectares in 1974. This means an increase of 32 million hectares in 10 years (FAO, 1976). Of this area, 23 million hectares are located in developing countries, especially in China, India, and Pakistan, which have increased their irrigated areas by 15 million hectares. Irrigation is practised in both dry and humid climates, most of it in alluvial plains and coastal low-lands. In all climatic regions it is generally accepted fact that irrigation and drainage are inseparable and the provision of irrigation should soon be followed by drainage so as to create a suitable root environment for the growth of crops. The reasons for providing drainage are

to remove excess soil water, to prevent soil salinization and to ensure the trafficability and workability of the soil.

Drainage facilities are being increased in the humid and arid regions of the world, and in both developed and developing countries. FAO estimates that to control waterlogging and salinity in the irrigated areas of developing countries, 52 million hectares of land need to be drained in the next 15 years. A great many of soil will fall within the range of difficult one's (fine sand, silts and dispersive soils), in which envelopes will be required to protect the drainage system against sedimentation and to improve the flow of water in the area immediately surrounding the drains.

Irrigation is one of the important factors for assured crop production. It permits better utilization of all other production factors and thus leads to increased yields per unit area and time. In India upto the end of 1981-82, about 60 million hectares were brought under irrigation. According to the latest estimates about 113 million hectares could ultimately be irrigated by 2000 A.D. as full irrigation potential of India. All the area that would come under irrigation, need drainage either surface or sub-surface.

The planning commission has projected that the population of the country by 2001 A.D. will be around one billion

and the food grains production would have to be stepped upto 225 million tonnes from the present 140 million tonnes. In order to meet this challenge, the Government of India has attached the highest priority for water resources development and efficient land and water management which includes irrigation and drainage.

Karnataka State having geographical area of 19 million hectares provides 11 million hectares of cultivable land, of which only 13.4 per cent of the area is under irrigation. The State has total potential surface and ground water resources to the tune of 5.4 million hectare-metre which irrigate only 50 per cent of the total cultivated area. Under the prevailing agro-climatic conditions, scarcity of irrigation water and lack of drainage system, adoption of efficient water management practices is a must, which would help to increase agricultural production besides preventing deterioration of productive soils. The major water management problems of the State may be listed as (1) Scarcity of good quality irrigation water, (2) Lack of efficient water distribution technology, (3) Lack of drainage system, and (4) Rise of water table and development of soil salinity in canal irrigated areas.

The relationship of soil, plant and water needs highest attention at every stage of crop production. Soil supports and supplies nutrients, while water as a media regulates the

life of the plant. Thus, maintenance of optimum moisture in root zone throughout the plant life is a prime need of irrigation practices in most of the Command Areas.

The ill effects of poor drainage (lack of proper drainage) due to excess of water are of many fold; water in excess of field capacity remain un-available for plants. Moreover, this water blocks aeration space of plant root-zone, thereby reducing beneficial activities of soil fauna. Apart from this, excess water creates the accumulation of salts in plant root zone, which in turn creates toxicity in the soil and unfavourable condition for tillage operation.

Wherever topography of sub-soil conditions obstruct the natural movement of water from the root zone, artificial sub-surface drainage becomes inevitable to maintain high productivity of soil. The present days tile drainage system took birth in England as early as 1910 and in India in 1925.

In sub-surface drainage, the excess water, either from soil profile or from surface water, is removed by providing some type of artificial drainage systems. The movement of water into artificial sub-surface drains is influenced by variables such as depth of drains, spacing of drains, opening of drains, hydraulic conductivity of soil and the distribution of flow potential at the boundaries. Execution of tile

drainage projects without appropriate technology, have resulted in failure, due to entry of silt leading to clogging up of the entire system. This is more so in non-cohesive soil where enough silt exists at drain depth. The movement of silt into tiles is influenced by soil permeability around the tile, extent of tile openings, location of tile openings and type of envelope material around the drain. The hydraulic gradient near the drain also play an important role in silt entry and ultimate sedimentation. The water approaching towards drains gains higher velocity as a result of convergence. The increased hydraulic gradient due to increased velocity may exceed artificial gradient, resulting soil movement into the drain pipe, according to Luthin, Tayler and Prietri (1958).

The design of a drainage system depends on several inter-dependent elements, (a) the kind of system (e.g. surface, sub-surface, mole drainage), (b) the shape of drained area for surface drainage system, (c) the type of field drains (e.g. ditches, pipes, wells for surface-drainage system, (d) the lay-out of the system (field drains, collectors, outlets), and (e) the depth and spacing^{of}/drains. In sub-surface drainage system, tiles and envelope materials play important role in keeping system efficient and also in the economy of the tile drainage system. Most of the drainage formulae used for design purpose are based on the assumption that the drains are

completely permeable flowing full without any back pressure. This is possible only in the presence of ideal envelope around the tiles or tubes. This would cause flow converging radially towards the drain; the hydraulic gradient will increase towards the drains and consequently the flow velocity will increase. If the larger drain diameter are used, the smaller the convergence and it would result into the lower hydraulic gradient. It is both impractical and un-economical to manipulate the drain diameter to keep the hydraulic gradient in the immediate drain vicinity small enough to avoid particle movement. Moreover, actual drains, with their relatively small area of inflow openings, are far from "ideal". Because of the additional concentration of flow lines towards the in-let openings, there will be a considerable extra flow resistance as compared with the flow to an "ideal" drain of equal diameter. The extra resistance was defined by Engelund (1957) as "entrance" resistance.

An increase in the density of the perforations in tile drains or pipes is the most effective way of decreasing the entrance resistance and approaching the "ideal" drain. For a specific opening area per running metre of pipe, a large number of small perforations, evenly distributed, is more effective in decreasing the entrance resistance than a smaller number of larger perforations. The findings by Diericks et al. (1981) indicate that the distribution of perforations further decreases the risk of occurrence of hydraulic gradient (failure) in the vicinity of the perforations.

The importance of number and distribution of perforations would decrease when the drain is provided with a permeable envelope. Even thin permeable envelopes, with sufficient tensile strength will decrease the entrance resistance considerably and prevent the occurrence of high hydraulic exit gradient. Experiments with different envelope materials showed that a decrease in resistance could be obtained more easily by increasing the envelope thickness than by larger pipe diameters or more perforations (Wesseling and Homma, 1960). In view of both the hydraulic properties and the critical exit hydraulic gradient it is better to use a smaller diameter drain plus permeable envelope than a larger drain without an envelope. Increasing the thickness any further will have no effect on the entrance resistance, but decreases the radial resistance and consequently increase the effective radius.

A decrease in the permeability of a drain envelope, by soil particles blocking the pores on its surface or entrapped inside, will increase the entrance resistance, and will result in higher hydraulic exit gradient. Depending on the envelope thickness, the original permeability and the rate of its decrease, clogging or blocking can lead to an early failure of the drainage system. High permeability values of the envelope are less effective in reducing the entrance resistance. The total porosity and pore-size distribution are critical for the selective filtering and the hydraulic properties of drain envelope.

The total porosity should be equal or greater than that of the drain abutting soil to guarantee the maximum number of pore connections at the boundry between soil and envelope.

The permeability of the envelope, which is related to porosity and pore-size distribution, should be several times that of the surrounding soil to decrease the hydraulic exit gradient and diminish the risk of soil particle movement.

The main functions of drain envelope materials are,

(a) selective filtration function; the material should prevent the entry of soil particles that would otherwise silt up and clog the drains, block the perforations and block or clog the envelope, (b) Hydraulic function; the material should maintain or create a highly permeable zone around the drain, thereby improving the rate of water entry, and (c) Stabilizing function; the material should provide suitable bedding for the drain and stabilize the soil material of the trench invert.

In the irrigated command areas of Karnataka the clay tile of 10 cm diameter and 60 cm long are being used for drains. They have been provided with perforations or slits on the body for entry of drainage water. The sub-surface drainage systems with clay tile drains often failed immediately after laying or within a year or two. After thorough examination, it was found that there was no adequate technological know-how for adoption of such tiles for sub-surface drainage. The main deficiencies noticed were lack of knowledge on number and size

of perforation required per tile, placement of perforated area of tiles in trenches for drainage water entry, right type of envelope materials to prevent silting and clogging of tile drains, and optimum bearing strength of tiles to take load when provided with number of perforations. In order to know the optimum information of the above mentioned technology four experiments were carried out with the following objectives:

- 1) To know the optimum size and number of perforations per tile for higher hydraulic and structural efficiency of clay tiles used in irrigated soils of Karnataka State.
- 2) To obtain precise information on the placement of perforated clay tiles in drainage trenches as sub-surface drains.
- 3) To find out the optimum bearing strength of perforated clay tiles under submerged hydrological condition in the soil.
- 4) To evaluate the hydraulic efficiency and structural stability of locally available envelope material for their economic use for sub-surface drains.

CHAPTER 2

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

2.1. General

A wide variety of materials is used for subsurface drains. These materials include clay pipes in short sections, concrete pipe in various lengths, blankets of gravel laid in the soil, fibrous wood materials such as willow branches buried in the soil, covered stone drains, bituminous, fiber materials, plastic pipe, and other materials which can be covered in the soil and which will remain intact for long period of time. Mole drains are also included as subsurface drains. The basic purpose of these drains is to collect the water that flows out of the soil and to carry this water into an outlet channel.

2.1.1. Drain Tube Materials and Installation:

Advances in drainage practices are often described in terms of changes and improvements in drainage materials and/or installation methods. New drainage materials, installation techniques and modernized equipment are being developed almost continuously to take advantage of technological advance provided through research and development. Progress occurred even before 1900 in the U.S.A according to Weavers (1964) History of Tile Drainage. According to Fouss (1968) and J.L.Fouss (1971), recent developments include plowed-in corrugated-wall plastic drainage tubing and use of the laser beam. According to Fouss and Fausy(1967) and Studebaker (1971), automatically control drainage machines for installing subdrainage at the proper depth and grade were developed.

Clay and concrete drain tile have been the principal drainage materials for many decades, but these products today are much improved over the tile used in the early 1900s. Edminster (1965) stated that "The clay tile industry has done an outstanding job in product improvement. Continuous study and testing have resulted in tile being available today that are unsurpassed in quality, uniform in diameter and roundness, uniform in length; sharp, clean-out edges; increasing reliability in density; low absorption qualities; uniform in bearing strength, absence of strength-reducing foreign material etc. Continuous process machine manufacture has reduced manufacturing costs, and palletized storage and transportation to the field has further reduced handling costs. The outstanding research of Manson and Miller (1948, 1954), Miller and Manson(1948a, 1948b), and many others in chemistry of concrete tile manufacture has resulted in an unprecedented quality and reliability for this drainage product. Recognition of the chemical problems involved in adopting concrete to a host of adverse soil conditions has resulted in a whole new series of specialized cements, new curing techniques and improved formation techniques and equipment.

French(1959) gave one of the earliest account of using a plow-type drainage machine the "Fowler Drainage Plow" developed and tested in England. Fowlers plow was pulled by a horse-powered cable windless, and the plow blade could be adjusted to control the grade on the drain line being pulled in.

Weaver (1964) relates that Mr. B. B. Briggs of Sharon, Medina country, Ohio in 1859, invented a machine which looks not very unlike a mole plow, to lay without digging a ditch". The operation described was similar to that given for Fowler's drain plow.

Wallan (1931) reported on the "poppelsdorf Mole-Tile Drainage system" developed in Germany, which was one of the later attempt to improve the scheme for practical use. However, just prior to world war II, German investigators did considerable work to develop continuous linings for mole drains. One such techniques using a tube formed from varnish-coated sheet metal was patented by Sack (1933), Sack's sheet metal mole liners failed rather quickly from corrosion, but forming drain tubing from coiled sheet materials was a new idea that led to much additional research. Sack also developed a light beam projection instrument to establish the desired grade line, and a machine mounted receiver for the light beam to aid the operator in controlling the depth of the drainage plow as per the G.O. Schwab (1951). Schwab describes a mole plow with special attachment developed about (1934) by Janert, another German Engineer, for laying continuous porous concrete lining in a mole channel. Later development research by Ede (1957) on a continuously formed concrete tube for drainage also never put into practical use, mainly because of materials handling problem and the heavy machinery required.

2.1.2. Plastic Drain Tubing

In 1947, polyethylene plastic, a British development was made available for manufacture in the U.S.A. According to Schwab, the U.S. Corps of Engineers investigated as early as 1946 the use of "Perforated plastic tubing" installed with "cable-laying machines" for airport drainage. However, Schwab's research from 1947 to 1954 (Schwab, 1955) is considered the beginning of the development and use of plastic drain tubes in the U.S.A. He installed several field experiments where polyethylene plastic tubes of various diameters and wall thickness were pulled into a mole-drain channel with a mole plow. Schwab(1955) indicated that it was necessary to handle the smooth-wall plastic drain tubing in 6 m. straight lengths, because the tubing would "Kink" when coiled. From these studies, he provided guidelines as to the minimum tube-wall thickness for various drain diameters to insure drain conduit deflection of less than 20 per cent of the original diameter. According to Fouss(1968), 17 years after installation, the test drains were still in very good condition. The results from these early field experiments provided much of the background data for today's minimum plastic drain strength requirements.

Dejager (1960) conducted experiments in the Netherlands with polyethylene tubes pulled into mole drains. The studies were abandoned because silt clogging the water entry "slits" in the tube walls during installation. Dejagar (1960) also developed a method of installing 6 m lengths of rigid vinyl

plastic drain pipe in a narrow trench dug with a high speed trenching machine. According to Van Someren(1964), this latter method received notable acceptance and use throughout the Netherlands during the 1960s. According to Myers et al.(1967); Rektorisk and Myers during the mid-1960s, 10 cm diameter polyethylene plastic drainage tubing installed as deep as 2.7 m with a special narrow-wheel trenches.

Janert (1952, 1955) developed a machine which formed and installed a semi-rigid vinyl plastic drain from rolls of sheet film. The plastic strip was heated to provide sufficient flexibility for forming it into a circular drain.

In 1956, a modified mole plow was developed by Busch(1958, 1960) for feeding a plastic strip into a mole drain channel and forming it into an "arch shaped" mole liner. This development was the beginning of a series of refinements and modifications by both U.S.A. and foreign investigators. These further studies led to the concurrent development and testing of the "zippered type" plastic mole liner by Fouss and Donnan (1962); J.L.Fouss (1962). Fouss (1965) and Ede (1957) later reported that the thin walled plastic mole linears, even for the zippered type were not strong enough to withstand deformation over even a 4 or 5 year test period. The plastic lined mole drain was largely abandoned in favour of corrugated plastic tubing placed in the mole channel.

By the mid-1960s most of the research on drainage materials had begun to focus on corrugated wall plastic tubing. Continuous extrusion and molding equipment had been perfected by German industry to fabricate corrugated wall plastic tubing and underground drainage with the new conduit caught rapidly in Germany and soon spread to other parts of Europe. According to Fouss (1965, 1958), research in the U.S.A. on using the corrugated plastic tubing as an agricultural subdrain was begun in 1965. By 1957, corrugated plastic drainage tubing was being fabricated commercially in the U.S.A. and this new industry has grown rapidly since. Many clay and concrete tile manufacturers also have set up plastic drain extrusion plants.

Schaftin (1976) reported from a review about design, production and use of pipes, fitting and filter for drainage and ground water control. They also reviewed the performance of plastic pipes with regard to silting up, deformation, impact resistance, hydraulic efficiency and suggested future trends in research.

Ami et al. (1978) suggested after study that the use of 75 mm dia tubing for subsurface drain laterals in Canada can result in definite economic savings and in easier handling, storage and transportation. It is particularly advantageous on rolling land with high grades and in soils with lower hydraulic conductivities where smaller spacings between laterals

can be used. They gave the areas drained and maximum length of sub-surface drain laterals for drainage coefficient of 9 and 12 mm per day, hydraulic gradient of 0.1, 0.2 and 0.3 and 0.5 per cent and drain spacings ranging from 9 to 50 m.

According to Fukunaka (1980), the working efficiency of a continuous polyethylene pipe was 20-30 times that of a tile drain and about 2-3 times that of a mole drain. The flux was also much greater than with a tile drain, particularly when laid in a weak foundation such as peat bog. Difference between the fluxes increased with time and mole drains showed least flux.

Further Fukunaka (1980) gave the working efficiency of tile drains, PVC pipes, drain-hose and continuous corrugated PVC piping. The three different covering material and mole drains were compared. The drainage capacity was greater for plastic drains than for tile or mole drains because of their continuous nature, or firm connection between the segments, which resisted stresses caused by differential settlement. As a result of the increased efficiency of the plastic drains, ground water levels and surface water levels dropped more markedly than in tile or mole drains.

Nwa (1981) reported that the use of bamboo in drainage by conducting a study. A set of uniform bamboo pipes were cut into 4 m length and 4 lines of 6 mm holes drilled around each pipe. Two parallel drains were installed across the slope and 4 m pipes were joined to make up the drain length.

Drain depth was in 1 m and the slope was 0.2 per cent. A series of ground water tubes were installed. The 2 drain lines proved fairly effective. The out-flow rate of the upper drain increased with the amount of rainfall and responded to the rainfall intervals. The study concludes that bamboo may be used effectively for drainage.

Linder and Schaffer (1984) compared the ceramic drain pipes with smooth walls with pipes having grooved surfaces for efficiency. In both the cases the pipes were enveloped with fibre glass fleece. Pipes with the grooved surfaces showed a lower inflow resistance and a 30 to 100 per cent higher out-flow. Water inflow increased with raising water pressure, drain pipes with 2 mm grooves being inferior to drain pipes with ≥ 3 mm grooves. Enlarging the grooves to more than 90 mm² total cross-section area gave no further significant increase in out-flow. The effectiveness of the grooved pipes was attributed to a reduction or complete suppression of any deflection and aggregation of flow lines at the joints.

2.2. Water Entry Area and Tile Out-flow:

In sub-surface pipe drains the water enter through the cracks between successive pipes or through holes provided in the pipe body. Sometimes inclined slit are provided in place of holes on the body of the tile which are made at the time of manufacturing of tiles. In some places porous pipes were

adopted and their performance was not satisfactory for sufficient water entry. In mole drains water enters over entire permeable perimeter of the mole channel as well as the open wedge above the mole.

The irregularities at the ends of the segments of pipe are adequate to provide the necessary space for the entry of water into the drain line. The pipe with smooth ends has been shown some difficulty in entry of water, by sealing the entry area. The envelope material placed around the pipe would act as though it were completely permeable. It is also true that the lateral permeability of the envelope is substantially greater than the soil. The envelope material enable to use longer section pipes without any noticeable effect on the flow into the drain. There is a requirement that ends of pipe segments must be butted together in all un-stable soils.

Drains are fabricated in number of ways to permit the entry of water into drains, namely, perforations, cracks between short tile length, or a combination of crack and perforations. Clay and concrete tile of 6 inches or less in diameter are generally made in 1-foot length. The crack spacing is governed by the placement of the tiles and by the squareness and roundness of ends. Metal, bituminous-fiber and plastic pipes are generally perforated with circular holes.

It was shown by Kirkham (1949) that the drain depth increases the amount of water entering the drain. This conclusion was based on a study of the flow through soil having water ponded on its surface. It was also stated that the drain intake rate increased with the depth, and this increase was somewhat greater at smaller depth than at the greater depth. He had also stated that the diameter of the drain apparently had little effect in the flow rate. If the drains were running nearly empty, the increase was larger, but it was still be relatively small. At a 4-foot depth, a 400 per cent increase of drain diameter increased the flow by 20 per cent when the drains were running full, and 50 per cent when running nearly empty.

Kirkham from the same study, stated that the drain inflow rate was independent of drain spacings for all spacing ordinarily used. It was stated that inflow into drains was not independent of the depth of the impervious layer unless the layer was 2 feet from the drain, and the drain inflow was decreased as the drain approaches the impervious layer.

The theoretical flow into a tile drain with cracks only, as derived by Kirkham (1950) and expressed by Dutz (1950) was

$$Q = \frac{2 \text{ II } K (t + d - r)}{1_n \frac{2d}{n} + \frac{2S^2}{K \text{ II}^2} \times \frac{S_1 + S_2}{2}}$$

Where, Q = flow rate per unit length of drain, K = hydraulic conductivity, t = height of ponded water on soil surface, r = outside radius of tile, S = one half the tile length plus one half the crack width, C = One half the crack width, and S_1 and S_2 = Summation terms as defined and tabulated by Kirkham (1950).

As per the Kirkham and Schwab(1951), the increased number of holes increased the relative increase in flow in decreasing order, particularly above 20 holes per foot. Doubling the diameter of the perforations from 1/4 to 1/2 inch at the 4-feet depth increased the flow 68 and 46 per cent for 4 and 10 holes, respectively. The effect of perforation in reducing the flow was less at greater depth than at shallow depth. The use of envelope materials around the drain pipe requires fewer perforations.

In solving the problems of flow into drains, they have used a theory based on Darcy's law, electrical analogue model experiment, and mathematical formulas to calculate the effect of a wide range of sizes and spacings of perforations. It was shown that if the perforations in a drain tube were assumed to equivalent to spherical.

The theoretical flow into a drain with spherical openings as developed by Kirkham and Schwab (1951) was

$$Q = \frac{2 \pi K (t+d-r)}{C + \ln (2d/r)} \text{ for spherical openings.}$$

Where C = an involved constant depending on the radius and spacing of perforations and on the drain radius. The other quantities similar to above equation.

It was further shown that the right hand side of the above equation yields the flow for drain tube perforation assumed to be plate circular openings in the tube, when multiplied by $2\sqrt{II}$.

The flow, Q , per unit length of completely porous drain tube was, $Q = \frac{2 II K (d+t - r)}{\log e \left(\frac{2d}{r}\right)}$. They drew the following conclusions, namely, (1) flow into perforated drain tubes in soil was much smaller than flow into the same tube embedded in gravel. For 6 inch dia drains at 4 feet depth with two 1/2 inch dia holes per foot, the use of gravel was increased the seepage rate 554 per cent and for two 1/2 inch dia holes per foot 149 per cent, (2) for four holes per foot or less the flow was roughly proportional to the number of holes per foot. Three holes per foot yield slightly less than three times as much flow as one hole per foot, (3) Above four holes per foot, additional holes does not proportionately increase the flow, but the increase in flow was rapid upto about 10 holes per foot. (4) Doubling the diameter of perforation does not double the flow, but does result in an appreciable increase. For 6 inch diameter drains at 4 feet depth, an increase in hole size from 1/4 in diameter to 1/2 in diameter, increase the flow, for four holes per foot 68 per cent and for 10 holes per foot, 46 per cent.

(5) The effect of perforation in reducing flow was somewhat less marked at large depths than at shallow depth. For 6 inch dia drains having four 1/2 inch dia holes per foot the reduction was 75 per cent at 4 feet depth, and 72 per cent at an 8 feet depth. (6) The other quantities being equal, large-size drains yield more flow than small drains. The relative increase in flow to be gained by embedding tubes in gravel was greater for large-size drains than for smaller. (7) The seepage rate into tile drains with various crack spacing was compared with perforated drain tube of the same diameter and depth. For 6 inch diameter drains at a depth of 4 feet, crack spacings of 1/8, 1/4 and 1/2 inch per foot of drain length yield the same seepage rate as 12, 17 and 31, of 1/2 inch holes per foot, respectively. If the holes of 1/4 inch in diameter, 25, 36 and 76 holes per foot were required.

The theoretical equations, derived which have the effect of drain tube perforation in drain tube performance in water saturated soils under a horizontal water table, were verified experimentally using electric models to simulate the seepage flow condition. The theory having been established, values of the seepage rate per unit length of drain tube, and the ratio Q/Q_0 were completed for 2, 4, 6 and 12 inch diameter drain tubes; for 2, 4 and 8 rows of holes; for 1/4 - 1/2 inch diameter perforations, for depth 1, 2, 4 and 8 feet and for 2 to 50 holes per foot.

Engelund (1953) derived a simpler equation to show the effect of perforation. His calculation show somewhat less flow than determined by Schwab and Kirkham. Although the maximum diameter of perforation to prevent inflow of soil was not determined experimentally, it was estimated to be about twice the permissible crack width for tile.

Truman Goins (1956) studied the flow characteristics of tile drains in the field and found that the tile flow during the fall was erratic and of short duration until the soil moisture had been replenished to a saturated condition continuously throughout the soil mass. The response of flow to rainfall was delayed when soil moisture was below the free water level. A variable, low intensity rainfall caused increased tile out-flow reflecting each storm period. The maximum flow rates in inches per 24 hour were usually in the order of tile lines 2 ft deep and 30 ft spacing, 3 ft. deep and 30 ft spacing, 2 ft deep and 60 ft spacing, and 3 ft deep and 60 ft spacing.

Tile flow response to rainfall was immediate for all practical purposes after the soil moisture was replenished following the growing season. The increasing flow varies directly with time except for low or variable intensity rainfall. The flow decreased after a storm inversely as same power of time. Maximum rate of flow per unit area were dependent on tile spacing as long as the carrying capacity of the tile was not exceeded.

Annual tile flow increases as tile depth increases and as spacing decreased. Drainage requirement differed by rotations and was a function of the demands of the particular dropping sequence.

Kirkham (1958) found that in the slit drain artifice streamlines were equally spaced, i.e. linearly distributed as they enter into the slit drain. The arch shaped position of the flow medium was disregarded and simple rectangular flow region was considered.

Miller and Synder (1944) and Pillsbury et al. (1960) concluded that the expansion of drain tile on wetting would be only a few thousands of an inch per foot and would not significantly affect the performance of a tile system. They did not evaluate the effects of chemical precipitation or soil deposition in the tile joints as possible sources of reducing flow into tile.

Jones (1960) found the maximum joint spacing to avoid sediment inflow should be $1/16$ inch for silt loam and $1/8$ inch for silt clay loam. Sub-mergence of the out-let increased the sediment flow by 30 to 100 per cent and would be a factor to consider in selecting the joint spacing.

Schwab et al. (1961) studied tile flow records in Ohio to evaluate the drains at 2 and 3 ft depths and at spacings of 30 and 60 ft in all combinations. They found that the annual tile

flow varied considerably from year to year, and the percentage variation was much greater than annual precipitation. The highest monthly flow for the year occurred in March, followed by April and practically no flow occurred during the months of August, September and October. In general, the highest peak flow, the greatest volume of flow and the total number of days of flow greater in March and decreased in the order for the months of April, May and June. For corn in the two-year rotation and for tile at 3-ft depth and 60-ft spacing the duration of flow at $\frac{3}{8}$ inch per 24 hour or greater was only 1.1 days, or about 1 per cent of the time, during the four months period from March through June.

Corn in two-year rotation with tile at 3-ft depth and 30 ft spacing produced the highest four month total and highest annual flow of any crop or combination drainage system. However, corn and second-year meadow in the four year rotation gave the lowest flow primarily due to low antecedent moisture conditions. The four-month total and annual flow from tile at depth of 3-ft were greater than the flow from tile at 2-ft. The tile flow from the 30-ft spacings was considerably greater than from 60-ft spacings for both the four-month period and calendar year. However, on the basis of the actual flow per linear foot of tile, the 60-ft spacings gave about 40 per cent more flow than the 30-ft spacings. The duration or percentage of time of various daily flow rates during the four-month period, March through June, was not consistent among the various depth and spacing combination.

Watts and Luthin (1963), Klimko and Passinskie(1966) measured the flow from perforated drains placed in sand tanks in the laboratory. Because of different boundry conditions, the theory could not be varified from their results. They had shown that the openings size was limited by sediment inflow rather than by the rate of water flow.

Schwab and Thiel (1963) found from the two year of study that under high antecedent moistuæ conditions, the tile drained plots gave about the same degree of drainage as the surface-drained plots. Although the total run-off volume was slightly greater from the combination tile-drained and surface drained plots; the differences were not significant. Surface drainage reduced the volume of water removed by the tile by 43 per cent and tile drainage reduced the volume of surface run-off about 40 per cent. Higher antecedent moisture increased tile flow volume 100 per cent and the surface run-off volume more than 150 per cent, while peak tile flow rates were increased about 20 per cent on the average. Doubling the rate of water applicatiør increased the peak tile and surface flow rates, but had little affect on the volume of flow. The results showed that surface drainage reduced tile flow and vice-versa, Evaluation of the drainage systems was based on hydrologic measurement rather than on crop response.

Pillsbury et al.(1964) reviewed and conducted series of experiment to understand the type of flow through joints.

They had used polished smooth stainless steel butt joints, in the laboratory of the University of California at Los Angeles, with variable width openings. Similarly, compared the studies in the field using clay and concrete tiles. They were conducted at a temperature of $21^{\circ}\text{C} \pm 1$ and evaluated the coefficient $C = Q/A \sqrt{2gh}$ and Reynolds number. Using this data they had developed a graph indicating the relationship of the coefficient C and Reynolds number for flow through smooth butt joint in a tile drainage line.

Youngs (1965) found that the flow through a joint space kept free of sand was as much as three times that from joints containing sand. He also found that the relative flow for a slotted plastic tube compared with an open drain was about 0.25 compared with 0.21 as interpolated from Kirkham (1950) (slots of same area as a joint).

Deboer and Johnson (1965) reported that perforated tile gave greater tile discharge than the regular plain tile. Further they stated that there was relatively a small difference in the discharge between the perforated tile with close spacing and the same tiles with the spacing sealed. Luthin(1966) reported that the water entered the tile through the cracks between successive tiles or through holes provided in the tiles. Some experiments on porous tile was made but in general little or no water entered through the walls of the tile.

Manson and Blaisdell(1966) conducted a laboratory study to determine energy losses at drain tile junctions. On 64 different junctions 2217 individual tests were made. The entry angles of the lateral to the main were varied from 15 to 165 deg by 15 deg increments. The velocity of flow in the main were varied from 2 to 65 ft and the pipes were flowing full all time. The quantity of water entering the main from the lateral was varied from 0 to 100 per cent. Junctions were constructed with the lateral entering the main at the centre and tangent to the crown. The theoretical equations used for practical application in design of drainage system; where $G_u = \frac{2Q_b}{Q_d} - (1 + 2 \frac{A_d}{A_b} \cos \phi) (\frac{Q_b^2}{Q_d^2})$ for main, and for the lateral, $G_b = 1 + 4 \frac{Q_b}{Q_d} - [(2 + 2 \frac{A_d}{A_b} \cos \phi) - (\frac{A_d^2}{A_b^2})] = \frac{(Q_b)^2}{Q_d^2}$, where, A = Cross sectional area of the pipe, Q = discharge, G = Junction end loss coefficient, ϕ = angle between the lateral and the upstream main, u = subscript denoting the upstream main, b = lateral or branch, d = subscript denoting the down stream main,

The junction energy loss coefficients calculated by the above equation were presented graphically and these graphs gave energy loss coefficient for any proportion of the flow entering from the lateral and for ratio of the lateral pipe diameter to the main pipe diameter. The use of the 45 deg junction in place of the 90 deg junction reduced the hydraulic grade line slope by 5/8-in per mile, and the total losses were same for all lateral spacings. From the study, they have stated for agricultural

drainage, where velocities were slow, the 90-deg junction design was as satisfactory as the 45-deg junction design, and that for ease of construction the lateral should join the main at the most convenient angle.

Williardson et al. (1966) studied six types of drainage conduits for characteristic flow rate and several types of drainage conduits were tested for load carrying capacity. The materials tested included 4-in diameter concrete drain tile one-ft long with butt ends, 4-in dia perforated bituminized fiber pipe; 3-in diameter polyvinyl chloride plastic semirigid polyethelene tubing with 0.078" walls; 3-in semi-circular galvanized steel with corrugated roof in 18 gauge and 28 gauge enameled steel tubing with 0.005 and 0.008-in wall with various types of closures and joints. All conduits were tested completely submerged and flowing full. The water temperature for the conduit tested in water was maintained at 20°C.

The results of the characteristic flow rate were given as the 28 gauge galvanized steel which had 24 times as much open area as the fiber glass wrapped plastic and discharges nine times much more water when placed in sand. Concrete tile has one of the smallest percentage of open area and had minimum discharge rate in sand.

It was also suggested that there is a need for additional research on both the hydraulic and physical properties.

Myres (1967) reported that several manufacturers made bell-end clay pipe with channels in the outside walls of the pipe to carry drainage water to the joints and some manufacturers built nipples of concrete (approximately 1/8" high) on the end of the butt end or V-notches at the end of the tile which ensured certain space opening between sections of tile and also the rigid plastic drain pipe was perforated with 1/4" or 3/8" diameter holes or slots.

Lembke (1967) found that in a stratified silt loam, lake plain soil, actual tile out-flow with a ponded layer on the soil surface was greater than that predicted by both auger holes and soil cores. Auger hole measurement, while being conservative, were recommended for measuring hydraulic conductivity in such a soil. It was also found that a tile drain embedded in a gravel filter under a ponded condition increased in-flow rate during the first two years after construction. This increase was attributed to removal and rearrangement of fine particles in and around the gravel filter.

Schwab and Fouress (1967) reported that when the meadow crop was sprinkled with 3-9 inch at 0.23-in per hour, surface drainage reduced tile flow by 53 per cent and tile drainage reduced surface run-off by 35 per cent. For similar soil moisture condition the following year, with 3.0 inch of water sprinkled on corn, the percentage flows were nearly reversed, namely, surface drainage reduced tile flow by 31 per cent, and the drainage reduced surface run-off by 51 per cent.

Williardson et al. (1968) studied the entry velocity control limits of drain sedimentation. They reported that the average velocity of flow, a channel that could be attained without dislodging soil particles, decreased with the increasing width of the channel. A constant channel width of 0.32 cm (1/8 in) was used with 0.42 mm to 0.59 mm size silica sand. A 40 to 50 per cent increase in the safe velocity was achieved by using some shape other than a square corner. Stokes law settling velocity for particles of this size was 22.4 cm per sec. one size of glass beads and two sizes of sand having particle diameter of 0.20 mm and 0.65 mm, respectively, used to determine the effect of particle size on the limiting average safe flow velocity.

The entry velocity can be limited by providing sufficient channel in-flow cross-sectional area by varying either size and number or both, of channels to meet the drainage discharge requirements. Uniform non-cohesive particles are most likely to cause sedimentation problems. Graded materials or cohesive aggregated soils are less susceptible to movement by flowing water.

The velocity control method of sedimentation prevention was not a filtering process. It operates on the principle of separation of water from soil without the undesirable plugging and water-impending actions that were inherent in filters.

For square opening (channel) the maximum limiting up-flow velocity was 0.74 cm per sec. with discharge rate of 2.38 cm^3 . For stream-line channel, 1.07 cm per sec. for 3.42 cm^3 discharge rate. For wedge type channel 1.15 cm per sec for 3.67 cm^3 discharge rate.

Schwab et al. (1969) analysed theoretically the effect of joint spacing on the flow into 1-ft lengths of drain tile, and the effect of perforation were summarized. The results showed not only relative in-flow rates, but also the effect on water-table draw-down for 6-in diameter drains of 6-ft deep. Several years of field results taken in Iowa showed that the theoretical effect of joint spacing could be applied to the draw-down case, provided the water table mid-way between the drain was at least 2-ft above the centre of the drain tile. No attempt was made to evaluate the effect of the opening size on sediment inflow. The spacing of perforations on the cylindrical surface of a drain has very little effect on the inflow when the ratio of the shortest to the highest spacing was greater than 0.2. From the data presented, it was possible to estimate the effect on water table draw-down for perforations or joints, and to appropriate the effect of a combinations of joints and perforations.

Luthin and Haig (1972) observed that decreasing the pipe segment length from 3-ft to 1-ft increased the rate of flow into the pipe more than $2\frac{1}{2}$ times, which was mainly due to the increased open area in the pipe for free entry of water.

Gulati(1973) reported that it was possible to minimize the entrance resistance and in-flow velocity by providing increased open area for in-flow. For same inflow area, the perforated drain not only reduced entrance resistance due to less convergence of flow in the vicinity of drain but also the length of critical bounding was reduced.

Evaluation studies of Bell and spigot end clay tiles with holes and slits indicated that the discharge was more from tiles with holes than the tiles with slits, which was mainly due to the total increased open area in tiles with holes (Anonymous,1974).

Sing and Michael (1974), in the laboratory study, with a tile in-flow meter, found that a spacing of 3 mm was optimum for 10 cm diameter 30 cm long tile with tongue and groove joints in vitrified clay soil.

According to Withers and Vipond (1974) plastic pipes used for drainage were usually slotted and their intake resistance reduced with reduction in total slot length per unit length of pipe. They recommended a slot width of 0.6 mm for general use.

Dierrick et al.(1975) reported that a corrugated plastic tube of 5 cm diameter with six perforation lines distributed all round (106 perforation per meter length) gave higher discharge compared to a drain tube with two perforation lines at the top, and a drain tube with two perforation lines at one side and also a drain tube with two perforation lines at the bottom in a sand model tank.

Misra and Bearleg (1975) conducted model studies to investigate the effect of high water velocity on the extent of soil movement. When corrugated plastic drain tubing was used as conduits for underground terrace on steep slope, no significant amount of sediment was drained into the tubing, even when the slope was 10 per cent and velocity approach was 9-ft per sec. The magnitude of the flow from the tubing to the soil was low in cohesive soil. But, with less cohesive soil this out-flow was greater and there were considerable movement of soil from around the tubing.

Dennis and Trafford (1975) analysed inflow to drain tile with various configurations of gravel envelopes under steady rainfall condition. They concluded that drain spacing could be increased by more than two fold by placing a thin layer of gravel around the tube to reduce the hydraulic resistance near the drain. These results, however, are not applicable to the transient condition of water table draw-down due to drainage, the most common situation in the field.

Sommerfeldt (1975) investigated various subsurface drainage materials and found from lysimeters study that the discharge from 55, 65 and 105 mm ID perforated plastic drains and 105 mm ID clay tile drains with and without gravel or fiber glass envelopes in CL and FSL soil. In the field, the rate and volume of discharge from the 55 mm rigid plastic drain was comparable to that from the tile drain, but without the envelope, it was

substantially less. Initial discharge from the 65 mm flexible plastic drain always exceeded that from the clay tile. But, as the experiment progressed, the rate of flow from each drain changed and at the end the discharge from the 65 mm drain was frequently less than that from the tile. The discharge from the 105 mm flexible plastic drain varied often between that from the 65 mm plastic and that from the 105 mm tile, and approached that from the tile with time in lysimeter studies. In the FSL soil without envelopes, the discharge from the 65 and 105 mm plastic drains was more than double that from the clay tiles. In the field, with fiber glass envelopes the volume of discharge from the 65-mm plastic drain was greater than that from the tile. In the field, with fiber glass envelopes, the volume of discharge from the 65-mm plastic drain was greater than that from the tile during the first year but later fluctuations were same about that from the tile. On the average, its discharge was about the same as that from the tile.

Bravo and Schwab(1978) used an electric analog model to determine the effect of openings on radial flow to corrugated drain tubes. Their data was to define r_e for the 114-mm (4.5-in) O.D. Tubing that they used. Assuming that flow near the drain was primarily in the radial direction during draw-down, radial flow from a cylindrical equipotential to a completely open drain could be characterized by the equation,

$$q_o = \frac{2 \pi k l \Delta H}{\ln(r_s/r)} , \text{ where, } q_o \text{ is the flow rate, } l \text{ is the length of tube, } H \text{ is the difference in hydraulic head between equipotential, } r_s \text{ is the radius of the source or outer}$$

equipotential, and r_e is the radius of the open tube. They found that for $r_s = 381$ mm (18-in) the ratio of flow to a commercial 4-in (114 mm O.D) corrugated drain tube with slots of 1.6-mm wide and 27-mm long to that for a completely open 114 mm diameter tube was $q/q_0 = 0.44$. This case represented the situation where soil filled the corrugation but did not block the slot openings. Assuming that the real tube could be represented by a completely open tube of radius r_e , the above equation may be written for the slotted tube, as $q = \frac{2 \pi k \Delta H}{\ln(r_s/r_e)}$. Then $q/q_0 = \ln(r_s/r_e) / \ln(r_s/r_e)$.

Ponu and Stammers (1976) found that smaller openings produced less flow resistance than large openings for specified area per unit length of drain with respect to curved water flow.

Sneyd and Hosking (1976) used numerical methods to solve an integral equation for the same problem considered by Kirkham. They had developed an asymptotic expansion to determine the flow rate as the gap width tends to zero.

Sneyd and Hosking also reported that the US soil conservation service requires a minimum water entry of $21 \text{ cm}^2/\text{minute}$ ($1\text{-in}^2/\text{ft}$) for corrugated tubing. The U.S. Bureau of Reclamation (Drainage Manual, 1978) requires the same minimum openings of $21 \text{ cm}^2/\text{minute}$. A wide range of total entry area reported by FAO (drainage materials, 1972) for different European countries as follows: (1) Australia; $1.7 - 10.5 \text{ cm}^2/\text{minute}$, (2) Germany(F.R.G); $7-10 \text{ cm}^2/\text{minute}$, (3) France; $9.5 - 12.5 \text{ cm}^2/\text{m}$. (4) Netherlands; $11.75 - 27.15 \text{ cm}^2/\text{m}$

(5) Sweden; 14 - 21 cm^2/m and (6) The United Kingdom; 6 - 9.5 cm^2/m .

Skaggs (1978) used an approximate method to estimate the effect of drain tube openings on water table draw-down rates. The method of Bravo and Schwab (1975) to find the effective radius, r_e , of a completely open drain ditch which offers the same resistance to in-flow as a real tube, which was partially open. Then the Hooghoudts equivalent depth was calculated in terms of r_e , and draw-down was determined from solutions of the Boussinesq equation. While this procedure gave a good approximation of the effect of drain openings and envelopes on draw-down. It was subjected to simplifying assumptions regarding two-dimensional flow, convergence near the drain and unsaturated flow above the water table.

Nieuwenhuis and Wesseling (1979) used numerical methods to solve the problems considered by Kirkham and also considered the case of radial flow to a drain with continuous longitudinal slits.

Skaggs and Tang (1979) conducted a study to find the effect of drain diameter, openings and envelopes on water table draw-down. They found that the use of either fabric wrap or gravel envelopes was increased in drain spacings without reducing the design draw-down rate. However, allowable spacing was smaller than previously reported with a maximum of 18 per cent

for the fabric wrap and 29 per cent for the gravel envelopes considered. The initial mid-point draw-down rate was relatively insensitive to change of one or two size in the drain tube diameter. The predicated mid-point draw-down was only 5mm less for the 89 mm outer diameter of (3-in) drain than for the 114 mm outer diameter of (4-in) drain. The effect of drain tube diameter or envelopes on water table draw-down was independent on drain spacing and profile depth as well as the hydraulic properties of the soil. Generally the effect of increasing the diameter of the drain or using an envelope was greatest for small L/d ratio's.

Walter et al. (1979) collected tile drainage data and analysed for a 16 year period on 12 plots in Central New York State. Average annual tile-flow was 7.7 cm or 7.5 per cent of the average annual precipitation. The maximum annual tile flow of 28.0 cm occurred during the wettest year, 1972. In 1962, one of the driest years, a low of 1.8 cm of tile drainage was recorded. The average annual precipitation is an un-reliable indicator of tile flow. The correlation coefficient between annual tile flow and annual precipitation for the 16 year period was 0.60 and when the data for the extremely year of 1972 were omitted, the correlation coefficient was only 0.20. The highest average monthly tile flows were typically 10 times as large as the flow during the driest months. The predominant effect of sub-drainage on these soils was removal of dormant season excess soil moisture. The greatest tile flow was 84 per cent of the

average annual tile flow. Growing season tile flow was only 16 per cent of total annual average tile flow. The correlation coefficient for the relationships of average monthly tile flow versus average monthly precipitation was only 0.09. Extremely high monthly tile flow occurred on 22 occasions during the 6 typically high flow months and only once during the low flow months. Also, extreme rainfall events (Hurricane) do produce high tile-flow inspite of normally high available soil moisture storage.

Stozsic and Sevic (1979) reported that water flow at low velocities through corrugated PVC Pipes results in the formation of a border layer of water between the ribs which was at rest, the roughness values being similar to those in smooth pipes. At higher velocities, the ribs function as a factor of roughness. The water flow to the drain through the opening was best when occurring in smooth pipes with long narrow slots. In corrugated pipes, the perforation of ribs on the outside have the greatest effect per 10 mm^2 , though their flow per opening was the weakest. The effect transversal oblong one opening per rib was very good individually, but was the poorest per 10 mm^2 .

Belgami (1979) found the percentage relative increase in tile out-flow was decreased with an increased number of circular openings of tile from 0 to 60. The optimum number of holes required per tile for removing maximum amount of salts under 2.5, 7.5 and 10.0 cm depth of irrigation were found to be

48, 36, 24 and 12, respectively, in decreasing order.

Youngs(1980) reported from their studies that the hydraulic effect of a filter surround greatly increases the effective radius of a non-ideal drain. It was also stated that the gravel envelope did not increase the effective radius to that of the envelope itself. This indicated some losses of hydraulic head within the gravel envelope as the water converge to the tube openings. The effective radius was expected to increase with greater envelopes thickness and higher hydraulic conductivity of the envelope.

Linder and Schaffer (1980) made comparative tests in a fine sandy soil with (1) corrugated polyvinyl chloride pipe (PVC-pipes) installed without envelope material and having slots of 0.5 and 1.0 mm in 1.0 and 2.0 mm in width, (2) Polyethelene pipes (P.E-pipes) covered with envelope material and with round openings of 3 mm diameter drain pipe with slots of 0.5 mm width showed the lowest discharge rate under equal ground water pressure head at the drain. Slots on the crest of the drain pipes were effective than slots in the trough in P.E. pipes and PVC pipe with slots of 2-mm in width showed almost equal high discharge rates under equal ground water pressure head at the drain in the second year after installation. Corrugated pipes without envelope material and having slots of 1-mm in width showed little entry resistance and high discharge rates in the first year after installation.

They also showed the highest degree of siltation. Glass fiber wool (60 g/m^2) used as an envelope material reduced siltation of the pipes to an acceptable level.

Meclean and Schwab (1982) investigated the flood peak rates of run-off and tile flow from trial plots to determine the effect of sub-surface drainage. Reduction in peak flow rate of upto 77 per cent was observed. The results were extended to a full scale agricultural water-shed to determine peak flow rate reductions of the order of 15 per cent observations on the trial plots. It showed improved soil structure due to the addition of sub-surface drainage, decreasing the peak rate of drainage flow and number and levels of floods on a water-shed.

Swamy(1982) found that maximum rate of out-flow to the extent of 0.690 litres per minute, was from 0.5 cm perforated tile. This was followed by the treatments 1.25, 0.75, 1.00 and 1.50 cm diameter perforated tiles.

David and Willardson(1983) reported from their studies on head loss at soil drain envelope interface and found that the physical restructuring of the interfacial zone as viscous drag causes soil particles or sand grain to bridge over or plug pores in the interface. Particle re-arrangement was an important process at all interface. The changing ratio of viscous and inertial forces occurring as water passes through exit interface. The geometry of the flow paths changed dramatically

during this passage, and this change in turn alters the distribution of viscous shear inertial forces acting between the water and the boundaries of individual flow paths. The Reynolds number for flow, through medium sand, was 0.13, 0.20 and 0.27 at the three principal rates. The data suggests that at least some inertial energy losses occur at low Reynolds numbers.

The principal conclusion drawn from this study was that head loss in soil was greater at exit interfaces than that would be predicted by laminar flow theory. Water leaving the soil and entering a drain or a very permeable drain envelope, demonstrate an excess energy loss. On the other hand, artificial internal interfaces in the soil do not show the same head loss as do exit interfaces. The high gradients at exit interface of porous medium means that hydraulic failure gradient occur under flow conditions that would theoretically be stable. Thus also reduced the apparent permeability of soil.

Experimental results for effective radius were compared to theoretical values obtained from Kirkham (1950) solution. The results were in close agreement with the predicted relationship for a 1.0 mm circumferential opening width.

Mohammad and Skaggs (1983) considered the most common drainage condition of water table draw-down, unlike ponded condition by others, which was approximately radial near sub-surface drains. The flow rate for radial flow from a cylindrical source

to drain tube was described by $Q = 2 \pi L k \frac{(h_e - h_t)}{\ln \left(\frac{r_s}{r_t} \right)}$, in which Q = flow rate (cm^2/hr), K = hydraulic conductivity of soil (cm/hr); L = length of tube (cm); h_s = hydraulic head of cylindrical source (cm); h_t = hydraulic head inside drain (cm); r_s = radius of source (cm) and r_t = radius of drain. This was obtained assuming a completely open tube flowing full with the wall of the drain offering no resistance to the entry of water. In practice drain tubes were not completely open and the method adapted was the effective drain radius, r_e . Then the equation modified was

$$Q = 2 \pi L K \frac{(h_s - h_t)}{\ln \left(\frac{r_s}{r_e} \right)}$$

Another method of characterizing the effect of drain tube openings on radial flow was defined as surface transfer coefficient or head loss near the drain (h). This was considered as the sum of a component due to radial flow and a component due to entrance resistance ($\Delta h = h_s - h_f = (h_s - h_r) + (h_r - h_t) = \Delta h_r + \Delta h_f$, in which h_s = hydraulic head at the cylindrical source. h_f = hydraulic head inside the drain; h_r = hydraulic head just outside the tube well; h_r = head loss due to radial flow ($h_s - h_r$); and h_f = head loss due to entrance resistance at the drain. A factor was suggested " α " analogous to the surface heat transfer coefficient.

$$\alpha = \frac{K}{r_f} \left(\frac{Q}{2 \pi L k (h_s - h_t) - Q \ln \left(\frac{r_s}{r_f} \right)} \right)$$

This 'K' was estimated by measuring rate flow (Q).

Laboratory tests were conducted in a sand tank to determine the effect of total opening area and location of openings on the rate of inflow to 100-mm drain (4-in) corrugated plastic drain under cylindrical flow conditions. One test was conducted with the drain tube surrounded with a 50 mm thick gravel envelope. The effective radius increased with total perforation area. The greatest response of the effective radius to increase in perforation area occurred between areas of 38 to 75 cm²/m in which r_e increased from 5 mm to 21 mm. The location of the drain perforation had little impact on the effective radius of the drain tube. The influence of a gravel envelope in r_e was large; the effect of the standard tube with 38.5 cm²/m open area was increased from 5 mm to 36 mm with the use of a 50 mm thick gravel envelope.

The drainage transfer coefficients " α " were calculated for all cases using the above equation, and the value of " α " increased with the entry area from less than 1 hr⁻¹ for a total entry area of 1.8 cm²/m of 33 hr⁻¹ for an entry area of 182 cm²/m.

Miller and Willardson(1983) reported that the hydraulic gradients at exit from porous media were greater than those predicted by laminar flow theory. Exit gradient affects project into the soil away from the exit interface in the manner of a back water curve. Head losses measured in the soil at an interface was twice those predicted. Laboratory hydraulic conductivities measured using only inflow and out-flow heads was lower than actual values.

Fausey et al. (1983) reported from their study that gravel backfill increased peak flow rates in silty clay soil, while mole drains did not. Tillage in the upper 25-cm caused reduction of peak flow rates. Marked reduction in peak flow rate occurred after mould-board ploughing when the soil was wet.

Derickx (1982) reported from his studies in cohesionless sandy soil, hydraulic gradients may cause soil particle movement into sub-surface drains. In unstable structured soil, high hydraulic gradients may lead to aggregate deterioration and soil erosion. For the radial flow case and for given design criteria, hydraulic gradients can theoretically be derived near ideal drains and using the concept of effective radius near real drains with and without envelope materials.

Sekendar (1984) found from his studies the entrance resistance of enveloped drainage pipes. The entrance resistance and the effective radius of corrugated PVC drain pipes without envelope, and with six different pre-wrapped envelopes were evaluated in a sand tank experiment. By applying the theory of resistance, the entrance resistance of the naked pipe was found to be 0.0136 days/m. With envelopes, the values were 0.0024 to 0.0067 days/metre depending on the type of envelope. The effective radius of the naked pipe was found to be 0.47 cm for a drain with an actual radius of 30 cm. This value increased to between 1.20 and 2.50 cm when envelope material was used. Then the values of the calculated entrance resistance were substituted in the

steady state drainage equation under normal field conditions to evaluate the effect on drain spacing. In all equation, a tendency towards increasing the drain spacing was observed when envelope material was used.

2.3. Load Bearing Strength and Perforated Area

One of the principal material used in drainage development has been the drain tiles. There are three main kinds in common use, namely, clay tiles, concrete tiles and plastic tubes. It is important to observe the simple principle outlined for tiles strength, in order to ensure a long-lasting tile drainage system, has been the bearing strength.

There were no standard specifications for drain tile prior to 1911. In March of that year, committee C-6 of the American Society for Testing Materials on standard tests and specification for drain tile was established. This committee was active from its inception under the able leadership of Dean Anson Marston who remained as Chairman until a short time his death in 1949. It was through the work of this committee that the first standard specifications for drain-tile were prepared and issued under the ASTM Designation C-4. These specifications adopted in 1914 and revised in 1916, 1921 and 1924 were rewritten under the auspices of sub-committee 10 of Committee C-15, Manufactured Masonary Units and now bear ASTM Designation C₄-50T(1950). Few of the essential provisions of C₄-50T differ

greatly from those of Designation C-4 as the principal change was deletion of the class, farm drain tile.

Good drain tile, to be used for agricultural purposes, must be regular, dense, strong and sound. These qualities are assured by specifying that all tiles used shall meet the standard specifications of American Society for Testing Materials. They carry requirements for three classes of tile, namely, farm drain + tile, standard drain tile, and extra quality drain tile, depending upon the purpose for which the tile are to be used. According to Ayres and Scoates (1939) a regular tile as specified by ASTM, allowable variation of average diameter below specified diameter is 5 per cent. Allowable variation between maximum and minimum diameter of same tile, or average diameter of adjoining tile, 85 per cent of thickness of wall and allowable variation from straightness is 5 per cent of length.

The amount of water that a dry tile will absorb is an indication of its strength. As a rule, tile which adsorb large quantities of water are weaker than those that absorb small quantities. The dense wall have lower absorption and hence stronger. According to Iowa State College of Engineering Experiment Station (Ayres and Scoats, 1939) suggested the following recommendations for absorption of tile. For farm tile made of concrete absorption was 8 to 11 per cent. The respective values for tiles made of clay were 8 to 16 per cent, for large

tile drains made of concrete it was 6.5 to 9 per cent and for large clay tile drains it was 6 to 7 per cent.

The idea has long been prevalent that a good tile should be capable of absorbing large quantities of water in order to insure that the water gets into the tile. The fact is that very little water gets into the tile by soaking through the walls, even-though the tiles are very porous. According to U.S. Department of Agriculture (1973), if water entered only through the pore it would require 139 days to remove 1/4 inch in depth of water from an acre, and 250 days when 3 in tile drains were used.

Tiles that are burried closer to the ground surface will be subject not only to loads due to the soil, but also to those imposed by equipment and animals on the ground surface. Tiles placed at greater depths will have only the load due to the soil above the tile. Since the loads due to machinery are concentrated and it affects shallow tiles than deeper tiles. Generally, if tiles support the concentrated load of a heavy man without cracking are considered to be satisfactory. Most tile that stand rough handling and shipping by rail, without showing signs of distress, are strong and tough enough to give good service. According to Ayres and Scoates (1931) the tiles upto 10 inches in diameter which would not be put deep enough, no specific testing is needed. Above 10 inches in size of tile,

that would be **buried** below 5 to 6 ft of soil, should be tested to match the load coming on the tiles.

For round tiles free from cracks, chips, soft spots, blisters and all other imperfections, American Society for Testing Materials recommends the following namely, allowable thickness for exterior blisters, lumps, and flakes is 25 per cent and allowable diameter for the above blisters, lumps and flakes is an internal diameter of 20 per cent.

According to U.S. Department of Agriculture, good quality clay tiles are preferable to concrete tiles where the soil and water are strongly alkaline. The sulphates of sodium and magnesium attack the cement and leach-out by chemical action. When the sulphate content of soil-water is more than 1500 parts per million and concrete tile should not be used unless they have been specially prepared to resist such action.

Miller (1921) had issued based on his studies which included chemical analyses of 1,062 water samples and 150 soil samples and these original studies left unanswered many questions. Miller and Mason(1951) conducted laboratory studies in the University of Minnesota and field studies in 1919 and 1920. Based on these studies, it was concluded that the trouble was caused by excessive quantities of sulfates in the soil in direct contract with the outer surface of the tile wall. The danger limit of total salts in direct contact with the outer surface of concrete drain tile of the quality of the ordinary was about

3000 parts per million (0.30 per cent). The most pronounced failures occurred where the total salt content of the soil water exceeded 4,500 parts per million (0.45 per cent). Except where disintegration had resulted from the action of soil sulphates, the concrete tile were giving satisfactory service throughout the area covered by investigations.

To load coming on tiles in trench could be calculated using well known Marston(1930) formula's, one for narrow trenches, called the ditch conduit load formula, as $W_c = C_d W B_d^2$, where W_c = the total load on pipe, C_d = The load coefficient, W = Unit weight of fill material, and B_d = Width of the ditch at the top of the conduit, and another for wider trenches, called projecting-conduit Formula, as $W_c = C_c W B_c^2$, where C_c = the load coefficient, B_c = the outside diameter of the conduit. Van Schilfgaarde et al. (1951) suggested Nomograph for loads on tile installed in thoroughly wet-clay for three different situations, which would be satisfactorily used to estimate the loads in all situations.

To test the strength of rigid drain pipe, the most commonly used methods are the three edge bearing test, and the sand-bearing test as suggested by ASTM-C4.12-60 (1960) for concrete drain tile, and ASTM C4-59T(1959) for clay drain tiles.

Lea and Desch (1935) reported that the main cause of acidity in natural water were carbondioxide and humic acid, and that the amount of free carbon dioxide which exceeds that necessary to maintain the chemical equilibrium was called aggressive carbon

dioxide acid and this does the real damage. Acid solutions attack cement inostars or concrete by dissolving some of the cementing constituents. The leaching of lime from crushed set cement was about 14 per cent of the original weight of the cement. The Miller and Manson(1948) published a report on the acid action on concrete tiles. The conclusions were based on tests of about 1,100 drain tile and 10,000 experimental concrete and mortar cylinders after field exposures in Minnesota, Wisconsin, and North Carolina for a period of 26 years for some tiles and for 17 to 20 years for the cylinders. The conclusions were as follows:

(1) Peat acidity, as measured by pH determination, was a fair indicator of the degree of corrosive action that would be expected on concrete, (2) Acidities of three mineral soils, as measured by pH determination, did not furnish so reliable an index of corrosive action on concrete as for the peats, (3) None of the six admixtures of different types increased resistance of the cylinders in which used (4) Variations of the soil acids with the exception of alumina cements, which were somewhat more resistant than that were any of the port-lands, (5) Specimens cured in steam at temperatures of 155, 212 or 285 degrees Fahrenheit did not resist peat action appreciably better than did water cured ones, but those cured at 345 degrees Fahrenheit held-up in strength throughout the 17 years of observation. (6) The only surface treatments used were linseed oil and a cut-back bituminous paint. Both of these some what increased

the resistance of the concrete cylinders to which they were applied. It was further concluded that the degree of corrosion varied with the activity of the peat and the unit strength of the test piece, whether drain tile or cylinder.

Miller and Manson (1951) based on his tests on 244 tiles, three point, stand out in particular, namely, the high resistance to frost action of the shale tiles under the depth of cover of 1.7 feet and generally poor performance of the surface clay tile. Also, the more satisfactory service from drain tile with fairly high absorptions, except at out-lets.

Concrete drain tile which meet American Society for Testing Materials requirements for standard drain-tile may ordinarily be expected to have satisfactory frost resistance.

The most deteriorating soil sulfates are of magnesium and sodium. Miller and Manson (1951) found that destructive action of these salts increased rapidly with the strength of the solution upto 0.5 per cent, then at a diminishing rate. It was also observed that in reaction with the tricalcium aluminate in the cement, the disruptive action of the Na_2SO_4 solution for calculated values.

Miller and Manson (1951) had drawn conclusions from 122 tests of port-land cement, as the primary requirement for sulphate-resistant concrete, was sulphate-resistant cement and the first requisite of a sulphate-resistant cement was tricalcium aluminate ($3\text{CaO} \cdot \text{Al}_2\text{O}_3$).

Holland and Visser (1954) reported that the plastic pipe should regain 90 per cent of its original diameter after the removal a weight of 50 kg by applying for a period of one minute at 20°C. For the pipes used in zero temperature, a ball weighing 1/4 kg of radius 12½ mm is dropped from a height of one metre on the pipe, should not crush less than 5 per cent of the pipe under test.

Load-bearing tests were conducted using a test cell developed by Watkins and Nelson(1964). The rigid conduits were considered to have failed when cracks appeared along the sides and at the inlets. Thin walled conduits having Zipper-type closures decreased in diameter with some shearing of the joint before failure occurred due to buckling. The 4-inch diameter bituminized fiber pipe was tested to 60,000 lb without failure. 9-inch diameter concrete pipe failed by cracking at the side and at the inverts. The 3-inch diameter PVC mole drain liver failed by longitudinal buckling. The 3-inch diameter steel reinforced fiber glass wrapped plastic was to the 80,000 lb limit to the test cell without reaching failure. The 18 and 28 gauge galvanized steel conduits with semi-circular cross section and flat corrugated roof reacted in an unusual manner. Initially the roof deflated slightly downward than lateral sand pressures caused inward deformation of walls at the edge of the roof and the walls eventually folded inward immediately under the roof. The enameled steel pipe gave way for circumferential loads and the conduits were reduced in diameter.

Willardson et al. (1966) studied six types of drainage conduits for characteristic flow rate, and seven types of drainage conduits were tested for load carrying capacity. The materials tested includes 4-inch diameter concrete drain-tile one foot long with butt joints; 4 inch diameter perforated bituminized fiber pipe; 3 inch diameter polyvinyl chloride plastic (PVC) mole liner with 0.015 inch wall thickness, 4-inch diameter semirigid polyethelene tubing with 0.078 inch walls; 3-inch diameter steel reinforced fiber glass wrapped plastic; semi-circular galvanized steel with a corrugated roof in 18 gauge and 28 gauge enameled steel tubing with 0.005 and 0.008 inch walls with various type of closures and joints. All conduits were tested completely submerged and flowing full. The water temperature for the conduit tested in water maintained at 20°C.

Belgami (1979) found that load bearing of the tile decreased with an increase in the number of holes in the tile from 0 to 60.

Walker and Armstrong (1980) studied the hydraulic characteristic of corrugated plastic drainage tubing and its flow capacity. An equation was developed relating deflection and other tubing parameters to the ratio of deflected flow capacity to undeflected flow capacity. Data were collected in the laboratory using normal 100 mm diameter tubing with idealized deflection. It was found that the flow capacity ratio for a length of continuously deflected tubing was a function of

deflection ratio alone, and is not a function of tubing size or roughness coefficient. The flow capacity ratio for intermittently deflected tubing was a function of both tubing diameter and roughness coefficient. Tubing continuously deflected by 15 per cent retains about 95 per cent of its undeflected capacity. Point deflection in 100 mm diameter tubing cause approximately the same resistance to flow as 1.0 m of tubing uniformly deflected (K_{ce}) the same amount. Tubing uniformly deflected 50 per cent had approximately the same capacity as undeflected tubing of the next smaller commercially available size. The equation developed was $K_{ce} = K_c + K_e = \frac{A_0^2}{A_d^2} \left(\frac{1}{C_e} - 1 \right)^2 + \left(\frac{A_0}{A_d} - 1 \right)^2$, where K_{ce} = minor loss coefficient for a contraction plus expansion, A_0 = Cross sectional area without deflection, A_d = Cross sectional area for a deflected section, and C_e = coefficient of Vena Contracta.

Schwab et al. (1982) developed a parallel plate metal to determine brittleness of 102-mm (4 inch) diameter corrugated plastic tubing when exposed to Ultraviolet (UV) radiation. Artificial exposure was obtained with an Atlas weather-Ometer Ci 35 using a Xenon-arc lamp. Proposed exposure time was 200 hours which was selected to stimulate two years or more of out-door exposure. Samples from ten manufactures were tested to evaluate proposed procedure. All samples passed the artificial UV exposure test, but three failed the parallel plate impact test due to a manufacturing problem at the mold seam and not due to embrittlement.

Goettelman et al. (1983) developed multi-spectral remote sensing techniques to determine the most suitable method for routinely monitoring agricultural sub-surface drain conditions. The methods were airborne scanning covering the visible through thermal-infrared (IR) portions of the spectrum; color-IR photography and natural color photography. Color-IR photography was determined to be the best approach, from stand point of both cost and information content.

2.4. Orientation of Tile Openings:

The advantage of using slotted and perforated tile drains for sub-surface drainage led to study of placement of water entry surface in relation to trench openings. At present, the placement of openings is not standardised as drain pipes are placed, either top facing, or bottom facing, or lateral facing. Irregular placement of openings might lead to excess silt movement into drains, causing total failure of the tile drainage system. Even though, the information available is theoretical and general nature, but it needs further evaluation with respect to clay tile drains used in Karnataka State, for specifying technique of orientation.

DeBoar and Johnson (1965) investigated the flow into tile joints and reported that the tile spacings did not have significant effects on the tile discharge. The larger spacings which were more susceptible to siltation, did not produce significantly

greater discharge in any of the soil involved in the study.

Also the tile discharge from clay and concrete tile showed no significant difference between the two kinds of tile.

The tile placed at a close spacing had a finite spacing between adjacent tile due to the irregularities of the ends of the tile. Even when the tile was rotated to obtain the closest possible fit, it was impossible to completely close the joint. With the water table at the soil surface, a close spacing was capable of transmitting water into the tile at a much greater rate than the rates normally associated with common drainage coefficients of $3/8$ to $1/2$ m per day for tile lines at 100 ft spacings.

Myers (1967) reported that tiles were usually placed with the holes on top and a continuous strip of fibre glass was layed over the holes. He also reported that in case of sodic soils, holes were placed downward to prevent the puddling of soils over the holes.

Luthin and Haig (1972) reported that for particular water table level in the soil, the location of the tile drain holes on the bottom of the pipe increased the outflow rate due to increased hydraulic gradient between water table and entry point in the pipe. Further they reported that locating the drain tile holes on the bottom had another advantage of draining soil to a greater depth.

Gulati et al. (1970) reported that sand accumulated in the tile drain was less when perforations were located at the bottom

as compared with the tile drain with perforations located at sides and top.

Ponu and Stammer (1976) reported from the experimental and analytical verification, the openings should be located in the lower half of the drain pipes for curved water boundary.

Dierick et al. (1975) reported that from sand tank model study that the normal drain gave higher discharge than by opening the two perforations lines at the top, the side or the bottom, respectively. During the first 10 minutes, the rate of sand discharge declined in the normal drain with six perforation lines and also in drain tubes with perforated top and perforated bottom. The decline continued until it reaches a constant negligible value at the end of the experiment. The rates of water discharge from the normal drain, the drain with the perforated top and the drain with perforated bottom show a decrease with a minimum value at about one minute followed by small increase until about 10 minutes. The sand which moved into the drain tube during the complete period of the experiment had almost the same particle size distribution as the original sand in the model. The weight of the accumulated sand in every drain tube for normal drain was 1373.2 g/m, for the drain with the perforated top was 1296.4 g/m, for the drain with perforated side was 1501.2 g/m, and for the drain with the perforated bottom 1112.1 g/m. The constant water discharge values were, for the normal drain 0.129 mm/second, for the drain with perforated top 0.085 mm/second,

for the drain with the perforated side 0.079 mm/second and for the drain with the perforated bottom 0.066 mm/second.

The concluding report by them was that the entrance of sand particle into a drain tube depends on the flow pattern. Under ponded water conditions the silting-up occurs through the whole perimeter of the drain tube. The cohesionless sand invading the drain tube had the same particle size distribution as the original sand around the drain tube. The first period in draining after the installation of the drain tubes was very critical from the point of view of silting up. The amount of sand discharge influences the amount of water discharge from the drain. The elevation of the accumulated sand inside the drain tube was negatively related to the water discharge.

Ami et al. (1978) reported that use of 75 mm drain tubing for sub-surface drain laterals in Canada was definite economic savings and particularly advantageous to rolling lands with high grades and in soils with lower hydraulic conductivities. The hydraulic capacity of 59 to 100 mm inside diameter were presented with areas drained and maximum length of sub-surface laterals for drainage coefficient of 9 and 12 mm per day. The hydraulic gradients of 0.1, 0.2, 0.3 and 0.5 per cent and drain spacings ranging from 9 to 50 m were given.

Bellin (1979) reported that accurate installation of a piped drain system was essential for its prolonged satisfactory functioning. High-speed installation machinery requires

careful monitoring of pipe laying accuracy in order to assess machine performance. Upto now, the tolerance acceptable in control of pipe installation had not been known.

Ireland (1980) investigated and reported that a back hoe installed tubing at 22 locations indicated that placing tubing along the trench side wall, compacting the bedding along the length of tubing and blinding for 150 mm above the tubing was an excellent installation method for corrugated plastic tubing, especially in back hoe trenches. The investigation also pointed out the importance of proper blinding.

2.5. Envelope Materials for Subsurface Drainage:

The primary reasons for placing envelope material around sub-surface drain tile are: (1) to prevent the movement of the soil particles into the drains (2) to provide material in the immediate vicinity of the drain openings; that is more permeable than the surrounding soil, (3) to provide suitable bedding for the drain, and (4) to stabilize the soil material on which the drains are being laid.

Considering the primary reasons for use of envelope materials would indicate that they are referred to as envelopes rather than filters. A filter is by definition (Websters, 1954) a porous mass through which fluid is passed to separate it

from matter held in suspension. A filter used with a sub-surface drain would be self-defeating, because particular matter would be deposited on or in the filter, thereby reducing its permeability. Microscopic suspended material in soil-water moving toward a drains should pass through the drain envelope with the water. The relatively coarse envelope material placed around the drain should stabilize the soil mechanically and hydraulically, but should not act as a filter.

Means of preventing soil materials from entering sub-surface drains have been sought since the beginning of tile drainage. Sission (1965) reported that in 1859, H.F. French recommended double-walled or sheathed drain with collars as one method of preventing drain sedimentation. French's second choice was clean, fine gravel. Brown (1915) reported use of gravel along the sides of wooden box drain in 1906. He concluded that unless the drain openings were protected by gravel and sand, covered drains could not be used in certain soil. Hart (1917) recommended graded gravel ranging from sand to 3-cm in diameter as an excellent filter. He recommended a porous fabric covering for the joints such as burlap or cheese cloth for quick sand condition.

Envelope materials used for sub-surface drains have included almost all permeable porous materials that are available economically in large quantities. They are divided into three general categories, organic, inorganic and man-made.

2.5.1. Organic materials

Organic materials that were byproducts of agricultural production have often been used as envelope materials.

Iyons et al. (1964) used safflower straw (Carmanthus tinetorius L.) around drains in a peaty muck soil in the Sacramentosan Joaquin Delta. A 13-cm layer of straw was used under the pipe and 15-cm of straw was on top. The 10-cm diameter bituminous fiber pipes with 1.6-cm diameter holes for every 10-cm. The drains with safflower straw envelopes drained the soil profile nearly 3 times faster than pipes of the same size laid without envelope materials. Further more, drain functioning had not deteriorated after 2 winters and 1 summer.

Baghott and Houston (1965) installed drains in the Tulare Lake Basin in north-eastern California using 15-cm of wheat straw (Triticum spp). as envelope materials around the pipe. After six years the drains were still controlling the water table effectively. They recommended straw as an envelope material where gravel was unavailable.

In a laboratory experiment by Cavelaars (1966), all of the various organic envelope materials compared were improved drain performance. Peat litter was about equal hydraulically to a single thin fiber glass sheet.

When iron oxide or other clogging of drains is expected, organic matter should be used with aeration. Even mixing organic matter with trench back-fill material may cause problems in some soils. Weir (1949) stated that neither straw nor brush should be used around a tile drain.

Coal should be used as envelope material but there is no experimental evidence to verify its suitability. The life and suitability of organic materials as envelopes for sub-surface drain are not known for a range of soil condition. Organic matter may effect chemical and biological reaction in the soil that result in clogging problems.

Sisson and Jones (1962) conducted laboratory experiment in which they included straw, saw dust, and corn cobs (Zea mays L.) The corn cobs were taken directly from a shell and were too coarse to exclude sediment. They reported flow rates for both water and soil from the drains for in their test facility. The flow rates of water from the drain for the soil, gravel, saw dust, and straw materials compared were 1.45, 0.81, 0.24 and 0.17 gallons per hour. Straw and saw dust performed well in delivering water while limiting sediment discharge.

Brownscombe (1962) inspected field installation where straw and wood-chips had been used. The straw was effective in excluding sediment and showed only moderate decay after 11 years. A hole had developed in the straw under the pipe that might have resulted in shifting of the pipe in less stable soil.

The wood chips had decayed only slightly after 9 years in the soil. Brownscombe suggested that deterioration might have been greater if the tile had free-flowing outlets. His statement raises the question of whether organic materials are more durable under submerged or well drained conditions. Brownscombe recommended that an organic envelope material when compressed around the drain pipe should be at least 8-cm thick. At least a 15-cm layer of loose material such as saw dust and wood chips would be required before compression.

Planes, D.B. and H.P. Johnson (1962) made field evaluation of flow through blind in-lets by back-filling a tile trench with various gradations of materials to increase the flow rate into the tile line and consequently reduce the time water stands in the surface depression. Four types of blind inlets were constructed and compared, namely, soil, sand, corncobs, and a combination of materials of varying sizes (graded). Relative performance was evaluated by the rate of water movement through free inlets. There was no statistically significant difference among the four in-lets. However, certain general trends were noted. Corn-cobs and graded inlets produced higher discharge rates than soil and sand inlets. Sand inlets consistently gave the lowest discharge rates, and no consistent year change in discharge rates were occurred.

Taylor and Goins (1967) applied 7.5 to 15.0 cm of each filter material of corn-cobs, wheat straw, stone and vermiculate,

directly over the drain and back-filled with excavated soil. Eight years after installation, it was found that wheat straw and corn-cobs had virtually disappeared leaving 1.25 cm residue around the upper two-thirds of the drain, the crushed stone appeared to be unchanged from its time of application and was free of soil.

Svobodova and Vinsova (1979) reported that a high nitrogen content in the soil and a high NO_3 content in the drainage water resulted in rapid decomposition of wheat straw, spruce, saw dust, spruce and oak-bark filter materials. The rate of decomposition and H_2O -sorption were higher in heavy clay rich in nutrients than they were in moderately heavy loam poor in nutrients and in both soil they were high at the maximum moisture capacity than at 50 per cent MMC.

Several filter envelope materials for corrugated plastics drain tube have been tested in the laboratory by Broughton, et al. (1976). The materials used were commercially available in North America. They were: cerex, Remay, Typar and knitted and other materials used were, polyester and rayon, coconut fiber, straw and concrete sand. Polyethylene tube with 0.8 mm wide slots and PVC tubes with 0.4 mm wide slots were used without envelope materials. The results show the changes in drainage rate which occur over flow periods of upto 80 days, and also for successive flow period of one week duration. The soil retention suitability of the materials was classified. Some field observations show difference in abrasive resistance.

Beltram (1978) conducted a study on a ten-ha field in 1974 using clay pipes with and without gravel filter and corrugated PVC pipes without filter and with gravel, barley straw, esparto fiber and coco-fibre filters. The entrance resistance to water flow and equivalent drain spacings were determined.

Blinder et al. (1978) used special laboratory equipment to find out the influence of water movement within five filter materials (gravel, glass fibre, polystyrene granules, peat, glass wool) on drain discharge was analysed. Hydraulic characteristics were given for glass-wool and polystyrene granules, relating them to hydraulic conductivity and resistance of the filters. Calculation of the head losses created by the drain filter was demonstrated.

Burghardt, W. et al. (1979) reported that the degree of decomposition of coconut filter upto 4 years old from chains of dried and pseudogleyed sandy soils, calcareous and non-calcareous marsh soils and slow-noor soils was measured by their content of soluble lignin. Decomposition was insignificant in the sandy soil. In the marsh soils, which were rich in clay, decomposition was related to the narrow C/W ratio, and was not affected by the CaCO_3 content and increased with increasing soil aeration.

The above authors reported the destruction of coconut fiber due to varied management practices. In marsh soils,

destruction of the filter was greater in grass land than in aerable land. Mineral fertilizers, slurry and lime, and the ploughing up of grass land did not effect destruction. Farm yard manure increased destruction highly, as a result of its effect on the C/N ratio of the soil. About 10 per cent of the destruction was not chemical or microbiological but was caused by mechanical stress during drain laying.

Scheffer and Kuntzo(1979) reported that from the experiments the drain filters rich in tannin the average discharge during 1973-1976 from drains laid in 1973 in a sandy Gley-podzol, was the same with Antoe and Due filters, although the Ke content of the filter and clogging of the drain openings were greater with Due filter. In autumn 1976, the percentage contents of HCl-insoluble material and wash in the sludge in the drain were higher and the percentage content of Fe in the sludge was lower with Antoe than with Due. Application of pig slurry to the soil increased the amount of sludge in the drain and the Fe content of the sludge. The slurry promoted decomposition of Antoe.

Hove (1982) reported the results of Laboratory and field experiments. The use of a suitable filter was of importance for the efficiency and life-span of drains. Filter of large volume (saw dust, fibrous peat and gravel of suitable partial size distribution), organic materials, should not be used where the drain line would be permanently submerged. Saw-dust and peat used as drain filters showed about 50 per cent decomposition over a period of 20 years.

Burghardt (1983) examined 60 coconut filter drain filters in marsh soils. Decomposition proceeded from the exterior inwards, at a rate of 1 mm/year. The decomposed organic filter material was partly deposited in the drain pipe. The deposition of soil material in the filter reduced the volume of filter pores by 3-9 per cent per year.

2.5.2. Inorganic Materials

The practice of covering sub-surface drain with a layer of top soil before back filling the trench actually provides drains with permeable envelope material. Surface soils in poorly drained areas tend to have a well developed, stable and permeable structure. In stratified soil drains are blinded by shaving the coarsest textured materials in the soil profile down over the pipe. Blinding is a standard recommended part of drain installation (Hove et al., 1960; Irwin, 1960, USDA soil conservation service, 1971; p.4-114), especially in humid regions

The most common and widely used envelope materials are naturally graded coarse sand and fine gravel. Such materials are widely available and are as permanent as the soil itself. The envelope materials used is primarily pit run sand with a minimum fines. In some instances (Univ.of Calif, 1965) uniform sized materials such as pea gravel has been recommended for coarse soil. Experiments by Lembke and Bucks (1970) and ASAE (1967) have shown that a graded fine gravel or sand envelope

placed around a sub-surface drain helps to protect it from sediment and improves its performance.

Blishay et al. (1975) reported from a sand tank experiment under ponded water condition to compare the effectiveness of three filters, either flex straw of 1-cm thickness, or conditioned sand with bitumen emulsion, or conditioned sand with PAM solution as envelopes of 4-cm thickness put around the drain tube. All of these treatments had prevented the silting-up completely. After 24 hours, when conditioned sand was used as filter around the drain tube, the water discharge was 1.3 times bigger than from the drain without filter, but 1.16 times less than using flax straw.

Until recently it has been necessary to excavate a trench for sub-surface drain installation. Introduction of flexible pipes made possible the use of drain flows. Some observation indicates that trenching and back-filling play an important role of the performance of sub-surface drainage systems. Fausy and Hundal (1980) made review of the studies made and they found that there were theoretical evaluation and field experiments. The particular conditions under which field evaluations were made are often difficult to establish and therefore, general conclusions are often difficult to formulate. In their opinion, the information available supports the following general conclusions: (1) Theoretical analysis always show that permeable trench back-fill increases drain flow rate and water table draw-down rate.

(2) Permeable trench back-fill enhances the removal of surface water and water in the cultivated soil layer. This might be short lived depending on subsequent management of the soil, (3) Permeable back-fill had little effect on mid-point water table draw-down rate in uniform soil, (4) Replacement of natural soil with stabilized soil aggregates, gravel, or peat as the trench back-fill does not change the conclusion (2) and (3) above, and was economically questionable, (5) Permeable trench back-fill was beneficial where shallow permeable layers or mole drains need a permeable hydraulic connection to a deeper drain, (6) Information comparing trencher installed drains with plow installed drain was insufficient to determine which was best from an efficient drainage stand point.

Willardson et al. (1978) conducted a study in Coachella valley of California to evaluate drain envelope materials on three types of drain pipes, namely, clay concrete and corrugated plastic drains. They have also tested three back-fill settlement, namely (a) initial flooding of the trenches for consolidation with the drain outlets open, (b) initial flooding with the drain outlets closed, and (c) sprinkled with the drain outlet closed. The two envelope materials used in treatment were: (a) pitrun and (b) pitrun with 5 per cent field soil added. They found that there was no essential differences between the more gentle back-fill settlement by sprinkling and the abrupt consolidation by flooding. The discharge rate from the drains with dirty envelope material was decreasing and the drains with clean envelope material had a continuously increasing rate.

The increase was not directly proportional and approximately 53 per cent of the water applied which was discharged from the drains. The drains having clean envelope materials; never had a water table standing above the drain. However, the water table frequently stood directly above the dirty envelope drains.

To investigate the biological effects, a special test was conducted in which water was applied continuously. The drains were cleaned by high pressure jetting equipment. The 375-ft long drains having dirty envelope materials produced approximately 0.5 cubic feet of sand and silt, and the clean envelope material drains produced about 0.2 cubic ft of clean sand. The jetting operation considerably improved the performance of both the clean and dirty envelope material drains. The water table was lowered and the discharge rate increased by jet cleaning for the three drains with dirty envelope materials.

The conclusions were that as little as 5 per cent of field soil in the envelope material seriously reduced drain envelope performance, and flooding trenches for consolidation of back-fill material does not significantly affect drain envelope performance, and also high pressure jet-cleaning of drains improves hydraulic performance of drain envelopes.

Beltram, J.M. (1978) studied the drainage and filter materials in saline silt clay soils of the Bardenas area, Spain. A ten hacter experimental field was established in 1974 in the

Bardenas irrigated area. Using clay pipes with and without gravel filter and corrugated PVC pipes without filter and with gravel, barley straw, esparto fiber and coco-fibre. The entrance resistance to water flow and equivalent drain spacing were determined.

Blinder et al. (1978) made model study of a drain filter for establishing the hydraulic and functional efficiency, using special laboratory equipment, the influence of water movement within five filter materials (gravel, glass fibre, polyethylene gravels, peat, glass wool) on drain discharge was analysed. Hydraulic characteristics are given for glass wool and polystyrene gravels, relating them to hydraulic conductivity and resistance of the filters. Calculation of head losses created by the drain filter was demonstrated.

Hundal et al. (1980) reported that at Ohio a highly permeable back-fill was created by trenching and back-filling and by subsoiling directly over drain installed 6 years earlier in clay soil. The drains were 5-cm diameter plastic tubing installed at 40 cm depth. The site had a cover of grasses and legumes. Trenching and back-filling increased flow rates by a factor of two to four during periods of ponding but had no effect on flow rates after ponding ceased. Trenching to drain depth gave greater flow rates than trenching to within 5-cm of the drain. Trenching and back-filling had no water table draw-down.

After 90 weeks, drain flow rates were essentially unchanged by trenching to within 5-cm of the drain but had declined 20 to 50 per cent with trenching to the drain. Sub-soiling to 16, 26 and 34 cm depths gave step-wise increase in drain flow rates during ponding. Sub-soiling to 34 cm resulted in flow rates that were approximately the same as trenching drain depth. The flow rates for sub-soil drain have not declined significantly after 92 weeks.

Taylor et al. (1981) reported from investigation that the permeable back-fill were created directly over drains installed 8 years earlier on a poorly drained, cultivated lake bed clay soil in Ohio by replacing soil with gravel or by trenching and refilling. The permeable zone extended from the bottom of the plow layer to the drain. The addition of gravel increased drain flow rates by a factor 2 to 3 during period of ponding but no effect on flow rate under non-ponded conditions nor no water table drawn-down rates. The ponded flow rates for drains with gravel have not changed after 3 years. During the first year, trenching and refilling had the effect on drain flow rates as gravel. During the second year, the ponded flow rate declined to only 50 or 60 per cent of those with gravel. Sediment concentration in the drain water were unaffected by back-fill alteration.

Hautala, E. and Menefee, E. (1981) reported that a montmorillonite type clay was sintered at 800°C to form a permeable gravel substitute suitable for use as a drainage envelope material.

The sintered soil was water-stable with deformation characteristic that resembled sand more than the original soil. Hydraulic conductivity of the soil was increased more than ten-fold (10) by sintering. The economics of sintering may be favourable depending on the cost of mixing and hauling gravel from local deposits.

Dennis, C.M. (1982) reported that new manous types of permeable materials were used over field drainage pipes, principally as hydraulic connection between mole drainage channels and the pipe itself. The data indicates that materials have simply been required to be clean and with in a certain size range. Material relation with mechanical strength, size and finness content were also briefly discussed. It was demonstrated that a more detailed performance based specification may not be written which covers the majority of materials encountered.

Broughton et al. (1982) reported from their studies that gravel performed satisfactory at allowing water enter the drain tubes and in preventing the entry of fine sand, when compared to Typun (spun bonded polypropylene) and the knitted nylon sock. Drain tubes without envelope filled with fine sand, the 0.7 mm wide slots in one kind of drain tubing were not small enough to keep the sand from flowing into the tube. The Reemay and ceren envelope materials suffered much abrasion damage in transport and handling before installation and were very flimsy when dug up in the field. Ochre deposits grew both inside and outside the drain tubes.

2.5.3. Man made material:

The unavailability of natural sand and gravel for use as envelope material in some area has led to a search for manufacturing process materials that could be used as substitute. The man made materials that has received the most attention is fiber glass which is relatively inexpensive and can be manufactured in large quantities of exact specifications. The fiber should be made of line borosilicate glass.

Overholt (1959) reported that the results of a tank experiment using a fiber-glass filter materials. The soil was fine sand that had given some sedimentation presence in the field installation of drains. A thin sheet of fiber glass was placed over the top 75 per cent of the drain circumference for some tests and completely around the drain for others. A tile drain with no fiber glass over 75 per cent of the circumference had a flow rate 1.7 times that of unprotected lines. The pipe with a complete wrap produced essentially silt free water and had a discharge rate 2.26 time that of unprotected pipe. The fiber glass material weighed 2.6 kg per 100m of pipe. By way of comparison, in some area of California 53,500 kg of sand per 100" specified length.

Nelson (1960) tested some randomly reinforced and longitudinally reinforced fiber glass sheets in the laboratory. His findings indicate that random reinforcing is better.

He recommended as a conservative stability criterion that 50 per cent size of the soil particle be equal to or greater than the average diameter of the openings in the fiber glass sheet. He developed a curve that could be used to determine the amount of a given soil that would pass through a fiber glass sheet, and presented a graph based on particle size analysis that could be used to determine whether fiber glass would adequately protect a drain placed in a particular soil. Nelson also noted that careless back-filling could cause rupture in the fiber glass sheet and recommended carefully placing a 5 cm cover of soil before back-filling.

Bures and Pillsburg (1963) conducted test on the longitudinal permeability of fiber glass sheets. They concluded that fiber-glass sheet around a drain would improve water movement towards the openings.

Watts and Luthin(1963) published the results of tests of permeability of 2.5 cm thick fiber glass mats. Compressing the mats to simulate a back-filled drain reduced the hydraulic conductivity of the mats; however, the compressed mats were as permeable as natural sands. Shull (1967) found fiber glass mats to be superior to fiber glass sheets in filtering properties.

Hansan (1963) found that drains in a number of soil in vermont would be better protected with a fiber glass sheet than with the local naturally graded gravel in current use.

Comparisons (Lyons et al., 1964) have shown that coarser or graded granular materials permit higher drain discharge than do fiber glass sheets under comparable conditions. In the Western USA, use of fiber glass mats and sheets as drain envelope materials has been diminishing in recent years except in the lower Rio grande Valley of Texas.

Hollis Shull (1967) conducted studies to determine the amounts of soil retained by the glass fiber mat as a function of soil particle size. He found that as the soil particle size increased from very small to about 0.05 mm, the percentage of soil retained by the filter sample increased rapidly as soil particle size increased. A few tests conducted with soil in the particle size range 0.074 to 0.147 mm, resulting in no soil moving through the filter samples. The entrapped soil particles had little effect on hydraulic conductivity of filter mat. It was concluded that the soil particles larger than very fine sand do not easily move through glass fiber mat material of the types tested.

Rektorik (R.J.Rektorik, 1971, Personal communication) reported that since 1965, where USDA Soil Conservation Service specification began requiring envelopes in all drains, 90 per cent of the drains in the lower Rio-grande Valley have been installed with glass mat envelopes. The other 10 per cent have been installed with gravel envelopes. Approximately 200,000 ft (66000 m) of drains are installed there annually. Rektorik recommended careful selection of the type of fiber glass used.

Fiber glass mats 2.5 cm thick are better than fiber glass sheet of 0.05 cm thick; coarse fiber glass and the glass should be of the borosilicate type.

Kent et al. (1972) developed and tested pre-fabricated filter fins for sub-surface drains. The use of such materials were justified based on premise that various materials placed around subsurface drain pipes for the purpose of filtering fine sand and silt from the inflowing water. The openings in the pipes were sometime covered with corn cobs pieces of turf or straw, but these materials deteriorates, with time and may loose the filtration capabilities. Gravels and coarse sand were often used in regions where available, but they pose difficulties in retention and placement. Fiber glass materials in the form of cloth tends to tear and mats of these materials were clogged by certain chemicals. A prefabricated under drain system that fulfils the requirement of free water-flow and exclusion of soil. The ground water is collected by a filter media, transmitted to the pipes as quickly as it can flow at of the deposit, but soil is excluded. This new system was made from synthetic materials and meets the requirements for an ideal envelope. The pre-fabricated filter media consists of a fin having vertical channels and covered with a fine mesh cloth. The channels were connected of the pipe by inserting the fins into longitudinal slots cut in the pipe. Water enters through the cloth, return down the channels into the pipe and away from the site. The performance indicates that the discharge water from the drain was closely

related to the amount of rain and the ground water conditions. The soils in which these under drains were placed highly stratified and non-homogenous and no theory was found adequate to predict the flow. Large out-flow of the drains were observed in spring and fall. During the summer months when the ground water table dropped, the flow stops or reduce to a trickle. The water coming from the drain was clean, indicating the soil was being filtered properly. There was no apparent decrease in discharge due to clogging. The cost of the material was approximately (\$ 0.30/ft) (\$1.12/m) for a 4-in hard plastic pipe, \$ 0.15/ft² (\$1.40/m²) for vinyl tube and \$ 0.575/ft² (\$1.40/m²) for vinyl tube fence and \$ 0.575/ft² (\$ 0.46/m²) for nylon chiffer. This adds up to a total material cost of \$ 1.55/ft (\$ 05.08/m) for a 5 ft (1.5 m) high drain system.

Hermesmeier (1976) reported that in many areas suitable gravel for drain envelope is becoming scarce and expensive, but the synthetic materials, now available may provide low cost drain envelope and may also simplify the installation of plastic drains. Comparison of laboratory studies on some of the physical and hydraulic properties of number of synthetic materials and gravel as drain envelope were reported. The effect of water table and soil salinity on the envelope material 4 years after installation were reported satisfactory.

Willardson et al.(1979) reported that synthetic drain envelope material currently available economically showed equal effectiveness. The material function primarily as mechanical

support for soil-drain openings interface. Soil had a limited characteristic resistance to internal hydraulic gradient. Flow causing gradient of the particular soil would result in failure of the soil structural skeleton and the drain envelope.

Burghardt (1979) reported from studies on plastic drain filters, that the hydraulic properties (resistance to inflow of water) and filter characteristics of drain pipes of 50 mm diameter without coating, with coconut fibre coating or polypropylene fibre. Filter pipes coated with coconut fibre and polypropylene fibre showed similar filter and hydraulic qualities. Best results were achieved using fibers of different gauge. Filter efficiency could be improved by matching fibre gauge to soil texture. Adequate thickness of the fibre coating was required.

Broadhead et al. (1980) conducted laboratory test to investigate the effect of synthetic envelope opening size on envelope performance. It was shown that the hydraulic failure gradient and the volume of soil passing on envelope depended on the envelope opening size and soil uniformity.

Wilardson et al. (1979) reported from their study that plastic drain tubing, surrounded by soft envelope material such as styrene plastic beads or other soft materials, deforms under soil loads. The amount of deformation was related to the

respective relative stiffness of the tubing and the envelope materials. Compression of the soft envelope materials affect the permeability. Vertical displacement of the drain would also occur. Drain tubing deflection in a soft envelope was less than tubing deflection of the soil.

Younghaichar et al. (1981) reported from their studies the hydraulic characteristics of non-woven filter fabric using a laboratory permeameter to simulate a soil/fabric sub-surface drainage system. By utilizing information of discharge, pressure permeability and fibre properties, conclusions were drawn concerning the correlation between the soil and the plastic filters. In sand with large concentration of fine particles, the migration of the fines was minimal and the soil controlled the hydraulic response of the system regardless of the filter fabric used. In fine soil where the water velocity was greatly reduced, bacterial activity within the soil could cause erroneous results. Some design criteria were developed for the use of plastic filter fabrics.

Theriault et al. (1982) used filtering drain as a new protection against material infiltration in sandy soil. Twenty four drainage systems were examined and data collected showed that the filtering drain was effective against infiltration of material where installed in sandy soil.

Boardheed, R.D. (1983) conducted a laboratory test to evaluate the ability of the synthetic envelopes to prevent sediment from entering sub-surface drains. A series of woven nylon screens with precise sized openings were used in order to determine the effect of envelope openings on soil movement. Nine sand samples in the sediment problem range were fabricated and tested. The quantity of sediment passing a screen relative to the hydraulic failure gradient was used as a measure of the stabilizing effect of screen. Sand stability was found to be a function of the envelope opening size, the D_{60} size of the sand and the particle size uniformity. It was also shown that the drain sedimentation could be prevented by selection of envelope openings size such that the envelope openings was less than (above) 2-4 times the diameter of the 60 per cent (D_{60}) size of the sand particle. For greater openings, sediment movement through the envelope was a function of the imposed hydraulic gradient in relation to the "failure gradient" of the particular sand mixture. At opening size less than 2.4 times the D_{60} sand size, sediment was essentially completely restrained regardless of the hydraulic gradient.

Fisher and Jarrett (1984) reported from their study of six synthetic filter fabrics for particle retention and water transmissibility when subjected to a flowing soil suspension. Four replicated tests were performed with sand, coarse silt and silt clay soil suspensions. All fabrics successfully removed sand particles ($> 75 \mu\text{m}$) from suspension. Various amounts of

coarse silt particle (75 to $37\text{ }\mu\text{m}$) were removed by the fabrics tested and these filter fabrics were generally ineffective filters of silt clay particles ($<37\text{ }\mu\text{m}$). Soil accumulation on a fabric was found to be directly influence a filter fabrics ability to transmit water flow. Thus, a certain degree of compromise exists between a fabrics ability to retain soil while transmitting water flow. None of these fabrics performed well in retaining silt or clay from flowing suspensions.

2.5.4. Drain Envelope Installation:

As water approaches the drains through openings whether through a relatively homogenous soil or through more porous envelope materials, the flow velocity increases due to convergence. The velocity increase is related to the cross-sectional area of the flow and the hydraulic gradient. Luthin et al. (1968) showed that gradient as high as $1/12\text{ cm}$ was developed at the surface of a completely permeable drain. Water flowing at high gradient through granular materials does not remain in the viscous flow regime. At high gradient inertial energy losses occur and therefore, flow does not follow Darcy's law. Researchers in India (Anandakrishna and Varadarajulu, 1963), reported that flow of water in sand at gradient greater than 1.0 is not laminar. They suggest that energy losses may be more greater than expected, which would result in lower flow rates from drains.

Increasing the hydraulic conductivity of the converging flow area adjacent to the drain and the drain openings, by placement of permeable envelope material, would reduce velocities and gradients. The efficiency of the hydraulic system would, therefore be increased.

2.5.5. Envelope Thickness:

One of the benefits of envelope placement is the increase in permeability along the pipe that enable water to flow more freely to the cracks or perforation. The effect is similar to converting pipe from one with limited openings to one that is completely permeable. This increased permeability can probably be obtained with an envelope of 1.5-cm thick. Increasing the diameter of the envelope reduces the water flow velocity at the soil envelope interface, thereby decreasing the probability of soil particle movement. The optimum thickness of envelope material around a drain has not been precisely determined. Kirkham (1949) has shown theoretically that increase of drain diameter will increase in flow, if the permeable envelope placed around the tiles. But there are practical limitations to increasing envelope thickness. The perimeter of the envelope through which flow occurs increase as the first power of the diameter of the envelope, while the amount of envelope material required increased as the square of the diameter. Doubling the diameter of the envelope and consequently decreasing the inflow velocity at the soil envelope interface by half, would require four times the volume of envelope material.

Recommendations for drain envelope thickness have been made by various agencies. The U.S. Bureau of Reclamation (Maierhofer, 1965, Supra) recommends a minimum thickness of 10 cm around the pipe. The soil conservation service of U.S. (1971) recommends an 8 cm minimum thickness. The Edward E Johnson Company (1966) recommends a minimum thickness of 20 cm as a gravel pack for a well. Des Bouvrie (Pillsbury, 1967) related envelope thickness to a envelope aquifer ratios at the 50 per cent grain size. Des Bouvrie suggested a 1.3 to 2.5 cm thick envelope for an envelope aquifer ratio of 12.0. For an envelope aquifer ratio 12.0 to 24.0 the envelope thickness should be 8 cm. Envelope quifer ratio of 24.0 to 28.0, 28.0 to 40.0 and 40.0 to 52.0 would require envelope thickness of 15, 23 and 30 cm, respectively. Further research is needed to precisely define envelope thickness requirements.

Bishay et al. (1975) reported from a sand tank model experiment under ponded water condition effect of thickness of filter. The filter used were 1-cm thick straw, conditioned sand with PA solution and conditioned sand with bitumen emulsion of 4-cm thickness. All the treatments have prevented the silting up, completely. After 24 hours, the conditioned sand used around the tile gave the discharge of 1.3 times higher than from the drain without filter materials, but 1.16 times less than flax straw.

2.5.6. Drain Envelope Design

The general procedure for designing a drain envelope for a given soil is to make a mechanical analysis of both the soil and the proposed envelope material, compare the two particle size distribution curves and decided by some set of criterion whether the envelope material is satisfactory. The criteria proposed by Terzaghi (U.S. Corps of Engineers, 1941) for what he termed a "filter" were (1) the particle diameter of the 15 per cent of the filter material should be atleast four times as large as the diameter of the 15 per cent size of the base material, (2) the 15 per cent size of the filter material should not be more than 4 times as large as the 85 per cent size of the base material.

Bertram (1940) conducted tests on natural sands and on Ottawa sand, on crushed quartz, and on crushed quartz and Ottawa sand to determine the critical ratio of the 15, 85 and 50 per cent size of base soil and envelope material. Using a graded base material and uniform envelope material, Bertram found the critical ratio to be 6 for 15 per cent size of envelope to the 85 per cent size of the base and 26 for ratio of the 15 per cent size of the envelope to the 15 per cent size of the base.

An investigation of the envelope requirements of under drains by the U.S. Corps of Engineers (1941), using laboratory and tank tests, led to conclusions not greatly different from Terzaghi's criteria. It was also found that curves for filter and base materials should be approximately parallel to minimize washing of the base material into the filter material.

K.P.Karpoooff (1955) of the Bureau of Reclamation published the results of extensive laboratory tests of design criteria, as (1) the ratio of the 50 per cent grain size filter material to the 50 per cent grain size of the base material should be between 5 and 10, for uniform grain size filters, the ratio of the 50 per cent grain size of the base material should be between 12 and 58, and the ratio of the 15 per cent grain size of filter material to the 15 per cent grain size of base material should be between 12 to 40, for graded filter materials. (3) In addition to ratio limits, he recommends that curves for base material and filter should be parallel. Also, filter must not contain more than 5 per cent of material sizes smaller than 0.07mm, and the maximum size of perforation or joint openings of the drain pipe should be selected as one half of the 85 per cent grain size of the filter material.

Jusela (1958) reported that specification for envelope gravel in fin-land also required that the 15 per cent size of the envelope be atleast four times the 15 per cent size of the soil to assure adequate permeability, and further specifies that the 15 per cent size of the envelope should not be more than 3 times the 85 per cent size of the soil to prevent movement of fines into the drain.

Kruse (1962) reported on investigation of gravel pack design where the criteria used were based on pack aquifer ratio of the 50 per cent sizes. The uniformity coefficient was also considered as a design factors.

<u>Aquifer</u>	<u>Gravel pack</u>	<u>Pack Aquifer ratio</u>
Uniform	Uniform	9.50
Uniform	Non-uniform	13.50
Non-uniform	Uniform	13.50
Non-uniform	Non-uniform	17.59

Kruse indicated that 1.78 uniformity coefficient for uniform material.

The soil conservation service (1971, p.4.93 ff) had combined the results of the research reported above for evaluating base and envelope materials. The 50 per cent size limits for the envelope were obtained as 12 and 58 times the 50 per cent base material size, the 15 per cent size limits were 12 and 40 times the 15 per cent base material size. All of the filter material should pass the 1.5 inch sieve, 90 per cent should pass the 0.75 inch sieve and not more than 10 per cent should pass the No.60 sieve. For uniformly graded filter and base material, the safe stability ratio was given as:

$$\frac{15\% \text{ filter size}}{85\% \text{ base size}} < 5$$

For placement around perforated tubing, the 85 per cent filter size should be no smaller than one-half the perforation diameter.

Pillsbury (1967) on the use of the standard deviation of the envelope material as one criterion of effectiveness of a drain envelope. The standard deviation was calculated from the difference between the 95 per cent and the 50 per cent size

of the envelope divided by 1.645. The other criterion used was the 50 per cent ratio of the filter to the aquifer material. Based on his observations in Imperial Valley of California, recommends an envelope aquifer ratio of less than 24, and a standard deviation greater than 1.00 mm would be satisfactory envelope material under most conditions.

An investigation by Sovern (1969) revealed that the design used by the Bureau were conservative. The Bureau of Reclamation had done some basic development work on drain envelope materials (Karpoff, 1955). Their present design procedure was based primarily on the hydraulic conductivity of the envelope material and the length of the drain pipe. The Bureau also specifies a 0.3 cm gap width at the joint for both tongue and groove and bell and spigot pipe. The design criteria was based on (Maieshofer, 1965) premise that the hydraulic conductivity and cross-sectional area of the envelope must be sufficient to receive all the incoming ground water without developing a back pressure.

Recommended USBR limits for gradation of envelope material

Gradation analysis, per cent passing sieve openings				
0.59 mm	2.38 mm	4.76 mm	19.1 mm	38.1 mm
0	50	98	100	-
0	4	6	75	100

Dierickx (1982) developed a laboratory equipment which assists the effects of down-ward and upward flow in soil envelope material system. This would help in assessing the need of envelopes.

2.6. Silt Discharge and Silt Accumulation in Tiles:

The movement of rainfall and detached particles or absorbed chemicals through a soil profile to a sub-surface drain is a complex hydraulic and transport process. These particles or chemicals which may eventually enter lakes and streams can contribute to accelerated actrophication, interfere with fish propagation or enter into numerous other water quality problems. Many factors influence the mechanisms involved the transport process, state of water flow (saturated or unsaturated), velocity of flow, physico-chemical effects on soil particle bonding, absorption-desorption of chemicals, diffusion, and chemical and biological transformations. At the field level factors such as soil cracking, freeze-thaw conditions, non-homogeneity and plant growth serve further complicate effects to describe sub-surface drainage transport mechanisms. Most of these factors have been studied either in the laboratory or theoretically for ideal-controlled conditions. However, for the field scale and multivariable systems, knowledge is still quite limited. Existing research has dealt primarily with water movement and not water quality, since root zone drainage is the primary incentive for subsurface drainage.

Bodman and Harradine (1939) studied the mean effective pore size and clay migration during water percolation in soils. They found that the soils ranging in texture from loamy sand to clay loam, would permit the movement of the finer silts (less than $2\ \mu$). The single soil examined would prevent movement of any but the finer clay ($14\ \mu$). The stockton clay permitted no measurable movement of any particle size class. Loamy sand showed a significant and fairly deep migration of material within the $50 > 5\ \mu$ class. The $5 > 2\ \mu$ and $2 > 1\ \mu$ classes, showed no regularity of trend in their depth distribution within any of the columns. From these, it was concluded that the magnitude of the pore diameter were associated with occurrence of particle migration. Decrease in water permeability with time appear to be the result of pore-blocking in the columns partly by dispersed and deeply migrated and partly by locally dispersed and locally migrated fine particles. The intensity of migration depends upon both physical and chemical properties of the soil concerned.

Brownscombe (1962) made field evaluation of tile drains laid with organic blinding materials. He found that tile with strain blinding gave no movement of mineral soil particles into or through the straw. Saw-dust particles and wood chips probably facilitated the entry of water by providing a porous medium near or connecting with the tile joints. His study reveal that neither wood chips nor straw were placed on tile laid in unstable sandy or silty subsoils. Therefore, the evaluation does not indicate the true filtering effectiveness of the organic materials in these unstable sub-soils. Graded materials

and saw dust or wood chips produced high water discharge rate. There was no statistically significant difference in soil discharge and the rate of water discharge for straw and saw-dust blinding materials. The corn-cobs were not effective in limiting soil discharge.

Meckenzie and Arnold (1962) developed a chemical method for rectifying tile systems clogged with precipitated oxide of iron and manganese. One method involves treating affected line with a solution of 0.3 per cent sulfuric acid, water and a concentrated solution of sodium metabisulphate, were simultaneously introduced into the upper end of tile laterals in the desired ratios. Meekerzic later found that injecting water and gaseous sulfur dioxide at a rate of one pound per 7.5 gallons of water was equally effective in dissolving mineral precipitation. Flow rate at the tile out-let in treated system had increased 2 to 250 times depending on how severely the system was affected.

Mackenzie, A.J. (1962) found from his studies that until researchers find ways for preventing the formation of the mineral deposits with tile lines, a chemical treatment every 4 or 5 years should help to keep the detrimental effects of such deposits at a minimum.

Spencer et al. (1963) reported that the rapid expansion of the florida citrus industry had resulted in almost complete utilization of the well drained soil considered most suitable for citrus. Sub-surface drains to maintain the water table

at least 3-ft below the surface of the soil was necessary for optimum growth of citrus trees. A red sludge like deposit was found in several tile systems and this deposit was found in several tile systems and this deposit prevented the tile from functioning properly by blocking the passage way through water entering the tile. The deposit was found to be due to primarily of iron bacteria which oxidise and precipitate reduced iron in the drainage water. Chemical analysis indicates a large proportion of the material was organic, probably, bacterial cell bodies and waste products. The inorganic portion was mainly hydrated iron and aluminium oxides. Bacteriological studies of the material indicated the following genera of bacteria were responsible for the formation of deposits. Gallionella leptothrix, Rhizobacillus crenothrix and Cladethrix. The deposits occur in both bituminous pipe and clay tile whether installed in saw-dust filter or wrapped fiber glass. The relative amount of deposits in tile at various locations were related to the amount of reduced iron extracted from the soil with an aluminium chloride solution.

Grass (1969) reported after investigation at the Imperial valley of California, the rise of water table that caused the reduced crop growth. The tile lines contained red and/or black precipitation which filled the joints of the lines, preventing water entry. Mackengic and co-workers found that the black deposits were primarily manganese compounds, containing 52 to 73 per cent manganese oxide and 0.7 to 1.9 per cent iron oxide.

Red deposits primarily iron compound varying from 35 to 61 per cent iron oxide and 0 to 14 per cent manganese oxide. Some of the tile system had ceased to function properly because the accumulated red and black precipitation which filled tile joints preventing the entry of water into the tile. They found that red material was primarily iron oxide compounds, whereas the black precipitation were primarily manganese oxide compounds. Silt or rats had also caused tile fracture in the valley. They also found that the formation of red or black deposits in tile drain was not related to location, soil type, kind of tile material or length of tile drain that had been in service.

Lyman et al. (1970) studied to suggest means to control sediment from entering tile drain. Laboratory tests were conducted using sands and glass beads to develop design parameter. A fraction of the Stokes law of settling velocity of the particle sizes to be excluded from the drain had been suggested as a reference velocity for design. A channel velocity of one-tenth of the settling velocity was tentatively recommended as being sufficiently low to prevent movement at the opening of the channel. Under adverse condition $1/80$ of the settling velocity was suggested. The velocity control method of sedimentation prevention was not a filtering process. It operates on the principle of separation of water from soil without the undesirable plugging and water impounding action of filter.

Ford (1979) reported that only limited success had been obtained by the method of adding two per cent sulfur dioxide in waters in Florida. A major reason was inability to maintain the acid within the pipes for the necessary holding period.

Grass and Meckenzie (1972) reported that high pressure jet cleaning drain had some disadvantage as (100 to 1300 psi) jetting pressure caused damage to gravel envelope by disorienting the sand and gravel. The gravel and sand also flowed into drains.

Gulati et al. (1970) found that saturated uniform porous media with particle diameters 0.1 mm to 0.25 mm were the most critical for causing sedimentation in subsurface drains because hydraulic conductivities were high and the velocities to set the particles in motion were low. The upward critical velocity required to set sand bead particles in motion were about 1 per cent of stokes settling velocity. For glass beads 0.026 mm to 0.425 mm dia average critical velocities were 0.0011 to 0.132 cm per sec, respectively. The average critical velocity for fine silica sand with the average diameter of 0.213 mm was 0.041 cm per sec.

The flow media-water interface at the level of the drain center, the ratio of the cover length 1, below the interface level to the interface width, was more effective in obtaining a uniform velocity distribution across the interface than the

shape or width of the lower end of the cover with an L/b ratio of 1.5, the velocity variation at the interface was not more than 10 per cent.

The average critical velocity in the up-flow channel increased with a decrease in the interface width. This effect was more pronounced for silica sand than for spherical glass beads.

Grass and Mackenzic (1972) reported that the restoration of sub-surface drain performance was of vital importance in preventing soil salinity build-up. Malfunctioning tile drains must be quickly recognised by effluent flow, water table elevation changes and soil profile or drain effluent salinity increases. Deposits of iron and manganese precipitates in tile drains clog the openings through which water enters the tile. This created a serious hazard to crops as a result of rising water tables and increased salinity. Chemical treatment with a mixture of 2 per cent SO_2 , by weight, gas and water was successful in restoration of drain efficiency by dissolving both Fe and Mn tile deposits. Other types of minerals deposits which had been encountered were gypsum (CaSO_4) and travertine (CaCO_3) gypsum deposits in the form of small crystals could be easily removed by high pressure water jetting equipment. Travertine would be susceptible to acid treatment, but chemical method for removing gypsum deposits had not been developed yet.

Accumulations of very fine soil sediment occasionally caused tile failure. They were most effectively removed by high pressure jetting equipments. High pressure jetting equipment was also removed accumulated fine roots, but long flexible rotating rods with cutting blades were best for removing larger roots.

Schweb et al. (1973) reported that sediment, dissolved solids, nine chemical elements or iron, five pesticides, electrical conductivity, pH and BOD in tile drainage effluent and in surface run-off were measured from one-half acre plots on Toledo silt clay soil near, Ohio. Sediment losses were about the same in the tile effluent and in the surface run-off. Sediment losses from tile and surface drainage water were several times greater for conventional tillage than for no tillage. Nitrate nitrogen losses were generally low (about 13 to 19 lbs per acre per year). Phosphorus losses were less than 1.5 lb per acre per year, but they were greater in the surface run-off than in the tile effluent. Potassium losses in surface run-off were 10-13 compared to 4 lbs per acre per year in the tile effluent. CaCO_3 , Cl and Na losses were higher in the tile effluent than in the surface run-off.

Bloomfield et al. (1973) reported from field investigation two distinct forms of ochre were known to occur in field drains. One form which was most common in wet peaty areas was caused by the growth of filamentous iron bacteria. The second

form was associated with *Thiobacillus ferrooxidans*, and occurs where the soil contains pyrite. Contrary to previous reports, liming decreases the rate at which pyrite was oxidised in soil and by decreasing the amount of iron entering the drains in a given period, should significantly increase the active life of the drainage system. Regarding liming was probably preferable to a single large initial dressing.

Trafford (1973) reported that ferrous iron was detected in the drainage water shortly after package through the cores, but oxidation occurred so quickly that none could be detected after an hour or so. The presence in the drains of active ferrous iron oxidizing bacteria shows that iron must enter the drains in the reduced form. The greater part of the sulphate and pyrite derived iron is retained in the soil in the form of basic sulphates.

Hundal et al. (1973) found that sediments in subsurface drainage systems were characterised in cultivated organic soils in the Willard Marsh. The permeability of the subsoil was quite low, ranging from 0.1 to 0.4 cm/hr. The plow layer permeability varied from about 1.5 to 2.5 cm/hr. Sediment from drain ranged from 100 per cent organic material to a mixture of organic and mineral materials. A maximum iron content of 35 per cent was found in an ochreous sediment. Ferrous iron in the soil increased markedly below drain depth. Sub-surface drainage appears to be impeded by two principle factors, one is the low permeability of the sub-soil and other is the accumulation of organic sediment and Ochre (iron) in drains.

Grass and Willardson(1977) conducted study and reported that two types of nozzles were used to clean the tile drains. The cleaning nozzle used mainly for removing silt and mineral deposits requiring a pump pressure of 1250 psi and a nozzle pressure of 700 psi; and the penetrator nozzle, used mainly for removing root plugs and the larger, more difficult accumulations of silt requiring pump pressure of 1000 psi and a nozzle pressure of 500 psi. A dewatering pump was used to remove the dislodged material arriving at the tile opening. The jet cleaning operation also located the breaks in sub-surface drain lines.

Ford (1974) found that there was no sand infiltration using gravel envelope 0.75 to 1.50 inch thick with corrugated plastic polyethylene pipe employed in drain installation in Florida. A low pressure jet cleaning system could function in 4 to 5 inch plastic drains upto 550 ft in length where ochre and FeS were the primary deposits to be removed. Cleaning of the gravel envelope was accomplished by surging action of the jetting pressure. Jetting should be performed at a slow entry rate and with a hydraulic head above the drain. In sandy areas where sludges were problem, jetting should be performed within two weeks after initial drain flow.

Dierick et al.(1975) conducted sand tank model studies to determine the extent and rate of silting up and water flow through the different perforation lines of corrugated drain tubes without any filter material. The test carried out were (a) normal drain

tube with six opened perforation lines was embedded in the back-fill of the sandy soil, (b) a drain tube with two opened perforation lines at the top, which was called "perforated top" was embedded in the back-fill of the sandy soil, (c) drain tube with two opened perforation lines at one side perforated side was embedded in the back-fill of the sandy soil, and (d) a drain tube with two opened perforation lines at the bottom, which was called perforated bottom was embedded in the back-fill of the sandy soil. The sand discharge from the different perforation lines of the drain tubes were found out. There was a negative relationship between sand discharge and time. During the first 10 minutes, the rate of sand discharge was declined in drains with six perforations, the drains with top perforation and bottom perforation. At the end of 24 hours the silt discharge declined to a negligible constant value. The rate of water discharge from these drains showed a decrease with a minimum value at about one minute, followed by a small increase until about ten minutes. The accumulation of sand inside the different drain tubes after the end of the experiment were, for the normal drain, 1373.2 g/m, for the drain with the perforated top 1296.4 g/m, for the drain with the perforated side and for the drain with the perforated bottom 1112.1 g/m. The constant water discharge values were for the normal drain 0.129 mm/sec for the drain with the perforated top 0.085 mm/sec, for the drain with the perforated side 0.079 mm/sec, and for the drain with the perforated bottom 0.066 mm/sec.

The conclusions were, under ponded water conditions the silting-up occurs through the whole perimeter of the drain tube. The cohesionless sand invading the drain tube had the same particle size distribution as the original sand around the drain tube. The first period in draining after the installation of the drain tubes was very critical of sand discharge influences the amount of water discharge from the drain. The elevation of the accumulated sand inside the drain tube was negatively related to the water discharge. A real drain filled with sand gave a water discharge values less by only 16.8 per cent compared with the discharge value of both the theoretical solution and the conductive paper model. By simulating a real drain, free from sand almost no difference (only 3.7%) was found. While by simulating a drain filled with sand on the conductive paper model a full agreement had been achieved.

Logan and Schwab (1976) reported from their study that the average nitrogen losses were 37, 19 and 0.6 pounds per acre per year in Central Ohio. Nitrogen concentration tended to decrease with time during each growing season. P, K and sediment losses were the result of single drainage events. In the light of the large acreages of poorly drained agricultural land in western and north western Ohio and adjoining states, the contribution of nutrient and sediment losses in tile drainage to total losses may be significant.

Schwab et al. (1977) found that sediment losses from tile and surface drainage system in a lakebed soil in Northern Ohio

were measured for six years (1969-74). Average annual losses were 2359 kg/ha from tile only and 3687 kg/ha for surface only. Calculated losses for the combination tile and surface drainage system were 2672 kg/ha. Annual measured losses ranged from about 100 to 9000 kg/ha. Average net losses from sprinkler irrigation were negligible and usually more sediment was added than removed in the drainage water. Sediment concentration in tile flow from irrigation increased significantly with the antecedent soil moisture content. Concentrations were high at the beginning of flow but decreased to a nearly constant level after 20 hr. A possible explanation for the high concentration was that the sediment moved in suspension with the water and not necessarily through the soil cracks.

Paterson Mitchell (1978) examined erosion deposits in tile drains and they found that the mechanism of silting up of tile field drains in two heavy textured surface water gley soils was characterized physical and mineralogical by deposits of clay, silt and sand, and were distinctly laminated. They appear to be the result of **initial** erosion of the soil. The operation processes seem to be (a) entry of soil through the drain joints, (b) sedimentation in the drain, (c) elution of very fine material. It was possible that this silting up phenomenon was not uncommon in the tile drains of surface water gley soils of Scotland.

Dennis (1978) found that a pipe drain in a predominately organic soil failed within three years. Detailed physical

examination revealed substantial ochre deposits within and around the pipe which were almost certainly the cause of failure. Attempts to restore performance by prolonged sub-irrigation sulphur dioxide treatment, drain rodding and water jetting all met with negligible or partial success.

Talman (1978) studied the interaction between iron ochre and pipe slots, in both clay and plastic drain with different slots. Water was passed through ochrous soil and then through the slots for a period of four months. The percentage of blocking was calculated using visual observations. The results indicate that slot width, the thickness of the materials and treatment with permeable fills, all played significant roles in determining the degree of blockage of the slots.

Grass et al. (1979) made an investigation on soil sediment deposits in sub-surface drainage. Field data on some of the physical and chemical characteristics of soil material found in drain pipes were reported and compared to the characteristics of the adjacent soil in order to establish possible causes of drain failure. Deposits varied considerably in texture and included sand loamy sand, sandy loam, loam silt, silt loam, clay loam and silty clay loam, but particle sizes were predominantly in the medium sandy loam range in most drain deposits. Most silting problems were in clay or bituminous pipes. Salinity was not an important factor in soil accumulation. Particle size distributions of soil deposits in drain, compared with that of

adjacent soil, showed the possible mode of sediment entry into the drain.

Scheffer and Kuntze (1979) in an experiment they found that the Fe content of the filter and clogging of the drain openings were greater with the Duo-filter. In winters, the percentage content of HCl in soluble material and wash in the sludge in the drain were higher and the percentage content of Fe in the sludge was lower with Antoe than with Duo. Application of pig slurry to the soil increased the amount of sludge in the drain and the Fe content of the sludge. The sludge promoted decomposition of Antoe.

Ford (1979) conducted studies on characteristics of slime and ochre in drainage and irrigation system, and they found that bacteria were associated with ochre formation and clogging of small openings. Under controlled condition, ochre formed within a few hours and adhered to glass, polyethylene (PE), polyvinyl-chloride (PVC), neoprene, stainless steel and soil organic matter. Chemically precipitated Fe (III) free of bacteria did not stick under water and the precipitate was porous. Citric acid was an excellent extracting agent for Fe (II) in discoloured ground water samples. The method had merit for estimating the potential for ochre formation drainage sites.

Schwab et al. (1980) found from their studies sediment losses from plots on silty clay soil in North Central Ohio

varied widely over a 10 year period, but averaged 2548 kg/ha in surface run-off, 1529 kg/ha in losses of NO_3 , for N 12.1, 18.7 and 11.2 kg/ha, for P 2.2, 1.2 and 0.8 kg/ha, and for K 31.6, 22.5 and 8.7 kg/ha, respectively for the three drainage systems. The conclusion drawn was (1) sediment losses for all years were highest in surface run-off, less in deep pipes flow, and least in shallow pipe flow (2) year to year variations in sediment were caused mostly by climatic effects and crop cover. (3) sediment losses during the 5-month dormant season with fall plowing for corn and soybeans were small compared with those from base soil and sod crops for the same period. (4) Dormant season losses of N, P and K in drain water ranged from 29 to 57 per cent of the annual losses and dormant sediment losses were 26 to 40 per cent. (5) Rain water falling on the site contained considerably more $\text{NO}_3\text{-N}$, and several times more P that removed in the pipe drain effluent.

Bottcher et al. (1980) developed a computer model, using the GASP IV simulation language to simulate the water flow and sediment movement from a sub-surface drainage system. The model used a one dimensional form of the Richard's equation and a steady state tile flow formula by Toksoz and Kirkham (1961) to express water movement process. The particle detachment position of the model, which was based on a force balance relationship, was controlled directly by the output of the flow position of the model. Data required by the model included rainfall, evapotranspiration, soil properties and drainage system layout.

A comparison of simulated and observed results indicate that the model will reliably predict water yield, sediment yield and sediment concentration curve. However, some difficulty in simulating the actual shape of the flow hydrograph occurred.

Ivarson and Sotak (1980) reported that 60 per cent of agricultural land in Southern Ontario was poorly drained, owing to the sealing of tile drains by Ochre produced by *Gellionella* and *Sphaerotilus*. Ochre sludge occurs chiefly in sandy soil, and bacterial growth was promoted by organic matter. Consequently back-filling of drainage with gravel free of organic matter was recommended to remove sand and silt in drainage water by filtration.

Miller and Munke (1980) studied in the laboratory, the sediment movement into drains from back-fill profiles, and compared with the fine envelope materials with one of the soil. There was a considerable difference in sediment yields between soil types; however, the envelope material had negligible effect on sediment reduction.

Johnson and Kelso (1980) reported that failure of field drains attributable to the oxidation of ferrous iron by soil micro-organisms producing hydrous ferric oxide and hydroxides giving deposits of "ochre" was discussed. Filamentous ochre was derived from the oxidation of ferrous iron in an aerobic environment such as field drain. Pyritic ochre, associated with

more acid conditions, accumulated in drainage systems under soils containing quantities of pyritic minerals.

Samani and Willardson (1981) found from their studies soil stability and density, represented by plasticity index and hydraulic failure of the soil structure occurs. Equation $HFG = \frac{1}{K} \exp (0.332 - 11400K + 1.07 \ln PI)$, in which HFG is the hydraulic failure gradient, K is hydraulic conductivity (m/s) and PI is plasticity Index, could be to estimate the hydraulic failure gradient of soils similar to those tested. Increasing soil density increases the value of the gradient at which hydraulic failure occurs. Hydraulic failure gradient data could be used with drainage design information to determine whether a drain envelope is needed.

Bottcher et al. (1981) found from their studies sediment, pesticide and nutrient losses from a 17 hectare sub-surface drainage system for the year 1976-78 using automatic sampling equipment. Sediment concentration data showed two major characteristics. The first was the relatively high sediment concentration at the short of most tile flow events which begin from zero flow, and secondly, the relatively constant sediment concentration after a rapid decay of the initial concentration. The average loss per year was less than 100 kg/ha. Only eight per cent of the total nitrogen loss was associated with the sediment. The majority of the soluble nitrogen being transported

was in the form of nitrate. Nitrate accounted for approximately seventy-five per cent of the total nitrogen loss. Approximately seventy per cent of the phosphorus loss was associated with sediment compared to 10 per cent or less for nitrogen. The total loss of the pesticides was of the order of one-tenth of one percent of that applied, which were 8 and 13 kg/ha for different fields.

The water quality impact of the well managed field was evaluated by comparing water, sediment and nutrient yields on a unit area basis. The reduced water yield was noticed from the area of sub-surface drainage and thus reduced yield had direct impact on sediment and nutrient loading. Sediment and nutrient loadings were much lower in drainage area. The following conclusions were drawn. (1) Hydraulic conductivity of the soil profile was improved sub-surface drainage, (2) Over seventy per cent of the nitrogen lost in the drainage water was in nitrate form, (3) Approximately seventy per cent of the phosphorus losses were in the form of sediment bound phosphorus, (4) Sediment, sediment bound phosphorus and pesticides were all able to move through the soil profile, indicating the presence of direct flow channels, (5) Rainfall had greatly increased losses of both nitrogen phosphorus through a sub-surface drainage system, (6) Sub-surface drainage reduced water and sediment losses as compared to the more normal drainage situation, (7) There was significant reduction in sediment bound nutrient loading.

Linder and Schaffer (1981) found from their studies that no significant difference in the degree of siltation was observed between corrugated drain pipes (63/56) covered with glass fiber flece (60 g/m^2) in which the pipes had slits with 1.0 and 2.00 mm wide openings in addition to round openings of 3.0 mm diameter, and corrugated drain pipes without envelope material in which the pipes had slits of 0.5 mm width. The latter however, showed greatly increased entry resistance as the slit openings become reduced to the presence of Fe(II), H & S and NaCl in the drainage water. The pipe with slits of 1.00 mm width were liable to a high degree of siltation unless installed with an envelope material. Corrugated drain pipes for ground water regulation which had slits of 2.00 mm width and a 30 cm thick glass fiber fleece cover showed signifiently greater siltation than pipes without envelope material where the slit width was 0.5 mm or pipe with envelope material where the slit width was 1.00 mm. Various envelope material tested did not vary markedly in their prevention of drain siltation.

Lidster and Ford (1981) reported in eleventh Congress on Irrigation and Drainage at New Delhi, that there are few satisfactory technique for predicting ochrous sites in advance of drainage or for removal of ochre from clogged drains. Sulfur dioxide (SO_2) gas is effective as a cleaning agent but it can be dangerous to both personal and the environment. Mechanical roto-rooter and hydraulic high pressure jet cleaners are not entirely effective in removing more mature ochre deposits.

Dry pelletized sulfonic acid ($\text{HSO}_3 \text{NH}_2$) was evaluated at the University of Florida and found to be effective for dissolving ochre, which could then be flushed from the drain.

Ford (1982) found from their studies for estimating the ochre potential of a site was to sample the ground water and evaluate soil samples. If only soil samples could be used because of drought, a reasonable estimate of the ochre forming potential could be formulated if topographic features, water flow pattern and soil characteristic were known. The types of soils showing the most potential for ochre formation were: fine sands and silty sands, organic soils and organic pans, mixed profiles containing organic matter, gullies, flood plains of rivers and depressions containing organic residues. The least likely were silty clay loams that were deficient in Fe(II) in the soil solution and the high amount of energy required to reduce the iron present on the clay.

Scheffer (1982) found that flushing of drains to remove sludges, by using high pressure water. About 66 per cent of the drain sludges was removed by high pressure. Repeated flushing during the discharge period gave still further improvement. After flushing, about 17 per cent of the blocked openings were reopened. Flushing showed little effectiveness however against incrusts and old iron cloggings, which change from ferrihydrite to goethite. Drain pipes subject to iron clogging should be flushed after a short period of use, and before the content of drain sludge became too high.

Kontze (1982) reported from 20 years of research that the iron clogging was caused by chemical and microbiological process. The causes of clogging in time and local differences in iron clogging could be interpreted in terms of genetics and hydrology of Fe^{++} contents and pH.

Gold and London (1982) found from their studies that nutrient, sediment and herbicide losses in tile drainage and conventional tillage fields. It was found that the minimum tillage appeared to increase losses of phosphorus and sediment in tile water. Combined effect of field losses of phosphorus and sediment from surface run-off and tile flow were less from the minimum tillage system than from the conventional system.

Schwab and Logan(1982) found that the sediment and nutrients in effluent from sub-surface drains at several location over a 11 year period, on medium to heavy soil on slopes generally less than 2 per cent. Sub-surface drains reduced soil erosion and most plant nutrient losses.

Bengtson (1982) found from their studies the effect of sub-surface drainage on water drainage on water pollution. In a land with sub-surface drainage run-off erosion experiment on clay loam alluvial was conducted over 3 years, surface run-off soil erosion, total potassium, and total phosphorus were, reduced 29 per cent, 16 per cent, 24 per cent and 32 per cent, respectively by sub-surface drainage.

Plamenae (1982) reported in 9th Conference of the soil tillage Research organisation that some results for conventional gravel filters and filter fabrics (PES-150 g/m² and 301-D of L 10 production) tested in laboratory models and in experimental drainage fields at various soils. Drain performance, particle size distribution of sediment entering the drain and some economic aspects were given.

Swamy (1982) found that the silt discharge was maximum of 2.83 g/l in tile drains with 1.50 cm diameter perforation. The tile drains with perforation of 0.5, 0.75, 1.0 and 1.25 cm gave less silt discharge when compared to tile drain with 1.5 cm diameter perforation.

Anderson(1983) investigated the effectiveness of different pipe and filter materials with trench-less and traditional drainage methods on various soil type. On ochreous soil type, the effectiveness of thin synthetic fiber material was poor because of rapid deposition of ochre in the filter. In non-ochreous stable soil types, the effectiveness of trench-less and traditional drainage methods was similar, use of a voluminous filter material showed no advantage in these soils. On non-ochreous, unstable soil types, however, the use of a voluminous filter material not liable to blockage with deposit material gave much better results.

Ganeda et al.(1983) made observations at an experimental site over 3 years period showed a reduction in the efficacy of

the drainage system. Associated with this, was the deposition of iron ochre in and around drains. The amount and type of ochre in drain was dependent on ground water temperature and drainage rates decreased and entrance head losses increased significantly over the period. It was not possible to separate the effect of ochre on the drainage system that of the development of a flow restricting soil layer around the drains.

Susser and Schwertman (1983) reported that iron oxide mineralogy of ochreous deposits in drain pipes and ditches. They had tested ten samples of ochreous precipitation from drain pipes and it contained poorly crystalline ferrihydrite ($5 \text{ Fe}_2\text{O}_3 \cdot 9\text{H}_2\text{O}$). One sample had contained some ferrihydrite (FeOOH). The surface area varied between 90 and 279 m^2 per gram and increased after H_2O treatment to 900-400 m^2 per gram. The Cl content was higher (5-12%) and SiO content was lower in other natural ferrihydrites. The ferrihydrites were considered to be the product of rapid (bacteria) oxidation of Fe (II) in the drain water.

Kanwar (1983) reported that a hydrologic and nitrate transport simulation model was used to simulate the major water and nitrogen transport processes occurring in a typical agricultural watershed during crop growth period. The data from a tile drainage experiment were used to evaluate the simulation model. Predicted values of tile flow volumes and nitrate concentrations in the tile effluent were compared with measured data,

although variable, were encouraging. Deviation between predicted and measured nitrate losses in the tile effluent existed on a daily basis but usually were small when considered over the entire crop growth period.

Vaughan et al. (1984) suggested a method to remove ferrous iron from field drainage water. They found that iron ochre deposits in field drainage system was produced as a result of chemical and microbiological oxidation of ferrous iron in soil solution to the insoluble ferric form. Confir bark from several plant species will adsorb ferrous iron from solution quickly and irreversibly, the bark changing colour from brown to blue in the process. This bark, unlike that from deciduous trees, contains only quantities of soluble phenolic components so it does not create an environmental problem under field conditions. Trials carried out at a test farm, where bark was placed within nylon mesh sacks and incorporated into the drainage system, were very successful and drainage pipes which had previously blocked twice yearly remained relatively free of ochre.

2.7. Salt Discharge in Tile Drainage:

In agriculture the harmful chemicals called alkali, as well as other salts, must be dealt with as they occur in soil and in irrigation water. Of the various problem soils in the world, saline and sodic soils occupy by far the largest area (323 million hectares). They are most widespread in arid and semi-arid

climates, but also occur in more humid climates, especially in coastal areas. Saline soils by definition is the electrical conductivity of saturation extracts of certain soil horizons. Sodic soils have at least 15 per cent exchangeable sodium that may decrease their physical stability. Most are alkaline, with a pH above 8.5 owing to the presence of sodium carbonate. Some are almost neutral and a few are acid. Some soils are both saline and sodic. There is clear definition of sodic soil as such because the distinctions made by FAO(1974) and the soil survey staff (1975).

The salts or exchangeable sodium in saline and sodic soils hinder crop growth. For efficient crop production they must therefore be leached from the root zone. Under favourable circumstances, most of the water applied to saline soil percolate through and removes the salts. More water is required to leach a sodic soil than a saline soil. This is because the usual chemical amendments are less soluble than the usual salts and because sodic soils are generally less permeable than saline ones. Hayward and Magistad (1946) made the distinction that saline (white alkali) soils usually have good structure, take water well and drain well. Alkali (black alkali) soils run together or puddle have poor structure, take water slowly and are difficult to leach. A saline soil may be made productive by leaching out the salt; but the alkali soil must be changed chemically by replacing the excessive sodium held by the soil with calcium and then leaching out the replaced sodium salts.

In various parts of Utah, Dorsey(1902), Harris(1920) and Israelsen(1935) reported marked decrease in total salts through 4-feet of depth of soil in 2 years time, through deep, carefully designed and installed tile drainage followed by heavy flooding. Fortier and Con(1909) reported similar satisfactory results from tile drainage and leaching in the San Joaquin Valley in California with excellent crops following in raisins, sorghum, and alfalfa on previously unproductive areas. Power (1919) reported the removal of maximum accumulation of alkali from the third foot of the heavy loams of eastern oregon by drains laid 6 to 8 feet deep to tap the permeable strata. Miller (1916) reported remarkable reduction in total salts to depths of $5\frac{1}{2}$ to 6 feet in the silt loam and above clays of the Colarado River Valley in Colarado from a single 90 day continuous flooding in 1913 over tile drains laid at various spacing and depth upto 6 feet. Reeve, Allizon and Peterson(1948) reported good results in leaching out of excess salts through permeable subsoils without artificial drains in the Delta area in Utah, resulting yields varying closely with the amount of flood water applied. Good results were clearly dependent on an ample supply of leaching water and adequate drainage, whereas without adequate drainage, attempted leaching may be detrimental rather than beneficial. Burgess (1928) also testifies to the marked reduction of alkali by successive leaching at the Yuma Valley Experiment Station. Along with leaching, Knight (1932) also suggests a blanket of 3 or 4 inches of sand over dense soils to stimulate water percolation.

Israelsen(1935) Hayward and Magistad (1946) agreed that the real solution of the alkali problem was leaching with abundance of water, accompanied by thorough and deep tile drainage strongly reinforced by abundant use of certain chemicals, whose function was to convert the black-alkali and other, not readily soluble forms to forms readily soluble in free soil water. The following reports of investigations among many others, show clearly that deep under-drainage, accompanied by heavy flooding was the best means of combating alkali.

According to Reeve (1953) and Richards et al.(1954) the leaching requirement depended upon the salt concentration of irrigation water and the maximum salt concentration that was permitted in the soil solution.

Kovda (1957), Wilson et al.(1961) and Nielsen et al. (1965) reported that the soil cracks provided the main avenue for water and salt transmission in heavy soils. During leaching, water passed rapidly through the cracks to the tile as a compared to the soil block itself. Under such situations continuous flooding represented no improvement in the leaching efficiency. Where ponding was the only available method for leaching, then intermittent ponding was better.

According to Miller et al.(1965), intermittent ponding of clay loam soil required less water compared to continuous ponding and the degree of leaching achieved was same under both methods. Miller et al.(1965) also reported that the amount of

decline of salinity was related to the number of irrigation, irrespective of quantity of water applied for irrigation. More leaching occurred with frequent small irrigation rather than with large ones even though the total amount applied was same.

Bigger and Nielsen(1967), reported that salt displacement was most efficient under unsaturated flow condition, which was obtained by either intermittent ponding or sprinkling. According to Abrol and Bumbla (1973), the application of gypsum aided in leaching of salts but the intermittent flooding was no more effective than continuous flooding. Hermsmeier (1973), reported increased water entry into the soil when water was applied at shorter periods of time with frequent intervals.

Van Bavel et al.(1968) reported that drainage rates were obtained as the difference between the rate of soil moisture depletion in the 170 cm zone, and the evaporation rate. The drainage rate was reduced to 10 per cent of its initial value in less than three days. In the laboratory study by Jensen and Hanks (1967), found that 90 per cent of the drainage volume from a 120 cm column of fine sand was collected in 1.3 days. Quantitative production of the drainage rate from soil columns or profiles in relation to time was moving in the direction of solution by digital computer.

Herman Bouwer (1969) reported from his studies that the drainage system could be designed on the basis of avoiding

water table rise above a certain level, knowing the relation between drainage from the lower boundry of the root zone and time. Steady state drainage theory could be employed in a step-by-step procedure to calculate the water table response.

Hermesmeier (1973) found that shallow drains installed at a 4 ft depth and 200-ft spacing in a clay and loamy clay soil removed only from 12 per cent to 7.2 per cent of the salt added by irrigation water during four cropping seasons over 2½ year period. The small amount of salt removed by the drain when compared with salt removed from soil by the natural drainage was sufficient to maintain a favourable salt balance. Maintaining a favourable salt balance in clay and clay loam soils when using irrigation water containing 1000 ppm of dissolved solids was difficult and requires good water management as well as good drainage.

Habib (1974) found that leaching at rates equivalent to two and three times the field capacity removed most of the salts from the top 1.5 m of soil. Further, leaching at four times the field capacity helped to desalinate heavy, stratified soil and was advantageous when the leaching water was very saline.

Tabolt and Bruce (1974) reported that short term leaching lowered total soluble salts concentrated in a soil salinized by 15 years of irrigation to that of a non-irrigated soil. The pH and SAR of saturation extract showed only minor changes.

According to Sharma et al. (1975), the water holding capacity, hydraulic conductivity were increased, whereas pH was decreased with increased gypsum (upto 6-8 t/ha).

Telati (1975) reported that the best results of the improvement of soil physical properties was obtained when gypsum at 15 tonnes per ha, calcium chloride at 7.5 tonnes per ha and farm yard manure at 75 tonnes per ha were applied. The infiltration rate was increased and the bulk density was decreased. Application of gypsum reduced the ESP values markedly.

Belgaumi et al. (1976) observed that large quantities of water was required to reclaim the salt affected soils. Further they stated that large amount of water (120 cm) applied in two split dose was better compared to four, eight, sixteen and thirty two split doses of water in reducing the salinity in black clay soils of Tungabhadra Project Area.

Bliesnar et al. (1977) found that the amount of salt removed in drainage water was appeared to vary directly with the quantity of drainage water.

Bernett et al. (1982) found from their studies a shallow sub-surface drainage system effectively controlled a high water table and reduced salinity in an irrigated soil near Magrath, Alberta. Plastic corrugated tubing was installed in 1976 at depths of 1.1 to 1.5 m and spacings of 15 to 30 m in a moderately

saline soil. During the irrigation period, the water table rose to within 0.3 m of the surface but was lowered to pre-irrigation levels within 48 hr. The water table was maintained at or below the depth of the drains between irrigation. The 15 and 30 m spacings of the drain lines were equally effective in providing water table control in this lacustrine soil which was underlain by a coarse sand and gravel layer. Salinity levels were decreased subsequently only within the surface 0.3 m soil depth. Quality of the drainage effluent remained constant throughout the growing season with only small dilution effects detected during irrigation. Barley yields increased to 3900 kg/ in 1978, 2 year following drainage of this saline soil which had been out of crop production for 20 year.

Harker (1983) monitored a net work of on farm tile drainage outlets for 6 years to establish effluent quantities, qualities and possible trends. Based on general trends tile drainage was not expected to affect river water quality seriously. Some short time negative effects might occur during period of extremely low water flow. However, the variability of site-specific data showed that the use of general trends to project effects on small receiving systems might not be accurate.

CHAPTER 3

MATERIAL AND METHODS

CHAPTER 3

MATERIAL AND METHODS

A series of field experiments were conducted to study the efficiency of burnt clay tiles, used in command area, in relation to number of circumferential perforations, size of circumferential perforations, orientation of perforations and the type of envelope materials, locally available. These experiments were conducted from 1980 to 1984 at the Agricultural College Farm, where the soils were identical with that of the soils of irrigated command area. The details of the experiments and the techniques adopted during the course of the investigations are presented below.

3.1. General Description of Experimental area

The Agricultural College Farm is situated at 15°12' North latitude and 75°7' East longitude, and altitude of the place is 732 meters above sea level. It lies in the transitional tract with uniform rainfall distribution from June to September. The western part of the Farm is predominant with latric soil of highly undulated topography, and Eastern part with medium to deep black cotton soil. The site in which the experiment located was comparatively porous for easy movement of water in the profile. This type of soil exist side by side in most of the black soil regions in Karnataka State.

3.2. Climate

The weather of the place was described as uniform and moderate temperature throughout the year and the annual rainfall is 822 mm (average of 30 years) and fairly well distributed from May to September. The temperature varies from maximum of 30.5°C to minimum of 18.2°C (average of 30 years) and evaporation rate was 5 to 6 mm per day.

The total rainfall during the experimental period during the years 1980-81, 1981-82, 1982-83, 1983-84 were 584.5 mm, 852.5 mm, 765 mm and 685.50 mm, respectively. The maximum temperature recorded was 36.4°C during 1980-81 and the minimum was 12.8°C during 1981-82. The corresponding highest and lowest relative humidities were 83 per cent and 42 per cent, respectively. The average evaporation was 5.3 mm and during summer months it varied from 7.1 mm to 7.77 mm per day.

3.3. Cultural condition of the Experimental Site:

The land was under cultivation from 20 to 25 years and became water logged due to raise of ground water level. Hence, it was under paragrass cultivation. The soil structure was typical of black soils coming under command areas in Karnataka State.

3.4. Investigation of the Site of the Experiment:

The parameters like topography, groundwater level, hydraulic conductivity of the soil, soil structure and soil classification were determined and the same are presented below.

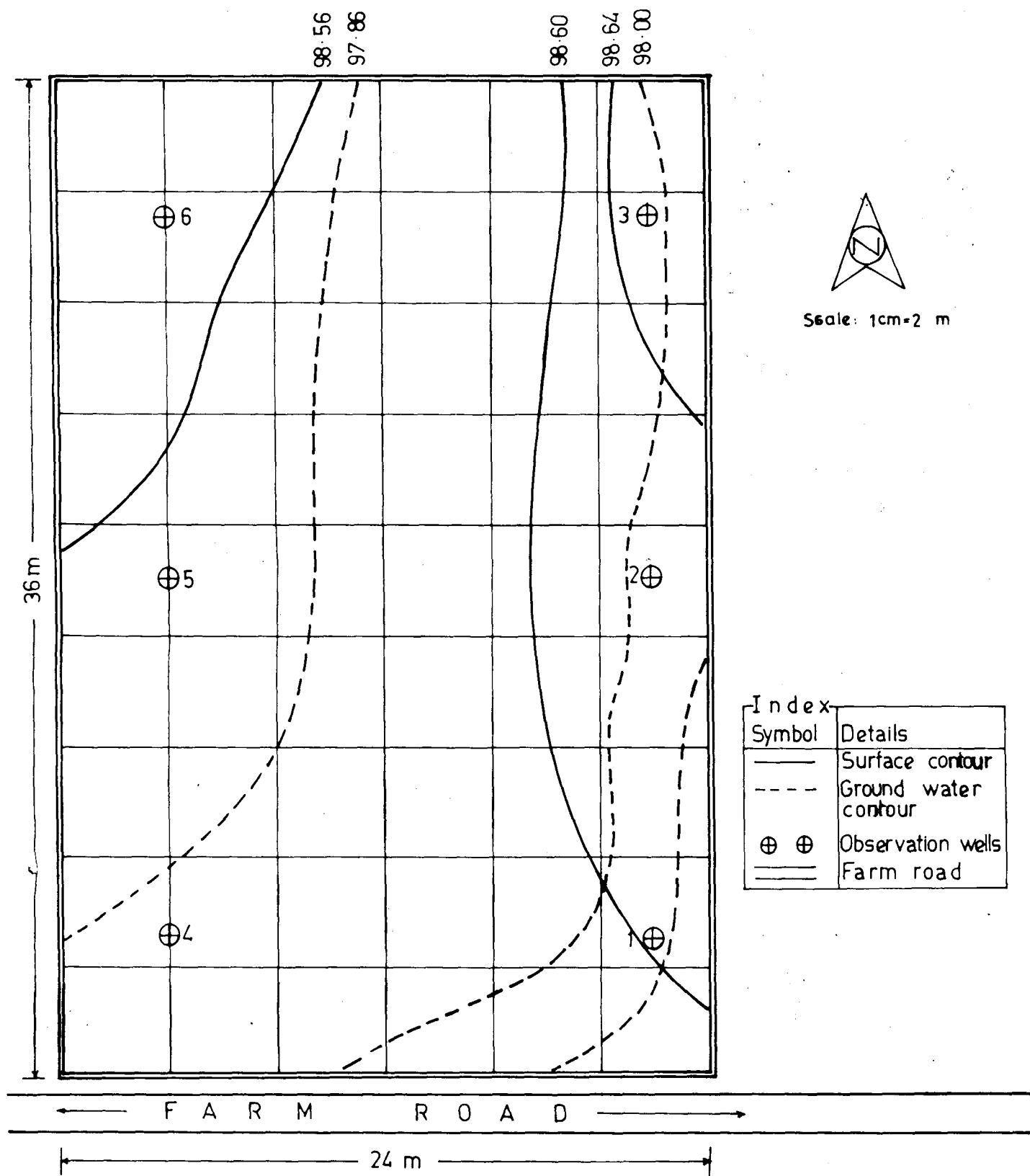


FIG. 1 PLAN OF TOPHOGRAPHIC AND GROUND WATER LEVELS OF EXPERIMENTAL SITE



Plate 1. Explanation of the piezometer installation (observation wells) for water level recording



Plate 2. Examination of the general Layout of the experiment.

3.4.1. Topography of the Experimental Area:

A series of levels were carried out at regular interval of 5 m and contour plan is prepared with contour interval of 0.10 m. (Fig. 1) and it was found that the average slope of the area was less than 0.5 per cent.

3.4.2. Water Table in the Experimental Site:

Six observation wells as shown in Plate 1 were installed in the experimental area and the water levels in these wells were recorded at weekly intervals for a period of four years from 1980-81 to 1983-84 during the months from August to July each year. The ground water contour map and hydrograph of water levels were prepared and presented in Fig. 1 and 2 respectively. The monthly variation of water table is also given in Table 1. The water table level was almost near the surface during the months of September and October and it was lowest during the months of March, April and May.

3.4.3. Quality of Ground water:

Ground water samples were collected from the observation wells of the experimental site during the different seasons of the year and analysed for their constituents as per the procedure given in U.S.D.A. Hand Book No.60. The results of analysis are presented in Table 2.

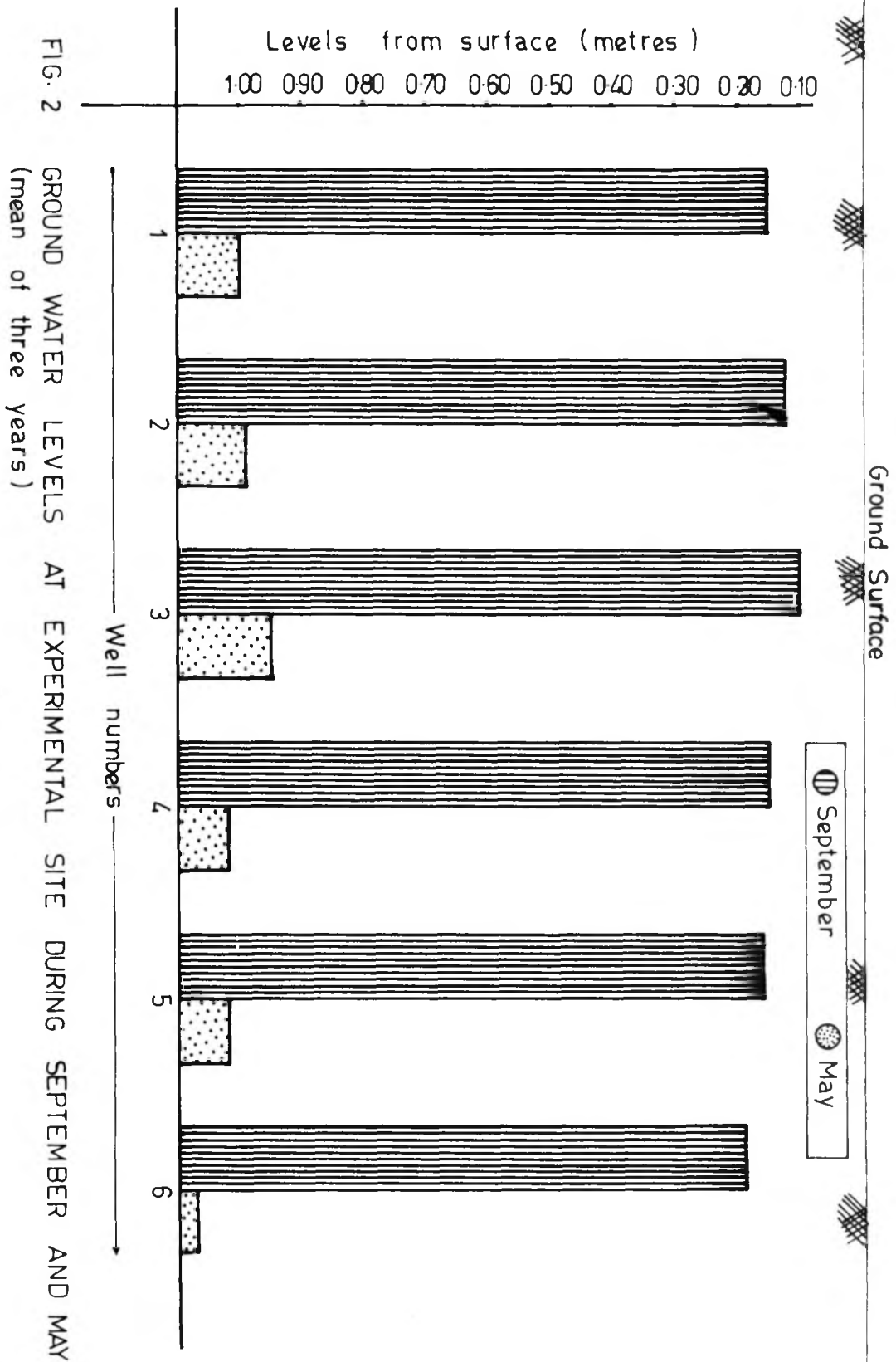


Table 1. Ground-water levels of the Experimental Site during the period of experiments

Month and year	Ground-water depth in observation wells(cm)						Mean
	1	2	3	4	5	6	
August 1981	26	23	23	26	29	30	26.17
September 1981	14	12	10	15	16	19	14.33
October 1981	5	5	2	8	10	11	6.83
November 1981	40	38	38	40	41	43	40.00
December 1981	54	53	52	55	59	66	56.50
January 1982	70	69	62	70	74	77	70.33
February 1982	83	81	79	85	87	93	84.67
March 1982	92	92	88	93	98	98	93.50
April 1982	97	96	92	98	100	102	97.50
May 1982	100	99	95	102	102	108	101.00
June 1982	75	74	71	82	86	87	79.17
July 1982	62	61	60	64	66	70	63.83

Table 2. Result of Irrigation and Ground Water Analysis of the
Experimental Site

Sl. No.	Water sample	pH	E.C. in mmhos/cm at 25°C	Meg/lit					SAR
				CO ₃ ⁻	HCO ₃ ⁻	Cl ⁻	Ca ⁺⁺ Mg ⁺⁺	Na ⁺	
1.	Irrigation Water	7.6	0.54	0.40	2.40	2.02	2.30	2.10	1.92
2.	Ground Water	8.2	2.15	0.90	10.42	8.45	6.60	13.30	7.32

3.4.4. Hydraulic Conductivity of the soil:

Hydraulic conductivity was measured in situ by digging an auger hole into the soil below the water table (Fig. 4). In in situ measurement, the soil sample used was large and the measurement was not greatly affected by the presence of rock or root holes adjacent to the auger holes. In addition, the measurement largely reflects the horizontal component of the conductivity, which was the important component from a drainage view point. The details of hydraulic conductivity are presented in Table 3 and Figure 3.

Dr.S.B.Hooghoudt formula for homogeneous soil was used in calculating hydraulic conductivity. Since the method is very simple and could be conducted with a simple equipment. The procedure was to dig a hole in the soil below the water table level. After allowing the water level in the hole to come to equilibrium with the water table in the soil, the water was pumped out of the hole and measurements were taken for the rate of rise of water in the hole. These measurement were then used to calculate the hydraulic conductivity of the soil profile.

The assumptions made in the derivation of Hooghoudt's formula are (a) the water table was not lowered around the auger hole when water was removed out of it, and (b) the water flows into the auger holes horizontally through the sides and vertically up from the bottom of the hole.

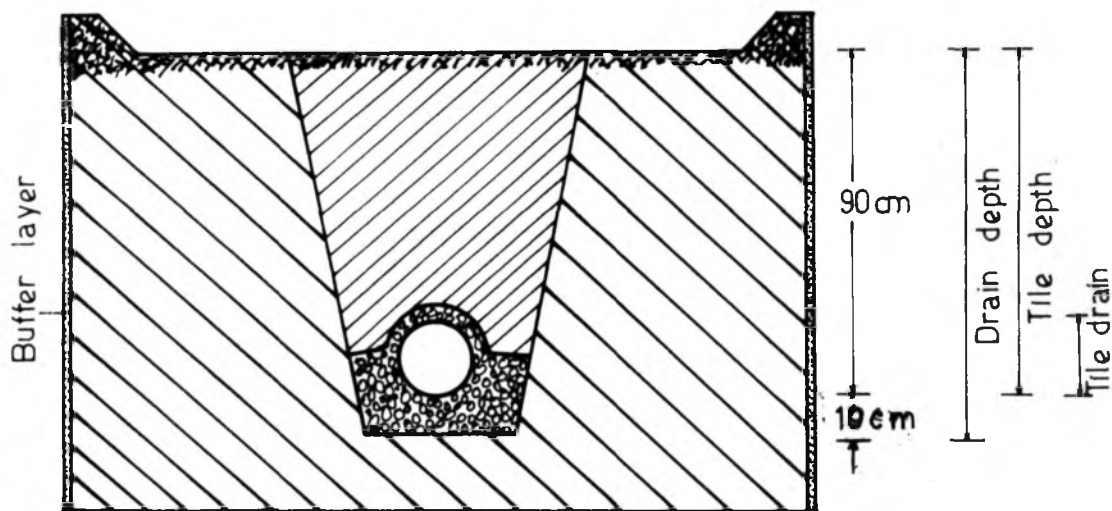


FIG.3 PLACEMENT OF TILES AND FILTER MATERIALS

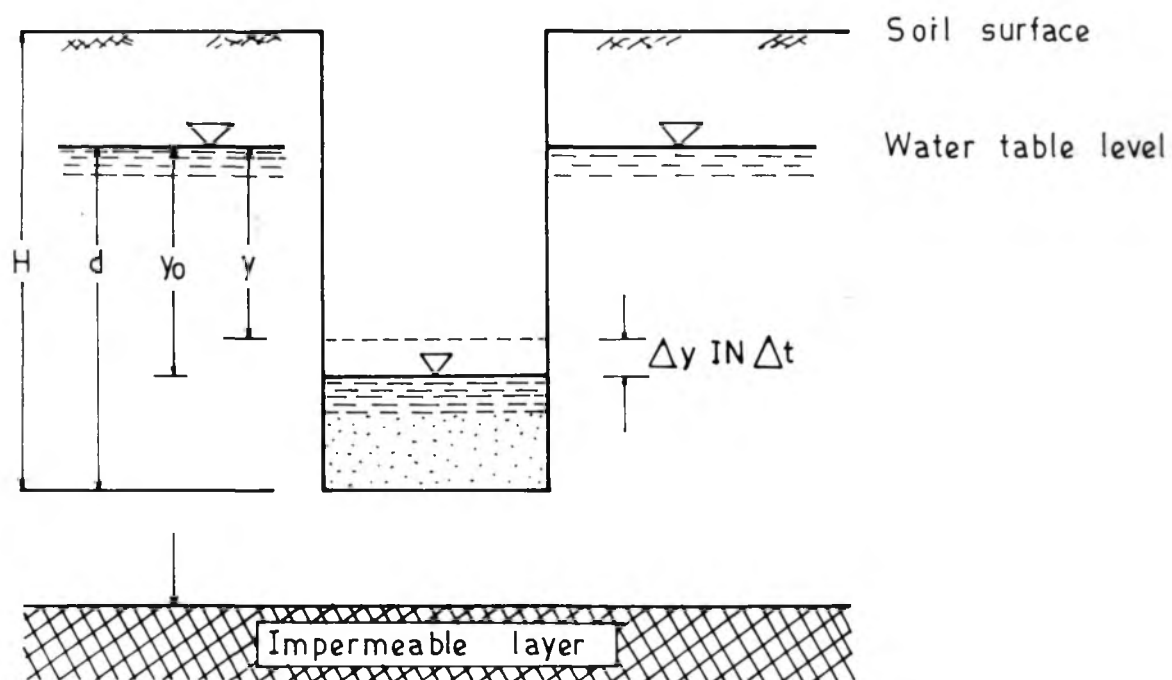


FIG.4 GEOMETRICAL QUANTITIES OF AUGER HOLE USED FOR MEASURING FIELD HYDRAULIC CONDUCTIVITY

Table 3. In situ Hydraulic Conductivity of Soil of the Experimental site by Single Auger Hole method

Test No.	Values of parameters used in the formula(cm)						Time (seconds)	(K=) Hydraulic conductivity of soil in m/day	Average of K in m/day
	H	d	y	Dy	a	t			
1	40	32	20	3.1	5	1800	1800	5.600	
2	76	68	34	8.0	5	1800	1800	5.850	5.560
3	110	110	42	12.0	5	1800	1800	5.220	

Where H = Depth of auger hole from soil surface

d = Initial water table level in the auger hole

y = Distance from static water table to elevation of water

Dy = Rise of water surface in auger hole during time interval

a = Radius of auger hole

K = Hydraulic conductivity of soil in m/day.

The Hooghoudt formula used was:

$$K = \frac{2.3 \text{ a.s}}{(2d+a)} \left\{ \log_{10} \frac{Y_0/Y_t}{t} \right\}$$

$$= \frac{23y \cdot 86,400}{0.19} \times \frac{a^2 d}{(2d+a)} \log \left(\frac{\Delta y}{\Delta t} \right)$$

where, a = radius of auger hole in metres

d = distance from the bottom of the hole to the water level in cm.

t = time in seconds (elapsed)

K = hydraulic conductivity in meters per day

y = rise of water in time t in cms.

Three auger holes of 10 cm diameter, at four spots in experimental site, were made for three depths of 40, 70 and 100 cm. The three depths were selected to account any heterogeneity of the soil in the profile. The bottom of the auger holes were considerably below the water table at the time of experiment. When the water level in holes were in equilibrium with the general water table, the water level in the auger holes were lowered for few centimeters, and the rise of water level for 5 minutes in each holes were recorded using a metallic tape attached to a float. The rate rise of water level in the hole was taken as a measure to calculate the hydraulic conductivity of the profile.

3.4.5. Soil Profile in the Experimental Site:

A soil profile pits were dug in the experimental site to identify the horizons of the profile and three distinct horizons were identified. The description of the profiles are given

as follows:

Horizon	Depth(cm)	Description
A	0-30	Dull yellowish brange (dry and dark brown (moist) sandy clay single grained; friable to hard when dry. Sticky when moist. Enclosed pebbles of ferrogonous quartz. Effervescence with dil. HCl, pH 8.5.
B	30-90	Dark brown (dry) and light dark (moist) clay, structure not developed friable to hard when dry and sticky when moist. Effervescence with dil. HCl, pH 8.6.
C	90-120	Dark brown (dry) and dark(moist) clayey, platy, friable to hard when dry and sticky to very sticky when moist, strong effervescence with dil. HCl, pH 8.1.

3.4.6. Soil Sampling and Soil Analysis:

Composite soil samples were collected from depths of 0 to 15 cm, 15 to 30 cm, 30 to 60 cm and 60 to 90 cm and analysed for physical and chemical properties (Table 10).

The physical properties for soil classification was done by mechanical analysis. The soil was first passed through a series of sieves to separate the particles larger than silt size.

In sieve analysis, the soil was separated into fraction by shanking the dry, loose material through a nest of sieves of increasing fineness. The particle lower limit for the use of sieves was No.200 sieve, which had opening of 0.074 mm square and 40,000 openings per square inch. The distribution of particle size less than 0.05 mm was determined by wet mechanical analysis by adopting pipette method suggested by Bouyoucos (Piper, 1966). The results of the analysis are presented in Table 4 and 5 and grain size distribution curve was drawn using the data and shown as in Fig. 5.

The chemical analysis was carried out using the method suggested in USDA Hand Book No.60 and Soil samples were analysed for soluble cations and anions, cation exchangeable capacity, exchangeable sodium, exchangeable sodium percentage and sodium absorption ratio. The pH was determined by Buckman's pH meter and electrical conductivity by Elico conductivity bridge in 1:2 soil water extract. The results of the analysis is given in Table 8.

3.5. Specification of Tiles used in Experiment:

In Command areas, where black and red clay are prevalent, the burnt clay tiles of 60 cm length and 10 cm diameter are being used in Karnataka State. The burning of the tile was done as per the ASTM Specification to get the quality tiles which would last for more than 20 to 25 years. The tiles used in the

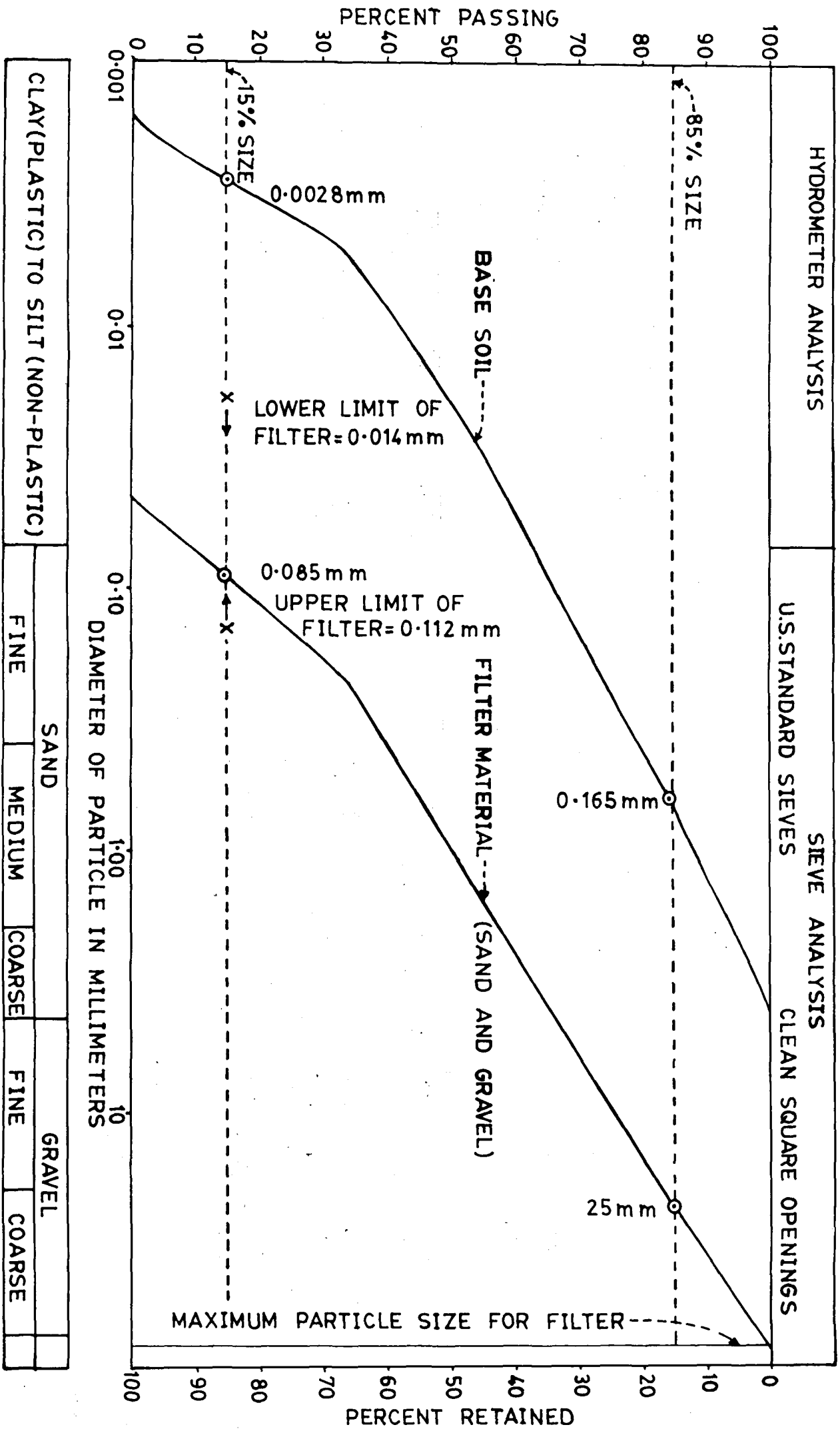


FIG.5 GRADATION CURVES OF BASE SOIL AND ENVELOPE FOR DRAINAGE EXPERIMENTS I, II, III AND IV

Table 4. Unifield Classification of Soil of the Experimental Site

Sl. No.	Depth of soil (cm)	Soil fraction in per cent				Textural classification
		Gravel	Coarse sand	Fine sand	Silt	Clay
1	0-15	2.00	27.50	20.29	9.00	40.75
						Sandy clay
2	15-30	1.85	26.73	19.55	10.35	42.28
						Sandy clay
3	30-45	1.65	19.35	20.05	12.15	46.65
						Sandy clay
4	45-60	1.60	18.41	20.15	11.25	48.60
						Clay
5	60-75	1.50	12.50	22.95	12.35	51.05
						Clay
6	75-90	1.49	12.65	23.25	12.25	51.00
						Clay

Table 5. Grain sizes of the soil of the Experimental Site by sieving and Wet-Mechanical Analysis

Sl. No.	Diameter of soil particles in mm.	Percentage Finer	Percentage Larger	Remarks
1	0.002	95.60	5.40	Check of the filter gradation against design criteria (Fig.5) a) $\frac{D_{15} \text{ of filter}}{D_{15} \text{ of Base}} = \frac{0.0850}{0.0028} = 303$; soil $5 < 303 < 40$, O.K. b) $\frac{D_{15} \text{ of filter}}{D_{85} \text{ of Base}} = \frac{0.085}{0.165} = 0.515$ soil $0.515 < 5$; O.K. c) $D_{85} \text{ of filter} = 25 \text{ mm}$, $25 \text{ mm} > 10 \text{ mm}$, O.K.
2	0.005	66.50	33.50	
3	0.020	48.00	52.00	
4	0.200	26.50	73.50	
5	0.350	20.40	79.60	
6	0.850	12.50	87.50	Sieve Analysis Hydrometer Analysis
7	1.200	6.00	94.00	

Table 6. Field Capacity, Bulk Density and Total Water-holding Capacity of the soil

Sl. No.	Depth of soil (cm)	Field Capacity (Oven dry basis)	Bulk density (g/cc)	Water-holding capacity (cm)	Remarks
1	0-16	31.05	1.35	6.25	
2	15-30	31.25	1.30	6.09	
3	30-45	31.50	1.25	5.91	
4	45-60	31.56	1.21	5.73	
5	60-75	31.35	1.20	5.64	
6	75-90	31.34	1.20	5.65	

experiments were similar to the ones used in Command Areas of 10 cm dia and 60 cm length, with bell and spigot ends. They were made up of special clay available locally by burning at 900°C in special kilns. The tiles were got prepared from Central Village Pottery Institute, Khadi and Village Industries Commission, Khanapur, Belgaum District, as per the treatments finalised for the experiment.

3.6. Design and Layout of Experiment on Size of Perforations of Clay Tile Drains:

The experiment was laid out in split plot design as this design was suitable for the treatment of the experiment (Fig.6). The experiments plot was 24 m x 20 m and this was divided into four replications. Each treatment was of the size 4 m x 5 m and separated by dykes of 20 cm width. Polyethelene sheet of 300 gauge was burried to a depth of 90 cm between treatments to prevent lateral movement of water from one treatment to ^{another} treatment.

An open ditch deeper than the tiled drain depth was provided in the middle of the layout to drain out all the discharge from the tile drains. Two irrigation channels were provided on either side of the layout with parshall flume installed across them to measure the irrigation water. At the lower end a common collection ditch was provided to drain away all excess water including the drainage water. A buffer polythelene dyke was provided to prevent seepage water from irrigation channel.

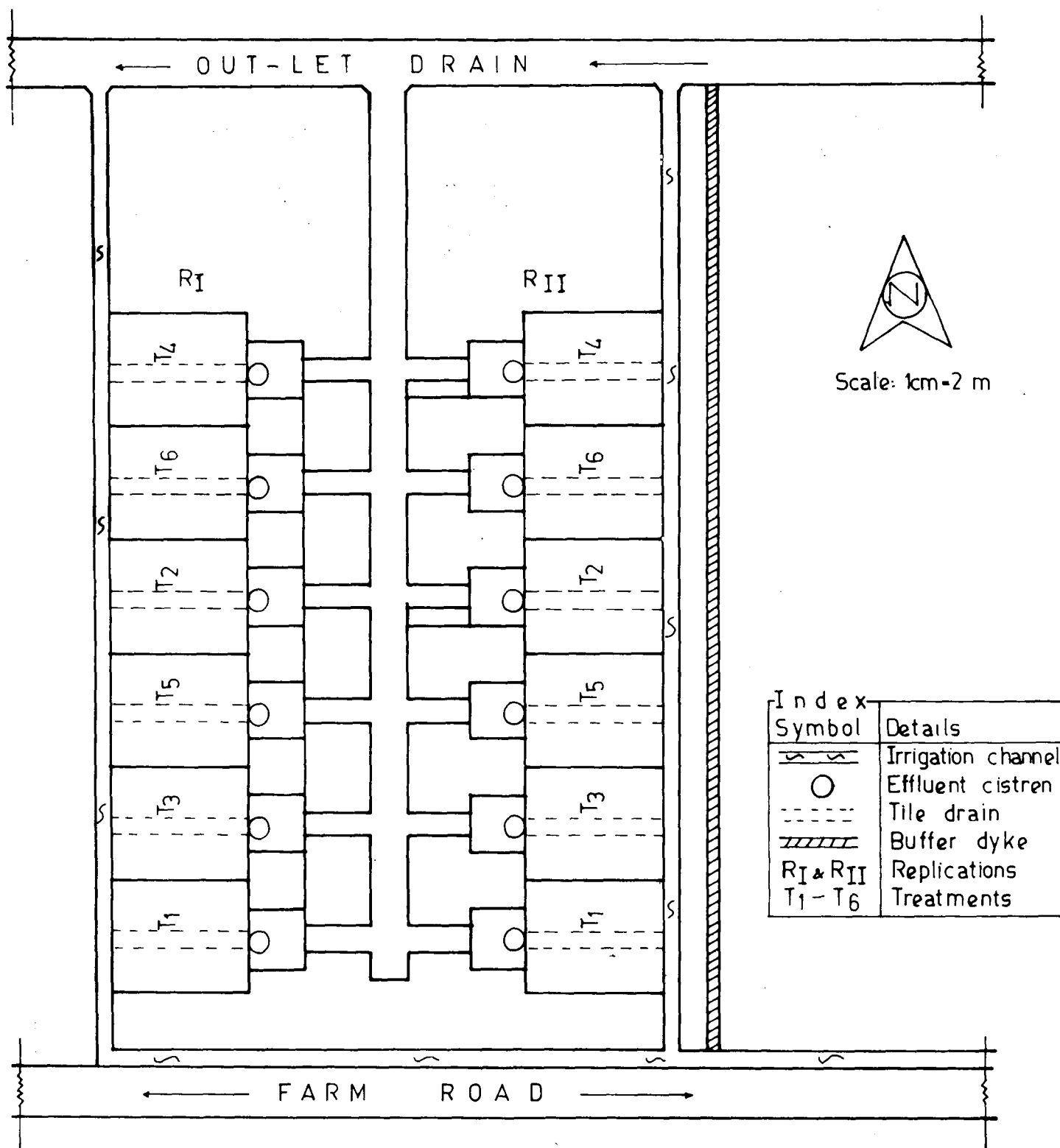


FIG. 6 LAY-OUT PLAN OF THE EXPERIMENT ON SIZE OF PERFORATIONS OF CLAY TILES



Plate 3. Tiles having perforations of 0, 0.50, 0.75, 1.00, 1.25, and 1.50 cm dia metre.



Plate 4. The outer end of tile drain protected with one way flap gate

3.6.1. Treatments of the Experiment:

The usual practice in the use of burnt clay tiles as sub-surface drainage in Command Area was to use one cm perforation on the entire body of the tiles and the number of perforations per tile was not defined for these clay tiles which had led to failure of drainage system. This experiment was planned to find out the suitable size of perforation on the hemispherical portion of the tile. For water entry area per tile based on earlier studies, it was decided to maintain 18.85 sq.cm. The number of treatments taken for experiment were plain tiles without perforations. 0.50, 0.75, 1.00, 1.25 and 1.50 cm dia perforations. In order to maintain a constant total entry area of 18.55 sq.cm, an additional hole of 0.60, 0.71, and 0.73 cm was provided in tiles with 0.75, 1.25 and 1.50 cm dia perforation respectively. The perforations were made in rows on the hemispherical portion of the tile, and at the time of moulding appropriate needlers were used to obtain the required size. To get the total entry area of 18.85 sq.cm, the number of perforation required were 96, 42, 24, 15 and 11, respectively for the tiles with perforation size of 0.50, 0.75, 1.00, 1.25 and 1.50 cm dia (Plate 3).

3.6.2. Installation of Tile Drains:

Narrow trenches of 45 cm width and 100 cm deep were formed for the full length of each treatment plot at the middle of the plots. Based on the practice in the Command Area and also on the requirement of gravity flow and outlet position, tile depth

90 cm on a grade of 0.20 per cent was laid out in all the treatments. The bedding adopted for placement of tile was of ordinary type. Since it was standard recommended practice in tile drainage installation in Agriculture. The tiles were positioned in the trenches in such a way that the perforation of the tiles were facing downward. The downward facing of perforations was assumed to be ideal for tile drain installation.

3.6.3. Filter Design and Placement:

Gravel filter was designed based on the grain size curve of the base material. The design criterion followed was the criteria proposed by U.S. Bureau of Reclamation in which the ratio of

$$\frac{50 \text{ per cent size of filter material}}{50 \text{ per cent size of base material}}$$
 should lie between 12 to 48, similarly, the

$$\frac{15 \text{ per cent fine size of filter material}}{15 \text{ per cent fine size base material}}$$
 should lie between 12 to 40.

The gradation curves of the base material and the filter material are presented in Fig. 5.

Suitably-mixed sand and gravel filter was placed from the bottom upto 3/4 circumference of the tiles and the average thickness provided around the tile was 7.5 cm. Then, the tile drains were covered with 300 gauge plastic strip and blinded

with loose excavated earth. The tile outlets were protected with one way flap gates to prevent the entry of rodent, and similar small animals into the tile drains (Plate 4)

3.6.4. Strength of Tiles used in the Experiment:

Tiles used in different treatments of the experiment were tested to find out the bearing strength, and the machine used for test was universal testing machine. This test was in conformity with ASTM C₄ - 59T, tentative specification for clay drain tile given in the concrete pipe Hand Book, published by American Concrete Pipe Association (1959). The data obtained from the test are given in Table 7. and each data was of the average for three specimens.

3.6.5. Load on Tile Drain Pipes:

Clay tile drain pipes that were burried at 90 cm depth were subjected to load due to back-fill soil, and equipment and animals that were passing on the field. As the tiles were burried at deeper depth, the load due to moving load was neglected. The static load of soil on tile drains was worked out by using formula given by Marston(1930), for both ditch conduct and projected conduit conditions. The formulae are given as below:

For Ditch Conduit

$$W_c = C_d W B_d^2$$

Table 7. Data on load Bearing Strength of Tiles used in Experiment

Sl. No.	Number of perforations per tile	Bearing strength in kg/line cm			Average load bearing strength (kg/line cm)
		Test-I	Test-II	Test-III	
1.	Plain tile	12.30	12.00	12.15	12.15
2.	Tile with 6 perforations	10.35	10.68	11.01	10.68
3.	" 12	9.25	9.60	9.55	9.50
4.	" 24	8.86	8.57	8.58	8.67
5.	" 36	7.42	7.34	7.08	7.28
6.	" 48	6.22	6.00	6.02	6.12
7.	" 60	6.11	5.03	4.95	5.03

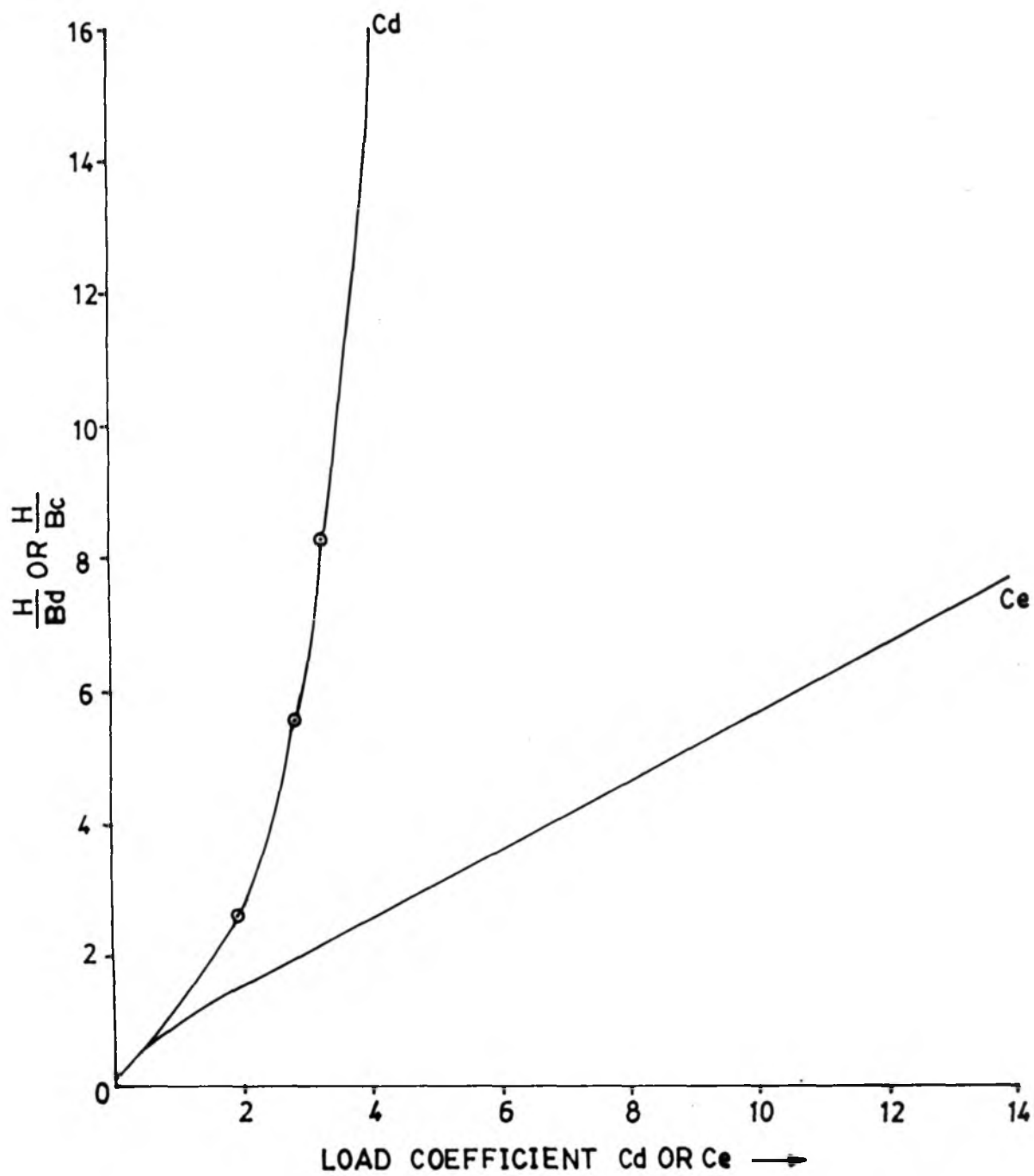


FIG-7 LOAD COEFFICIENTS FOR RIGID DRAIN TILE
(SPANGLER, 1947)

For Projected, conduit

$$W_c = C_c W B_c^2$$

where, W_c = Total load on the conduit

C_d = Load coefficient for ditch conduit

C_c = Load coefficient for projecting conduit

W = Unit weight of back-fill material

B_d = Width of ditch at top of conduit

B_c = Outside diameter of the conduit

The load coefficients that were used in the Maraton(1930) formula were taken from the graph proposed by Spangler (1947). The data obtained from the calculation are given in Table 7.

3.6.6. Irrigation to Experimental Plot:

The depth of water required to bringing the soil moisture to the field capacity for the entire depth of 90 cm was worked out by using the following equation:

$$d = \sum_{i=1}^n \frac{M_{fci} - M_{bi}}{100} \times B_{di} \times D_i$$

where, d = depth of water to be applied in cm

n = number of soil layers

M_{fci} = field capacity of i^{th} layer in percentage

M_{bi} = Moisture content before irrigation of i^{th} layer in percentage

B_{di} = Bulk density of i^{th} layer

D_i = Depth of i^{th} layer.



Plate 5. Use of Parashell-flume for measurement of irrigation water in experimentation



Plate 6. Plastic cisterns provided at the end of tile drains to measure tile drains out-flow.

The soils profile as considered as two layered soil and lower depth between 30 to 90 cm was considered as 1th layer. Because of this consideration, the samples were drawn from the layer between 30 to 90 cm depth for moisture estimation. Before applying of irrigation water for each treatment, soil samples from 0 to 15, 15 to 30, 30 to 60 cm and 60 to 90 cm depths, were collected and the available moisture for each treatments was determined.

The source of irrigation water was from a surface tank of the nearby village of Dharwad city, and the run-off from the rain was the only source of water to the tank. This tank water was used for irrigating the lands of Agricultural College, Dharwad. This water was conveyed through channel to the experimental plots, and it was measured by using a parshall flume, before leading into plots as shown in Plate 5.

3.6.7. Tile drain out-flow Measurement:

After every irrigation, the out-flow was measured from each treatment using the measuring jar and conical flask. At the end of the each tile line, a plastic cistern of 10 litres capacity were burried and fixed permanently (Plate 6) and the over-flow from the cistern was arranged to flow into common drain meant to drain out of the experimental plot without interference.

After each irrigation, the out-flow was noticed after 10 minutes, and the total out-flow was measured by collecting all the water. The rate of out-flow was measured by measuring the out-flow during each minute separately, from all the drain treatments.

Drainage out-flow was also sampled for measuring silt discharge during each minute of flow. The collected samples were decanted after 48 hours and oven dried, and silt discharge at each minute was calculated. The data of total tile out-flow, the rate of tile out-flow, silt discharge and silt accumulated were recorded.

3.6.8. Measurement of Accumulated Silt in Tile Drain:

After completion of the experimental study, the tile drains were excavated and tiles were carefully removed without allowing other soil to enter the tile drains. The accumulated silt was collected by washing the inner side of the tiles and the solution was decanted and dried. Finally, washed and recorded for further analysis. The results of the oven dried soil was recorded after washing from each drain.

3.6.9. Statistical Analysis:

The experiment was laid out in split plot design, the data was analysed for F and T test by the method of Panse and Sukatme (1976). The critical differences were found at 0.05 level, and the abstract of above tables is given in Appendix-II.

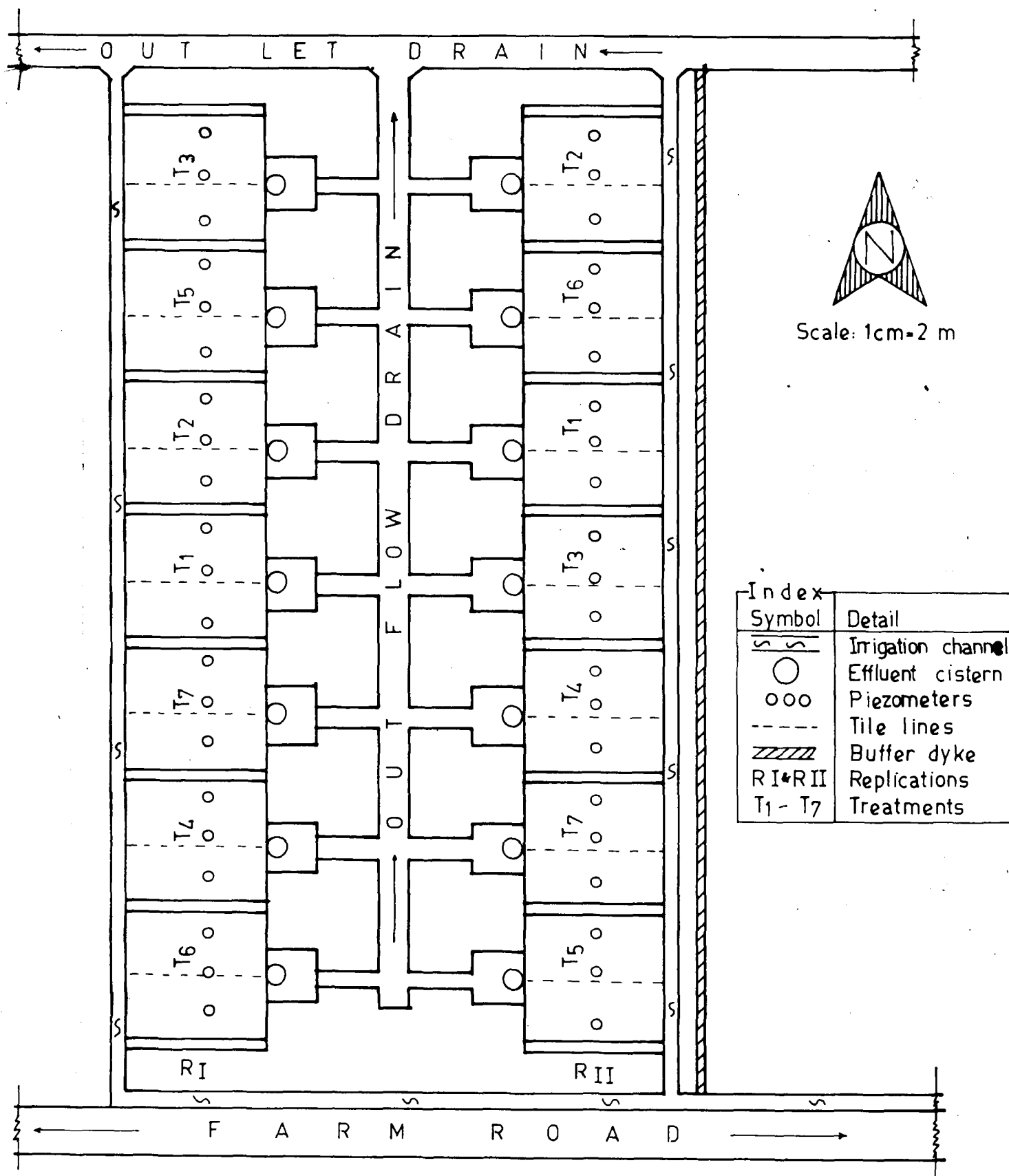


FIG. 8 LAY OUT PLAN OF THE EXPERIMENT ON NUMBER OF PERFORATIONS PER TILE

3.7. Design and layout of Experiment on Number of Perforations per Tile:

The experiment was laid out in split plot system as this design was suitable for the treatments of the experiment. The tile drains with different number of perforations (main treatment) were allotted to seven different plots in each replication, and the treatments were random in nature within each replication. The depths of irrigation water applied were considered as sub-treatments, and were also randomised during the experiment in each replication. The experimental plot was 36 m x 24 m and this was divided into two replications of 36 m x 6 m. In each replication, seven individual treatment units of 5 m x 5 m size were laid out and each treatment was separated by earthen bunds of 30 cm wide and 30 cm height (Fig. 8). The soil within the treatment units was levelled. Polyethylene sheets of 300 gauge were buried to a depth of 90 cm, and also around three sides of the plots with projection on the top of the bund to prevent lateral movement. A main drain was provided in the middle to collect all drainage water to lead out side the field and also the irrigation channel to apply the known quantity of water. In between irrigation channel and experimental plots, a buffer layer was provided to prevent lateral movement. Irrigation channel was suitable for fixing parshall flume for measuring water.

3.7.1. Treatments of the Experiment:

The experiment was designed with seven main treatments of



Plate 7. Tile with perforations of 0, 6, 12, 24, 36, 48 and 60 numbers per tile of 1 cm dia each.



Plate 8. Leaching of salts from experimental plots before starting of the experimentation.

perforations of one centimeter in rows on the body of the tile of 60 cm length and 10 cm dia. The treatments were: (1) tiles without any perforations, (2) tiles with 6 perforations, (3) tiles with 12 perforations, (4) tiles with 24 perforations, (5) tiles with 36 perforations, (6) tiles with 48 perforations, and (7) tiles with 60 perforations. The perforations of the tiles were provided on one half of the tile surface in rows, according to the number of perforations required. The sub-treatments were 2.5, 5.0, 7.5 and 10.0 cm depth of irrigation water above field capacity (Plate 7).

3.7.2. Specification of Tiles used in the Experiment:

In irrigated areas the red and white clay soils are prevalent in the pockets of black soil area. The burnt clay tiles of 60 cm length and 10 cm diameter made out of locally available clay were commonly used for subsurface drains by the farmers of the Command areas in Karnataka State. The method of manufacture and other details of burning in kilns were more or less agreement with the ASTM specification, and also it does not require any additional special skill for rural artisans for manufacture of tiles. Using the same specification, the tiles with different perforations of 1 cm dia (treatment) were got done at the Central Village Pottory Institute, Khadi and Village Industries Commission, Khanapur, Belgaum District.

3.7.3. Installation of Tile Drains:

Narrow trenches of 30 cm wide and 90 cm depth were formed for the entire length of the experimental units. Ordinary bedding system was adopted since this method was widely adopted and followed in Agricultural Drainage. The tile gradient of 0.2 per cent was provided in all the treatments for free gravity flow and this was the standard recommended grade for self-cleaning. The tiles were laid at 90 cm depth with perforations facing downward.

3.7.4. Design and Placement of Filter Material:

The mixture of sand and gravel material was designed based on the gradation curve of the base material. The design criteria followed was the criterion proposed by the U.S. Bureau of Reclamation, which is as follows:

$$\frac{50 \text{ per cent size of filter material}}{50 \text{ per cent size of base material}} = 12 \text{ to } 58$$

$$\frac{50 \text{ per cent fine size filter material}}{15 \text{ per cent fine size base material}} = 12 \text{ to } 40$$

The gradation curve of the base material and the filter material are presented in Fig.5. Filter was placed from bottom upto the height of the tile and thickness of the filter provided was 7.5 cm (Fig. 3). All the tile drains after the placement of filter were covered with a 300 gauge plastic strip and was blinded with the loose excavated earth. The tile outlets were protected with one way flap gates to prevent the entry of rodents and small animals into the tile drains.

3.7.5. Strength of Tile used in the Experiment:

The tiles used in the experiment were of typical of the tiles used in irrigated areas for sub-surface drains. The tiles used in the experimental treatments were tested for bearing strength by method of three edge bearing tests, and the machine used was universal testing machine. The test was in conformity with ASTM C₄-59T, tentative specification for clay drain tile given in concrete pipe Hand Book Published by American Concrete Pipe Association (1959). The data obtained from the test are given in Table 7, and each value was the average of the three observations.

3.7.6. Load on Drain Pipes:

Tile drains were burried at 90 cm depth and the load coming on the tile was due to load due to soil from back-fill, and also due to moving equipment and animals. Since the tiles were placed at deeper depth, the load due to equipment and animals was neglected. The static load of soil on tile drains was worked out by using formula given by Marston(1930), for both ditch conduit and projecting conduit conditions. The formula used were given as below:

Ditch conduit

$$W_c = C_d \ W \ B_d^2$$

Projecting conduit

$$W_c = C_c \ W \ B_c^2$$

where, W_c = Total load on the conduit

C_d = Load coefficient for ditch

W = Unit weight of fill material

B_d = Width of ditch at top of conduit

B_c = Outside diameter of the conduit

The load coefficients that were used in the Marston(1930) formula were read from the graphs proposed by Spangler (1947) was used (Fig. 7). The data obtained from the calculations are given in the Table 7.

3.7.7. Salt Status of the Soil of the Experimental Site:

Before starting of these evaluation studies, soil samples from individual experimental units were collected to find out the saline status of the soil. Soil samples were obtained from 0-15, 15-30, 30-60 and 60-90 cm depths and analysed for pH and E.C. as per the standard procedure given in USDA Hand Book No.60. The results of analysis are presented in Table 8.

3.7.8. Leaching of Salts of the Soil of the Experimental Site:

The soils were alkaline in nature and the gypsum requirement for neutralisation was worked out as per the standard procedure given in USDA Hand Book No.60 and this gypsum was uniformly applied to all the experimental units. Leaching requirement of irrigation water was calculated as 20 cm depth, and applied in four split doses of five cm each at an interval of six days. This leaching was done before starting of each experimental work (Plate 8 and 9).

Table 8. pH and E.C. values of Initial and Final Soil Samples of Individual Treatments

Sl. No.	Treatment with number of perforation per tile	Soil sample depth (cm)	Initial Soil samples		Final soil samples	
			pH	E.C. in mmhos/cm at 25°C	pH	E.C. in mmhos/cm at 25°C
1.	Tile without holes	0-15	8.5	1.42	7.8	2.85
		15-30	8.4	1.25	7.9	2.23
		30-60	8.3	1.16	8.0	2.14
		60-90	8.2	1.15	8.2	2.10
2.	Tile with 6 holes	0-15	8.7	1.96	7.9	2.83
		15-30	8.4	1.60	8.0	2.14
		30-60	8.2	1.70	8.1	2.02
		60-90	8.1	1.65	8.0	2.10
3.	Tile with 12 holes	0-15	8.6	2.14	7.6	2.83
		15-30	8.3	1.60	7.6	2.60
		30-60	8.2	1.34	8.0	2.05
		60-90	8.0	1.32	8.1	2.02
4.	Tile with 24 holes	0-15	8.5	2.05	7.5	3.07
		15-30	8.4	1.25	7.7	2.60
		30-60	8.0	1.25	7.3	2.02
		60-90	8.1	1.30	7.4	2.10
5.	Tile with 36 holes	0-15	8.6	1.78	7.5	3.70
		15-30	8.3	1.78	7.6	2.60
		30-60	8.1	1.51	7.9	2.02
		60-90	8.2	1.58	7.8	2.10
6.	Tile with 48 holes	0-15	8.5	2.23	7.7	3.46
		15-30	8.4	1.34	7.6	3.05
		30-60	8.0	1.25	7.9	2.25
		60-90	8.1	1.20	7.8	2.30
7.	Tile with 60 holes	0-15	8.7	1.60	7.4	3.45
		15-30	8.6	1.44	7.5	3.42
		30-60	8.2	1.37	7.8	2.05
		60-90	8.3	1.32	7.6	2.15

3.7.9. Irrigation of Experimental Units:

The depth of water to be applied to bring the soil moisture to the field capacity for the profile depth of 90 cm was worked out by the following equation:

$$d = \sum_{i=1}^n \frac{M_{fci} - M_{bi}}{100} \times BDi \times Di$$

where, d = depth of water to be applied in cm

n = number of soil layers

M_{fci} = field capacity of i^{th} layer in percentage

M_{bi} = moisture content before irrigation of i^{th} layer in percentage

BDi = Bulk density of i^{th} layer

Di = depth of i^{th} layer.

During the experimentation, known depth of water as per the treatment above field capacity, was applied at an interval of every 15 days to the individual experimental plots. The source of irrigation water was from the irrigation lake situated near the farm and this irrigation water was analysed for their constituents by following the standard procedure given in the USDA Hand Book No.60. The results of the analysis are given in Table 9. A portable parshall-flume of 7.5 cm throat width was used at the site of the experiment for measuring irrigation to individual plots (Plate 5).

3.7.10. Measurement and Analysis of the Out-flow:

In each irrigation, the out-flow from individual treatment was measured using conical flask and measuring jar.

Table 9. Results of Analysis of Drainage Water (average)

Tile drains with number of perfora- tions per tile	Depth of irrigation (cm)	pH	E.C. mmhos/ cm	Meg/lit						SAR
				CO ₃ ⁻	HC0 ₃	CL ⁻	Ca ⁺⁺	Mg ⁺⁺	Na ⁺⁺	
0		7.2	5.83	0.60	4.65	16.34	7.54	3.33	43.75	18.71
6		7.4	5.69	0.70	4.85	13.05	9.43	3.10	47.55	17.08
12		7.8	5.12	0.50	4.90	12.48	8.87	2.15	36.80	15.95
24	2.5	7.2	4.94	0.45	3.95	12.32	9.07	3.15	33.90	13.62
36		7.3	4.63	0.40	4.20	13.13	7.22	2.45	33.65	15.50
48		7.2	4.32	0.30	3.40	9.06	6.42	2.85	27.80	13.41
60		7.4	3.78	0.55	4.30	7.50	7.87	2.81	26.95	11.67
0		7.5	5.16	0.30	5.15	15.48	9.38	3.41	37.90	15.29
6		7.4	5.02	0.70	6.15	13.28	8.17	2.56	35.20	15.17
12		7.6	4.77	0.65	4.20	14.47	8.52	2.51	34.95	14.98
24	5.0	7.3	4.51	0.45	5.30	13.26	7.34	3.69	31.80	13.61
36		7.7	4.66	0.80	4.90	14.50	7.42	2.96	30.10	14.29
48		7.8	3.83	0.30	4.00	8.41	5.81	2.50	26.72	13.52
60		7.6	2.35	0.40	3.65	6.34	4.78	2.28	22.09	13.06
0		7.7	5.06	0.60	5.05	15.45	9.32	2.81	37.75	15.72
6		7.6	5.03	0.65	6.15	12.27	7.55	2.62	35.15	15.37
12		7.4	4.58	0.75	4.55	9.20	8.37	2.40	34.10	15.32
24	7.5	7.6	4.14	0.40	3.40	9.81	8.67	3.36	21.25	10.64
36		7.6	2.89	0.40	4.30	6.85	5.46	2.36	20.52	10.43
48		7.3	2.27	0.30	4.55	4.83	5.71	1.46	16.05	8.83
60		7.4	1.91	0.40	4.20	4.33	2.98	1.73	12.41	8.08
0		7.6	4.05	0.50	5.80	14.01	5.66	1.70	32.80	17.24
6		7.9	3.47	0.70	4.85	13.18	6.42	1.96	22.57	11.41
12		7.8	3.12	0.80	6.25	10.71	3.97	1.50	24.94	16.33
24	10.0	7.6	2.71	0.45	4.20	11.07	4.76	2.10	19.75	11.19
36		7.6	2.08	0.92	5.30	6.91	3.91	1.85	18.45	15.68
48		7.4	1.02	0.55	4.25	5.69	3.16	1.49	15.84	10.65
60		7.4	1.69	0.50	3.60	4.24	3.28	1.12	10.05	6.89



Plate 9. Picture showing the location of piezometers in each experimental plots.



Plate 10. Position of Orientation of the perforated face of the tiles for drainage water entry

To collect the total out-flow from the individual tile drains, 10 litre capacity plastic cistern were used which were burried at the end of the tile drain (Plate 6).

The water samples drawn from the individual tile drain out-flow was analysed for their constituents following the standard procedure given in the USDA Hand Book No.60. The data of the tile drainage water sample analysed are presented in Table 8 and 9.

3.7.11. Nature of Draw-down of Percolating Water:

Three piezometer, one on the tile drain and one each on either side of the tile drain at a distance of 2 meters and to a depth of 90 cm were installed in each experimental unit (Plate 9). The lowering of water in each piezometer at every 3, 6 and 24 hours after irrigation were recorded by using a multimeter.

3.7.12. Final Salt Status of the Soil in the Experimental Site:

Composite soil samples were collected at 0-15, 15-30, 30-60 and 60-90 cm depth from experimental plots and were analysed for pH, electrical conductivity, soluble cations and anions, exchangeable sodium, cation exchange capacity, sodium absorption ratio and exchangeable sodium percentage.

Further, soil samples from individual experimental units were obtained at the same depth and analysed for pH and electrical conductivity by following Standard Procedure given in USDA Hand Book No.60. The results of the analysis are presented in Table 10.

3.7.13. Statistical Analysis:

The experiment was laid out in split plot design and the data was analysed following the Fischer's analysis of variance technique as given by Panse and Sukhatme (1967). The abstract of analysis of Table are presented in Appendix IV.

3.8. Design and Layout of Experiment on Orientation of Tile Perforations

The experiment was laid out in split plot design as this design was suitable for the treatments of the study. The experimental plot was 30 m x 20 m and this was divided into four replications of 6 m x 15 m size were laid out and each experimental unit was separated by earthen bund of 20 cm width (Fig.9). The land in the experimental area was completely levelled. Polyethylene sheet of 300 gauge was buried to depth of 90 cm, projecting on the top of the bund, in all the three sides of each experimental unit (treatment) to prevent lateral ground water movement. In the middle of the layout, a central open drain was provided to drain away the water from all the tile drains of the treatments.

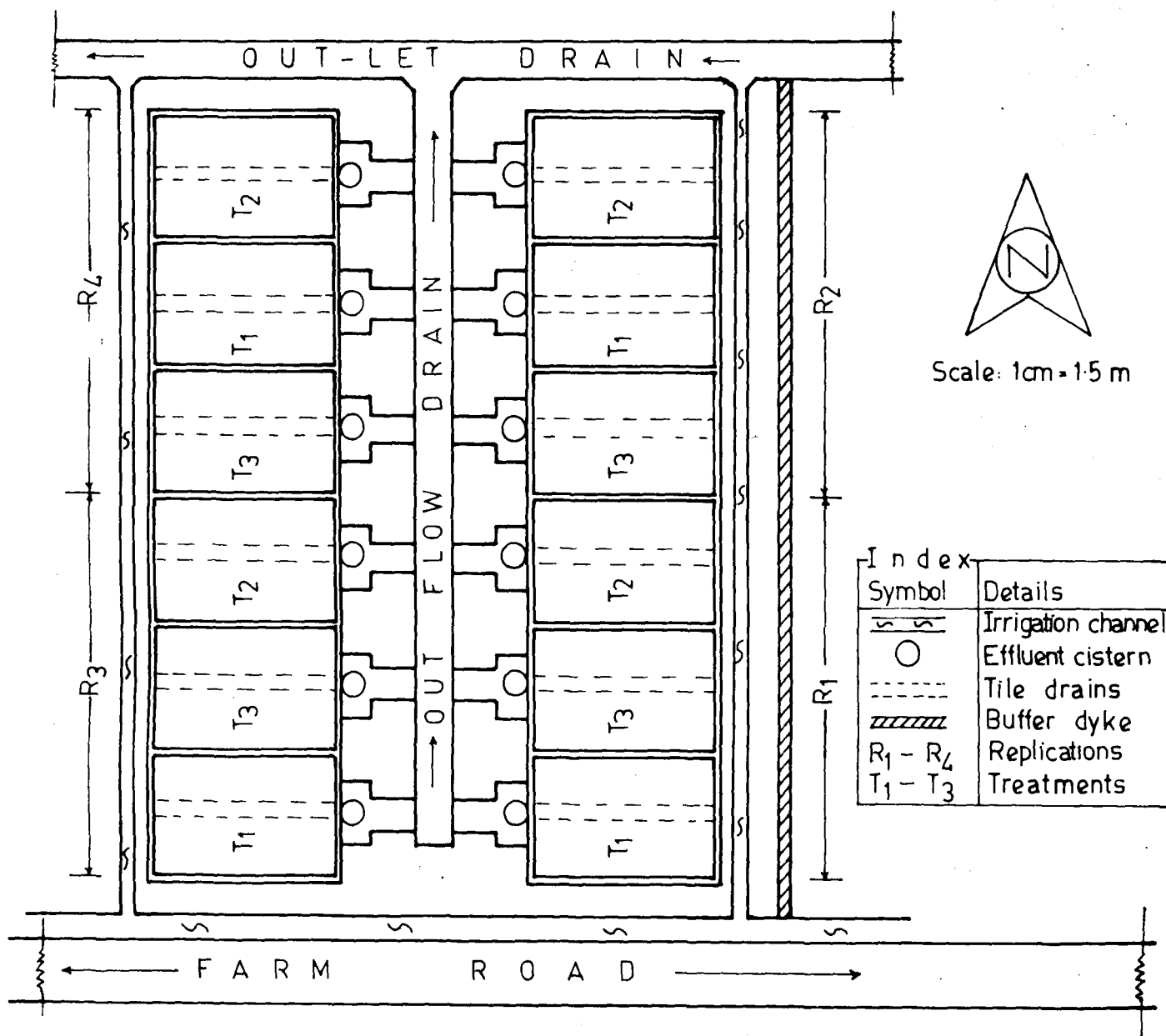


FIG. 9 LAY OUT PLAN OF THE EXPERIMENT ON ORIENTATION OF TILE PERFORATIONS

Table 10. Chemical Constituents of Initial and Final Composite Soil Samples (1:2 Soil^W Water Extract) (average)

Sl. No.	Soil sample depth (cm)	pH	E.C. in mmhos/cm	Meg/lit						Meg/100g			
				CO ₃ ⁻	HCO ₃ ⁻	Cl ⁻	SO ₄ ⁻	Ca ⁺⁺ Mg ⁺⁺	Na ⁺	SAR	ESP	Ex. Na	CEC
Initial samples													
1	0-15	8.6	1.44	0.50	1.90	7.84	2.84	1.00	11.13	15.68	17.63	6.63	38.22
2	15-30	8.6	1.34	0.54	2.20	7.44	1.55	1.40	10.30	14.26	16.33	6.91	42.30
3	30-60	8.1	1.30	0.60	2.50	7.04	1.96	1.60	9.95	11.18	15.63	7.30	46.70
4	60.90	8.0	1.31	0.56	2.30	6.98	1.62	1.62	9.85	11.02	14.75	7.20	46.50
Final samples													
1	0-15	7.4	3.46	Trace	1.75	3.35	43.96	28.20	21.82	5.82	5.78	1.91	33.06
2	15-30	7.6	2.83	0.30	2.16	3.62	30.84	14.92	20.60	7.55	10.57	4.13	39.11
3	30-60	8.0	2.02	0.54	2.16	4.65	15.33	4.41	18.32	12.38	10.36	4.26	41.08
4	60.90	8.2	2.50	0.21	2.10	4.30	15.20	3.92	17.85	10.45	10.56	3.65	40.50

3.8.1. Treatments of the Experiment:

The experiment was designed with three main treatments, namely, top orientation of tile circumferential perforation, lateral orientation of tile circumferential perforation and bottom orientation of tile circumferential perforation. These treatments were allocated in random in each replication. The number of replications selected were four, two each on either side of the main drain (Plate 10). Four subtreatments of irrigation, 5, 10, 15 and 20 cm were selected above the field capacity for this study.

3.8.2. Specification of Tiles used in the Experiment:

The clay tiles used for the study were of 10 cm diameter and 60 cm length with a facility for bell and spigot joint. The circumferential perforation provided on one half of the tile body in three rows. The burnt clay tiles used were typical ones that were used in irrigated command area as sub-surface drainage. The tiles were made out of special clay which was available locally and they were got prepared from the Central Village Pottery Institute, Khadi and Village Industries Commission, Khanapur, Belgaum District, Karnataka State. The 24 perforations per tile were selected based on the conclusion of previous study in the present investigation.

3.8.3. Installation of Tile Drains:

Narrow trenches of 30 cm wide and 90 cm deep were formed in the middle of the experiment for the installation of tiles. The ordinary bedding was adopted as this was the recommended practice for all agricultural sub-surface tile drainages. The tile depth of 90 cm on uniform grade of 0.2 per cent was adopted for all treatment. The 0.2 per cent of grade was designed for free gravity and self-cleaning flow to the outlets.

3.8.4. Design and Placement of Envelope Material:

The mixture of sand and gravel envelope was designed based on the gradation curve of the base material. The design was based on the criterion proposed by U.S. Bureau of Reclamation. The gradation curve of the base material and the envelope material are presented in Fig. 5. First the envelope material was placed from bottom upto $\frac{3}{4}$ th height of circumference of the tile, and then the thickness of the envelope was raised to 7.5 cm (Fig. 3). The tile drains were covered with a 300 gauge plastic strip and it was blinded with the loose excavated earth on the top. The tile drain out-lets were protected with one way flap gates to prevent the entry of rodents and any small animals (Plate 4).

3.8.5. Salt content of the soil of the Experiment:

Soil samples from individual experimental units were collected to find out the salt content of the soil. The soil

samples were drawn from 0-15, 15-30, 30-60 and 60-90 cm depths and analysed for pH and EC as per the standard procedure given in USDA Hand Book No.60. The results of analysis are presented in Table 10.

3.8.6. Leaching of Salts from the Soil Profile:

The soil was of alkaline nature and the gypsum requirement for neutralisation was worked out as per the standard procedure given in USDA Hand Book No.60. The experimental plots were leached by applying 20 cm depth irrigation water in four split doses at one week interval.

3.8.7. Irrigation of Experimental Units:

Before application of water for each treatment plots, soil samples from 0-15, 15-30, 30-60 and 60-90 cm depth were drawn and the total moisture present in the soil was estimated. The depth of water to be applied to bring the soil to field capacity for the entire profile depth of 90 cm was worked out by using the equation:

$$d = \sum_{i=1}^n \frac{M_{fci} - M_{bi}}{100} \times B_{di} \times D_i$$

where, d = depth of water to be given in cm

n = number of soil layers

M_{fci} = field capacity of ith layer in percentage

M_{bi} = moisture content before irrigation of ith layer in percentage

B_{di} = bulk density of ith layer

D_i = depth of ith layer.

The known depth of water as per the sub-treatment above field capacity was applied at the interval of 10 days to the experimental units during the investigation period.

The irrigation water was from irrigation lake situated about 4 km from the Farm, and this water was conveyed to the experimental site through the open channel. Before application to the individual plots, the water was measured using parshall-flume (Plate 5).

3.8.8. Measurement of Tile Out-flow:

In each application of water the out-flow from treatments were measured using conical flask and measuring jar. The rate of out-flow in each minute was recorded and the water samples of 200 ml was collected to determine the rate of silt discharge (Plate 6). The silt in each sample was estimated by decanting after 48 hours of storing. Finally oven dried and weighed gravimetrically.

3.8.9. Measurement of Accumulated Silt in Tile Drains:

After completing the experiment, the tile drains were excavated carefully to prevent the entry of any soil into the tiles. The accumulated soil was collected from the tiles by washing the inner side of the tile. The wash out was dried and estimated by weighing gravimetrically.

3.8.10. Final Salt Status of the Experimental Units:

The soils samples were drawn from 0-15, 15-30, 30-60 and 60-90 cm depth from each experimental units, and analysed for pH and EC values. The analysed data are given in Table 10.

3.8.11. Statistical analysis:

The data was analysed by following the Fisher's analysis of variance technique as given by Panse and Sukratha (1967). The abstract of analysis is given in Appendix IV.

3.9. Design and Layout of Experiment on Envelope Material:

The burnt clay tiles used as sub-surface drains were invariably provided with some type envelope materials such as graded gravel, saw-dust, coconut-fiber, corn-cob, paddy straw, and paddy husk, in irrigated areas of Karnataka State. In some of the places, the tile drains were used without envelope material. Consequently, the indiscriminant use of envelope materials and also inadequate information on the use of sub-surface drains in the irrigated areas, lots of complaints were noticed about the use of sub-surface drains. Therefore, the experiment was planned to evaluate the locally available envelope materials and also to standardise the techniques for the use of burnt clay tiles as sub-surface drains in irrigated areas of Karnataka State.

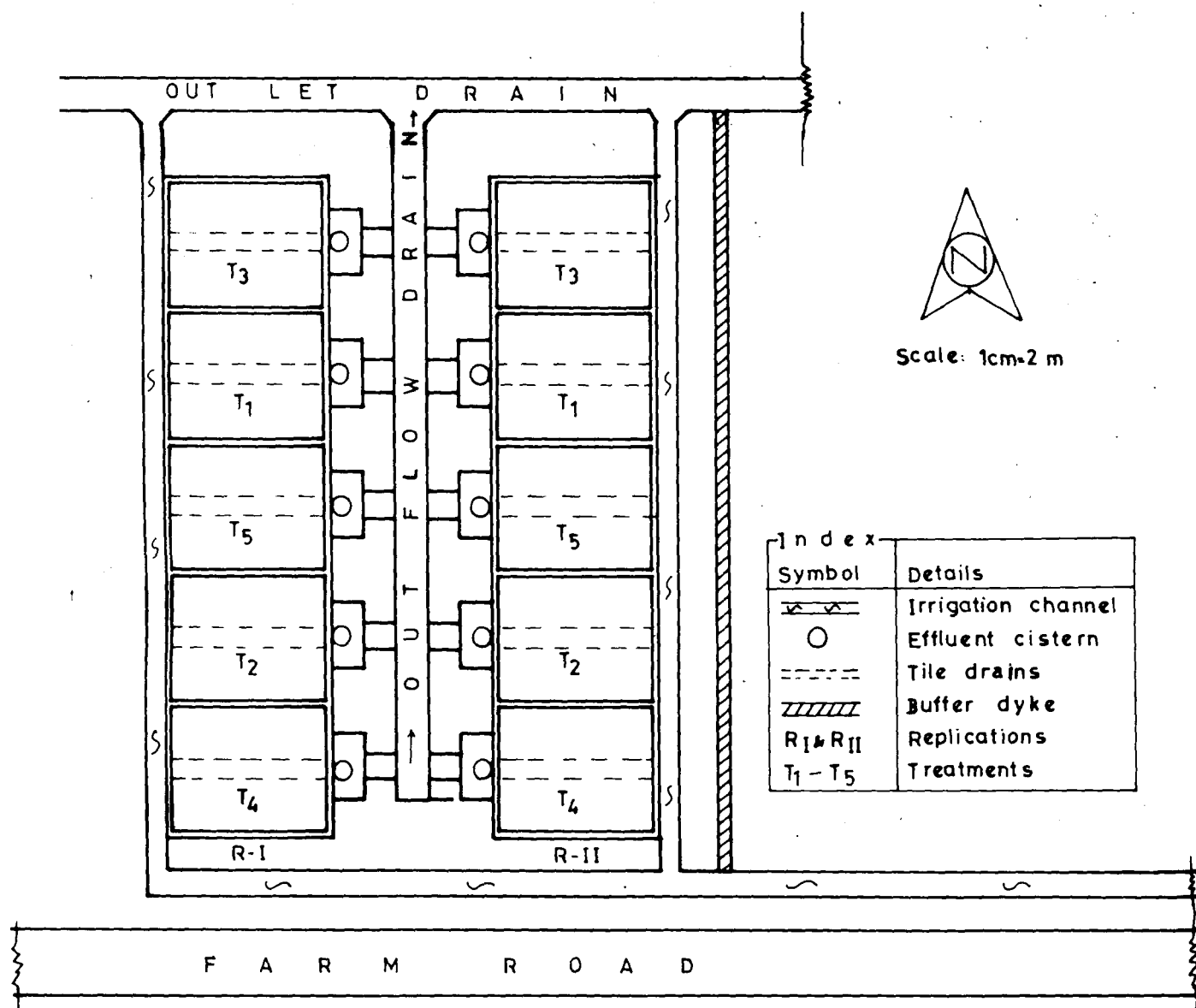


FIG.10 LAY OUT PLAN OF THE EXPERIMENT ON FILTER MATERIALS

The locally available five envelope materials were selected, namely, graded gravel, saw-dust, corn-cob and coconut fiber along with a treatment of top soil for evaluation work, and designated these envelope material as main treatment. Four depth of irrigation above field capacity was selected as sub-treatments, namely, 5.0, 7.5, 10.0 and 12.5 cm.

The size of the experimental plot was 50 m x 15 m consisting of two replications of 25 m x 5 m. In each replications there were five experimental units of 5 m x 5 m and every experimental unit was separated by earthen bund of 30 cm width. Individual plots were levelled uniformly in the entire experimental layout. In the middle of the layout there was a central open ditch to serve as outlet drain from all the individual plots (Fig. 10).

To prevent the lateral movement of water from one experimental unit to another, polyethylene sheet of 300 gauges was burried to a depth of 90 cm from top alround three sides of the individual unit. The side wall towards the outlet was stabilized by using stone pitching.

3.9.1. Tile Drains Specification:

The tiles used in the experiment were got prepared at the Central Village Pottery Institute, Khadi and Village Industries Commission, Khanapur, Belgaum District. They were made out of clay, locally available, using standard technique by burning

at 900°C. The tiles were 60 cm in length and 10 cm in dia with bell and spigot ends. The circumferencial perforation of 1 cm dia were made at the time of casting using simple nails, and 24 number of perforations were provided on one half of the circumference. The total water entry area worked out as 18.85 sq.cm for 24 perforations of 1 cm dia per tile. From the earlier study 24 perforations of 1 cm dia per tile gave better performance and also the load bearing strength of tile was 8.47 kg per sq. cm.

3.9.2. Installation of Tile Drains in the Experimental Units:

For the purpose of laying tile drains in each experimental unit, narrow trenches of 30 cm wide and 90 cm deep were formed and back-filled after laying. Ordinary bedding was adopted as it was the generally practised methods in Agricultural tile installation. The tiles used in each treatment were identical in both in manufacture and in laying. Tiles were laid at a depth of 90 cm with the gradient of 0.2 per cent for all treatments, which was sufficient for free gravity flow with self-flushing velocity.

3.9.3. Main Treatment Design and Application:

Among the five envelope materials, namely gravel envelope, coconut fiber corn-cob, saw-dust, and top soil, the gravel envelope was designed based on the particle size analysis of the base material. The design criteria followed was as proposed by the US Bureau of Reclamation, which was:

$$\frac{50 \text{ per cent size of envelope}}{50 \text{ per cent size of base material}} = 12 - 58$$

$$\frac{15 \text{ per cent fine size envelope}}{15 \text{ per cent fine size of base material}} = 12 - 40$$

The base material (soil) was subjected to in mechanical and hydrometer analysis to find out the grain size distribution. A smooth gradation curve was obtained by plotting particle diameter size on horizontal scale and percentage finer on vertical scale on semilog paper. Using the U.S. Bureau of Reclamation criteria, as mentioned above, the lower and upper limits from gradation curve were obtained for fitting the filter design curve and was drawn as shown in Fig. 5, and also the results of the analysis is presented in Table 5 .

The graded gravel as per the design was placed in the inverted form to thickness of 7.5 cm from bottom to three fourth circumference of the tile. The saw-dust (coarser), corn-cobs (shelled), coconut-fiber (loose) and top soils were simply laid to a thickness of 7.5 cm from the bottom of drain trenches corresponding to their allotted units.

3.9.4. Placement of Tile Drains in Envelope Material and Blinding:

The tile drains were laid above the envelope material keeping circumferential perforations facing downward, and the sides were fully covered with envelope materials as shown in Fig.3. Then the tile drains were covered with 300 gauge plasti

strips and the loose excavated earth was back-filled for blinding tile drains.

3.9.5. Anticident Moisture Estimation:

Before application of irrigation water to each treatment, soil samples were drawn from 0 to 15, 30-60 and 60-90 cm depths in all experimental units to determine the moisture percentage on oven-dry weight basis. Using the available moisture level as the basis, the amount of water required to bring the soil to field capacity was worked out. The bulk density of four depth of soil layer were also found out for the purpose of estimating of irrigation water.

3.9.6. Irrigation of Experimental Plots:

The depth of water applied to bring the soil moisture to field capacity, for the profile depth of 90 cm was worked out by the following equations:

$$d = \sum_{i=1}^n \frac{M_{fci} - M_{bi}}{100} \times B_{di} \times D_i$$

where, d = depth of water applied in cm

n = number of soil layers

M_{fci} = field capacity of i^{th} layer in percentage

M_{bi} = moisture content before irrigation of i^{th} layer in percentage

B_{di} = bulk density of i^{th} layer

D_i = depth of i^{th} layer.

Using the respective values of field capacity and initial moisture percentage of soil, the depth of water applied was worked out. The parshall flume was used to measure the irrigation water. The source of water was from nearby channel flowing from irrigation tank, which was situated at a distance of 4 km from the site of experiment.

3.9.7. Measurement of Tile Drains Out-flow:

After application of known quantity of water to each treatments, the out-flow was measured using beaker and measuring jar in every minute of flow. The total outflow and rate of flow was also obtained. Samples of 400 ml were collected during second and fourth minute tile discharge to determine the amount of soil discharging. The samples were allowed to de-cent over a period of 48 hours and then the de-cented samples were dried and washed for weighing. For convenience of analysis, the values of silt discharge were converted into grams per litre. The results of tile out-flow and soil discharge for main and sub-treatments are recorded.

3.9.8. Measurement of Soil Accumulated in Tile Drains:

After completion of the experiment, the tile drains were excavated and each tile was carefully handwashed from inside. The washout was collected and weighed.

3.9.9. Statistical Analysis:

The values of all observations were analysed following the Fisher's analysis of variance technique as given by Panse and Sukhatme(1961). The abstract of the analysis of variance table are presented in Appendix-V.

CHAPTER 4

EXPERIMENTAL RESULTS

CHAPTER 4

EXPERIMENTAL RESULTS

Four experiments were conducted in water-logged soils in plot number 177 of 'G' Block at Agricultural College Farm, Dharwad, during the years 1980-81, 1981-82, 1982-83 and 1983-84, to understand the effect of size of circumferential perforations of tiles, number of circumferential perforations per tile, orientation of perforated side of tile for ground water entry, and the nature and type of envelope materials suitable for the clay tile drains, on the drainage efficiency, silt discharge in tile drain outflow, amount of silt accumulation in tile drains, and the load bearing strength of clay tiles of 10 cm dia and 60 cm long, used in Command Areas of Karnataka State.

The first experiment was conducted on optimum size of circumferential perforation of tiles suitable for tile drains used in irrigated Command Areas in Karnataka State. The main treatments adopted were (i) plain clay tiles without perforation, clay tiles with perforation, (ii) of 0.50 cm, (iii) 0.75 cm (iv) 1.00 cm, (v) 1.25 cm and (vi) 1.50 cm. The sub-treatments were four depths of irrigation, namely 8, 10, 12 and 14 cm above the field capacity of the soil profile.

The second experiment conducted was on optimum number of circumferential perforations required for clay tile drains. The main treatments were plain clay tiles (i) without perforation, clay tiles (ii) of 6 perforations, (iii) 12 perforations,

(iv) 24 perforations, (v) 36 perforations, (vi) 48 perforations, and (vii) 60 perforations of 1 cm dia. The sub-treatments were four depths of irrigation, namely, 2.5, 5.0, 7.5 and 10.0 cm, above the field capacity of the soil profile of 90 cm.

The third experiment was on the effect of orientation of circumferential perforation of tiles to the direction of water entry. The main treatments were placement of perforated area of tile drain facing i) upward, ii) downward, and iii) side-ward, and these treatments were called top orientation, bottom orientation, and lateral orientation. The sub-treatments were 5.00, 10.00, 15.00 and 20.00 cm depth of irrigation above the field capacity of the soil profile of the 90 cm depth.

The fourth experiment was on the identification of suitable locally available envelope materials for the circumferentially perforated clay tile drains used in Command Areas of Karnataka State. The main treatments were top soil, coconut fibre, saw-dust, corncobs and graded gravel. The sub-treatments were 2.5, 5.0, 7.5 and 10.0 cm depth of irrigation water above the field capacity of the soil profile upto depth of drain.

The results of the above four experiments are given below:

4.1. Nature and position of land in Experimental site:

The land was fairly level in nature with the slope of 0.2 to 0.5 per cent in the direction of length of tile drains

and 0.1 to 0.3 per cent in the lateral direction. The experimental site was situated in the low laying area of the Farm and the topographic map of the area is given as shown in Fig. 1.

4.2. Nature and class of soil in the Experimental Site:

The results of mechanical analysis of the soil of the experimental site are presented in Table 5. The top layer was sandy clay and the other two layers below were clay textured. The clay content in these layers varied from 40.75 to 52.00 per cent and the silt content was from 9.00 to 11.25 per cent. Gravel, coarse sand and fine sand content were varied from 1.48 to 2.00 per cent, 12.25 to 20.25 per cent and 19.50 to 23.25 per cent, respectively. The percentage of clay and silt increased with increased depth of soil profile. Gravel and coarse sand content were decreased with increase in depth of soil profile.

4.3. Hydraulic conductivity of the soil of the Experimental site:

The details of auger hole used for the determination of hydraulic conductivity and the values of parameters for determining hydraulic conductivity are given in Table 3 and Fig. 4. The hydraulic conductivity was varied from 5.6 m/day to 6.2 m/day (19.5 cm/hr to 22.7 cm/hr). This soil comes under the hydraulic conductivity class "Moderately high" according to O'Neal(1949) and on an average it was found to be 4.8 m per day(21.4 cm/hr).

4.4. Irrigation and Ground Water Analysis:

The pH and electrical conductivity of irrigation water were 7.8 and 0.53 mmhos/cm at 25°C, respectively. The contents of calcium + magnesium, and sodium were 2.30 and 2.10 meg/lit, respectively. The other constituents like carbonates, bicarbonates, and chlorides of the irrigation water were 0.40, 2.40 and 2.02 meg/lit, respectively. The SAR value was 1.92. The details of the results of analysed irrigation water are given in Table 2.

The pH and Electrical conductivity of the ground water were 8.3 and 2.15 mmhos/cm at 25°C respectively. The calcium + magnesium content was 6.60 meg/lit, whereas the sodium content was 13.30 meg/lit. The concentration of carbonates, bicarbonates and chlorides were 0.90, 10.40 and 8.45 meg/lit, respectively. The SAR value of this water was 7.32. The detailed results of analysed ground water are given in Table 2.

4.5. Status of Water Table at the Experimental site:

The water table level was at maximum in the month of September with average depth of 6.85 cm from the surface, and minimum in the month of May with average depth of 101.0 cm from the surface. During other period, the water level was varying gradually between maximum and minimum levels. The water levels in all the six observation wells were increased from June month onwards till October and decreased from November onwards till May.

The hydrography of water table is as shown in Fig. 2, and the corresponding monthly average levels of water table from surface are given in Table 1. The plan showing the ground water and topographic contours of the experimental site are presented in Fig. 1. The direction of ground water flow was from East to West in the Experimental site.

4.6. Results of Experiment on Size of Perforation of Tile Drains:

The tile drains which were formed out of burnt clay tiles had circumferential perforation of 0.50, 0.75, 1.00, 1.25 and 1.50 cm and also a plain tile drain without perforation was used as control. These tile drains were evaluated for tile drain out-flow, silt discharge in tile drain out-flow, silt accumulation in tile drains and bearing strength of tiles. The observations recorded in the table were the average of three readings taken at the time of experiment. The results are presented in Table 11 and 12.

4.6.1. Tile Drain perforations:

The number of perforations per tile to get the total surface water entry area of 18.85 sq.cm were 11, 15, 24, 42 and 96 respectively for tiles with 1.50, 1.25, 1.00, 0.75 and 0.50 cm dia, perforations. The tile drains with plain surface (control) without circumferential perforations, had inter-tile crack spacing of 6.30 sq.cm, and it was assumed to be uniform for all joints. Including the inter-tile crack space, the total water entry area for individual tile with perforation of 1.50, 1.25,

Table 11. Depth of Irrigation and Mean Tile Drain Out-flow

Sl. No.	Depth of irrigation in cm	Total tile drain out-flow in litres						Mean tile drain out-flow in litres
		Size of tile drain perforation in cm						
		Plain surface	1.50	1.25	1.00	0.75	0.50	
1	8.00	162.0	405.0	482.0	526.0	566.0	590.0	450.0
2	10.00	213.0	450.0	536.0	616.0	640.0	680.0	522.0
3	12.00	313.0	560.0	636.0	756.0	792.0	830.0	648.0
4	14.00	364.0	605.0	670.0	836.0	866.0	910.0	712.0
Mean		263.0	505.0	576.0	516.0	696.0	116.0	
		S.Em _±			C.D.(5%)			
1. For comparison of size of perforation		NS			NS			
2. For comparison of depth of irrigation for the same or different size of perforation		NS			NS			

Table 12. Mean Tile Drain Out-flow Under Different Depth of Irrigation

Sl. No.	Size of perforation (cm)	Number of perforations	Total water entry area (sq.mm)	Total Tile out-flow in litres				Mean drain out-flow in litres
				Depth of irrigation (cm)				
				8.00	10.00	12.00	14.00	
1	plain surface	-	6.30	162.00	213.00	313.00	364.00	263.00
2	1.50	11	25.15	405.00	450.00	560.00	605.00	505.00
3	1.25	15	25.15	482.00	536.00	636.00	670.00	576.00
4	1.00	24	25.15	526.00	616.00	756.00	836.00	686.00
5	0.75	42	25.15	566.00	640.00	792.00	866.00	716.00
6	0.50	96	25.15	590.00	680.00	850.00	910.00	750.00
Mean				455.00	522.00	648.00	712.00	-

S.Em_t C.D(5%)

1. For comparison of size of perforation

0.287 0.84

2. For comparison of depth of irrigation for the same or different size of perforation

0.7635 NS

1.00, 0.75 and 0.50 cm dia was 25.15 sq.cm, and for tile drain without perforations was measured as 6.30 sq.cm per tile in average.

4.6.2. Depth of Irrigation Water Applied:

Four depths of irrigation water were applied namely, 8.0, 10.00, 12.00, 14.00 cm, above field capacity, to each experimental plots. The total tile drain out-flow under 8 cm depth of irrigation were 405.0, 482.0, 526.0, 560.0 and 590.0 litres respectively in tile drains with 1.50, 1.25, 1.00, 0.75 and 0.50 cm dia perforations, and in tile drain without perforation the out-flow was 162.0 litres. Similarly, under 10 cm depth of irrigation, the total out-flows from tile drains with 1.50, 1.25, 1.00, 0.75 and 0.50 cm perforation were 450.0, 536.0, 616.0, 640.0 and 680 litre, and in tile drain without perforation out-flow was 213 litres. For 12.00 cm depth of irrigation, the respective tile drain out-flows were 560.0, 636.0, 756.0, 792.0, 830.0 and 313 litres. Also in the experimental treatments under 14.00 cm depth of irrigation, the total respective outflows were 605.0, 670.0, 836.0, 866.0, 910.0 and 364.0 litre. The details of the observation are given in Table 11 and 12.

4.6.3. Total Out-Flow from Tile Drains:

In tile drain with plain surface gave 162.0, 213.0, 313.0 and 364.00 litre out-flow, respectively, under 8, 10, 12, 14 cm depth of irrigation above field capacity. The out-flow from

tile drain of 1.50 cm dia perforation were 405.00, 450.00, 560.00 and 605.00 litres under 8, 10, 12 and 14 cm depth of irrigation. Similarly, in tile with 1.25 cm dia perforation, the out-flows were 482.0, 536.0, 636.0 and 690.00 litre under same depths of irrigation. For the tile drain with 1.0 cm dia perforation under 8, 10, 12 and 14 cm depth of irrigation, the out-flows respectively of 526.00, 616.00, 756.00 and 836.0 litre. In the same way the out-flow from tile drains with 0.75 and 0.50 cm dia perforation were 566.00, 640.00, 792.00, 860 litres and 590.00, 680.0, 830.0, 910.0 litres respectively. The details of the observation are given in Table 12.

4.6.4. Rate of Drain Discharge During Different Time Interval:

The results of observations of rate of tile drain out-flow are given in Table 13 and these observations are the average of three readings. In the drains with plain surface gave the discharge rate 0.021, 0.028, 0.035 and 0.048 litres per minute during first, second, third and fourth minutes, respectively. The tile drain with 0.50 cm dia perforation recorded 0.094, 0.138, 0.189 and 0.240 litres per minute during the same time intervals. Similarly, the rate of tile drain out-flow recorded were 0.087, 0.129, 0.170, 0.220 l/m, in 0.75 cm dia perforation tile drains and in 1.00 cm dia perforations tile drains, the out-flow rates were 0.065, 0.108, 0.153 and 0.201 l/m during first, second, third and fourth minute of discharge. The tile with 1.25 and 1.50 cm dia perforation, the discharges rates were 0.045, 0.058, 0.094, 0.166 l/m and 0.023, 0.046, 0.075, 0.106 l/m, respectively.

Table 13. Tile Drain Discharge Rate at Different Time Interval

Sl. No.	Size of the perforations (cm)	Tile drain discharge rate in litres/minute				Mean
		I	II	III	IV	
1.	Plain surface	0.021	0.028	0.035	0.048	0.033
2	0.50	0.094	0.138	0.189	0.240	0.165
3	0.75	0.087	0.129	0.170	0.220	0.152
4	1.00	0.065	0.108	0.153	0.201	0.132
5	1.25	0.045	0.088	0.094	0.166	0.098
6	1.50	0.023	0.045	0.075	0.106	0.063

S.Em_t CD (5%)

1. For comparison of size of perforations 0.273 0.84

2. For comparison of size of perforations with time interval 0.286 0.914

3. For comparison of tile drains of perforations 1.00, 1.25 and 1.50 cm dia. 0.785 NS

The mean rate of tile drain discharges were 0.033, 0.152, 0.132, 0.098, 0.063 l/m, respectively, from tile drain with plain surface and tile drains with 0.50, 0.75, 1.00, 1.25 and 1.50 cm dia perforations.

4.6.5. Rate of Silt Discharged in Tile Drains:

The rate of silt discharged at first to fourth minute duration is given in Table 14, indicating the average weight of three samples, and their respective percentages. The mean rate of silt discharges were 0.27, 2.02, 1.37, 0.96, 0.69 and 0.45 g/l, respectively, in tile drain without perforations, and tile drains with 1.5, 1.25, 1.00, 0.75 and 0.50 cm dia perforations.

The rate of silt discharge during first to fourth minute in plain, tile drain was 0.12, 0.21, 0.32 and 0.44 g/l. In tile drains with 0.50 cm dia perforation, the silt discharge was 0.28, 0.36, 0.52, 0.76 g/l from first to fourth minutes. Similarly, silt discharges in tile drains with perforations of 0.75, 1.00, 1.25 and 1.50 cm dia were respectively, of 0.38, 0.52, 0.82, 1.02 and 0.56, 0.79, 1.11, 1.32 and 0.98 and 0.98, 1.33, 1.62, 1.83 and 1.64, 2.03, 2.14, 2.24 g/l during first to fourth minutes duration.

4.6.6. Total silt Accumulated in Tile Drains:

The total silt accumulated in tile drains from all the replications are averaged and given in the Table 15.

Table 14. Silt Discharged through Drainage out-flow at Different Time Interval

Sl. No.	Size of perfora- tion(cm)	No.of perfora- tion/ tile	Silt discharge at different time interval in grams/ litre								Mean value	
			First minute		Second minute		Third minute		Fourth minute		Wt.	%
			Wt.	%	Wt.	%	Wt.	%	Wt.	%		
1	0.00	-	0.12	3.56	0.210	3.90	0.320	4.93	0.436	5.85	0.272	4.55
2	0.50	96	0.20	6.10	0.363	6.74	0.547	7.96	0.758	10.17	0.460	7.74
3	0.75	42	0.48	14.69	0.665	13.51	0.811	9.09	1.120	18.58	0.694	13.46
4	1.00	24	0.56	17.31	0.785	14.80	1.11	17.95	1.963	22.61	0.960	18.53
5	1.25	15	0.98	30.78	1.330	26.41	1.63	26.21	1.830	25.39	1.370	26.54
6	1.50	14	1.64	53.30	2.030	39.24	2.13	34.50	2.237	33.19	2.020	39.48
Total			3.37	-	5.383	-	6.49	-	7.44	-	5.427	-

			S.E.m±		C.D(5%)							
1. For comparison of size of perforations			0.452		1.392							
2. For comparison of size of perforations with single or different time interval			0.365		0.986							
3. Comparison of size of perforations of 0.0, 0.50, 0.75 and 1.0 cm dia tiles			0.7604		NS							

NS = Not Significant

Table 15. Silt Discharged and Silt Accumulated in the Tile Drains

Sl. No.	Size of perforation of tiles (cm)	Mean silt discharge in tile drains g/l	Mean silt accumulated in tile drains in grams	Mean tile drain out-flow (litres)	Mean tile drain discharge in lit/minute
1	Plain surface	0.27	2.65	263.00	0.033
2	1.5	2.02	7.88	505.00	0.063
3	1.25	1.37	6.53	570.0	0.098
4	1.00	0.96	6.00	668.00	0.132
5	0.75	0.69	5.61	716.0	0.152
6	0.50	0.45	5.04	750.0	0.165

S.E.m_t C.D.(5%)

0.85

1. For comparison of size of perforations

2. For comparison of size of perforations of 1.00, 0.75 and 0.50 cm dia

NS

NS = Not Significant

The accumulated silt in plain tile drain was 2.65 grams and in tile drains with 1.50, 1.25, 1.00, 0.75 and 0.50 cm dia perforation, the respective silt accumulations were 7.88, 6.58, 6.00, 5.61 and 5.04 grams.

4.6.7. Bearing Strength of Tiles used as Tile Drains:

The load bearing strength of tiles with different perforation are given in Table 16. The load bearing strength of tile without perforation was 12.13 kg/cm^2 , and it was 9.86 kg/cm^2 for tile drains with 11 perforation of 1.50 cm diameter. In tiles with 15 perforation of 1.25 cm dia, the load bearing strength was 9.25 kg/cm^2 . For 1.00 cm dia perforation tile, the load bearing strength was 8.67 kg/cm^2 with 24 perforations. The tile drains with 0.75 cm dia had load bearing strength of 6.75 kg/cm^2 with 42 perforation. Similarly, for 0.50 cm dia tiles with 96 perforation gave 5.68 kg/cm^2 load bearing strength.

4.7.0. Results of Experiment on Optimisation of Number of perforations per Tile:

This experiment was carried out with seven treatments namely, a tile drain with plain surface, and six other treatments, with 6, 12, 24, 36, 48 and 60 number perforations of 1 cm dia. Since the earlier experiment on size of perforations indicated that one cm dia perforations were optimum for clay tiles of 10 cm diameter and 60 cm long. The tiles with one cm perforation were evaluated for tile drain out-flow, silt discharge in tile drain out-flow, silt accumulated in tile drains, and bearing

Table 16. Mean Tile Out-flow, Number of Perforations per tile and Bearing Strength of Individual Tiles

Sl. No.	Size of tile perforations (cm)	Number of perforations per tile	Mean tile out-flow (litres)	Bearing strength of tile (kg/cm ²)	Reduction of strength of tile ----- kg/cm ² Percentage -----
1	Plain surface	-	263.0	12.13	-
2	1.50	11	505.0	9.86	2.27 18.71
3	1.25	15	576.0	9.25	2.88 23.74
4	1.00	24	668.00	8.67	3.45 28.52
5	0.75	42	716.0	6.75	5.38 44.35
6	0.50	96	750.0	5.68	6.45 53.17

	S.Em _t	C.D.(5%)
1. For comparison of size of perforations	0.3215	0.8932
2. For comparison of bearing strength of each tile perforations of 1.00, 0.75 and 0.50 cm dia.	0.4732	0.0974

strength of tiles. Each observation recorded in the tables were the average of three readings taken at the time of experiment and the results were presented as below:

4.7.1. Number of perforation per Tile:

The number of perforations per tile in each treatment were varied keeping the size of the perforations same in all treatments. Plain surface tile drain was taken as control, and the other treatments were 6, 12, 24, 36, 48 and 60 perforations of one centimeter diameter. The total surface area in each treatment was varied, namely, in plain surface tiles, the water entry area was 6.30 sq.cm, due to inter tile crack spacing, and in other treatments, the areas were 11.00, 15.70, 25.10, 34.50, 43.90 and 53.40 sq.cm, respectively per tile with perforations of 6, 12, 24, 36, 48 and 60 numbers.

4.7.2. Depth of Irrigation Water:

Four depths of irrigation water were applied, namely, 2.5, 5.0, 7.5 and 10.0 cm, above field capacity considering 90 cm depth of soil profile. The total tile drain out-flows were 46.20, 70.50, 84.50, 112.00, 132.00, 145.50 and 152.00 litres respectively from tile drains with 0, 6, 12, 24, 36, 48 and 60 perforations of one cm dia under 2.5 cm depth of irrigation. Similarly, under 5.0 cm depth of irrigation, the total tile drain out-flows were, 92.00, 144.00, 167.00, 221.00, 270.00, 307.50 and 318.50 litres. For 7.5 and 10.0 cm depth of irrigation,

the out-flows recorded were 122.50, 191.00, 228.00, 310.00, 382.00, 434.00, 446.00 litres and 143.00, 225.50, 263.00, 352.50, 432.00, 488.50, 505.00 litres, respectively. The mean of the total tile drain out-flows were 105.85, 155.13, 183.63, 248.87, 308.38, 336.25, 356.38, from tile drain with tile perforations of 0, 6, 12, 24, 36, 48 and 60 per tile. The details of the observations are given in Table 18.

4.7.3. Total Out-flow from Tile Drains:

The tile drain without surface perforation gave 40.00, 92.00, 122.50 and 143.00 litres of out-flow, respectively, under 2.5, 5.0, 7.5 and 10.0 cm depth of irrigation above field capacity. The out-flow from tile drains with 6 perforations recorded the out-flow of 70.50, 144.00, 191.00, and 215.50 litres under 2.5, 5.0, 7.5 and 10.0 cm depth of irrigation. Similarly, from tile drains with 12, 24, 36, 48 and 60 perforations per tile, the out-flows recorded were 84.00, 167.00, 228.00, 253.00 litres and 112.00, 221.00, 310.50, 352.50 litres and 132.00, 276.00, 386.00, 485.50 litres and 145.50, 307.00, 434.50, 482.50 litres and 152.00, 318.50, 446.00, 505.00 litres respectively. The details of the observations are given in Table 19.

4.7.4. Rate of Tile Drain Out-Flow:

The results of observations of rate of tile drain out-flow are given in Table 20 and these observations are the average of three readings. In tile drain with plain surface gave

Table 17. Total Tile Drain Out-flow in Relation to Depth of Irrigation

Sl. No.	Depth of irrigation water (cm)	Total tile drain out-flow in litres					
		Water entry area due to perforation of the tiles in square cm					
		6.3	11.0	15.70	25.10	34.50	53.40
1	2.5	46.00	70.50	84.00	112.00	132.00	152.00
2	5.0	92.00	144.00	167.00	221.00	276.00	318.50
3	7.5	122.50	191.00	228.00	310.50	386.00	446.00
4	10.0	143.00	215.50	255.00	352.50	435.50	505.00
Mean		105.85	152.62	196.00	248.8	308.38	356.38
1. For depth of irrigation		F Test		S. Em _t		C.D. (5%)	
		Significant		1.51		4.80	
2. For interaction of depth of irrigation with size tile perforations		Significant		10.65		21.98	

Table 18. Number of Perforations per Tile and Total Tile Drain Out-flow in litres

Sl. No.	No. of perforations per tile	Total tile drain out-flow in litres				Mean tile drain out-flow (litres)
		Depth of irrigation above field capacity in cm				
		2.5	5.0	7.5	10.0	
1	Plain surface	46.00	92.00	122.50	143.00	105.85
2	6	70.50	144.00	191.00	225.50	155.13
3	12	84.50	167.00	228.00	263.00	183.63
4	24	112.00	221.00	310.00	352.50	248.87
5	36	132.00	270.00	382.00	432.00	308.38
6	48	145.50	307.50	434.50	488.50	336.25
7	60	152.00	318.50	446.00	505.00	356.38
Mean		105.53	272.10	296.00	343.00	-
1. For tile perforations		F Test		S. Em _t	C.D(5%)	
		Highly significant		5.32	10.98	
2. For interaction of tile perforation with depth of irrigation		Significant		10.65	21.98	

Table 19. Number of Perforations per Tile and Total Drain Out-flow in cm

Sl. No.	Number of perforations per tile	Total tile out-flow in centimetres				Mean out-flow (cm)
		Depth of irrigation above field capacity (cm)				
		2.5	5.0	7.5	10.0	
1	Plain surface	0.182	0.437	0.486	0.533	0.409
2	6	0.251	0.602	0.716	0.852	0.605
3	12	0.318	0.779	0.862	0.968	0.732
4	24	0.440	1.062	1.188	1.473	1.041
5	36	0.527	1.365	1.523	1.721	1.284
6	48	0.584	1.568	1.674	1.942	1.442
7	60	0.610	1.682	1.759	2.027	1.514
Mean		0.416	1.071	1.72	1.358	-
		F test				C.D. (5%)
1. For tile perforations		Highly significant				5.32
2. For interaction of tile perforations with depth of irrigation		Significant				10.65

Table 20. Number of Perforations per Tile and Rate of Tile Drain Out-flow

Sl. No.	Number of perforations per tile	Rate of tile discharge in litres per minute				Mean rate of out-flow (l/m)
		Depth of irrigation water above field capacity (cm)				
		2.5	5.0	7.5	10.0	
1	Plain surface	0.032	0.064	0.086	0.099	0.071
2	6	0.049	0.100	0.133	0.150	0.108
3	12	0.059	0.116	0.158	0.177	0.128
4	24	0.078	0.153	0.215	0.245	0.173
5	36	0.091	0.192	0.268	0.302	0.213
6	48	0.101	0.214	0.302	0.335	0.238
7	60	0.106	0.221	0.310	0.351	0.247
Mean		0.074	0.151	0.210	0.238	-
1. For tile perforations		F Test				C.D. (5%)
		Highly significant				0.0458
2. For interaction of tile perforation with depth of irrigation		Significant				0.0875

Table 21. Rate of Tile Drain Out-flow in Relation to Depth of Irrigation

Sl. No.	Depth of irrigation (cm)	Rate of tile drain out-flow in litres per minute								Mean
		Number of perforation per tile								
		0	6	12	24	36	48	60		
1	2.5	0.032	0.049	0.059	0.078	0.091	0.101	0.106	0.074	
2	5.0	0.064	0.100	0.116	0.153	0.192	0.214	0.221	0.151	
3	7.5	0.086	0.133	0.158	0.215	0.268	0.302	0.310	0.210	
4	10.0	0.099	0.150	0.177	0.245	0.302	0.335	0.351	0.230	
Mean		0.071	0.108	0.128	0.173	0.213	0.238	0.247	-	

F test S.E.m⁺ C.D. (5%)

1. For depth of irrigation

Highly significant 0.0065 0.0207

2. For interaction of depth of irrigation and tile perforation

Significant 0.0424 0.0675

the discharge of 0.032, 0.064, 0.086, and 0.099 litres per minute, respectively under 2.5, 5.0, 7.5 and 10.0 cm depth of irrigation. The tile drain with 6 perforations of one cm dia, gave the discharge rate of 0.049, 0.100, 0.133, 0.150, litres per minute under 2.5, 5.0, 7.5 and 10.0 cm depth irrigation, respectively. Similarly, for the tile drains with 12, 24, 36, 48 and 60 perforations per tile, the rate of discharges were 0.059, 0.116, 0.158, 0.177 l/m and 0.078, 0.153, 0.215, 0.245 l/m, and 0.091, 0.192, 0.268, 0.302 l/m, and 0.101, 0.214, 0.302, 0.335 l/m the mean rate of and 0.071, 0.108, 0.128, 0.173, 0.213, 0.238, 0.247 l/m, respectively in tile drains with perforations of 0, 6, 12, 24, 36, 48 and 60 number per tile.

4.9.5. Rate of Silt Discharged in Tile Drains:

The rate of silt discharged in all seven treatments under four depths of irrigation are given in Tables 22 and 23 and each observation is an average of three readings. The tile drain with plain surface and silt discharge of 0.145, 0.395, 0.630 and 0.874 g/l, respectively under 2.5, 5.0, 7.5 and 10.0 cm depth of irrigation. The tile drain with 6 perforations per tile discharged 0.186, 0.472, 0.830 and 1.116 g/l and the corresponding depth of irrigations were 2.5, 5.0, 7.5 and 10.0 cm. Similarly in tile drains with perforations of 12, 24, 36, 48 and 60 per tile, the rate of silt discharges were 0.235, 0.564, 1.057, 1.385 g/l and 0.296, 0.692, 1.380, 1.776 g/l and 0.391, 0.882, 1.853, 2.344 g/l and 0.531, 1.162, 2.554, 3.186 g/l and 0.715, 1.530, 3.478, 4.293 g/l, respectively. The mean rate of silt

Table 22. Silt Accumulated and Silt Discharged in Tile Drain

Sl. No.	Number of perforations per tile	Total water entry area (sq.cm)	Mean tile out-flow (lit)	Mean silt discharged (g/l)	Mean silt accumulated in tile drain (g)
1	Plain surface	6.30	105.85	0.586	5.68
2	6	11.00	152.62	0.744	8.76
3	12	15.70	196.00	0.925	10.46
4	24	25.14	269.50	1.184	13.23
5	36	37.45	308.38	1.562	16.65
6	48	43.90	336.25	2.124	20.54
7	60	53.40	356.38	2.863	25.04
	Mean	27.56	246.43	1.427	14.34

	F Test	S.Em _±	C.D(5%)
1. For tile perforations	Highly significant	0.0212	0.0438
2. For depth of irrigation	Highly significant	0.0065	0.0207
3. For interaction of depth of irrigation in tile perforation	Significant	0.0424	0.0875

Table 23.- Mean Silt Discharge and Mean Tile Drain Out-flow in Relation to Surface Water Entry Area per Tile

Sl. No.	Surface Water Entry Area/Tile No. of perforation/ tile	Mean tile drain out-flow (litres)	Mean silt discharge (g/l)	Relative variation of silt discharge (g)	Relative variation of silt discharge (%)
1	plain surface	6.30	0.586	-	-
2	6	11.01	0.744	0.158	26.96
3	12	15.72	0.925	0.181	24.32
4	24	25.14	1.184	0.259	28.00
5	36	34.56	1.562	0.378	31.93
6	48	43.98	2.124	0.562	35.98
7	60	53.40	2.863	0.739	34.79
Mean		27.56	1.472	0.325	26.80

	S.E.m _t	C.D.(5%)	F Test
1. For tile perforations	0.0212	0.0438	Highly significant
2. For depth of irrigation	0.0065	0.0207	Highly significant
3. For interaction of depth of irrigation in tile perforation	0.0424	0.0875	Significant

discharges for tile drains with 0, 6, 12, 24, 36 and 60 perforations per tile were 0.586, 0.744, 0.925, 1.184, 1.562, 2.124 and 2.863 g/l, respectively.

4.7.6. Total Silt Accumulated in Tile Drains:

The total silt accumulated in tile drain from all the replications are averaged and given in the Table 22. The accumulated silt in plain tile drains was 5.68 grams and in tile drains with 6, 12, 24, 36, 48 and 60 perforations per tile were 8.76, 10.46, 13.23, 16.65, 20.54 and 25.04 grams respectively.

4.7.7. Salt removed along Drainage Water:

The salts that were discharged in drainage water are given in Table 24 and 25, and each observation is the average of two readings. The tile drain with zero surface perforation had discharged 69.50, 146.50, 160.40, and 169.30 kg/ha, under 2.5, 5.00, 7.50 and 10.00 cm depth of irrigation, respectively. For tile drain with 6, 12, 24, 36, 48 and 60 perforation per tile, the salts discharged through drainage water were 83.00, 176.45, 204.00, 212.00 kg/ha and 106.20, 216.50, 247.70, 256.50 kg/ha and 131.86, 291.60, 309.50, 319.50 kg/ha and 159.30, 285.86, 329.25, 344.90 kg/ha, and 164.25, 296.36, 334.28, 358.45 kg/ha and 168.85, 301.50, 340.50, 362.65 kg/ha under 2.5, 5.0, 7.5 and 10.0 cm depth of irrigation, respectively.

Table 24. Salts Discharged through Drainage Out-flow in Relation to Number of Perforations

Sl. No.	Number of perforations per tile	Salts discharged through drainage water (kg/ha)				Mean
		Depth of irrigation water(cm)				
		2.5	5.0	7.5	10.0	
1.	Plain surface	69.50	146.50	160.40	169.30	136.43
2.	6	83.00	176.45	204.00	212.50	171.45
3.	12	106.20	216.50	247.70	256.50	204.23
4.	24	131.86	271.60	309.50	319.50	260.61
5.	36	159.30	285.96	324.25	344.90	281.28
6.	48	164.25	296.36	334.28	358.45	287.33
7.	60	168.85	301.50	340.50	362.50	292.38
Mean		126.14	242.13	274.38	289.12	-
		S.E.m _t	C.D.(5%)	F Test		
1. For tile perforation		3.47	7.16	Highly significant		
2. For interaction of tile perforation with depth of irrigation		6.95	14.35	Highly significant		

Table 25. Salts Discharged Through Drainage Out-flow in Relation to Depth of Irrigation

Sl. No.	Depth of irrigation	Salts discharged through drainage Water (kg/ha)								Mean
		Number of perforation per tile								
		0	6	12	24	36	48	60		
1.	2.5	69.50	83.00	106.20	131.86	159.30	164.25	168.85	126.14	
2.	5.0	146.50	176.45	216.45	271.60	285.96	296.36	301.50	242.13	
3.	7.5	160.40	204.00	247.70	309.50	324.25	334.28	340.50	279.38	
4.	10.0	169.30	212.50	256.50	319.50	344.90	358.45	362.65	289.12	
Mean		136.43	171.45	204.23	206.61	281.28	287.33	292.38	-	

S.Em_t C.D.(5%) F Test

1. For depth of irrigation

37.39 119.61 Significant

2. For interaction of depth of irrigation with tile perforation

6.95 14.35 Highly significant

4.7.8. Bearing Strength of Tile:

The load bearing strength of tile with varied number of perforations are given in Table 26 and 27. The bearing strength of tiles without surface perforation was 12.15 kg and the tiles with 6, 12, 24, 36, 48 and 60 perforations per tile had the corresponding bearing strength of 10.68, 9.50, 8.67, 7.28, 6.12 and 5.03 kgs and the corresponding total water entry of tiles in tile drains were 6.3, 11.0, 25.10, 34.50, 43.90 and 53.40 sq.cm per tile.

4.8.0. Results of Experiments on Orientation of Area of perforations of Tiles:

The tile drains which were made out of perforated clay tiles were evaluated for orientation of perforated area to the water entry direction. The drainage water converges to the tile drains from all directions and the efficiency of tiles depends on the direction of tile open area in the least resistant direction for the water entry. For this purpose, three positions were selected, namely, top orientation facing the perforations upwards, bottom orientation facing the perforations downwards and lateral orientation facing the perforation sideways. In each treatment, the tiles with 24 perforations of one cm dia on one half the tiles were used. Because, the earlier experiments indicated that this combination of one cm dia of 24 perforations were better than other combination. Evaluation of treatments were done in relation to tile drains out-flow, the rate of tile drains out-flow, the rate of silt discharged in tile drains, silt accumulated in tile drains

Table 26. Load Bearing Strength and Total Number of Perforations per Tile

Sl. No.	Total area of perforations per tile ----- Number of perforations per tile	Total water entry area (sq.cm)	Load bearing strength of tile (kg/cm)	Mean tile drain out-flow (litres)	Mean silt discharge (g/l)
1	Plain surface	6.3	12.15	105.85	0.586
2	6	11.00	10.68	152.62	0.745
3	12	15.70	9.50	196.00	0.925
4	24	25.10	8.67	247.87	1.184
5	36	34.50	7.28	308.38	1.562
6	48	43.90	6.12	336.25	2.124
7	60	53.40	5.03	356.38	2.863

Mean		27.56	8.48	246.43	1.427

			S.E.m _t	C.D. (5%)	F Test
1. For tile perforation			0.0212	0.0438	Highly significant
2. For depth of irrigation			0.0065	0.02207	Highly significant
3. For interaction of depth of irrigation on tile perforation			0.0424	0.0875	Significant

Table 27. Results of Surface Water Entry Area, Tile Drain Out-flow, Silt Discharge and Bearing Strength of Tiles

Sl. No.	Number of perforation per tile (1 cm dia)	Total water entry area/ tile (sq.cm)	Mean tile out-flow (litres)	Silt discharge in tile drains (g/l)	Bearing strength of tile (kg/cm ²)	Remarks
1	Plain surface	6.30	105.85	0.586	12.13	-
2	6	11.01	152.62	0.744	10.68	-
3	12	15.72	196.00	0.925	9.50	-
4	24	25.14	248.87	1.184	8.67	-
5	36	34.50	308.38	1.562	7.28	-
6	48	43.98	336.25	2.124	6.12	-
7	60	33.40	356.38	2.863	5.03	-
Mean		27.56	246.43	1.427	8.48	-

	S.Em _t	C.D. (5%)	F Test
1. For tile perforation	0.0212	0.0438	Highly significant
2. For depth of irrigation	0.0065	0.0227	Highly significant
3. For interaction of depth of irrigation in tile perforation	0.0424	0.0875	Significant

and bearing strength of tiles.

4.8.1. Total Drainage Out-flow:

The results of tile drain out-flow from different treatments are given in Table 28. The total mean out-flow from tile drains with lateral, top and bottom orientation were 211.24, 247.34 and 428.84 litres, respectively. The tile drain out-flow of 104.04, 217.68, 312.00 and 403.80 litres were observed respectively under 5.0, 10.00, 15.0, 20.0 cm depth of irrigation. Similarly, in top and bottom orientation, the total out-flows were 128.90, 269.16, 362.96, 457.80 litres and 22.696, 426.60, 633.96, 787.80 litres, respectively in the same order of depth of irrigation.

4.8.2. Depth of Irrigation Water Applied:

Four depth of irrigations were applied, namely, 5.0, 10.0, 15.0 and 20.0 cm above field capacity, to all the treatments (Table 29). Under 5 cm depth of irrigation, the total drains out-flows were 104.04, 126.90 and 225.96 litres, respectively in lateral, top and bottom orientation. Similarly, under 10, 15 and 20 cm depth of irrigation, the tile drain out-flows were 217.68, 269.16, 426.60 litres and 312.00, 345.96, 633.96 litres and 403.80, 451.80, 787.80 litres respectively in lateral, top and bottom orientation. The mean total out-flow in tile drains with lateral, top and bottom orientation were 211.24, 247.34 and 428.84 litres, respectively.

Table 28. Results of Total Tile Out-flow in relation to Orientation of Tile Drain Perforations

Sl. No.	Orientation of perforations of tiles	Number of perforation per tile	Bearing strength of tiles (kg/cm ²)	Total tile drain out-flow in litres				Mean tile drain out-flow (lit)

				Depth of irrigation above field capacity (cm)				

				5.00	10.00	15.00	20.00	
1.	Lateral	24	8.67	104.04	217.68	312.00	403.80	211.24
2.	Top	24	8.67	128.90	269.16	362.96	451.80	247.34
3.	Bottom	24	8.67	225.96	425.60	633.96	787.80	428.84

Mean								

				S.Em _t	C.D.(5%)			
1. For orientation of perforations				0.219	0.657			
2. For comparison of orientation of perforation at the same depth of irrigation				0.4382	NS*			
3. For comparison of depth of irrigation at the same or different orientation of perforation				0.372	NS*			
				* Not Significant				

* Not Significant

Table 29. Results of Total Tile Drains Out-flow in relation to Depth of irrigation

Sl. No.	Depth of irrigation (cm)	Total tile drain out-flow in litres			Mean tile drain out-flow (lit)
		Lateral orientation	Top orientation	Bottom orientation	
1	5.00	104.04	128.90	225.96	152.30
2	10.00	217.68	269.16	426.60	304.48
3	15.00	312.00	345.96	633.96	340.64
4	20.00	403.80	451.80	787.80	547.80
Mean		211.24	247.34	428.84	-

S.Em+ C.D.(5%)

1. For orientation of perforation

0.219 0.657

2. Comparison of orientation of perforation at same depth of irrigation

0.6382 NS*

3. Comparison of depth of irrigation at same or different orientation perforation

0.6750 NS*

*Not Significant.

4.8.3. Rate of Tile Drain Discharge:

The results of the observations of rate of tile out-flow are given in Table 30 and these observations are taken as the average of three readings. In tile drains with lateral, top and bottom orientation gave the rate of out-flow of 0.233, 0.260 0.483 litres per second under 5 cm depth of irrigation. Similarly, under 10, 15 and 20 cm depth of irrigation, the respective rate of tile discharges were 0.300, 0.350, 0.533 l/m, and 0.376, 0.435, 0.633 l/m, and 0.450, 0.525, 0.761 l/m. The mean rate of discharges in lateral, top and bottom orientation were 0.340, 0.393, and 0.604 litres per minute.

4.8.4. Rate of Silt Discharge in Tile Drains:

The results of rate of silt discharged in second and fourth minutes duration is given in Table 32, and these observations are the average weight of three samples. The mean rate of silt discharged during second minute were 3.54, 4.54 and 3.41 grams per minute under lateral, top and bottom orientation of tile drains. Similarly, during the fourth minute of duration, the rate of silt discharged were 1.82, 2.03, and 1.65 grams per litre respectively, in the above order of orientation. During second minute, the silt discharge in tile drains of lateral orientation were 4.29, 4.44, 4.54 and 4.86 g/l under 5, 10, 15 and 20 cm depth of irrigation. Similarly in top and bottom orientation, the rate of silt discharges were 4.71, 4.95, 5.45, 5.52 g/l and 3.19, 3.25, 3.43, 3.78 g/l in the ascending order of depth of irrigation. During the fourth minute,

Table 30. Results of Rate of Tile Drain Out-flow in relation to Orientation of Tile Drain Perforations

Sl. No.	Orientation of perforations of tile	Number of perforations/tile	Bearing strength of tile (kg/cm ²)	Rate of tile drain out-flow(l/m)				Mean tile drain Out-flow (lit)

				Depth of irrigation above field capacity in cm				
				5.00	10.00	15.00	20.00	
1.	Lateral	24	8.67	0.233	0.300	0.376	0.450	0.340
2.	Top	24	8.67	0.260	0.350	0.435	0.525	0.393
3.	Bottom	24	8.867	0.483	0.533	0.633	0.767	0.604

Mean

S.E_m± C.D. (5%)

1. For orientation of perforations

0.315 0.785

2. Comparison of orientation of perforations at the same depth of irrigations

0.4182 NS*

3. Comparison of depth of irrigation at same or different orientation of perforations

0.372 NS*

* Not Significant

Table 31. Results of Rate of Tile Drain Out-flow in Relation to Depth of Irrigation

Sl. No.	Depth of irrigation (cm)	Rate of tile drain out-flow (l/m)		Mean rate of out-flow (l/m)
		Lateral orientation	Top orientation Bottom orientation	
1	5.00	0.233	0.260 0.423	0.325
2	10.00	0.300	0.350 0.533	0.393
3	15.00	0.370	0.435 0.633	0.480
4	20.00	0.450	0.525 0.767	0.581

Mean		0.340	0.393 0.604	

		S.Em±	C.D.(5%)	
1. For depth of irrigation		0.1352	0.6456	
2. Comparison of orientation of perforations at the same depth of irrigation		0.3824	NS*	
3. Comparison of depth of irrigation at same or different orientation of perforations		0.472	NS*	

* Not Significant

Table 32. Results of Silt Discharged Through Tile Drains during Second and Fourth Minute of Out-flow

Sl. No.	Orientation of perforations of tiles	Number of perforations per tile	Silt discharged(in g/minute)				Mean silt discharge/grams/minute
			Depth of irrigation in cm above field capacity	5.0	10.0	15.0	
<u>Second minute</u>							
1.	Lateral	24	4.29	4.44	4.54	4.86	3.54
2.	Top	24	4.71	4.95	5.45	5.52	4.54
3.	Bottom	24	3.19	3.25	3.43	3.78	3.41
	Mean		4.14	4.38	4.41	4.65	
<u>Fourth minute</u>							
1.	Lateral	24	1.63	1.75	1.85	1.95	1.82
2.	Top	24	1.88	2.02	2.16	2.23	2.03
3.	Bottom	24	1.48	1.57	1.71	1.84	1.65
	Mean		1.76	1.81	1.85	1.96	
1. For orientation of perforations			S.E.m±			C.D.(5%)	
						NS*	
2. Comparison of orientation of perforations at same depth of irrigation						7.45	
						NS*	
3. Comparison of depth of irrigation at same or different orientation of perforation						2.79	
						NS*	

* NS = Not Significant

the rate of silt discharges were 1.63, 1.75, 1.86, 1.95 g/l, and 1.88, 2.02, 2.16, 2.23 g/l and 1.48, 1.57, 1.71, 1.84 g/l in the above said order of irrigation depths.

4.8.5. Total Silt Accumulated in Tile Drains:

The total silt accumulated in tile drains of all replications are averaged and given in Table 33. The mean accumulated silt in the tile drains with top, lateral and bottom orientation were 10.30, 5.60 and 3.50 grams. In tile drains with top orientation, the accumulated silt in tile drains under 5, 10, 15 and 20 cm depth of irrigation were 6.95, 10.45, 11.45 and 13.50 grams. Similarly, in lateral and bottom orientation the silt accumulated were 3.60, 5.50, 6.65, 7.80 grams and 2.20, 3.55, 4.10, 4.80 grams in the above said order of irrigation.

4.8.6. Bearing Strength of Tile:

In all the treatments, the tiles used were manufactured with 24 perforations of 1 cm dia. The bearing strength and total water entry area recorded were 8.67 kg/cm² and 25.10 sq cm, respectively.

4.9.0. Results of Experiment on Envelope Materials for Tile Drains used in Command Areas:

Five filter materials which are locally available, namely; coconut fibre, corn cobs, sawdust, graded gravel and

Table 33. Results of Silt Accumulated in Tile Drains

Sl. No.	Orientation of perforation of tiles	Number of perforation per tile	Bearing strength of tile (kg/cm)	Total silt accumulated in tile drain(g)				Mean silt accumulated in tile(g)
				Depth of irrigation(m) above field capacity				
				5.0	10.0	15.0	20.0	
1.	Top	24	8.76	6.95	10.45	11.45	13.50	10.3
2.	Lateral	24	8.67	3.60	5.50	6.65	7.80	5.6
3.	Bottom	24	8.67	2.20	3.20	3.55	4.10	3.5

S.E.m_t C.D.(5%)

1. For orientation of perforations

9.32

NS*

2. Comparison of orientation of perforations at same depth of irrigation

7.35

NS*

3. Comparison of depth of irrigation at same or different orientation of perforation

2.207

NS*

* Not Significant

back-fill soil were evaluated for the tile drains of 24 perforations of one cm dia. These tiles of 60 cm length and 10 cm dia manufactured locally and were standardised for 24 perforations of 1 cm dia. The main treatments of this experiment were coconut fibre, corn cobs, sawdust, graded gravel and back fill soil, and sub-treatments were four depth of irrigation, namely; 5.00, 7.50, 10.00 and 12.50 cm, above field capacity. The evaluation of treatments were done in relation to tile drain out-flow, the rate of tile drain out-flow, silt discharge in drainage water, and silt accumulated in tile drains.

4.9.1. Total Drainage Out-flow:

The results of total out-flow from different treatments are given in Table 34. The total mean out-flow from tile drains with different envelope materials, namely; coconut fibre, corn cobs, back-fill soil, sawdust and graded gravel were 183.80, 222.10, 244.80, 282.10 and 310.00 litres respectively. The tile drain out-flow from coconut fibre under 5.0, 10.0, and 12.5 cm depth of irrigation were 101.20, 145.00, 195.00, 225.00 litres, respectively. Similarly, the tile drain outflow from corn-cobs, back-fill soil, sawdust and graded gravel were 133.00, 190.00, 259.10, 306.50 litres, 153.70, 214.30, 291.40, 340.00 litres, 178.80, 246.00, 324.30, 380.00 litres and 221.00, 283.00, 360.00, 422.00 litres, respectively.

Table 34. Total Tile Drain Out-flow in relation to Envelope Material

Sl. No.	Envelope material	Total tile drain out-flow in litres				Mean tile drain out-flow (litres)
		Depth of irrigation above field capacity(cm)				
		5.0	7.5	10.0	12.50	
1.	Coconut fibre	101.20	145.00	195.00	225.00	183.30
2.	Corn cobs	133.00	190.00	259.10	306.50	222.10
3.	Back fill soil (control)	152.70	214.30	291.40	340.00	244.80
4.	Saw dust	178.80	246.00	324.30	380.00	282.10
5.	Graded gravel	221.00	283.00	360.00	422.00	310.00
Mean		153.80	219.30	280.20	342.80	-

C.D. (5%)

S.E.m_t

0.942

0.3218

NS

1.0700

NS*

0.7604

* Not Significant

4.9.2. Depth of Irrigation Water:

Four depths of irrigation water were applied for each treatment, namely: 5.0, 7.5, 10.00 and 12.5 cm (Table 35). The mean out-flow from graded gravel, sawdust, back-fill soil, corn cobs and coconut fibre were 319.00, 282.20, 249.85, 222.10, and 166.62 litres, respectively. The out-flow from tile drain with coconut fibre envelope under 5.0, 7.5, 10.0, 12.5 cm depth of irrigation were 101.20, 145.00, 195.00 and 225.30 litres, respectively. The tile drain with corn-cobs had given 133.00, 190.00, 259.00 and 306.50 litres, respectively under 5.0, 7.5, 10.0 and 12.5 cm depth of irrigation. Similarly in back-fill soil, sawdust and graded gravel gave 153.70, 214.30, 291.40, 340.00 litres, 178.80, 246.00, 314.00, 380.00 litres and 221.00, 283.00, 350.00, 422.00 litres of tile drain out-flow respectively.

4.9.3. Rate of Tile Drain Out-Flow:

The results of observations of rate of tile drain out-flow with different envelope materials are given in Table 36 and the mean rate of out-flows were 0.443, 0.522, 0.564, 0.570 and 0.620 litres per minute in tile drain with envelope materials, namely: coconut fibre, corn cobs, back-fill soil, sawdust and graded gravel under 5.0, 7.5, 10.00 and 12.50 cm depth of irrigation. The tile drains with coconut fibre envelope had given the discharge rate of 0.307, 0.413, 0.475, 0.543 litres per minute under 5.0, 7.5, 10.00, 12.5 cm depth of irrigation, respectively.

Table 35. Results of Total Tile Out-flow in relation to Depth of Irrigation

Sl. No.	Depth of irrigation (cm)	Total tile drain out-flow in litres				Mean tile drain out-flow (litres)
		Graded gravel	Saw-dust	Backfill soil (control)	Corn cobs	Coconut fibre
1.	5.00	221.00	178.80	153.70	133.00	101.20
2.	7.50	283.00	246.00	214.30	190.00	145.00
3.	10.00	350.00	214.00	291.40	259.60	195.00
4.	12.50	422.00	380.00	340.00	306.50	225.30
	Mean	319.00	282.20	249.85	222.10	166.62
					S.Em _t	C.D.(5%)
1.	For comparison of depth of irrigation				0.4818	2.1560
2.	For comparison of filter materials at same depth of irrigation				1.0732	NS
3.	For comparison of depth of irrigation at same or different envelope materials				0.7505	NS*

* Not Significant

Table 36. Results of Rate of Tile Drain Out-flow Relation to Envelope Material

Sl. No.	Envelope material	Rate of tile drain out-flow (l/m)				Mean tile drain out-flow (l/m)
		5.00	7.50	10.00	12.50	
1.	Coconut fibre	0.307	0.412	0.475	0.543	0.443
2.	Corn cobs	0.392	0.490	0.572	0.622	0.522
3.	Back fill soil	0.442	0.533	0.618	0.682	0.564
4.	Saw dust	0.450	0.544	0.635	0.690	0.570
5.	Graded gravel	0.495	0.605	0.720	0.783	0.620
Mean		0.403	0.523	0.607	0.642	-

S.Em± C.D.(5%)

1. For comparison of envelope materials

0.1456

2. For comparison of envelope material at depth of irrigation

0.9565

NS

3. For comparison of depth of irrigation or different envelope materials

0.7505

NS*

* Not Significant

Similarly in tile drains with envelopes of corn cobs, back-fill soil, sawdust and graded gravel gave the discharge rate of 0.392, 0.490, 0.572, 0.622 l/m, 0.442, 0.533, 0.614, 0.682 l/m, 0.450, 0.544, 0.690 l/m, and 0.495, 0.605, 0.720, 0.783 l/m, respectively under four depth of irrigation in the increasing order.

4.9.4. The Rate of Silt Discharge in Tile Drain:

The results of rate of silt discharged in tile drains with different envelope materials are given in Table 37 and 38. The mean rate of silt discharge during second minute were 0.681, 0.825, 0.938, 1.483 and 1.570 grams per litre in tile drains with envelope materials, respectively of the saw-dust, graded gravel, coconut fibre, corn-cobs and back-fill soil (control). The mean rate of silt discharge during the fourth minute were 0.412, 0.503, 0.543, 1.063 and 1.158 grams per litre in tile drains with envelope materials, namely; the saw-dust, graded gravel, coconut fibre, corn cobs, and back-fill soil, respectively.

During the second minute, the rate of silt discharge in tile drains with saw-dust as envelope material was 0.895, 0.720, 0.620 g/l in tile drains and the graded gravel gave 1.055, 0.840, 0.715, 0.690 g/l. Similarly in tile drains with coconut fibre, corn-cobs and back-fill soil, the rate of silt discharges were 1.200, 0.990, 0.835, 0.795, 0.938, g/l, and 1.860, 1.480, 1.310, 1.250 g/l, and 1.930, 1.540, 1.390, 1.315 g/l, respectively.

Table 37. Rate of Silt Discharged during Second Minute in relation to Envelope material

Sl. No.	Envelope material	Rate of silt discharged during the second minute of out-flow (g/l)			Mean silt discharge rate (g/l)
		5.00	7.50	10.00	12.50
1.	Saw dust	0.895	0.720	0.620	0.590
2.	Graded gravel	1.055	0.840	0.715	0.690
3.	Coconut fibre	1.200	0.990	0.835	0.795
4.	Corn-cobs	1.860	1.450	1.310	1.250
5.	Back fill soil (control)	1.930	1.540	1.390	1.315
Mean		1.388	1.114	1.024	0.904

C.D. (5%)

S.E.m_t

0.156

0.4875

NS*

0.9625

NS*

0.9511

* Not Significant

1. For comparison of envelope materials

2. For comparison of envelope material at same depth of irrigation

3. For comparison of depth of irrigation at same or different envelope materials

Table 38. Rate of Silt Discharged During the Fourth minute in relation to Envelope Material

Sl. No.	Envelope materials	Rate of silt discharged during the fourth minute of out-flow(g/l)			Mean silt discharge rate(g/l)
		5.00	7.50	10.00	
1.	Graded gravel	0.525	0.450	0.395	0.285
2.	Coconut fibre	0.675	0.560	0.450	0.345
3.	Saw dust	0.705	0.580	0.480	0.412
4.	Back fill soil (control)	1.430	1.335	1.145	1.020
5.	Back fill soil	1.430	1.335	1.145	1.020
Mean		0.915	0.769	0.692	0.556

S.E.m_t C.D.(5%)

1. For comparison of envelope materials 0.9852 0.292

2. For comparison of envelope of materials at same depth of irrigation 0.1956 NS*

3. For comparison of depth of irrigation at same or different filter materials 0.1813 NS*

* Not Significant

Table 39. Rate of Silt Discharged During Second Minute in relation to Depth of Irrigation

Sl. No.	Depth of irrigation	Rate of silt discharged during the second minute of out-flow (g/l)					Mean
		Saw dust	Graded gravel	Coconut fibre	Corn cobs	Back fill soil(control)	
1	5.00	0.895	1.055	1.200	1.860	1.930	1.388
2	7.50	0.720	0.840	0.990	1.480	1.540	1.114
3	10.00	0.620	0.715	0.835	1.310	1.390	1.024
4	12.50	0.590	0.690	0.795	1.250	1.315	0.904
Mean		0.690	0.825	0.938	1.484	1.570	-

S.E.m_± C.D. (5%)

1. For comparison of depth of irrigation 0.4154 0.187

2. For comparison of envelope materials at same depth of irrigation 0.9565 NS*

3. For comparison of depth of irrigation at same or different filter materials 0.951 NS*

*Not Significant

Table 40. Rate of Silt Discharged During the Fourth Minute in relation to Depth of Irrigation

Sl. No.	Depth of irrigation	Rate of silt discharged during the fourth minute of out-flow(g/l)				
		Graded gravel	Coconut fibre	Saw dust	Corn-cobs	Back fill soil (control)
1	5.00	0.525	0.675	0.705	1.240	1.430
2	7.50	0.450	0.560	0.580	1.112	1.315
3	10.00	0.395	0.450	0.480	1.00	1.145
4	12.50	0.285	0.345	0.412	0.875	1.020
Mean		0.421	0.540	0.543	1.063	1.158

S.E.m_± C.D.(5%)

1. For comparison of depth of irrigation 0.5265 NS*

2. For comparison of envelope materials at same depth of irrigation 0.1963 NS*

3. For comparison of depth of irrigation at same or different filter materials 0.1831 NS*

* Not Significant

During the fourth minute in the increasing order, the silt discharges were 0.525, 0.450, 0.395, 0.285 g/l and 0.675 0.56, 0.45, 0.345 g/l, and 0.705, 0.580, 0.480, 0.412 g/l, and 1.240, 1.112, 1.00, 0.875 g/l, and 1.430, 1.315, 1.145, 1.020 g/l in tile drains with envelope materials, namely, the graded gravel coconut fibre, saw-dust, corn-cobs and back-fill soil in the above said order.

4.9.5. Total Silt Accumulated in Tile Drains:

The results of total silt accumulated in tile drains are given in Table 41. In the increasing order of silt accumulated were 1.20, 2.18, 2.84, 4.60 and 6.84 grams respectively, in tile drains with envelope materials of graded gravel, saw-dust, coconut fibre, corn-cobs and back-fill soil.

4.9.6. Bearing Strength of Tile:

In all treatments, the tile used were manufactured with 24 perforations of 1 cm dia. The bearing strength and total water entry area recorded were 8.67 kg/cm² and 25.10 sq.cm, respectively.

Table 41. Total Accumulated Silt in Tile Drains at the End of the Experiment

Sl. No.	Envelope material	Mean value of silt accumulation (g)	Total variation		Relative variation	
			Weight in grams	Per cent	Weight in grams	Per cent
1.	Graded gravel	1.20	-	-	-	-
2.	Saw dust	2.18	0.98	81.67	0.98	81.67
3.	Coconut fibre	2.84	1.64	136.67	0.66	30.28
4.	Corn cobs	4.60	3.40	283.33	1.76	61.98
5.	Back fill soil (control)	6.84	5.64	470.00	2.24	48.70

	S. Em $\pm$	C.D. (5%)	F Test
1. For comparison of envelope materials	0.9356	1.652	NS*
2. For comparison of depth of irrigation	0.4154	0.187	Significant
3. For comparison of depth of irrigation at same or different envelope materials	0.9511	2.254	NS*

* Not Significant.

CHAPTER 5

DISCUSSIONS

CHAPTER 5

DISCUSSION

Four sets of experiments with various combinations were conducted to optimise the physical parameters of clay tiles used in irrigated soils of Karnataka State. The various parameters were size of circumferential perforations, number of circumferential perforations, orientation of circumferential perforations for water entry, and the type of envelope materials suitable for these clay tiles. The other parameters measured to evaluate the efficiency of tile drains were total out-flow from drains, rate of drainage out-flow, silt discharged in drainage water, silt accumulated in tile drains and bearing strength of tiles.

The first experiment conducted was on size of circumferential perforations. The size of perforations adopted were 0.5 cm, 0.75 cm, 1.00 cm, 1.25 cm, and 1.50 cm dia and plain tiles without perforations were used as reference.

The second experiment conducted was on number of circumferential perforations and the number of perforations adopted were 6, 12, 24, 48 and 60 of 1 cm diameter. Plain tile without perforation was used as reference.

In the third experiment, the placement of openings on tile drains facing up-ward, side-ward and of bottom, were evaluated for their hydraulic performance.

In the fourth experiment five locally available envelope materials, namely, coconut fibre, corn-cobs, sawdust, back-fill soil and graded gravel were evaluated for hydraulic performance and structural stability.

5.1. Slope and Position of the Experimental Site:

The experimental site was the representative of the Command Area Soils with 0.2 to 0.5 per cent average slope in the direction of tile drains and 0.1 to 0.2 per cent in the lateral direction (Fig. 1). This slope was considered as mild on the field scale to hold water for considerable time on the surface for water logging. In each treatment the general slope was maintained by providing dykes to impound irrigation water. The water was impounded on the surface more than 2 hours. Similar is the field condition in Command area. Walter et al. (1979) and Mohammed and Skeggs (1983) found from their studies a similar situation was sufficient to create water logging for long time.

5.2. Nature of Soils in the Experimental Site:

The top layer was classified as sandy clay and the other two layers below as clay textured. The clay content in the lower layers was varied from 40.75 to 51.00 per cent and the variation of silt content was from 9.00 to 11.25 per cent. The percentage clay and silt content increased with increased depth of soil. Gravel and coarse sand content decreased with increase in depth of soil (Table 4).

5.3. Hydraulic Conductivity of the soil:

The hydraulic conductivity of soil in the experimental site was varied from 0.56 m/day to 0.62 m/day, and it was classified as "moderate" according to O'Neal(1949). The permeability was considerably high. Hence, the site and soil were ideal for conducting field verification studies for tile drainage system in short interval of time.

5.4. Quality of Irrigation and Ground Water:

The irrigation water was medium in salinity and RSc value was quite low (0.54 meg per lit). The water was found to be fit for irrigation for most of the crops grown in black soil. According to Richards(1954), the water used for irrigation might contain 0.1 to as much as 1.52 tonnes of salts per 0.1 Hect-m of water, and the annual application of water amounts to 1.50 times or more. Thus considerable quantity of salt would be added to irrigated soils over a short period of time under improper drainage conditions. According to the classification of irrigation water, given in the USDA Hand Book No.60, any particular irrigation water with an electrical conductivity value of 0.534 mmhos/cm at 25°C and SAR of 1.92 comes under the class C_2-S_1 (medium-salinity-low sodium) (Table 2).

The electrical conductivity value of the ground water was quite high with the value of 2.15 mmhos/cm at 25°C and contained considerable amount of cat-ions and an-ions. The R.Sc and SAR values were as high as 4.70 meg per litre, and 7.32

respectively. According to the classification given by Richards (1954), the ground water belongs to the class C_3-S_2 (high salinity and medium sodium). Thus saline ground water, which rises within the root zone, was mainly responsible for the accumulation of salts in the soil profile (Table 2).

5.5. Status of Water Table at the Experimental Site:

The fluctuation of water-table at the experimental site indicated that the highest elevation of water table was during the month of October and the lowest during May. The variation of water table was guided by the change of seasons in the year. The monsoon rains and inadequate drainage were the main causes for the rise of water-table. Similar findings were reported by Mehta (1954) (Table 1).

The location of the land was also one of the reason to some extent for the rise of water-table. The land was situated at the low-lying area of the farm and the area situated at higher elevation adjoining to the experimental site was under irrigation. The seepage from higher lands was one of the main reason for the rise of water-table during the rainy season. Same was indicated by the direction of ground water flow from the ground water plan (Fig. 1) and this agrees with the findings of Roe(1954), Thorne and Peterson(1954), and Michael and Ojha(1978). Richards (1954) reported that the rise of water-table five to six feet within the soil profile, made the ground water to move upward into the root zone and to the soil surface, which contributed to the salinisation of the soil. Similar findings were also reported

by Basu(1950) and Hooghudts(1952).

5.6.0. Size of Circumferential Perforations of Clay Tiles:

The clay tiles of 10 cm diameter and 60 cm long tiles are being used in irrigated soils of Karnataka State as tile drains to control water table for crop production. These tiles are laid in the trenches with bell-mouth joints. Consequently, these bell-mouth joints fails to provide adequate crack space for the entry of water into tiles. Joints formed out of 60 cm long tiles were long enough for proper convergence of water lines into drain pipes. To overcome the problem of inadequate crack space and convergence losses, the perforations were provided on the body of tiles for water entry. To standardise the size of the holes in relation to total drainage out-flow, the rate of drainage out-flow, rate of silt discharge, the amount of accumulated silt in tile drains and bearing strength of tiles for soil over-burden, a field experiment was conducted in the Agricultural College Farm. No such specific study was conducted for the clay tiles in Karnataka State, and also similar studies were not conducted elsewhere to use the techniques to increase the hydraulic and structural efficiency of clay tile drains. The information available in literature is too inadequate and not comprehensive for this purpose. Hence this study was conducted to identify the optimum techniques for tile drains for higher efficiency.

In this experiment the treatments selected were tiles without surface perforations, tiles with 0.5 cm dia perforations, tiles with 0.75 cm dia perforations, tiles with 1.0 cm dia perforations, tiles with 1.25 cm dia perforations and tiles with 1.50 cm dia perforations. The number of perforations in each treatment were varied to get the constant water area of 18.85 sq.cm.

5.6.1. Tile Drain Out-Flow:

The mean out-flow was varied from minimum of 263.00 litres in tile drains without surface perforations to maximum of 750 litres in tile drains with 0.50 cm dia perforation of 96 holes per tile. The change in out-flow in increasing order was significant upto in tile drain with 1.0 cm dia perforations, and became less significant in tile drains with 0.75 and 0.50 cm dia perforations. This could be seen from the Table 44 and Fig. 11, that the relative increase of out-flow in tile drains beyond 1.00 cm diameter perforations were 4.53 and 4.20 per cent. The relative increase of out-flow was 92.00 per cent in tile drain with 1.50 dia perforation as compared to out-flow from tile drain without surface perforations. Similarly, higher relative increase of out-flow of 18.06 and 15.10 per cent was found in tile drain with 1.25 and 1.00 cm diameter perforations when compared with out-flow from tile drains with 1.50 and 1.25 cm dia perforations, respectively. From the above discussion, it could be said that any further decrease in size of perforations beyond 1 cm diameter perforations does not increase hydraulic efficiency.

Table 42. Variation of Total Out-flow in Different Tile Drains

Sl. No.	Size of perforations (cm)	No. of perforations per tile	Total open area for water entry (sq.cm)	Mean outflow (litres)	Variations of out-flow ----- Litres Percent	Relative variation of out-flow ----- Litres Percent
1.	Plain surface	0	6.30	263.00	-	-
2.	1.50	11	25.15	505.00	242.00	92.02 242.00 92.00
3.	1.25	15	25.15	576.00	313.00	119.01 81.00 18.06
4.	1.00	24	25.15	686.00	423.00	160.8 90.00 15.10
5.	0.75	42	25.15	716.00	453.00	172.2 40.00 4.53
6.	0.50	96	25.15	750.00	487.00	185.17 34.00 4.20

Table 43. Variation of Tile Out-flow and Number of Perforations per Tile

Sl. No.	Size of perforation (cm)	Number of perforation per tile	Variation of Number of perforation/tile		Mean tile out-flow (lit)	Mean variations of tile out-flow	
			Number	Percent		Number	Percent
1.	Plain surface	0	-	-	263.00	-	-
2.	1.50	11	11	110.00	505.00	242.00	92.02
3.	1.25	15	15	150.00	576.00	333.00	126.61
4.	1.00	24	24	240.00	686.00	423.00	160.84
5.	0.75	42	42	420.00	716.00	453.00	172.24
6.	0.50	96	96	960.00	750.00	487.00	185.17

Table 44. Relative Variation of number of Perforation per tile and Tile Out-flow.

Sl. No.	Size of perforations (cm)	No. of perforations/tile	Relative variation of number of perforation per tile		Mean tile out-flow (lit)	Relative variation of out-flow	
			Number	Per cent		Litres	Per cent
1.	Plain surface	-	0	-	263.00	-	-
2.	1.50	11	11	110.00	505.00	243.00	92.00
3.	1.25	15	4	33.40	576.00	76.00	18.00
4.	1.00	24	9	60.00	686.00	90.00	15.10
5.	0.75	42	18	75.00	726.00	40.00	4.53
6.	0.50	96	54	128.57	760.00	34.00	4.20

The rate of out-flow was highest (Table 45 and Fig. 11) in tile drains with 0.50 cm dia perforations and lowest in tile drains without surface perforations. The rate of increase of rate of out-flow was significant in three treatments namely, tile drains with 1.50, 1.25 and 1.00 cm diameter perforations. The corresponding percentage relative increases were 90.90, 55.56 and 69.23 (Table 46). Further reduction in size of perforations did not give any significant increase in rate of out-flow. The relative increase in rate of out-flow was 90.90 per cent in tile drain with 1.50 cm dia perforation. Similarly, in 1.25 and 1.00 cm dia perforated tiles, the percentage relative increases were 55.56, and 69.23. In tile drains with 0.75 cm and 0.50 cm dia perforations, lesser increased changes of 15.15, and 8.50 per cent rate of out-flow were noticed. In case of total out-flow 15.10 per cent was treated as significant for the purpose of hydraulic performance. But, the rate of increase of out-flow of 15.15 per cent had been considered less significant in view of the higher percentage increase at higher diameter perforations in tile drains.

The relative change of number of perforations in each treatments for constant water entry area of 18.85 square centimetre is shown in Tables 43 and 44 and these relative changes were not uniform. The general trend in change of mean out-flow had followed the increase in number of perforations. But the trend is not uniform. Hence, it may not be possible to develop any type of relationship. Similarly increase in mean out-flow

Table 45. Rate of Tile Drain Discharge under varied size of Perforations of Tiles

Sl. No.	Time interval (minutes)	Rate of tile drain discharge in litres/minute						Remarks
		Diameter of perforation of tiles (in cm)						
		0.0	0.50	0.75	1.00	1.25	1.50	
1.	I	0.020	0.094	0.087	0.065	0.045	0.023	-
2.	II	0.028	0.138	0.129	0.108	0.088	0.046	-
3.	III	0.035	0.189	0.170	0.153	0.094	0.075	-
4.	IV	0.048	0.240	0.220	0.201	0.166	0.106	-
	Mean	0.033	0.165	0.152	0.132	0.098	0.063	-

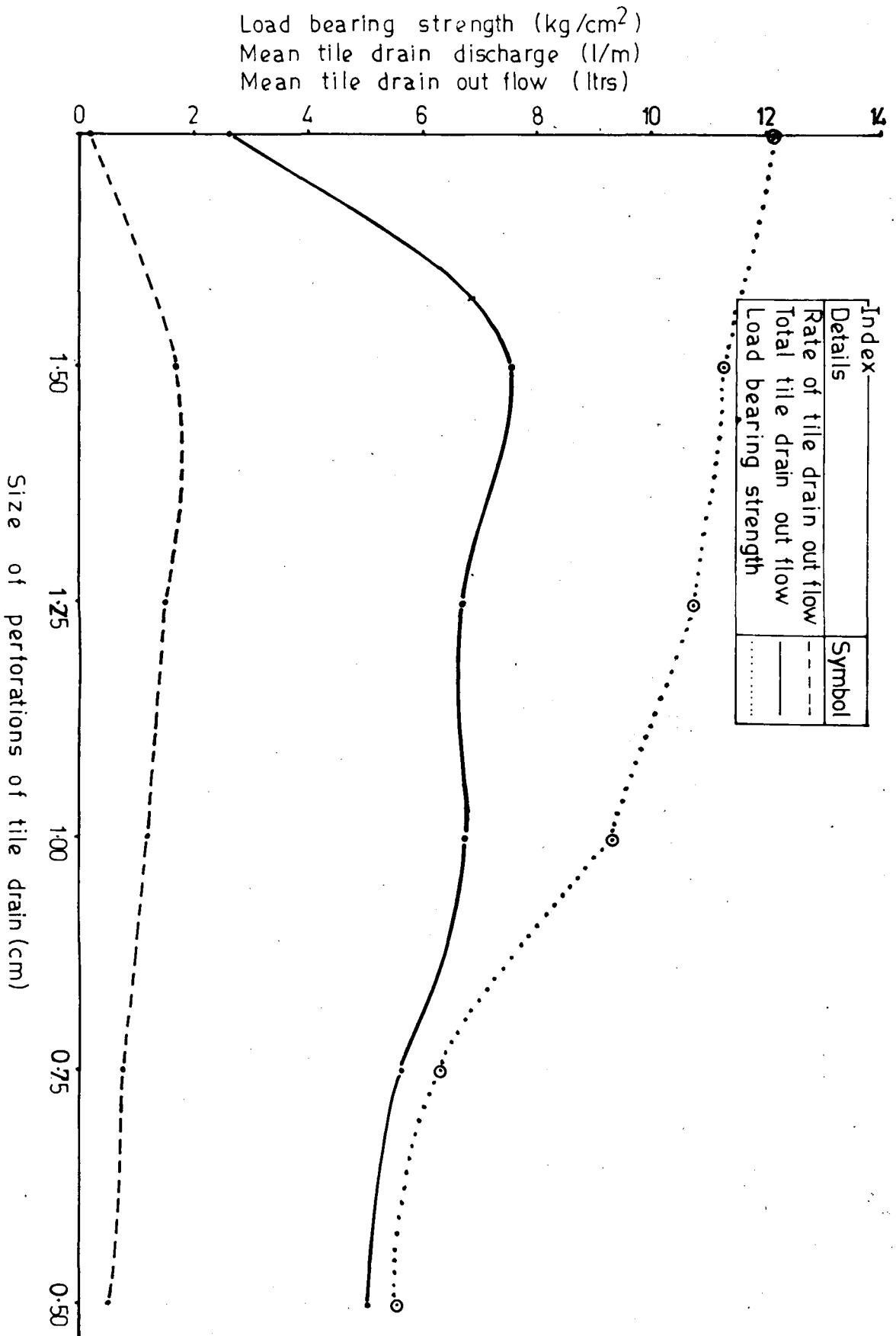


FIG. 11 RELATIONSHIP BETWEEN PERFORATIONS AND TOTAL TILE DRAIN OUT FLOW, TILE DRAIN DISCHARGE AND LOAD BEARING STRENGTH OF TILES

Table 46. Variation of Rate of Out-flow in Different Tile Drains

Sl. No.	Size of perforations (cm)	No. of perforations per tile	Total open area for water entry (sq.cm)	Mean rate of out-flow in l/m	Variation of rate of out-flow in l/m		Relative variation of out-flow	
					l/m	Percent	l/m	Percent
1.	Plain surface	-	6.30	0.033	-	-	-	-
2.	1.50	11	25.15	0.063	0.030	90.90	0.030	90.90
3.	1.25	15	25.15	0.098	0.045	136.36	0.035	55.56
4.	1.00	24	25.15	0.132	0.088	266.67	0.054	69.23
5.	0.75	42	25.15	0.152	0.118	357.58	0.020	15.15
6.	0.50	96	25.15	0.165	0.132	400.00	0.013	8.55

could be seen from the Table 43 and 44. By comparing the total increased variation of number of perforations, the increase in mean out-flow appears to be uniform. Even here also it was not possible to develop any relationship. The increase in number of perforations was from 110 to 960 per cent when the size of perforations decreased from 1.50 cm to 0.50 cm, and the corresponding mean out-flow was from 92.02 to 185.17 per cent. Reduction in size perforations upto 1 cm dia with 24 perforations per tile had followed the trend in increased mean out-flow from 92.02 to 160.84 per cent. Any further decrease in size of perforations from 1 cm to 0.75 cm diameter, which had resulted in increases of number of perforations from 24 to 42, the corresponding change in mean out-flow was from 160.84 to 172.24 per cent. Further reduction in size of perforation to 0.5 cm increased the number of perforation per tile to 96. Therefore, it was considered that any reduction in size beyond 1 cm dia would have considerable effect on the process of manufacture of tiles, and also no significant increase of hydraulic efficiency (Fig. 11).

The reduction in bearing strength as compared to increase in number of perforations, and also increase in mean tile drain out-flow are given in Fig.11 and Table 50. The per-centage increase in number of perforations were 110.00, 150.00 and 240.00, and the corresponding decrease of bearing strength were 18.71, 23.74 and 28.52 per cent. Reduction beyond 1.00 cm dia perforations, the increase in number of perforations was 420 per cent

at 0.75 dia, and also the corresponding reduction in bearing strength was 44.35 per cent. Hence there is a sudden decrease in strength of tile by further reducing the size below 1 cm dia perforation.

From the above discussion, the perforation size of 1-cm diameter looks to be more suitable. Small diameter perforations were structurally and hydraulically not efficient in addition to posing a problem of manufacture.

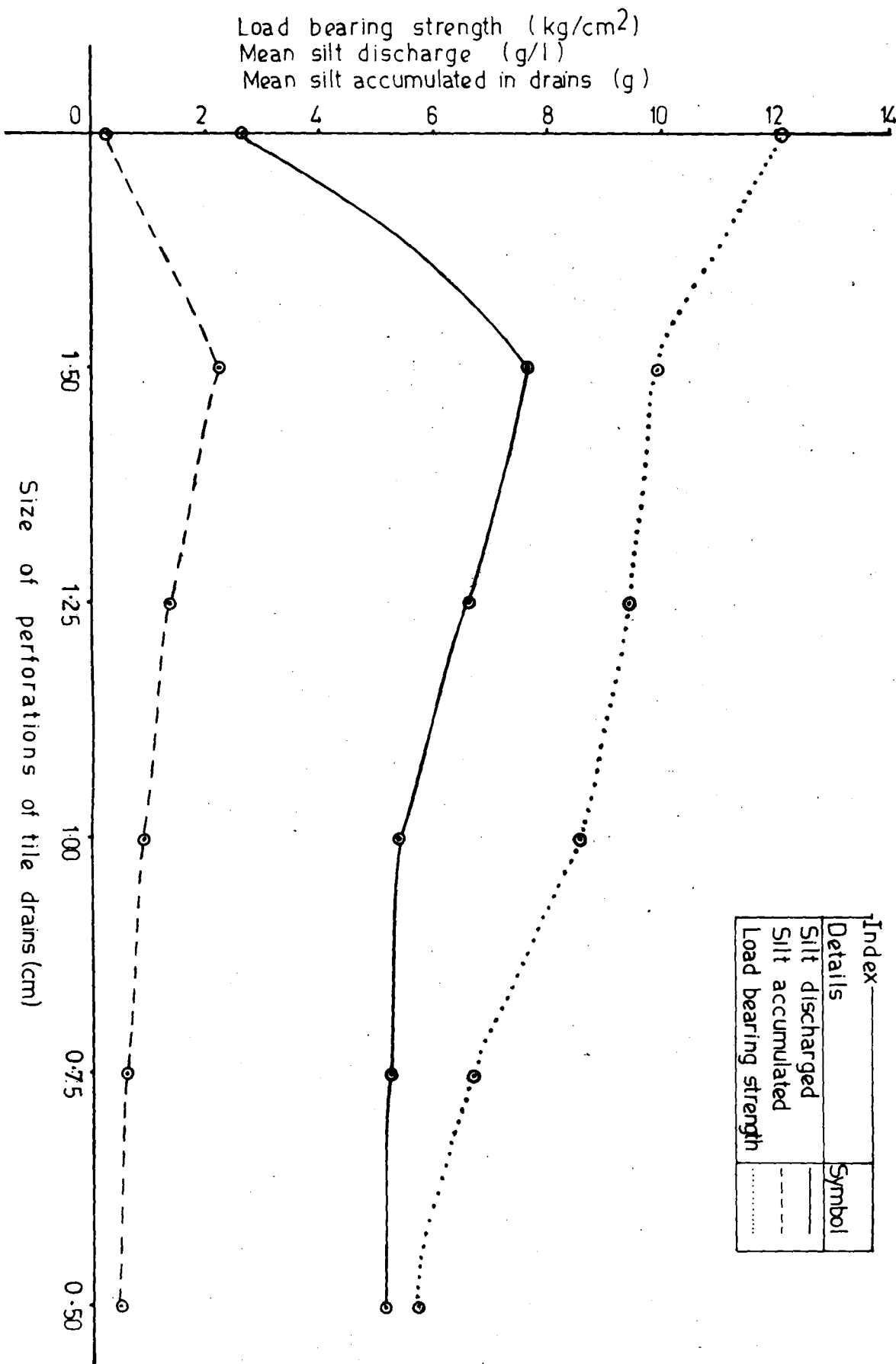
Kirkham and Schwab (1951) found from their studies that for 6 in (15 cms) diameter drains at 4-ft (1.12 m) depth, an increase in hole size from $\frac{1}{8}$ (6 mm) inch to $\frac{1}{4}$ (12 mm) inch diameter increase of flow for four holes per foot was 68 per cent, and for 10 holes per foot was 46 per cent. They also found that crack spacings of $\frac{1}{8}$ (3 mm), $\frac{1}{4}$ (6 mm) and $\frac{1}{2}$ (12 mm) inch per foot of drain length yielded the same seepage rate as 12, 17 and 31 of $\frac{1}{2}$ inch (12 mm) holes per foot, respectively. Kirkham(1958) found that in the slit drain artifices streamlines were equally spaced as they enter into the slit drain. Watts and Luthin (1963) found that the openings size was limited by sediment inflow rather than by the rate of water flow. Luthin and Haig(1972) found that by increasing the open area in the pipe for free entry of water increased the rate of flow more than $2\frac{1}{2}$ times. Gulati (1973) reported that the perforated drains reduced entrance resistance due to less convergence of flow in the vicinity of drain and also reduced the length of critical boundry. Sing and

Michael (1974) found that 3-mm spacing of opening for 30-cm long tile with tongue and groove joints. Ponu and Stammers (1976) found that smaller openings produced less flow resistance than large openings for specified area per unit length of drains. Swamy(1982) found that maximum rate of out-flow of 0.69 litres per minute from 0.5 cm dia perforated tiles.

5.6.2. Silt discharge and Accumulation of Silt in Tile Drains:

The variation of silt discharge in each treatment as compared to mean rate of tile drain out-flow is given in Table 47, and Fig.12. The pattern of decrease in mean silt discharge had followed the increased mean rate of tile drain out-flow, and it was negative variation between these parameters. But, the decreasing trend in mean silt discharge had followed the decrease in size of perforations, and it had positive relationship between these two parameters. From this, it could be stated that the smaller size perforations had positive effect in preventing silt entering into drains. The percentage decrease in silt discharge was from 640.80 in tile drains with 1.50 cm dia perforation to 69.31 in tile drains with 0.50 cm dia perforations. The decrease in silt flow in drainage was marked even in 1.00 cm dia perforated tile drains. Here also, the tile with 1 cm dia perforations had acted critical to prevent silt entering into tile drains.

During the first minute of out-flow the silt discharge was minimum of 0.12 grams per litre in tile drains with 0.50 cm dia perforations, and maximum of 1.64 grams per litre in tile with



Index	
Details	Symbol
Silt discharged	—
Silt accumulated	- - -
Load bearing strength	

FIG. 12 RELATIONSHIP BETWEEN SIZE OF PERFORATIONS AND SILT DISCHARGED, SILT ACCUMULATED AND LOAD BEARING STRENGTH OF TILES

Table 47. Silt Discharge through Drainage Water from Tile Drains of varied size of Perforations

Sl. No.	Time interval (minutes)	Silt discharge through different tile drains in g/l					Mean silt discharged (g/l)
		Diameter of perforations in cm					
		0.0	0.50	0.75	1.00	1.25	1.50
1	I	0.12	0.28	0.48	0.56	0.98	1.64
2	II	0.21	0.36	0.56	0.78	1.33	2.03
3	III	0.32	0.52	0.81	1.10	1.62	2.13
4	IV	0.44	0.76	1.02	1.36	1.83	2.83
Mean		0.272	0.450	0.674	0.955	1.368	2.015

1.50 cm dia perforations. The same increase of silt out-flow was noticed during second, third and fourth minutes tile discharge (Table 47 and Fig.13). The relative variation of mean silt discharge was calculated and compared in Table 48. The relative variation was maximum of 640.00 per cent in tile drains with 1.50 cm dia perforations as compared to tile drain without perforations. Further decrease of perforation size to 1.25 cm had relative variation of 37.12 per cent in relation to silt out-flow in tile drains with 1.5 cm dia perforations. The relative decrease of silt discharge became almost same in tile drains with 1.00, 0.75 and 0.50 cm perforations. From the data, the silt discharge in tile drains did not give any specific indication for the relation of size of perforations for tile. The reason, probably that silt that had entered the zone of free flow from the soil profile might have entered the tile drain. The reduction in silt discharge in lower diameter perforations was due to less turbulent velocity around the free water flow zone.

In Table 48, the mean rate of tile out-flow and mean silt discharges were compared. The mean rate of tile out-flow was increased as the size of the perforation decreased whereas mean silt discharge decreased with decrease in size of perforations of tile drains. As per the relative increase of rate tile drain out-flow, 1-cm diameter perforations of tiles gave significant out-flow. Therefore, 1-cm diameter perforations could be taken as critical limit.

In Table 49, the mean tile out-flow and mean silt

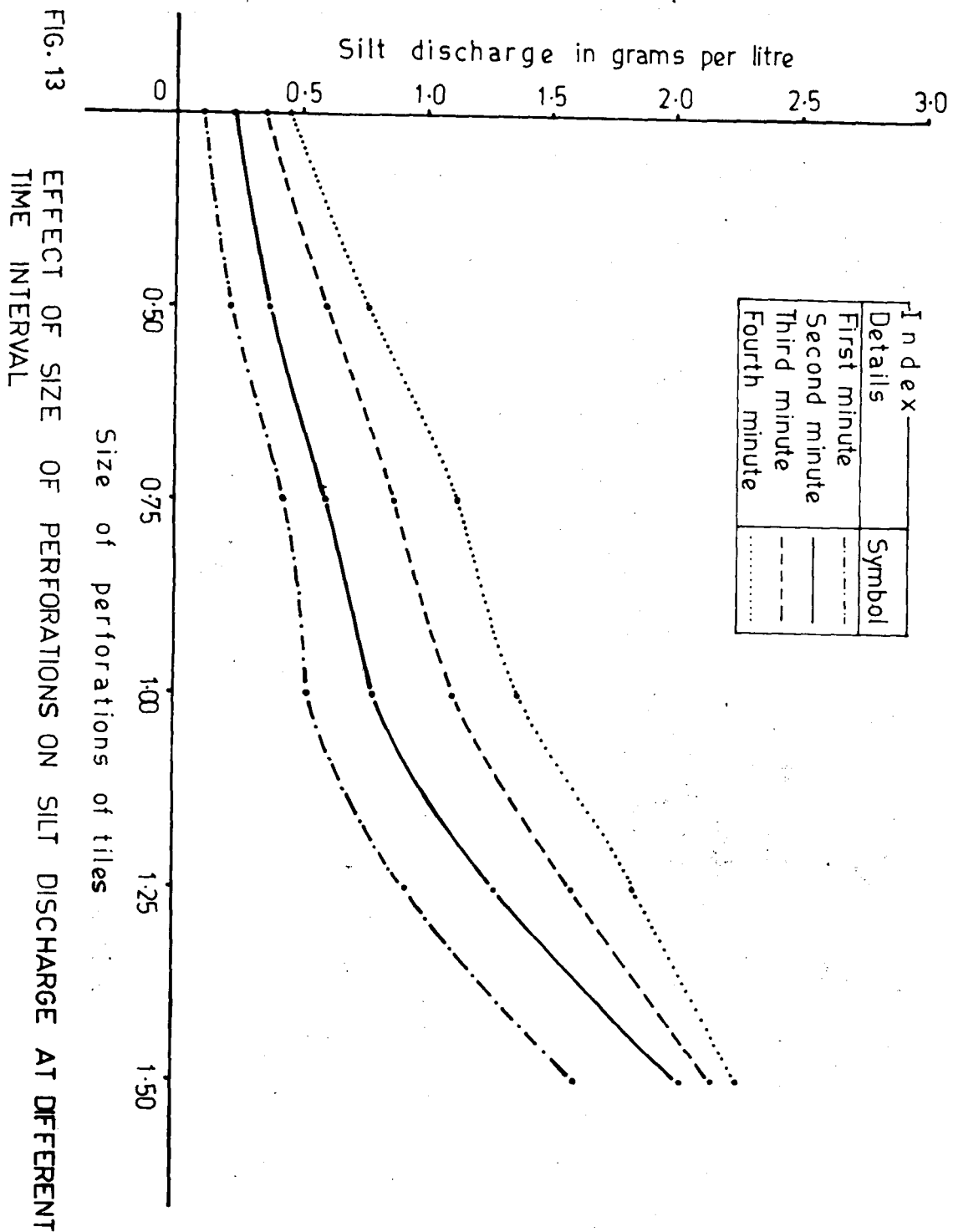


Table 48. Variation of Silt Discharge in Different Tile Drains

Sl. No.	Size of perforations (cm)	Mean rate of tile drain out-flow (lit/min)	Mean silt discharge (lit/min)	Variation of silt discharge		Relative variation of silt discharge	
				g/m	Per cent	g/m	Per cent
1.	Plain surface	0.033	0.272	-	-	-	-
2.	1.50	0.063	2.015	1.743	640.80	1.743	640.80
3.	1.25	0.098	1.368	1.096	402.94	0.647	37.12
4.	1.00	0.132	0.955	0.683	251.10	0.413	37.68
5.	0.75	0.152	0.694	0.422	155.15	0.261	38.21
6.	0.50	0.165	0.450	0.188	69.31	0.240	35.45

Table 49. Variation of Silt Accumulated in Tile Drains

Sl. No.	Size of perforations of tile (cm)	Mean tile drain out-flow (litres)	Mean silt accumulated in tile drains (g)	Variation of silt accumulated		Relative variation of silt accumulation	
				Weight	Percent	Weight	Per cent
1.	Plain surface	263.00	2.65	-	-	-	-
2.	1.5	505.00	7.88	5.23	197.36	5.23	197.36
3.	1.25	586.00	6.53	3.88	146.42	1.35	17.13
4.	1.00	668.00	5.50	2.85	107.55	1.03	15.77
5.	0.75	716.00	5.16	2.51	94.48	0.34	6.18
6.	0.50	750.00	5.04	2.39	90.19	0.12	2.33

accumulated were compared. The mean silt accumulated was maximum of 7.88 grams in tile drain with 1.50 cm dia perforation and minimum in tile drain without surface perforations. The mean silt accumulation in tile drain with 1.00 cm dia perforation and below, became almost same with little variation. The relation variations of 197.36 per cent was noticed in tile drain with 1.50 cm dia perforations as compared to silt accumulated in plain surface tile drain. Similarly, the relative decrease of silt accumulations were 17.13, 15.77, 6.18 and 2.33 per cent, respectively in tile drains with 1.25, 1.00, 0.75 and 0.50 cm dia perforations. The same relative variation became highly significant in tile drains with 1.0 cm dia perforations. Any further reduction in size of perforation did not have any significant effect on accumulation of silt in tile drains. According to silt accumulation factor, the 1.0 cm dia perforations may be ideally selected for clay tiles for water entry purpose.

From the laboratory studies, Watts and Luthin(1963) and Klimko and Passinskie(1966) had shown the openings size was limited by sediment in flow rather than by the rate of water flow. In the sand tank laboratory studies, the envelope around tile drains have limited role to play in preventing silt entering the tiles. The same is not true in field study as the envelope materials play major role in preventing silt entering into tile drains. Misra and Bearley(1975) conducted model studies to investigate the effect of high water velocity on the extent of soil movement, and concluded that the magnitude of flow of soil into the tubing was low in cohesive soils.

5.6.3. Bearing Strength of Tiles:

The bearing strength of tiles were decreased due to decrease in size of the perforations, but the mean out-flow was increased (Table 50). Mean tile out-flow was increased in the order of 92.02, 126.61, 160.84, 172.24 and 185.17 per cent and the corresponding reduction of bearing strength of tiles were 18.71, 23.74, 28.52, 44.35 and 53.17 per cent due to increased number of perforations per tile. The increase in number of perforations, the increase in tile drain out-flow and decrease in bearing strength does not bear any relation, but there was a significant effect on the bearing strength due to increased number of perforation. The relative variation of bearing strength (Table 51 and Fig. 11) had markedly decreased beyond less than 1 cm dia perforation, namely 14.5 and 17.30 kg/cm². By looking into increased number of perforations, mean tile out-flow and bearing strength, the tiles with 1 cm perforations were optimum for higher hydraulic efficiency and structural strength.

5.6.4. Effect of Depth of Irrigation on Tile Drain Out-flow:

The sub-treatments of the experiment were depths of irrigation and the variation of depth of irrigation did not have much effect on the size of perforations of the tile drains. The data from Table 52, it could be seen that variation of out-flow was more or less uniform under all depths of irrigation.

Table 50. Variation of Tile Out-flow, Number of Perforations and Bearing strength of Tiles

Sl. No.	Size of perforations(cm)	No. of perforations per tile	Variation of No. of perforations per tile		Mean tile out-flow (lit)	Mean variation of tile out-flow		Bearing strength of tiles in kg/cm ²	Reduction of strength of tiles in	
			Number	Percent		Litres	Percent		kg/cm ²	Percent
1.	Plain surface	0	-	-	263.00	-	-	12.13	-	-
2.	1.50	11	11	110.00	505.00	242.00	92.02	9.86	2.27	18.71
3.	1.25	15	15	150.00	576.00	333.00	126.61	9.25	2.88	23.74
4.	1.00	24	24	240.00	686.00	423.00	160.86	8.67	3.46	28.52
5.	0.75	42	42	420.00	716.00	453.00	172.24	6.75	5.38	44.35
6.	0.50	96	96	960.00	750.00	487.00	185.17	5.68	6.45	53.77

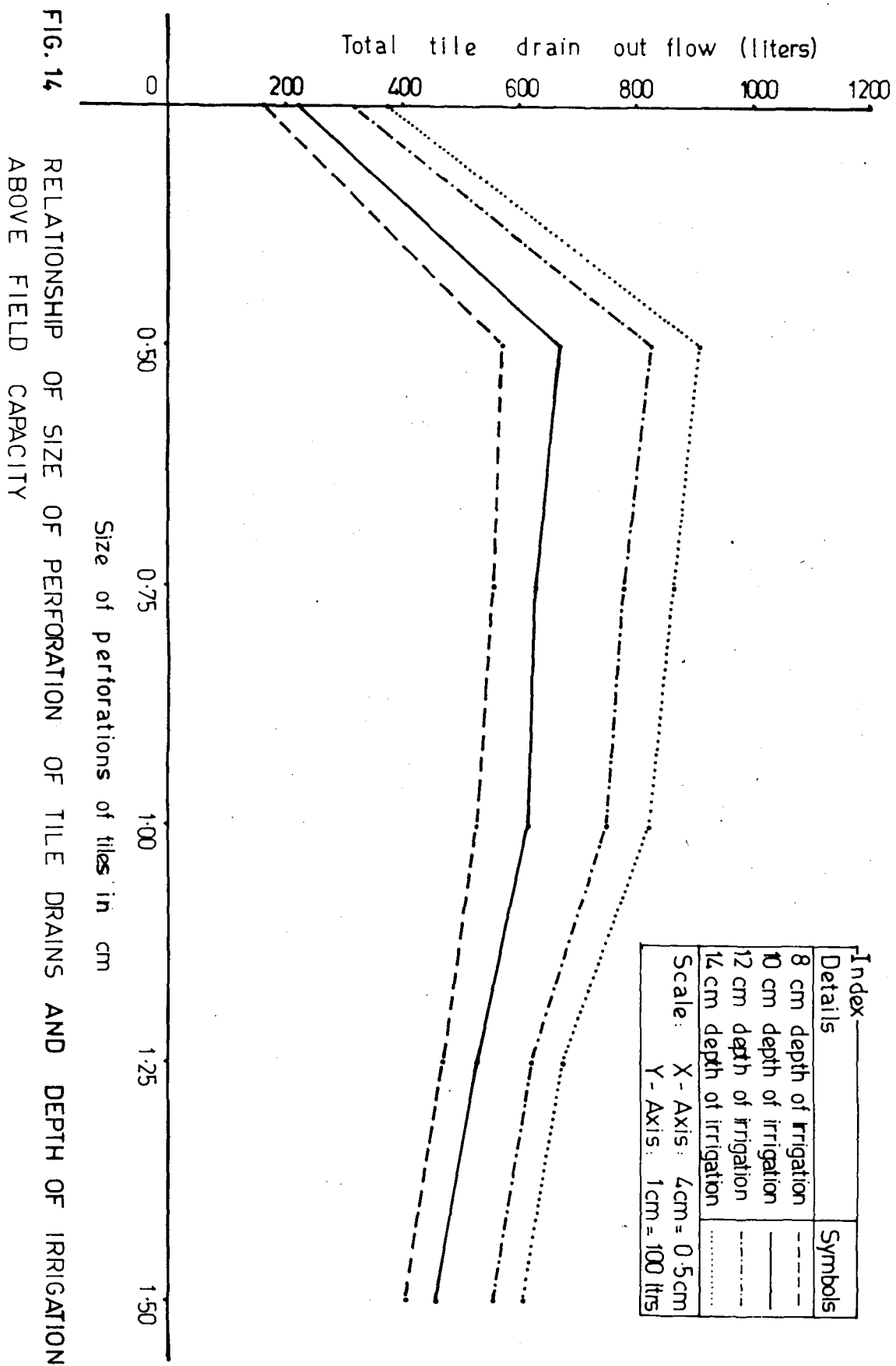
Table 51. Relative variation of number of perforations per tile, tile out-flow and Bearing strength of Tile

Sl. No.	Size of perforation in cm	No. of perforations per tile	Relative variation of number of perforation per tile		Mean tile out-flow	Relative variation of mean tile out-flow		Bearing strength of tile kg/cm ²	Relative reduction in strength of tile	
			Number	Percent		litres	Percent		kg/cm ²	Percent
1.	Plain surface	-	-	-	263.00	-	-	12.13	-	-
2.	1.50	11	11	110.00	505.00	242.00	92.00	9.86	2.27	18.71
3.	1.25	15	4	33.40	576.00	91.00	18.00	9.25	0.61	1.25
4.	1.00	24	9	60.00	686.00	90.00	15.10	8.37	0.78	4.85
5.	0.75	42	18	75.00	726.00	40.00	4.53	6.95	1.32	14.50
6.	0.50	96	54	128.57	760.00	34.00	4.20	5.68	1.27	17.30

Table 52. Relative variation of Total Tile Out-flow under varied Depth of Irrigation

Sl. No.	Depth of irrigation in cm.	Total tile drain out-flow in litres									
		Size of perforations of tiles									
		Plain surface		1.50		1.25		1.25		1.25	
		lit.	Percent	lit.	Percent	lit.	Percent	lit.	Percent	lit.	Percent
1.	8.00	162.00		405.00		482.0					
2.	10.00	213.0	51.0	31.0	450.0	45.0	11.50	536.0	54.0		11.60
3.	12.00	313.0	100.0	52.0	560.0	100.0	22.0	636.0	100.0		19.50
4.	14.00	364.0	51.0	16.5	605.0	45.0	8.5	670.0	34.0		4.30

		1.00		0.75		0.50		0.50		0.50	
		lit.	Percent	lit.	Percent	lit.	Percent	lit.	Percent	lit.	Percent
1	8.00	526.0		560.0		590.0					
2.	10.00	616.0	90.0	22.0	640.0	74.0	12.0	680.0	90.0		16.30
3.	12.00	756.0	140.0	24.0	792.0	152.0	20.0	830.0	50.0		19.80
4.	14.00	836.0	80.0	11.3	860.0	68.0	11.3	910.0	80.0		10.20



The mean out-flow was 263.00 litres in plain surface tile drains and 505.00, 526.00, 685.00, 716.00 and 750.00 litres in tile drains with 1.50, 1.25, 1.00, 0.75 and 0.50 cm dia perforated tile drains, respectively. In a soil system, where tiles are buried deep below, the depth of irrigation water had little effect on the tile drain out-flow. This agrees with the findings of Mclean and Schwab(1982), Linder and Schaffer(1980), Watter et al.(1979) and Swamy(1982).

From the Table 52, it could be seen that the increase of tile drain out-flow in all treatments. By increasing the depth of irrigation from 8 to 10 cm, the percentage increase in tile out-flow in plain surface drain was 31.00, and the corresponding increase in tile drains with perforations of 1.50, 1.25, 1.00, 0.75 and 0.50 cm dia were 11.50, 11.60, 22.00, 12.00 and 16.30 per cent. Similarly, by increasing the depth of irrigation from 10 to 12 cm, the corresponding percentage increases were 52.00, 22.00, 19.50, 24.00, 25.00 and 19.80. Further increase of depth of irrigation to 14 cm from 12 cm, the proportionate increase were 16.50, 8.50, 4.30, 11.30, 11.30 and 10.20 per cent. The increased depth of irrigation uniformly did not give the same uniform tile drain out-flow. This could be attributed to the reason that air entrapped in the soil profile might have caused unequal pressure at various points in soil.

In view of uniform variation of tile drain out-flow in all treatments under different depth of irrigation, the depth of

irrigation was not taken as an indicator to draw conclusion for optimisation of size of perforations for clay tiles. The earlier conclusion were drawn based on definite scientific factors, the 1-cm diameter perforations are found to be more suitable for 60 cm long 10 cm dia clay tiles used as sub-surface drains in command areas in Karnataka State.

5.7.0. Number of Circumferential Perforations Per Tile:

The clay tiles of 10 cm dia and 60 cm long are being used in the irrigated soils to control the rise of water table. These tiles are laid in the trenches with bell mouth joints, and ultimately these joints would serve as crack space for water entry into tile drains. The joints at 60-cm length are too long enough for convergence of water lines. The expansion property of some of the black soils would also affect the bell-mouth joints by closing completely for water entry.

To overcome the problem of inadequate crack space for water entry and to reduce the convergence losses, the perforations were provided on the hemi-spherical body of the tiles. From the earlier experiment, it was found that 1-cm diameter spherical perforations were optimum for 60-cm long tiles of 10-cm diameter. The 1-cm diameter perforations were hydraulically and structurally proved better as they could give higher rate of tile out-flow, reduces silt entering and depositing in tiles. The bearing strength of tiles was sufficient to carry dead and live load coming on them for specified life time.

In order to find out the number of 1-cm dia perforation required for each tile of 60-cm long and 10-cm dia an experiment was conducted in the field. No such precise study was conducted in Karnataka or elsewhere to use the information for adoption for clay tiles in irrigated clay soils. The information available in literature was too inadequate and also not comprehensive for this purpose. Hence, this experiment was conducted to find out the optimum number of perforations per tile for higher hydraulic efficiency.

In this experiment the treatments selected were plain tiles without (0.24% opening) perforation, 6 (0.42% opening) perforations of 1-cm dia per tile, 12 (0.58 % opening) perforations of 1-cm per tile, 24(0.95% opening) perforations of 1-cm per tile, 36(1.31 % opening) perforations of 1-cm per tile, 48(1.67% opening) perforations of 1-cm per tile and 60(2.02% opening) perforations of 1-cm per tile. All the perforations were 1-cm dia spherical in shape and made on one half of the hemispherical surface. The total entry area in each tile was varied depending on the number of perforations.

5.7.1. Tile Drain Out-Flow:

As a measure of hydraulic efficiency, the total tile drain out-flow and rate of tile drain out-flow were measured and compared. The mean tile drain out-flow was varied from minimum of 105.85 litres in tile drains without surface perforations to maximum of 356.28 litres in tile drain with 60 perforations per tile.

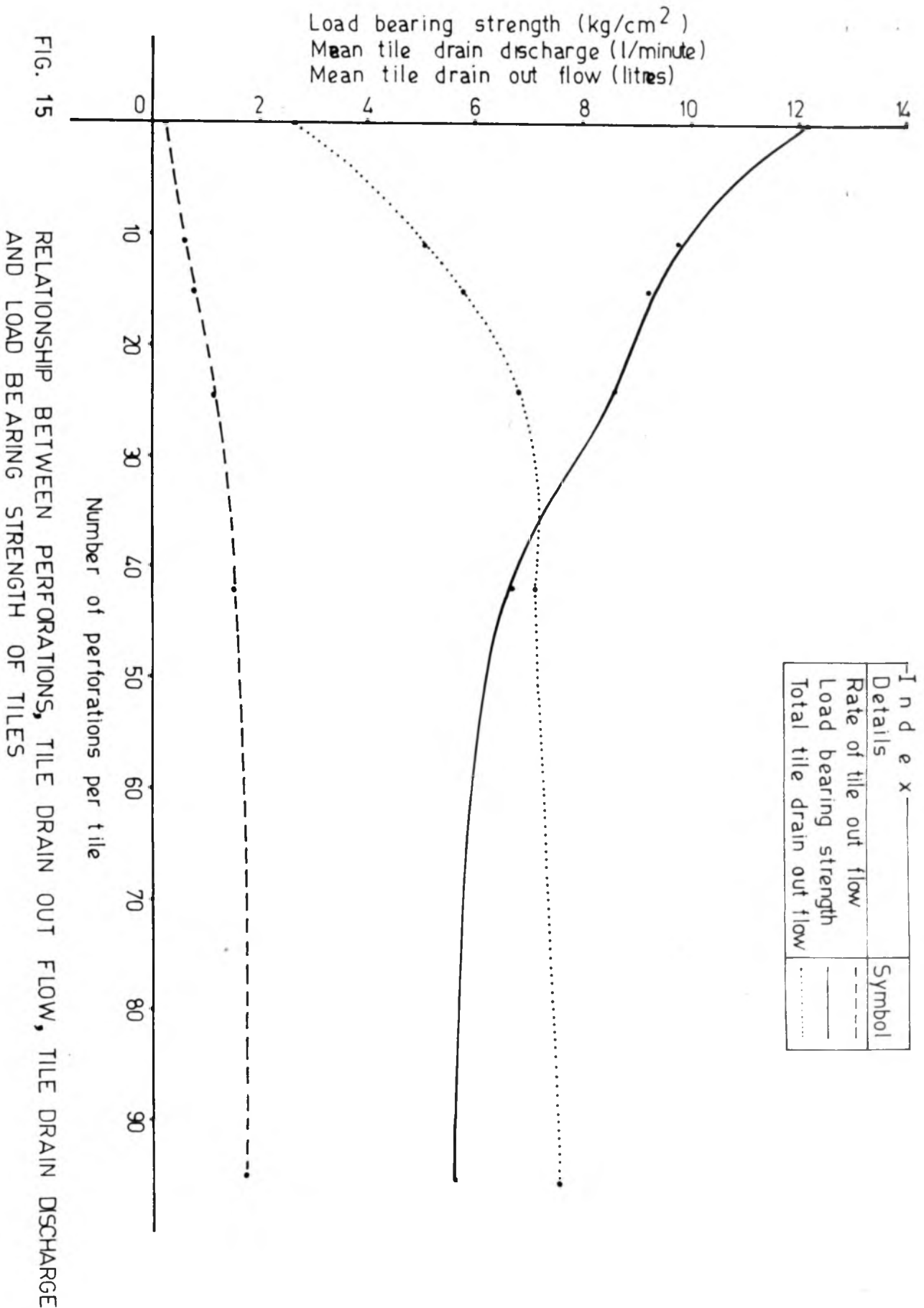


FIG. 15 RELATIONSHIP BETWEEN PERFORATIONS, TILE DRAIN OUT FLOW, TILE DRAIN DISCHARGE AND LOAD BEARING STRENGTH OF TILES

The change in out-flow increasing order was significant in tile drains upto 24 perforations per tile and became less significant in tile drains with 36, 48 and 60 perforations per tile. From Tables 53 and 54 and Fig. 15, the increased variation of mean tile drain out-flow as compared to out-flow from tile drains with plain surface tile are given. It shows that minimum variation of 46.77 per cent to maximum variation of 250.53 per cent when the number of perforation of 1-cm dia varied from 6 to 60 per tile. The variation in mean tile drain out-flow with 12, 24, 36 and 48 perforations per tile were 87.15, 143.02, 202.53 and 230.40 per cent. The corresponding increased variation of water entry area per tile due to increased number of perforation, were 149.52, 299.05, 448.57, 598.10 per cent. The maximum and minimum variation of water entry area were 74.50 and 747.62 per cent in tile drains with 60 and 6 perforations per tile. These comparisons indicate that approximately for every three times increase of water entry area there was only one time increase in total tile drain out-flow. It is very clear from the figure 15, that the curves of total tile drain out-flow and number of perforation varied widely. The curve drawn for total water/^{entry}area had shown straight line relationship, where the curve drawn for total variation had become almost parallel to the X-axis after 36 holes per tile, and after 24 perforations/^{the}change was highly significant. Therefore, it may be concluded that 24 (0.95% opening) perforation of 1-cm dia per tile were hydraulically more efficient and it may be considered as optimum. From Fig.16,

Table 53. Relative Change of Mean Tile Drain Out-flow and Mean Surface Water Entry Area per Tile

Sl. No.	Area of total perforation per tile		Relative change of water entry area		Relative change mean tile drain out-flow	
	No. of perforations per tile	Water entry area per tile sq.cm	Area in sq.cm	Area in percent	Litres	Percent
1.	Plain surface	6.30	-	-	-	-
2.	6	11.01	4.71	74.50	46.77	44.18
3.	12	15.72	4.71	42.50	40.38	26.46
4.	24	25.14	9.42	59.92	55.87	28.95
5.	36	34.56	9.42	37.47	59.51	23.66
6.	48	43.98	9.42	27.26	27.87	9.10
7.	60	53.40	9.42	21.42	20.13	5.98

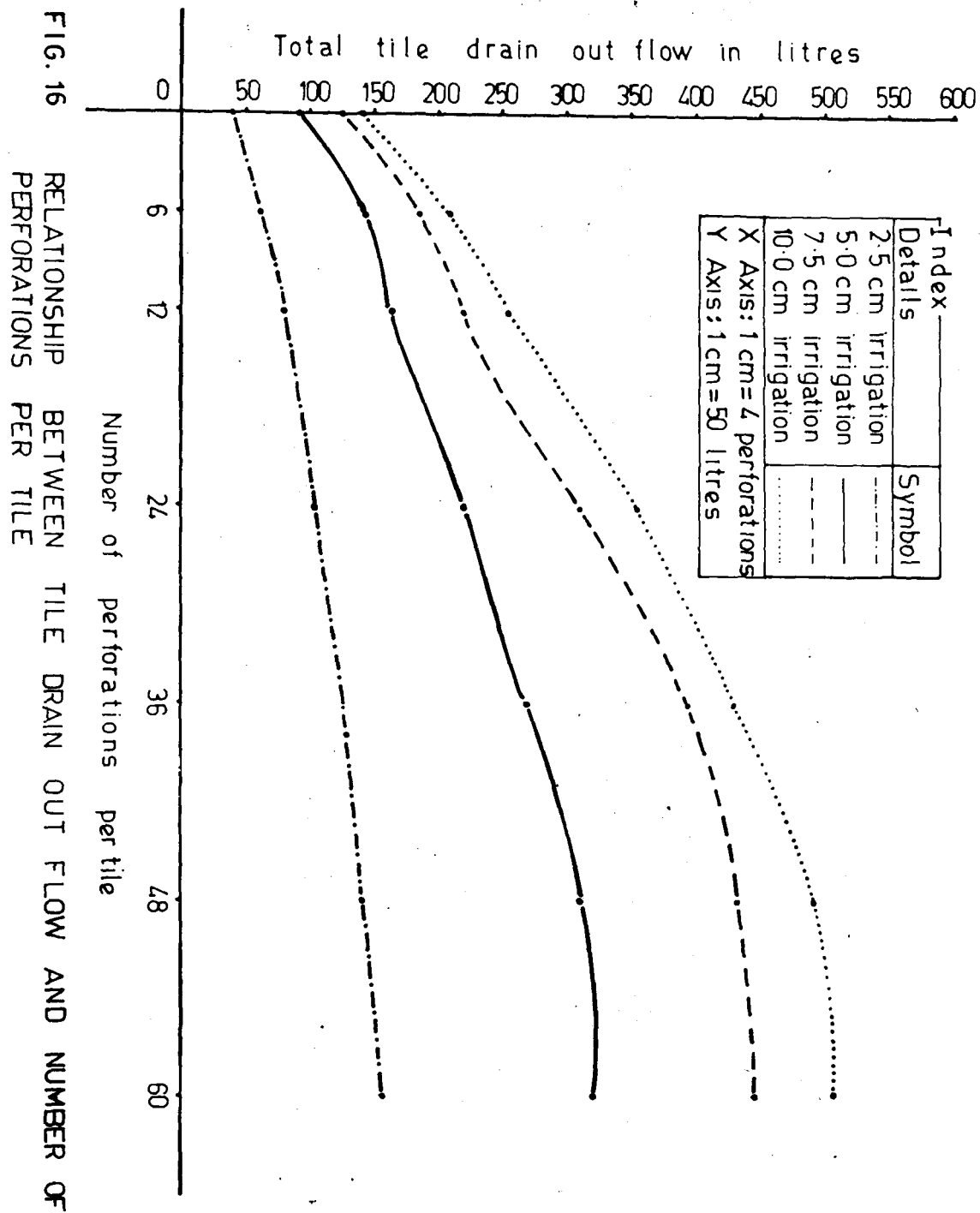


FIG. 16 RELATIONSHIP BETWEEN TILE DRAIN OUT FLOW AND NUMBER OF PERFORATIONS PER TILE

Table 54. Change of Total Mean Tile Drain Out-flow and Mean Surface Water Entry Area

Sl. No.	Area of total perforation per tile		Change in mean tile drain out-flow		Change in water entry area per tile	
	No. of perforation per tile	Water entry area per tile(sq.cm)	Litres	Percent	Sq.cm.	Per cent
1.	Plain surface	6.30	-	-	-	-
2.	6	11.01	46.77	44.18	4.71	74.50
3.	12	15.72	87.15	82.23	9.42	149.52
4.	24	25.14	143.02	135.16	18.84	299.05
5.	36	34.56	202.53	191.35	28.35	448.57
6.	48	43.98	230.40	217.67	37.68	598.10
7.	60	53.40	250.53	236.68	47.10	747.62

it could be seen that the total increase of out-flow decreased as the number of perforation per tile increased, and it was also an indicative that more number of perforation per tile (i.e. higher area of opening) did not have higher hydraulic efficiency. From Table 55 and Fig. 17, the relative variation of number of perforation per tile and the corresponding variation of total tile drain out-flow are depicted. It was also very clear that beyond 24 perforations per tile the tile drain out-flow was significantly less.

The relative change of water entry area 9.42 square cm remains the same for every increase of 12 perforations of 1-cm per tile, but the relative increase tile out-flow decreased substantially beyond 24 perforations per tile. Therefore, 24 perforations of 1-cm diameter per tile are sufficient for higher hydraulic efficiency for 60 cm long 10 cm dia clay tile drains.

The above conclusion agrees with Kirkham and Schwab(1951) that the increased number of holes increased the relative increase in out-flow in decreasing order, particularly above 20 holes per foot. Debar and Johnson(1965) reported that perforated tile gave greater tile discharge than the regular plain tile. Willardson et al.(1966) reported from their study that the 28 gauge galvanised steel tubes had 24 times as much open area as the fiber glass wrapped plastic and discharged nine times much more water when placed in sand. Schwab et al.(1969) reported that the spacing of perforations on cylindrical surface

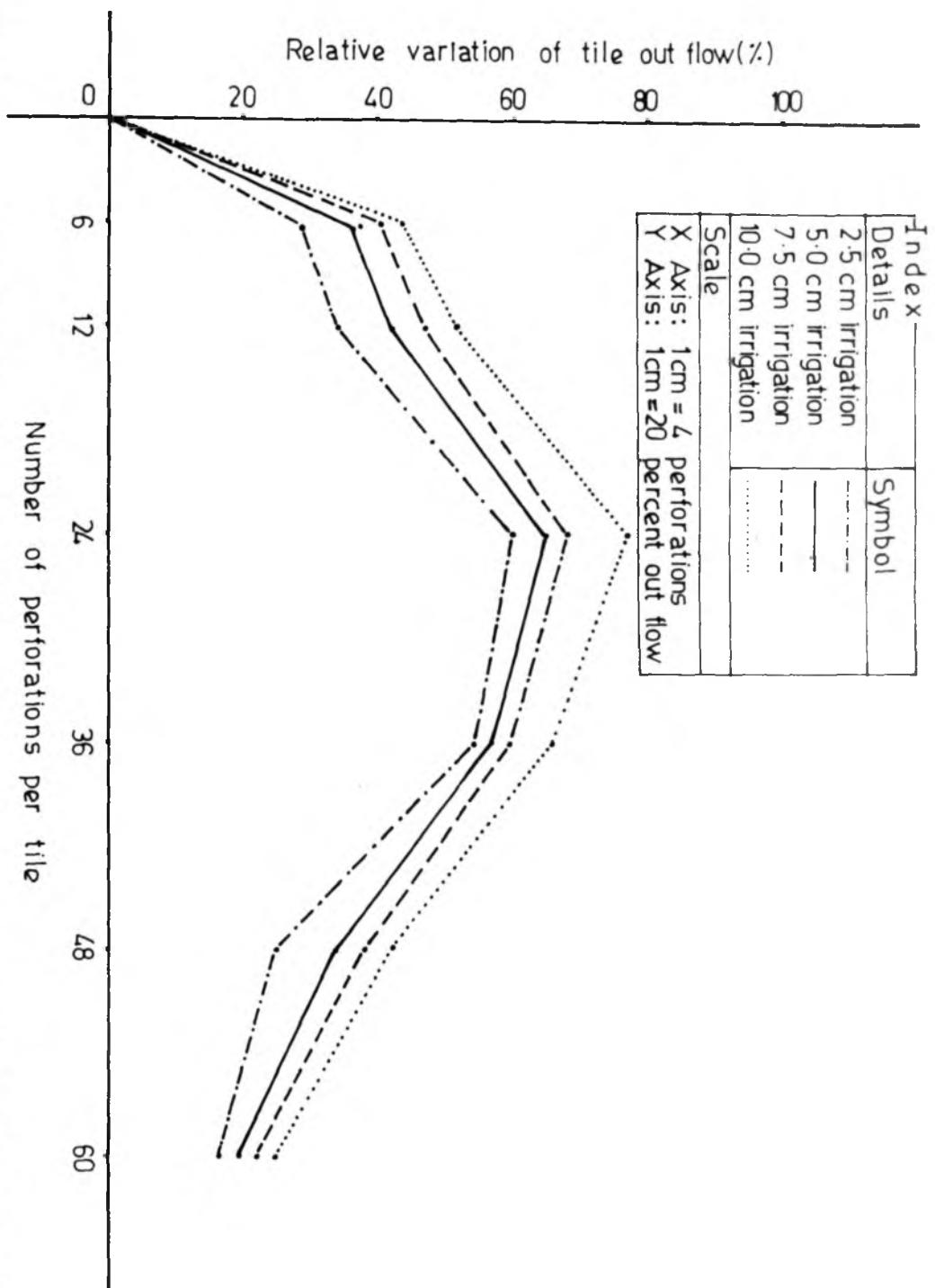


FIG. 17 RELATIONSHIP OF RELATIVE PERCENTAGE VARIATION OF TOTAL TILE DRAIN OUT FLOW AND NUMBER OF PERFORATIONS PER TILE

Table 55. Relative Variation of Total Tile Drain Out-flow under different Depth of Irrigation

Sl. No.	No. of perforations per tile	Total Tile Drain Out-flow in litres								Mean tile drain out-flow litres	Relative variation
		Depth of irrigation water above field capacity in cm									
		2.5	Relative variation	5.0	Relative variation	7.50	Relative variation	10.0	Relative variation		
		litres		litres		litres		litres		litres	
1.	Plain surface	46.00	—	92.00	—	122.55	—	143.00	—	—	
2.	6	70.50	34.50	144.00	52.00	191.00	68.50	225.50	82.50	155.13	
3.	12	84.50	15.00	167.00	23.00	228.00	37.00	263.00	47.50	183.63	
4.	24	112.00	27.50	221.00	54.00	310.00	82.00	352.50	88.50	284.87	
5.	36	132.00	20.00	270.00	49.00	382.00	72.00	432.00	79.50	308.38	
6.	48	145.50	13.50	307.50	37.50	434.50	52.50	488.50	56.50	336.25	

Table 56. Tile Drain Out-flow in Relation to Number of Perforations per Tile

Sl. No.	Number of perforation no. per tile	Tile drains out-flow in percentage				Mean
		Depth of irrigation above field capacity(cm)				
		2.5	5.0	7.5	10	
1	0	7.20	6.90	6.20	5.40	6.52
2	6	10.20	9.80	9.20	8.60	9.45
3	12	12.80	11.90	10.70	9.80	11.30
4	24	17.60	16.50	15.10	14.80	16.00
5	36	21.00	19.80	18.50	17.20	19.15
6	48	23.20	22.10	21.80	19.50	21.70
7	60	24.20	23.20	22.20	20.40	22.55
Mean		16.65	16.20	22.20	13.65	-

Table 57. Total Tile Drain Out-flow and Depth of Irrigation

Sl. No.	Depth of irrigation water (cm)	Total tile drain out-flow in litres				
		Surface water entry area in sq.cm per tile				
		6.30	11.01	15.72	25.14	34.56
						43.98
						53.40
1.	2.5	46.00	70.50	84.00	112.00	132.00
						145.50
						152.00
2.	5.0	92.00	144.00	167.00	221.00	270.00
						307.50
						318.50
3.	7.5	122.50	191.00	228.00	310.50	382.00
						434.50
						446.00
4.	10.00	143.00	225.50	263.00	352.50	432.50
						488.50
						505.00
Mean		105.85	152.62	196.00	248.00	308.38
						336.25
						356.30

of a drain had very little effect on the in-flow where the ratio of the shortest to the highest spacing was greater than 0.2. Luthin and Haig(1972) observed that decreasing the pipe segment length from 3 ft to 1 ft increased the rate of flow into the pipe more than 2½ times. Gulati(1973) stated that by increasing the open area for inflow minimise the entrance resistance and in-flow velocity. Singh and Michael(1974) reported from their study that a spacing of 3 mm was optimum for 10-cm diameter, 30-cm long tiles with tongue and groove joints in vitrified clay soil. Dierrick et al.(1975) reported that 106 perforations per metre length in plastic tube gave higher discharge compared to a drain with 36 perforations. Belgaumi(1979) found that the relative increase in tile out-flow decreased with an increased number of circular openings.

From the Table 58 and Fig. 18, the rate of tile drain out-flow are depicted for illustrations. The water entry area increases from 74.50 per cent in tile drain with 6 perforation per tile to 747.62 per cent in tile drain with 60 perforations per tile. The rate of tile drain out-flow was 52.11 per cent increase in tile drain with 6 perforations per tile, and it was increased to 80.28, 143.66, 200.00, 235.21 and 247.88 per cent, respectively in tile drain with 12, 24, 36, 48 and 60 perforations per tile. Here also, it is clear that by three fold increase in water entry per tile had caused only one fold increase of out-flow rate. From the Fig. 18, the water entry area

Table 58. Change in Rate/Tile Discharge and Number of Perforation per Tile

Sl. No.	Area of total perforations per tile		Change in water entry area per tile		Change in mean rate of tile drain discharge	
	No. of perforation per tile	Water entry area per tile (sq.cm)	Area (sq.cm)	Percent	Litres per minute	Per cent
1. Plain surface	6.30		-	-	-	-
2.	6	11.01	4.71	74.50	0.071	52.11
3.	12	15.72	9.42	149.52	0.057	80.28
4.	24	25.14	18.84	299.05	0.102	143.66
5.	36	34.56	28.25	448.57	0.142	200.00
6.	48	43.98	37.68	598.10	0.167	235.21
7.	60	53.40	47.10	747.62	0.176	247.88

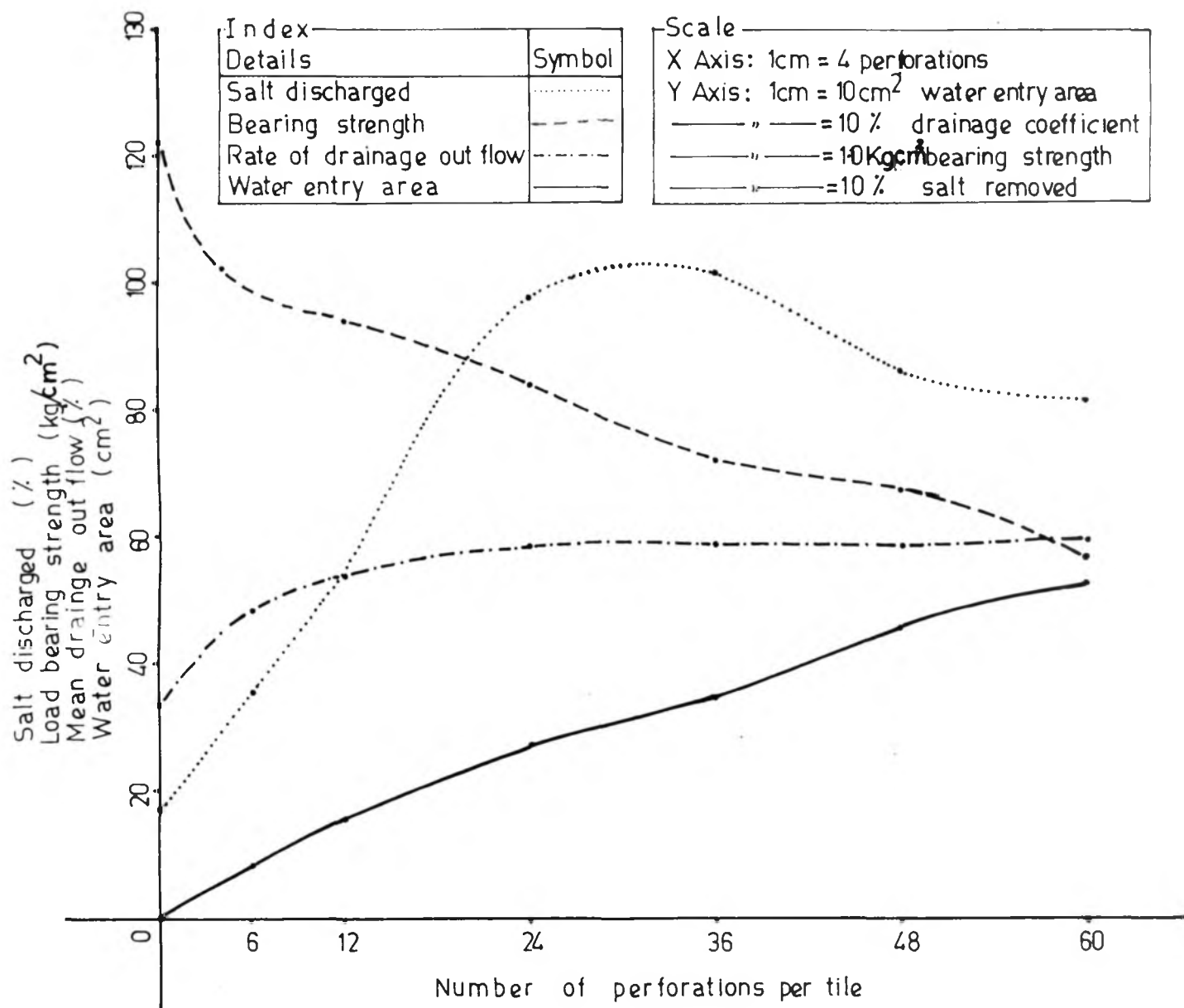


FIG. 18

RELATIONSHIP BETWEEN PERFORATIONS AND WATER ENTRY AREA, RATE OF OUT FLOW, SALT DISCHARGED AND LOAD BEARING STRENGTH OF TILES

increased in straight line relation for every increase of 12 perforations per tile, but in case of rate of tile drain out-flow, the curve was almost parallel to x-axis beyond 24 perforations per tile. In Table 58, the relative change of rate of out-flow is illustrated. The relative change of water entry area was maximum in tile with 6 holes per tile, and this relative change was decreased in order of 42.50, 59.92, 37.47, 27.26, and 21.42 per cent in tile drains with 12, 24, 36, 48 and 60 perforations per tile. Similarly, the corresponding the relative decrease of rate of out-flow were 52.11, 28.52, 32.16, 23.12, 11.17 and 3.78 per cent. From this data we could conclude that not only there was decreased rate of tile out-flow, but also beyond certain number of perforations per tile would not give same proportion of tile drain out-flow. Since the controlling factor for tile drain out-flow was in-flow of drainage water into the vicinity of free water area rather than increased water area per tile. The increased rate of out-flow decreased in tile drains/^{having}more than 24 perforations per tile. Therefore, we can select 24 perforation of 1-cm dia per tile.

5.7.2. Silt Discharge and Silt Accumulation in Tile Drains:

The data on mean silt discharge and mean silt accumulation in tile drains is presented in Table 25 and also in Table 61. The silt discharge was minimum of 0.586 grams per litre in tile drain with plain surface tile and maximum of 2.863 grams per litre in tile drain with 60 perforations per tile. In other

Table 59. Relative Change in Rate of Discharge and Number of Perforation Per Tile

Sl. No.	Area of total perforation per tile		Relative change of water entry area per tile		Relative change in rate of tile drain discharge	
	No. of perforations per tile	Water entry area per tile (sq.cm)	Area (sq.cm)	Area in Per cent	Litres per minute	Per cent
1.	0	6.30	-	-	-	-
2.	6	11.01	4.71	74.50	0.071	52.11
3.	12	15.72	4.71	42.50	0.020	18.52
4.	24	25.14	9.42	59.92	0.045	35.16
5.	36	34.56	9.42	37.47	0.040	23.12
6.	48	43.98	9.42	27.26	0.025	11.17
7.	60	53.40	9.42	21.42	0.009	3.78

Table 60. Relative Variation of Rate of Tile Drain Out-flow under Different Depth of Irrigation

Sl. No.	No. of perforations per tile	Rate of tile drain out-flow in litres per minute												Mean rate out-flow tile	Relative variation Per cent
		Depth of irrigation water above field capacity in cm.													
		2.5		5.0		7.5		10.0		Relative variation		Relative variation			
		l/m	Percent	l/m	Percent	l/m	Percent	l/m	Percent	l/m	Percent	l/m	Percent		
1.	Plain surface	0.032	-	0.064	-	0.086	-	0.099	-	0.071	-	0.071	-	-	
2.	6	0.049	53.13	0.100	56.25	0.133	54.51	0.15	51.52	0.108	52.11	0.108	52.11	52.11	
3.	11	0.059	20.41	0.116	16.00	0.020	15.04	0.177	18.00	0.128	18.52	0.128	18.52	18.52	
4.	24	0.078	32.20	0.153	31.98	0.215	40.52	0.245	38.42	0.173	35.16	0.173	35.16	35.16	
5.	36	0.091	16.67	0.192	25.50	0.268	24.65	0.302	23.27	0.213	23.12	0.213	23.12	23.12	
6.	48	0.101	10.98	0.214	11.46	0.302	12.68	0.335	10.93	0.238	11.17	0.238	11.17	11.17	
7.	60	0.106	4.95	0.221	3.33	0.310	2.65	0.381	4.78	0.247	3.78	0.247	3.78	3.78	

tiles, the rate of silt discharge was higher and proportional to increased number of perforations per tile. In Table 62, water entry area per tile, rate of tile drain out-flow and mean rate of silt discharge are compared and illustrated. The change of water entry area was maximum in tile drain with 24 perforation per tile and also the relative increase in rate of tile drain out-flow had decreased in the same tile drains. The relative increase in silt discharge was continuously increased as per the relative increase of water entry area per tile. This could be seen from the data that minimum and maximum relative increase of discharge of silt was in tile drains with ^{perforations} 6 and 60/ per tile, respectively. The silt discharge increase was probably due to turbulence created by the open area around the tile, and also the availability of silt would not have become critical as the tiles water entry area was oriented downward.

The total variation of silt discharge as compared to tile drain without surface perforation was (Table 61) increasingly higher and became more significant in tile drains with more than 24 perforations per tile. The tile drains with 6, 12, 24, 36, 48 and 60 perforations per tile gave respectively 26.96, 57.85, 102.05, 166.55, 262.46 and 388.57 per cent high rate of silt discharge. In Table 62, the relative variation of silt discharge had been shown and the data indicates that there was continuous relative increase of silt discharge as the water entry area increased. The minimum and maximum relative increase of

Table 61. Total Variation of Surface Water Entry Area, Bearing Strength of Tiles, Silt Accumulated in Tile Drains and Tile Drain Out-flow

Sl. No.	Number of perforation per tile	Total variation of water entry area per tile (%)	Total decrease in bearing strength of tile (%)	Total mean variation of tile drain out-flow (%)	Total increase in silt accumulated in tiles (g)	Total increase in silt discharge in tile drains (g/l)
1.	0	-	-	-	-	-
2.	6	74.50	15.00	44.18	54.23	26.96
3.	12	149.52	22.25	82.23	84.15	57.85
4.	24	299.05	30.17	135.16	132.92	102.05
5.	36	447.57	40.00	191.35	193.14	166.55
6.	48	598.13	49.55	217.67	261.62	262.46
7.	60	747.62	58.53	236.68	340.85	388.57

Table 62. Relative Variation of Silt Discharged in Tile Drains under Different Depth of Irrigation

Sl. No.	Number of perforation per tile	Silt discharged in tile drain in grams per litre												Mean rate of silt discharge g/l	Relative variation %
		Depth of irrigation water above field capacity in cm													
		2.5		5.0		7.5		10.0		Relative variation					
		g/l	%	g/l	%	g/l	%	g/l	%	g/l	%	g/l	%		
		g/l	%	g/l	%	g/l	%	g/l	%	g/l	%	g/l	%		
1.	Plain surface	0.145	-	0.395	-	0.630	-	0.874	-	0.586	-				
2.	6	0.186	28.26	0.472	19.50	0.750	23.05	1.116	27.68	0.744	26.96				
3.	12	0.235	26.34	0.564	19.56	1.077	30.60	1.385	29.10	0.925	24.33				
4.	24	0.296	25.96	0.692	22.70	1.380	35.65	1.776	28.23	1.184	28.00				
5.	36	0.391	32.10	0.882	27.46	1.853	34.28	2.344	31.98	1.562	31.92				
6.	48	0.531	35.80	1.162	31.75	2.554	37.83	3.186	35.92	2.124	36.62				
7.	60	0.715	34.65	1.530	31.67	3.478	36.85	4.293	31.38	2.863	34.78				

silt discharges were 26.96 and 36.62 per cent in tile drains with 6 and 48 perforations. The tile drain with 24 perforations per tile gave relative increase of 28.00 per cent silt discharge which was relatively less as compared to the tile drains with higher number of perforation. Though, it cannot be considered as one of the deciding factor to draw clear conclusion, still it could be considered for comparison as it would limit silt flowing in tile discharge.

The accumulated silt in tile drains with 60 perforations per tile was highest and lowest in tile drain with plain surface (Table 63). The factor responsible for variation of silt accumulation was the grade in tile drains, and it was uniformly maintained in all treatments and there was no other external influencing factors for accumulation. The silt accumulated was 5.68, 8.76, 10.46, 13.23, 16.65, 20.54, 25.04 grams in tile drains with plain surface, and tile drains with 6, 12, 24, 36, 48 and 60 perforations, respectively. The data in Table 63 indicate that the total and relative change of silt accumulation in tile drains. The total increased change of silt accumulation was minimum and maximum in tile drain with 6 and 60 perforations per tile. But in other tile drains the silt accumulation was in increasing order as the number of perforations per tile increased. Similarly, the relative increase of silt accumulation in tile drain did not become an indicative factor to decide the number of perforations per tile. However, the tile drain with 24 perforations had 16.0 per cent relative increase of silt accumulation as compared to

Table 63. Relative Variation of Surface Entry Area, Bearing Strength of Tiles, Silt Accumulated in Tile Drain and Tile Drain Out-flow

Sl. No.	Number of perforation per tile	Relative increase in water entry area (sq.cm)	Relative decrease in strength of tiles (%)	Relative mean increase in tile drain out-flow (%)	Relative increase of silt accumulated in tile drains (%)	Relative increase of silt discharge in tile drains (%)
1	0	-	-	-	-	-
2	6	74.18	12.10	44.18	54.23	26.96
3	12	42.78	11.05	26.46	29.92	24.33
4	24	59.92	11.42	28.95	48.77	28.00
5	36	37.47	16.03	23.66	61.00	31.93
6	48	27.26	15.93	9.12	68.48	35.98
7	60	21.14	17.81	5.98	78.00	24.80

19.15, 21.70 and 22.55 per cent in tile drain with 36, 48 and 60 perforations per tile. Therefore, we can conclude that the tile with 24 perforations are more suitable to prevent silt discharge and silt accumulation than tile with higher number of perforations.

Williardson et al. (1968) reported from their study that uniform non-cohesive soils are most likely to cause sedimentation in tile drains and graded materials are less susceptible for the movement of soil. Brownscombe (1962) reported that there was no statistically significant difference in soil discharge and rate of water discharge. Spencer et al. (1963) reported that the amount of deposits in tiles at various locations were related to the amount of reduced iron in soil. Grass (1969) found that the formation of red or black deposits in tile drain was not related to location, soil type, kind of tile material or length of tile drain in service. Gulathi et al. (1970) found that saturated uniform porous media with particle diameter 0.1 mm to 0.25 mm were the most critical for causing sedimentation in sub-surface drains because hydraulic conductivities were high and the velocities to set the particles in motion were low. Grass and Meckenze (1972) found that the deposits of iron and manganese precipitates in tile drains clog the openings through which water enters the tile. This result is in conformity with the findings of other investigators.

Dierick et al. (1975) reported from their sand tank model studies that the accumulated sand inside the drain tube was negatively related to the water discharge. Grass et al. (1979) found from his studies that the important factors for accumulation of soil was the partical size distribution of soil adjoining to tiles. Gameda et al. (1983) found that deposits of iron Ochre in and around drains depends upon ground water temperature and drainage rates.

5.7.3. Salts Discharged in Tile Drains:

The analysed data are presented in Tables 64 and 65 and its relationship with number of perforation per tile is depicted in Fig. 18. The salt discharge was steadily increased in all tile drains under all depth of irrigation. The mean silt discharge in tile drain with plain surface tiles was the lowest with 136.43 kg/ha, and the tile drain with 60 perforation per tile gave the highest with 292.38 kg/ha. The other tile drains with 6, 12, 24, 36 and 48 perforations gave mean salt discharge of 171.45, 204.23, 260.61, 281.28 and 287.33 kg/ha, respectively. The salt discharges were statistically significant and considerable quantity was discharged in drainage water.

The percentage increase of salt discharge had been worked out and indicated in Table 64 and 65 and this analysis had shown that the rate of salt discharge decreased as the number of perforations increased. The total variation salt discharge (Table 64) was considerably decreased in tile drains with higher perforations

Table 64. Total Variation of Salt Discharged through Drainage Out-flow

Sl. No.	Number of perforation per tile	Variation of salt discharged in percent				Mean salt discharge variation %
		Depth of irrigation water (cm)				
		2.5	5.0	7.5	10.0	
1.	0	-	-	-	-	-
2.	6	20.14	29.95	27.18	25.52	25.70
3.	12	52.42	48.78	49.20	51.50	50.48
4.	24	104.12	88.54	92.95	88.61	93.56
5.	36	129.21	98.19	102.58	102.39	108.10
6.	48	136.33	102.29	105.88	111.72	114.06
7.	60	142.95	105.80	112.28	114.20	118.81

Table 65. Relative Variation of Salt Discharged through Drainage Out-flow

Sl. No.	Number of perforation per tile	Relative variation of salt discharged in percent				Mean relative variation (%)
		Depth of irrigation(cm)				
		2.5	5.0	7.5	10.0	
1.	0	-	-	-	-	-
2.	6	20.14	29.95	27.18	25.52	25.70
3.	12	27.95	22.70	21.42	20.70	23.19
4.	24	24.16	25.45	24.75	24.75	24.73
5.	36	20.81	5.28	5.10	7.95	9.79
6.	48	3.11	3.64	3.06	3.93	3.44
7.	60	2.80	1.73	1.86	1.17	1.89

per tile, especially after 24 perforations per tile. Also, the relative rate of increase of salt discharge (Table 65) was markedly decreased after 24 perforations per tile. The curve (Fig. 18) indicates that the rate of salt discharge was changed after 36 perforation per tile, and more significantly after 24 perforations per tile.

The drainage water which contains dissolved salts were related to total and rate of tile drain out-flow. The rate and total tile out-flow was related to total water entry area of tiles. Therefore, the salt discharge was controlled by tile drain out-flow, and it became less significant beyond 24 perforations per tile. The tile drains with 24 perforations per tile looks to be more hydrologically suitable for 10-cm dia and 60-cm long clay tiles.

Hermesmeir (1973) found that shallow drains installed at 3 ft depth and 200 ft spacing in a clay and loamy clay soil removed only from 12 per cent to 7.2 per cent of the salt added by irrigation water. Bliesnar et al. (1977) found that the amount of salt removed in drainage water was appeared to vary directly with the quantity of drainage water. Barnett et al. (1982) found from their studies a shallow sub-surface drainage system effectively controlled a high water table and reduced salinity in an irrigated soil. Harker (1983) found from his studies that the out-flow from tile drainage system was not expected to affect river water quality seriously. These studies does not give any information regarding salt leached under specified field conditions.

5.7.4. Load Bearing Strength of Tile:

The load bearing strength of tiles with different number of perforations are given in Table 26. The maximum of 12.15 kg/cm² and minimum of 5.03 kg/cm² was found in tile drains without perforations and tile with 60 perforations per tile respectively. The bearing strength was gradually decreased in tiles with 6, 12, 24, 36 and 48 perforation in the order of 10.68, 9.80, 8.67, 7.28 and 6.12 kg/cm², respectively. From the Table 61 and 63, the total and relative decreases in tile strength had been compared. According to ASTM(1959) specification 30 per cent decrease in strength was recommended for clay tile, and the ^{of} strength/tiles with 24 perforations was near to 30 per cent decrease. Hence, the tile with 24 perforations was structurally suitable to act as sub-surface drains to function satisfactorily for the average life period of tiles.

The relative decrease of load bearing strength of tiles was varied from 12.10, 11.05, 11.42, 16.03, 15.93 and 17.81 per cent in tile with 6, 12, 24, 48 and 60 perforations per tile. The relative decrease of strength upto 24 perforation was around 11 per cent and beyond 24 perforations per tile the decreasing rate increased more significantly. Hence, the tile with 24 perforations of 1-cm dia for 60-cm long tiles of 10-cm dia are structurally suitable.

5.7.5. Depth of Irrigation:

There were four depths of irrigation, which were used as sub-treatments, namely, 2.5, 5.0, 7.5 and 10.0 cm above field capacity of the 90-cm layer of the soil. The frequency of irrigation was 15 days. The tile drain out-flow from each main treatments due to the depth of irrigation are given in Table and the tile drain out-flow were continuously increased as the number of perforations per tile increased. The minimum out-flow was recorded in tile drain without surface perforations and maximum in tile drain with 60 perforations per tile and the same was true under all depths of irrigation.

The percentage of total tile drain out-flow increase due to increased depth of irrigation is given in Table 66. There was steady increase of out-flow in tile drains as compared to tile drain out-flow under 2.5 cm depth of irrigation. The relative increased variation of out-flow in percentage is given in Table 68 and the relative increase was highest in all main treatment under 5.0 cm depth of irrigation as compared to out-flow under 2.5 cm depth of irrigation, and lowest in out-flow under 10.0 cm depth of irrigation. The phenomenon of decreased relative increase was general in all treatments. Hence, the depth of irrigation did not have any significant effect on the tile drain out-flow in all main treatments (Fig. 19).

Table 66. Effect of Irrigation Water on Tile Drains Discharge in Percentage

Sl. No.	Depth of irrigation (cm)	Drain out-flow in percentage of irrigation				
		Water entry area of tiles in square cm				
		6.3	11.01	15.72	25.14	34.56
						43.98
						53.40
1.	2.5	7.20	10.20	12.80	17.60	21.00
						23.20
						24.20
2.	5.0	6.90	9.80	11.90	16.50	19.80
						22.15
						23.20
3.	7.5	6.20	9.20	10.70	15.10	18.50
						21.80
						22.20
4.	10.0	5.40	8.60	9.80	14.80	17.20
						19.50
						20.50

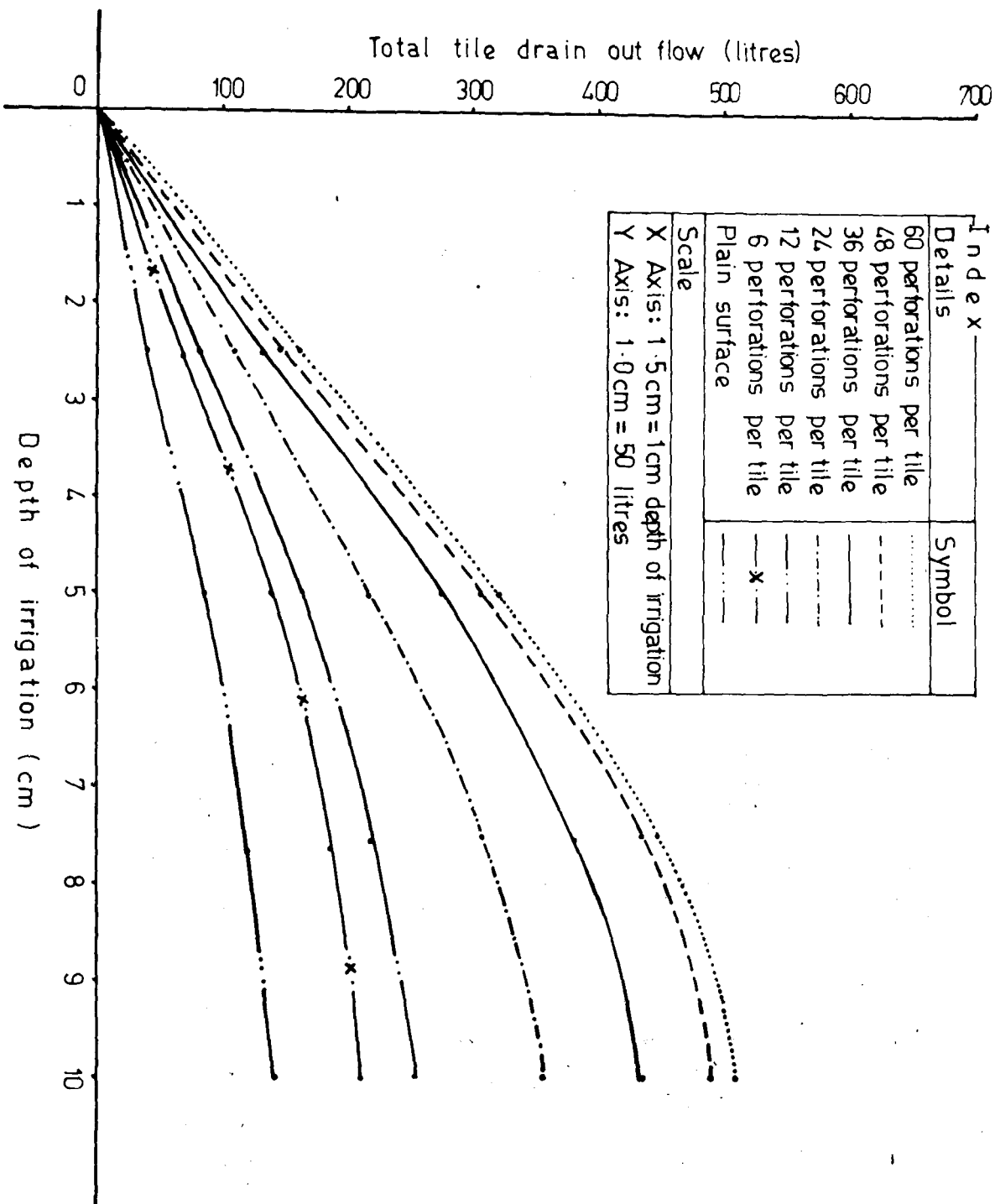


FIG. 19 RELATIONSHIP OF DEPTH OF IRRIGATION AND TOTAL TILE DRAIN OUT FLOW

For the purpose of comparison, the total tile drain out-flow under each depth of irrigation in all main treatments and their relative variation are given in Tables 67 and 68. The relative increase in out-flow was decreased uniformly in all treatments namely, tile drain with 6, 12, 24, 36, 48 and 60 perforations per tile, and maximum increase was in tile drain with 6 perforations and minimum in tile drain with 60 perforations per tile. Beyond 24 (0.95% opening) perforations per tile, the increase in out-flow was less significant, and it was in the order of 17.85 to 23.23 per cent in tile with 36 perforations, 10.22 to 13.88 per cent in tile drain with 48 perforations and 2.65 to 4.50 per cent in tile drain with 60 perforations per tile. Whereas in tile with 24, 12 and 6 perforations per tile the increased out-flows were in the order of 32.75 to 35.96 per cent, 21.40 to 25.97 per cent and 55.92 to 75.00 per cent, respectively. Therefore, the 24(0.95% openings) perforations per tile looks to be more reasonably respond for increased depth of irrigation.

Similarly, situation could be seen in Table 68 which gives the relative increase of rate of tile drain out-flow. In tile drains with 6, 12 and 24 perforations per tile, the response of rate of out-flow for increased depth of irrigation was significant and less significant in tile drain with 36, 48 and 60 perforations per tile. Hence, hydrologically the tile drains with 24 (0.95% opening) perforations of 1-cm dia for 10 cm dia 60 cm long clay tile were more suitable than tile with 36(1.31% opening), 48(1.67% opening) and 60(2.02% opening) perforations.

Table 67. Total Variation of Mean Tile Drain Out-flow in Relation to Depth of Irrigation

Sl. No.	Depth of irrigation (cm)	Total variation of tile drain out-flow in percentage						
		Surface water entry area (sq.om)						
		6.30	11.01	15.72	25.14	34.56	43.98	53.40
1.	2.5	-	-	-	-	-	-	-
2.	5.0	100.00	102.26	99.81	99.32	109.10	111.34	109.54
3.	7.5	166.30	170.92	171.43	174.78	186.40	198.63	193.42
4.	10.0	210.87	219.86	213.10	214.73	227.65	235.74	232.24

Table 68. Relative Variation of Total Tile Out-flow in relation to Depth of Irrigation

Sl. No.	Depth of irrigation water (cm)	Relative variation of tile drain out-flow in percentage				
		Surface Water entry area (sq.cm)				
		6.30	11.01	15.72	25.14	34.56
						43.98
						53.40
1	2.5	-	-	-	-	-
2	5.0	100.00	102.26	99.81	99.32	109.10
						111.34
						109.54
3	7.5	33.15	32.64	36.53	40.50	40.74
						41.30
						40.03
4	10.0	16.73	15.57	16.23	13.53	14.82
						13.45
						13.23

5.7.6. Silt Discharge:

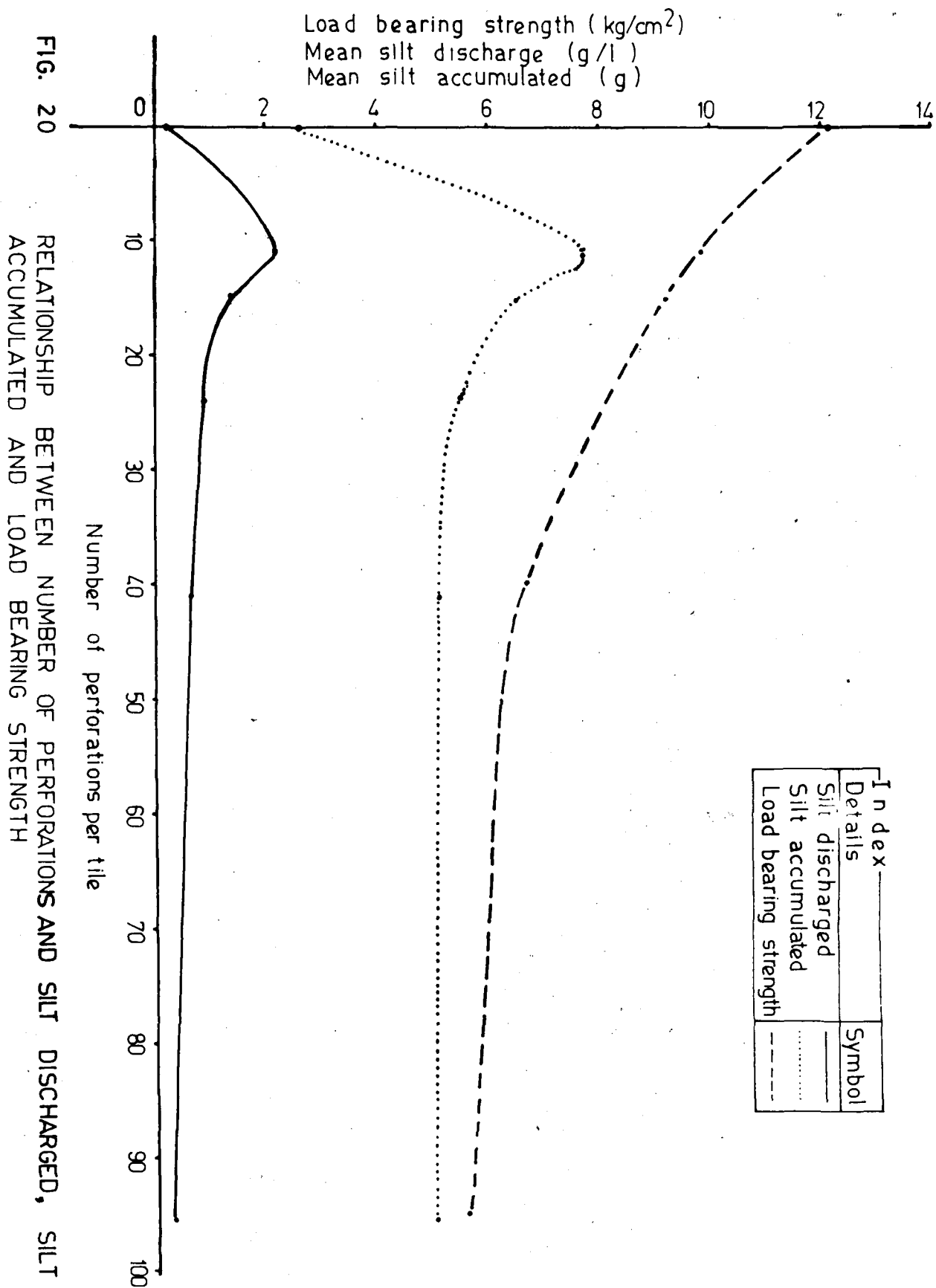
The silt discharge under 2.5, 5.0, 7.5 and 10.0 cm depth of irrigation in all main treatments are given in Table 69. The highest discharge of 2.863 grams per litre in tile drains with 60 perforations per tile and 0.586 grams per litre being the lowest in tile drains without perforations. There was steady increase in rate of silt discharge as the number of perforations per tile increases. From Table 62, the relative increase in silt change due to increased surface water entry area under all depth of irrigation are given. The relative increase of silt discharge was highest in tile drain with 60 perforations and lowest in tile drains with 6 perforations per tile in all 2.5, 5.0, 7.50 and 10.0 cm depth of irrigation. Probably, the soil adjoining the tile drains might have contributed continuously the finer particle of soil to the free water entry zone. Though the silt discharge in tiles did not give any specific indication to decide the number of perforations per tile, based on the other factors as discussed earlier, 24 (0.95% opening) perforations per tile could be more reasonably used to prevent silt entering the tiles as the rate of silt discharge was less than 25 per cent.

5.8.0. Orientation of Circumferential Perforations of Tiles in Drainage Trenches:

The clay tiles of 10-cm diameter and 60-cm long are being used as drains in irrigated soils to control the rise of water table. These tiles are laid in the trenches with

Table 69. Rate of Silt Discharge and Depth of Irrigation Water

Sl. No.	No. of perforation per tile	Rate of silt discharge (grams per litre)				Mean silt discharged in g/l
		Depth of Irrigation Water in cm				
		2.50	5.00	7.50	10.00	
1.	Plain surface	0.145	0.395	0.630	0.874	0.586
2.	6 perforation	0.186	0.472	0.830	1.116	0.744
3.	12 "	0.235	0.564	1.057	1.385	0.925
4.	24 "	0.296	0.692	1.380	1.776	1.184
5.	36 "	0.391	0.882	1.853	2.344	1.562
6.	48 "	0.531	1.162	2.554	3.186	2.124
7.	60 "	0.175	1.530	3.478	4.293	2.863



bell and socket joints, and ultimately these joints would serve as crack space for water entry into tile drains. The joints at 60-cm long would be too long for convergence of flow lines of water to tiles. The expansion and contract property of some of the soils have been also responsible for the closing joints.

To overcome the property of inadequate crack space for water entry and to reduce the convergence losses, the perforations were provided on the hemispherical body of the tiles. From the earlier experiments, it was found that 1-cm diameter 24 perforations per tile were optimum for 60-cm long tiles of 10-cm dia. The tiles with 24 perforations of 1-cm dia proved hydraulically and structurally better as they would give higher rate of tile out-flow with reduced silt entering and depositing in tile. The bearing strength of tiles with 24 (0.95% opening) perforations had sufficient factor of safety to carry the load coming for specified life time.

In order to find the suitable orientation of circumferential perforations of these tiles in trenches for easy water entry, this experiment was conducted. No such study was conducted in Karnataka or elsewhere to use the information for adoption for 10-cm dia 60-cm long clay tile drains used in irrigated clay soils. This work was carried out to find the suitable orientation of perforation of tiles on the drainage bedding for higher hydraulic efficiency.

In this experiment the treatments selected were top, bottom and lateral orientation of perforations of 10 cm dia 60 cm long clay tiles. The sub-treatments were four depth of irrigation above field capacity, namely, 5.00, 10.00, 15.00 and 20.00 cm.

5.8.1. Tile Drain Out-Flow:

The results of total tile drain out-flow in top, bottom and lateral orientation under 5.00, 10.00, 15.00 and 20 cm depth of irrigation are presented in Table 30. The lowest tile drain out-flow was recorded in tile drain with perforation oriented towards bottom. The mean tile drain out-flow of 211.24, 247.34 and 428.84 litres were recorded respectively in tile drains perforations oriented lateral, top and bottom.

The table-70 and 71 gives the comparative statement showing total increased tile drain out-flow in top and bottom perforation oriented tile drain in relation to lateral orientation of perforations. The increase in tile drain out-flow in top perforation orientation as compared to lateral was in the order of 23.57, 23.65, 15.29, 4.89 percentage, whereas the increased tile drain out-flow, as compared to bottom orientation were 115.18, 95.60, 95.19 and 95.10 percentage. The increased tile drain out-flow in bottom orientation of perforation was considerable and highly significant. From the Table 70, it could also be seen that the total increased variation of tile drain out-flow. The relative variation of total tile drain

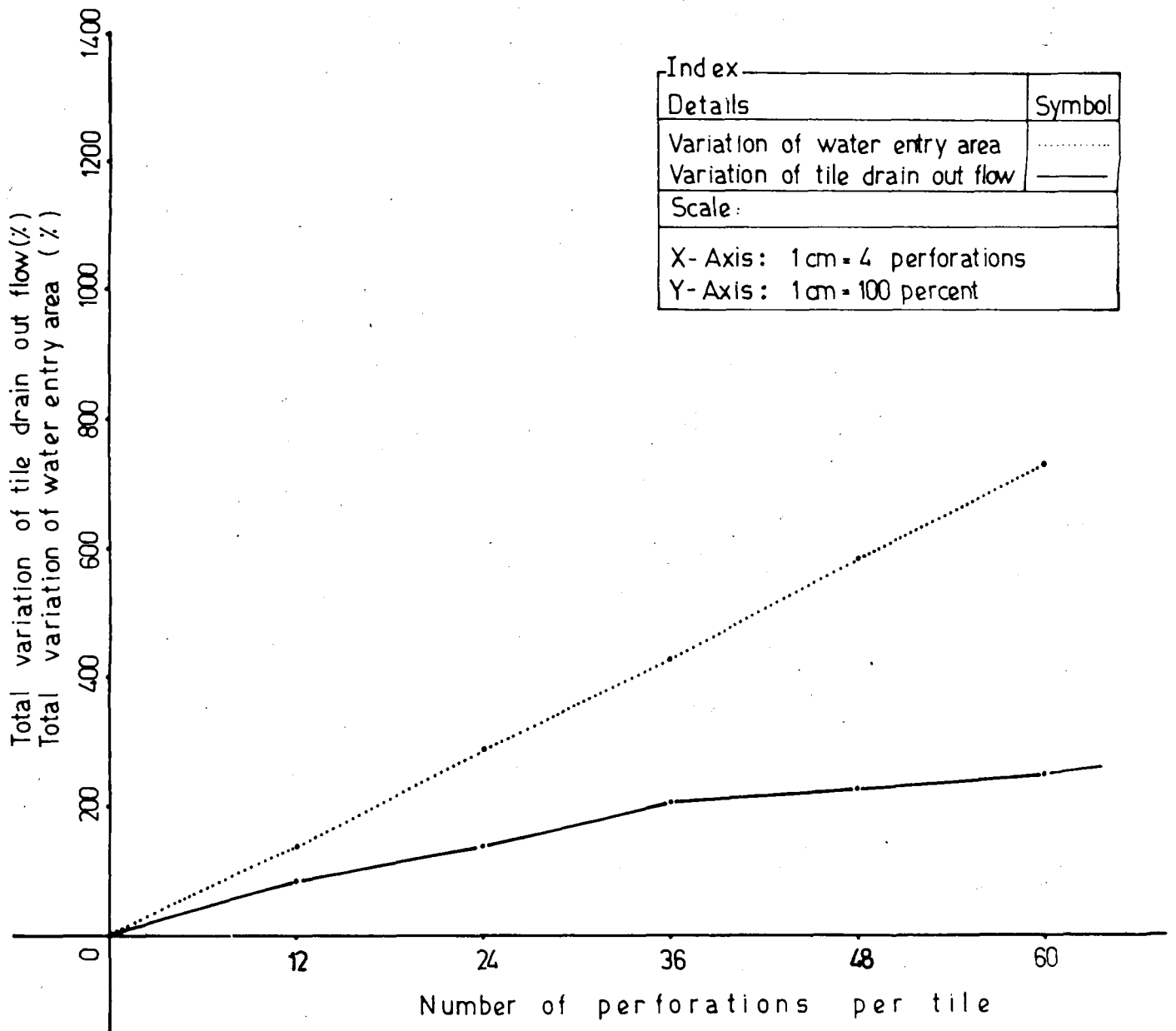


FIG. 21 EFFECT OF NUMBER OF PERFORATIONS ON TOTAL TILE DRAIN OUT F

Table 70. Variation of Total Tile Drain Out-flow in relation to Orientation of Perforation of Tiles

Sl. No.	Orientation of tile perforations	Total variation of tile drain out-flow (in litres)				Mean variation of tile drain out-flow in litres

Depth of irrigation above field capacity (cm)						

		5.00	10.00	15.00	20.00	

1.	Lateral	-	-	-	-	-
2.	Top	24.86	51.48	50.96	48.00	43.83
3.	Bottom	120.32	208.92	301.96	384.00	253.80

Table 71. Variation of Total Tile Drain Out-flow in relation to Orientation of Perforation of Tiles

Sl. No.	Orientation of tile perforations	Total variation of tile drain out-flow in per cent			Mean variation of tile drain out-flow in per cent

		Depth of irrigation above field capacity (cm)			
		5.00	10.00	15.00	20.00
1.	Lateral	-	-	-	-
2.	Top	23.57	23.65	15.29	4.89
					18.60
3.	Bottom	115.18	95.60	95.19	95.10
					100.27

out-flow given in Table 71, indicates that variations were higher in bottom oriented tile drains than in top oriented tile drains. In bottom orientation, the tile drain out-flows were increased in order of 115.18, 95.60, 95.19 and 95.10 per cent under 5.00, 10.00, 15.00 and 20.00 cm depth of irrigation as compared to lateral orientation. The same for the top orientation were 23.57, 23.65, 16.34 and 20.51 per cent. Hence, the bottom perforations oriented tiles gave higher hydraulic efficiency (Fig. 22). The probable reason would be that the increased hydraulic gradient and also easy convergence of flow lines of water into tile drains. Therefore, on the basis of total tile drain out-flow, bottom orientation of perforation of tiles is more suitable for hydraulic efficiency.

From the Table 30, the rate of tile drain out-flows recorded were 0.233, 0.300, 0.376, and 0.45 litres per minute in lateral orientation, which was lowest and the highest rate of tile drain out-flow of 0.483, 0.533, 0.633 and 0.767 litres per minute were observed in bottom orientation. In Table 72 and 73 the increased tile drain out-flow and the corresponding percentages were given as compared to lateral orientation. The order of increase of the out-flow in percentage in top orientation were 11.59, 14.29, 14.94, 14.29 and in the tile drains with bottom orientation gave the increased out-flow of 85.77, 52.28, 45.52 and 45.10 per cent under 5.00, 10.00, 15.00, and 20.00 cm depth of irrigation. Based on the rate of tile drain out-flow, it was found that the bottom orientation of perforation of tiles are hydraulically more efficient.

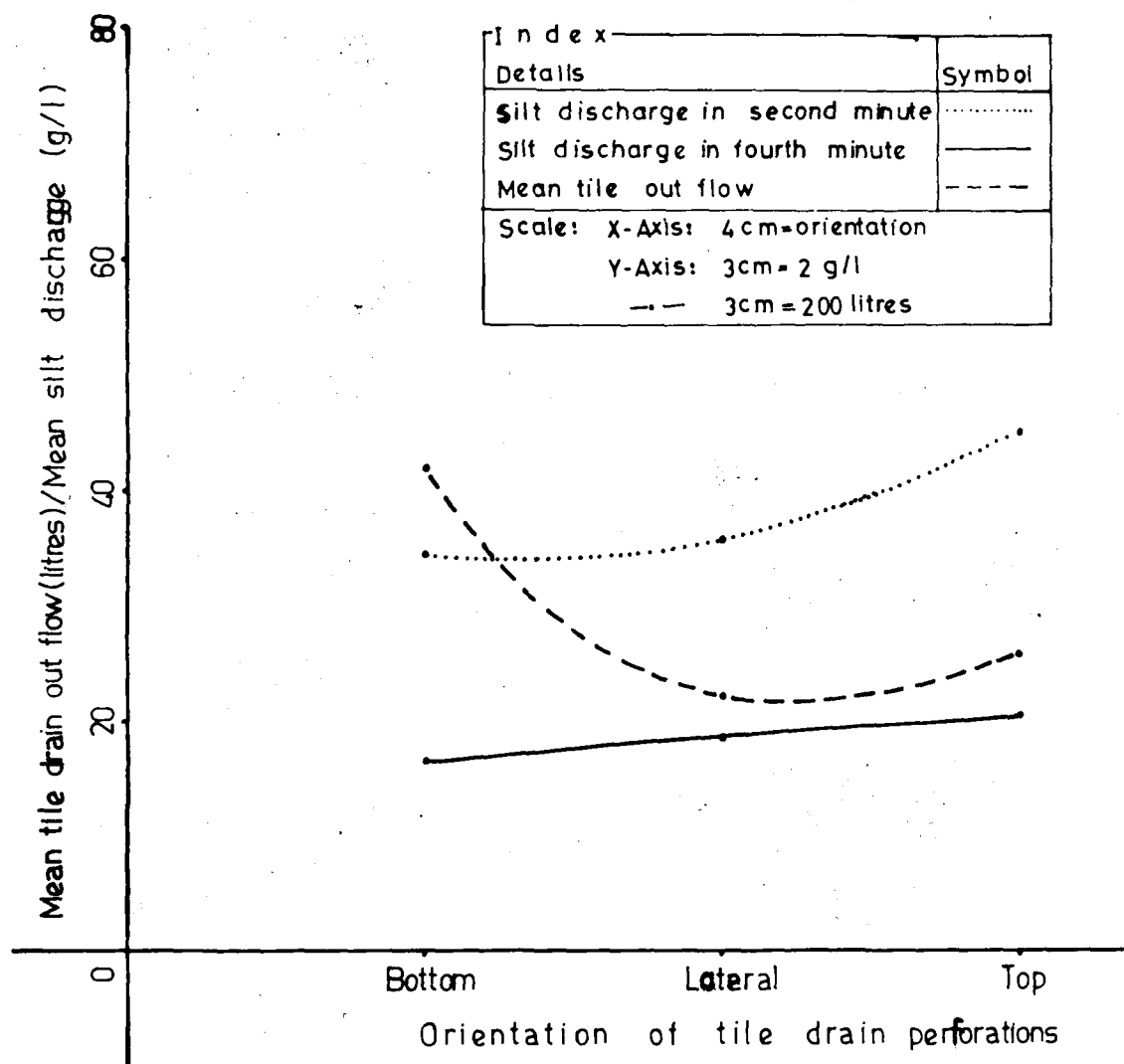


FIG. 22 RELATIONSHIP BETWEEN ORIENTATION OF TILE PERFORATIONS, AND TILE DRAIN OUT FLOW AND SILT DISCHARGE

Table 72. Variation of Rate of Tile Drain Out-flow in relation to Orientation of Tile Perforations

Sl. No.	Orientation of tile perforations	Variation of rate of tile drain out-flow(l/m)			Mean rate of variation (l/m)
		5.00	10.00	15.00	
		Depth of irrigation above field capacity(cm)			
		20.00			
1.	Lateral	-	-	-	-
2.	Top	0.027	0.05	0.065	0.075
					0.054
3.	Bottom	0.223	0.183	0.198	0.242
					0.212

Table 73. Variation of Rate of Tile Drain Out-flow in relation to Orientation of Tile Perforations

Sl. No.	Orientation of tile drain perforations	Variation rate tile drain out-flow in per cent				Mean rate of variation in per cent

		Depth of irrigation above field capacity (cm)				
		5.00	10.00	15.00	20.00	

1.	Lateral	-	-	-	-	-
2.	Top	11.59	14.29	14.94	14.29	13.78
3.	Bottom	85.77	52.28	45.52	45.10	57.42

5.8.2. Silt Discharge and Silt Accumulated in Tile Drains:

The silt discharge during the second and fourth minute in tile drains with lateral, top and bottom orientation of perforation of tiles are presented in Table 32. The silt discharge during second minute was highest in tile drains with top orientation of perforation and lowest in tile drains with bottom orientation under all four depth of irrigation. The same was true during fourth minute of tile drain discharge. The mean silt discharges were 4.54, 3.54 and 3.41 grams per litre during the second minute in top, lateral and bottom orientation, respectively and in the same order, the mean silt discharge during the fourth minute were 2.03, 1.82 and 1.65 grams per litre.

The silt accumulated in tile drains with top, lateral and bottom orientation under all the four depth of irrigation are given in Table 33. The highest accumulation of 6.95, 10.45, 11.45 and 13.50 grams in tile drains with upward orientation of perforations and lowest of 2.20, 3.55, 4.10 and 4.80 grams in tile drains with bottom orientation under 5.00, 10.00 15.00 and 20.00 cm depth of irrigation, respectively. The total increase of silt accumulation in tile drains with lateral and top orientation was compared with silt accumulated in tile drains with bottom orientation. The respective increase of silt accumulation under 5.00, 10.00, 15.00 and 20.00 cm depth of irrigation in lateral and top orientations were 1.15, 2.10, 2.50, 13.05 grams and 3.70, 4.70, 4.85, 5.70 grams. The top

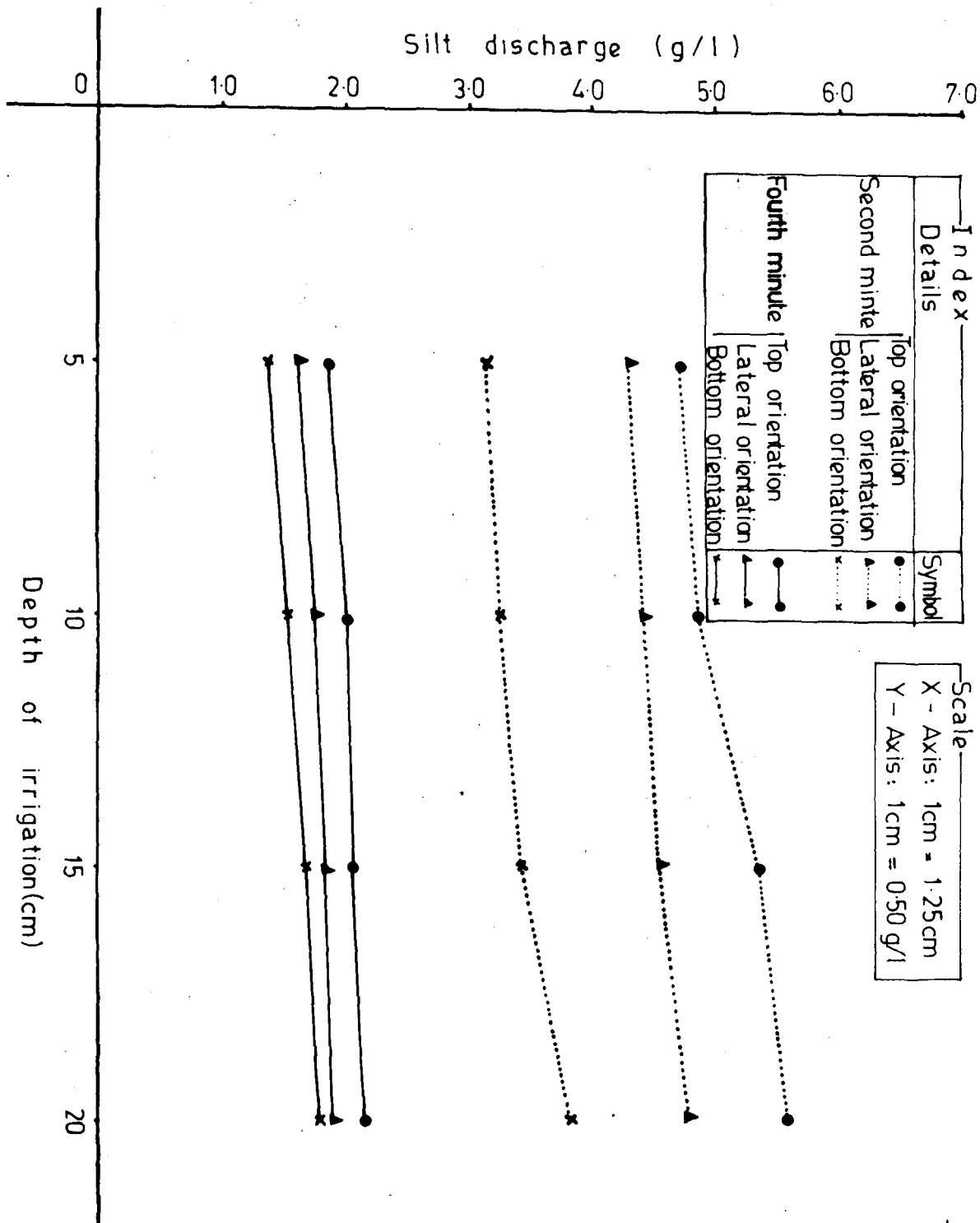


FIG. 23 RELATIONSHIP OF SILT DISCHARGE AND DEPTH OF IRRIGATION IN SECOND AND FOURTH MINUTE

orientation was more prone to silt accumulation than lateral and bottom orientation of tile perforations. The relative increase of silt accumulation of 1.40, 1.95, 2.55, 3.00 grams in lateral orientation and 4.75, 6.90, 7.35 and 8.70 grams in bottom orientation as compared to top orientation. From this it could be seen that top orientation of tile perforation was much susceptible for silt accumulation in tiles.

From the figure 23 the relationship between orientation and silt discharge during second and fourth minute of tile drain-out-flows follows the same nature of slope but at different level. The relationship between orientation and mean tile drain out-flow follows the same nature of slope between top and lateral orientation, but slope becomes very steep between lateral and bottom orientation. From the data as well as from the curves, it was very clear that bottom orientation of tile perforations had considerable advantage to reduce the silt deposition in tile drains.

5.8.3. Depth of Irrigation:

The total tile drain out-flow under 5.00, 10.00, 15.00 and 20.00 cm depth of irrigation in tile drain with lateral, top and bottom orientation of perforation of tiles are given in Table 29. The mean tile drain out-flow of 211.24, 247.34 and 428.84 litres in lateral, top and bottom orientation respectively, and the out-flows were statistically significant

Table 74. Variation of Mean Silt Discharge in relation to Orientation of Tile Perforation

Sl. No.	Orientation of tile perforations	Mean silt discharge decrease in (g/l)		Mean silt discharge decrease in percentage	
		Second minute	Fourth minute	Second minute	Fourth minute
1.	Top	-	-	-	-
2.	Lateral	1.01	0.21	22.03	10.34
3.	Bottom	0.13	0.17	36.72	9.34

Table 75. Variation of Silt Accumulated in Tile Drains in relation to Orientation of Tile Perforation

Sl. No.	Orientation of tile drain perforations	Variation of silt accumulated in tile drains (in grams)				Mean variation of silt accumulated in tile drains(g)
		Depth of irrigation above field capacity(cm)				
		5.00	10.00	15.00	20.00	
1.	Bottom	-	-	-	-	-
2.	Lateral	1.15	2.10	2.50	3.05	2.20
3.	Top	3.70	4.70	4.85	5.70	4.74

for orientation of openings. In Table 76, the increased variation of tile drain out-flow under 10, 15, 20 cm depth of irrigation as compared to 5 cm depth of irrigation in all the three types orientation are given. In tile drains with lateral orientation, the increase in tile drain out-flow due to increase in depth of irrigation from 5 to 10, 10 to 15 and 15 to 20 cm were 109.23, 199.88 and 288.12 per cent. Similarly in tile drain with top and bottom orientation, the increased out-flows were 108.82, 181.58, 249.88 per cent, and 88.75, 180.56, 248.65 per cent, respectively. The higher tile drain out-flows were found at higher depth of irrigation.

The relative variations of tile drain out-flow were worked out and shown in Table 77. From the data, it could be seen that tile drain out-flow was considerably high when the depth of irrigation increased to 10 cm from 5 cm. But the same higher rate of increase was not found when the depth of irrigation increased to 15 from 10 cm. Further increase in depth of irrigation to 20 cm from 15 cm had caused relatively less increase in out-flow, when the depth of irrigation increased to 10 cm from 5 cm, the percentage increase of out-flows were 109.23, 108.82 and 88.75 respectively in tile drains with lateral, top and bottom orientation of tile perforations. Similarly, when the depth of irrigation increased to 15 cm, the percentage relative increase in out-flows were 43.33, 34.85 and 48.61 in lateral, top and bottom oriented tile drains. The corresponding

Table 76. Variation of Total Tile Drain Out-flow in relation to Depth of Irrigation

Sl. No.	Depth of irrigation (cm)	Variation of total tile drain out-flow						Remarks
		Lateral orientation		Top orientation		Bottom orientation		
		Litres	Percent	Litres	Percent	Litres	Percent	
1.	5.00	-	-	-	-	-	-	
2.	10.00	113.64	109.23	140.26	108.82	200.64	88.75	
3.	15.00	207.96	199.88	234.06	181.58	408.00	180.65	
4.	20.00	299.76	288.12	322.10	249.88	561.84	248.65	

Table 77. Relative Variation of Total Tile Drain Out-flow in relation to Depth of Irrigation

Sl. No.	Depth of irrigation (cm)	Relative variation of tile drain out-flow(l/m)					
		Lateral orientation		Top orientation		Bottom orientation	
		l/m	Percent	l/m	Percent	l/m	Percent
1.	5.00	-	-	-	-	-	-
2.	10.00	113.64	109.23	140.26	108.82	200.64	88.75
3.	15.00	94.32	43.33	93.80	34.85	207.36	48.61
4.	20.00	91.80	29.42	88.04	24.26	153.84	24.27

relative increase of tile drain out-flows in lateral, top and bottom orientation tile drains were 29.42, 24.26 and 24.27 per cent. From the discussion, the orientation of tile drains did not respond significantly for higher depth of irrigation. This is probably the flow media, the soil profile, act as controlling factor for flow of water to tile drains. The increased hydraulic gradient in bottom orientation of tile perforation might not be sufficient to create significant effect to increase the tile out-flow due to increased depth of irrigation. The constant permeability of the soil profile which controlled the flow to the tile drains was responsible for relatively less increase of out-flow at high depth of irrigation.

The rate of tile drain out-flow under 5, 10, 15 and 20 cm depth of irrigation in lateral, top and bottom orientation are given in Table 31. The mean rate of tile drain out-flow in lateral, top and bottom orientation of tile perforations were 0.340, 0.393 and 0.604 litres per minute. There were significant difference among different types of tile perforation orientation under all depths of irrigation. From the Table 78, the total rate of increased out-flow due to increased irrigation depths are given. The irrigation depth had caused total increased rate of tile drain out-flow. In lateral orientation of tile perforations, 28.76, 58.80 and 93.13 per cent increase of rate of out-flow was noticed due to respective increase in depth of irrigation from 5 to 10, 10 to 15 and 15 to 20 cm. Similarly in tile drains with top orientation of perforation, the percentage increase

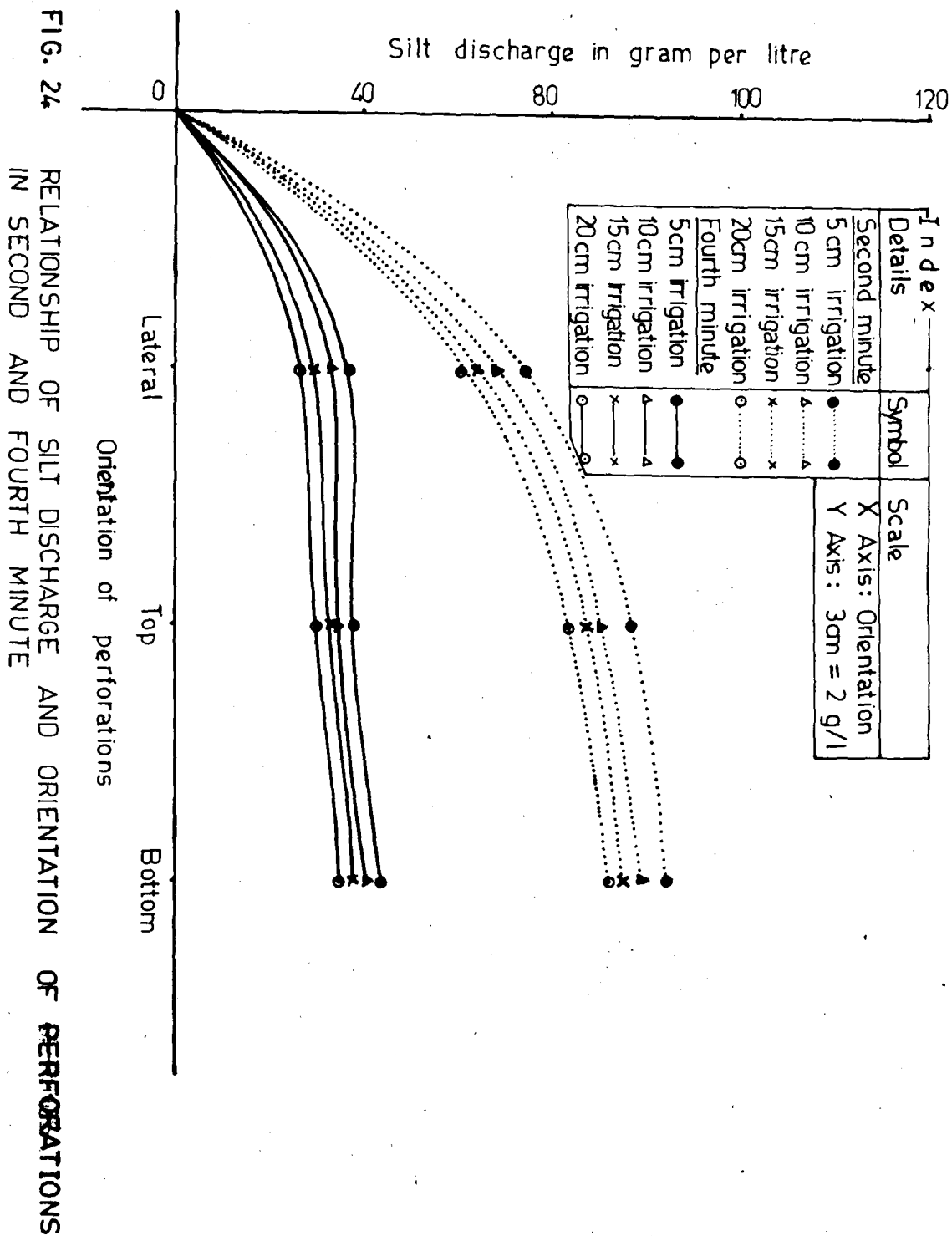


FIG. 24 RELATIONSHIP OF SILT DISCHARGE AND ORIENTATION OF PERFORATIONS IN SECOND AND FOURTH MINUTE

Table 78. Total Variation of Rate of Tile Drain Out-flow in relation to Depth of Irrigation

Sl. No.	Depth of irrigation (cm)	Variation of rate of tile drain out-flow					
		Lateral orientation		Top orientation		Bottom orientation	
		l/m	Percent	l/m	Percent	l/m	Percent
1.	5.00	-	-	-	-	-	-
2.	10.00	0.067	28.76	0.09	34.62	0.11	26.00
3.	15.00	0.137	58.80	0.175	67.30	0.21	49.65
4.	20.00	0.217	93.13	0.265	101.90	0.344	81.32

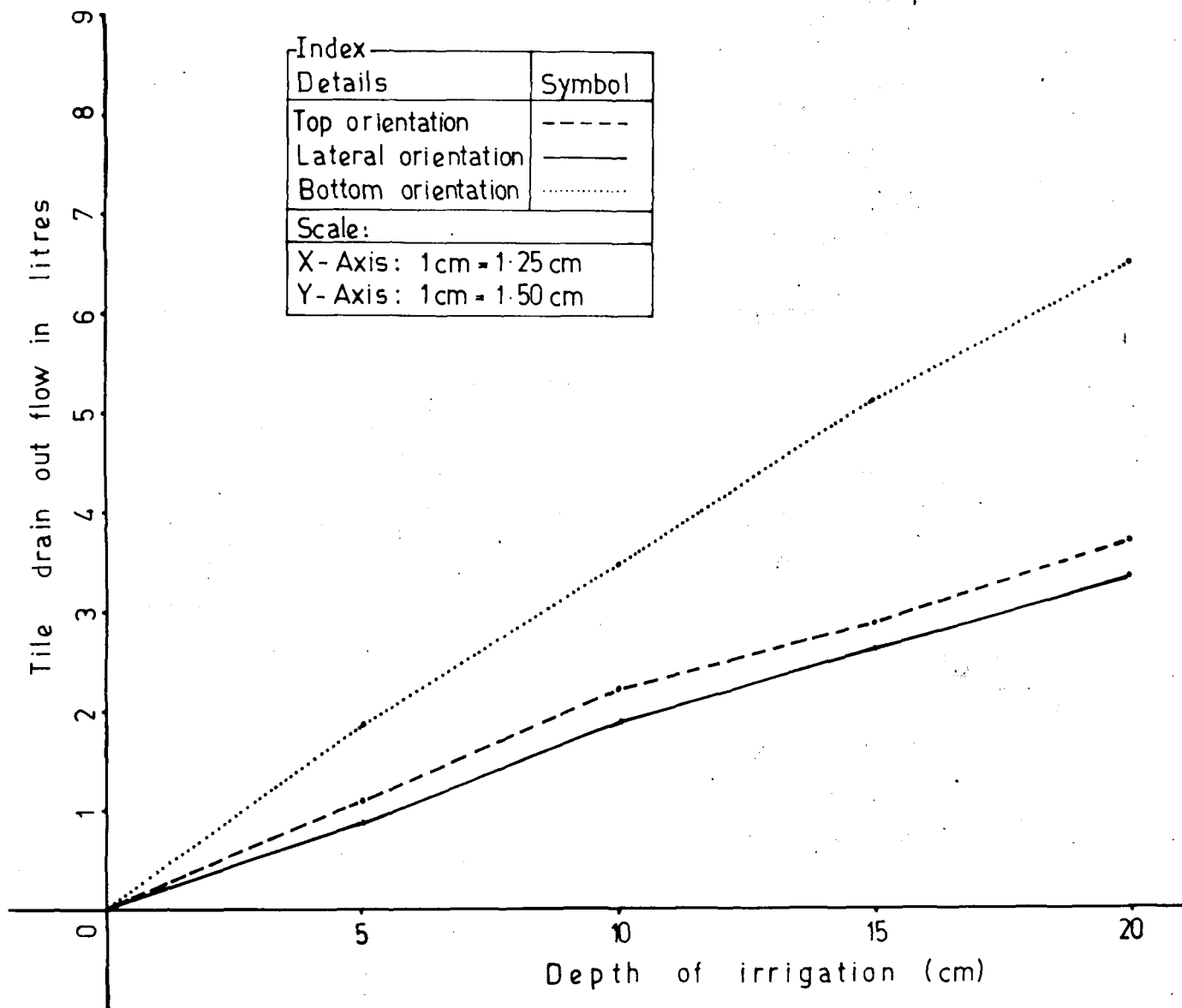


FIG. 25 RELATIONSHIP BETWEEN DEPTH OF IRRIGATION AND ORIENTATION OF PERFORATIONS AND TILE DRAIN OUT FLOW

Table 79. Relative variation of Rate of Tile Drain Out-flow in relation to Depth of Irrigation

Sl. No.	Depth of irrigation (cm)	Relative variation of rate of tile drain out-flow					
		Lateral orientation		Top orientation		Bottom orientation	
		l/m	Percent	l/m	Percent	l/m	Percent
1.	5.00	-	-	-	-	-	-
2.	10.00	0.067	28.76	0.090	34.62	0.11	26.00
3.	15.00	0.070	23.33	0.085	24.28	0.10	18.00
4.	20.00	0.080	21.62	0.090	20.69	0.13	21.17

in the same order were 34.62, 67.30 and 101.90 and also in tile with bottom orientation, the respective percentage out-flows were 26.00, 49.65 and 81.32.

The relative rate of tile drain out-flow under 5, 10, 15, and 20 cm depth of irrigation in lateral, top and bottom orientation of tile perforations were 28.76, 23.33, 21.62 per cent, and 34.62, 24.28, 20.69 per cent, and 26.00, 18.76, 21.17 per cent, respectively. The relative rate of increase of out-flows were decreased as the depth of irrigation increased in all pattern of orientation of perforations of tiles. Therefore, the depth of irrigation did not indicate any significant hydraulic usefulness for any particular orientation of tile perforations. As discussed earlier, the permeability which would be constant under a set of hydrological condition of a soil layer was not responded for higher depth of irrigation.

5.9.0. Envelope Materials for Clay Tile Drains:

The clay tile of 10 cm diameter and 60 cm long are being used as drains in irrigated soils to control the rise of water table. These tiles were laid in the trenches with or without any type of envelope materials. The ball and socket joints that would serve as openings for water entry into tile drains were too long for the convergence of water lines. Also, due to inadequate or devoid of envelope materials would cause clogging of crack space. The excessive contraction and expansion of

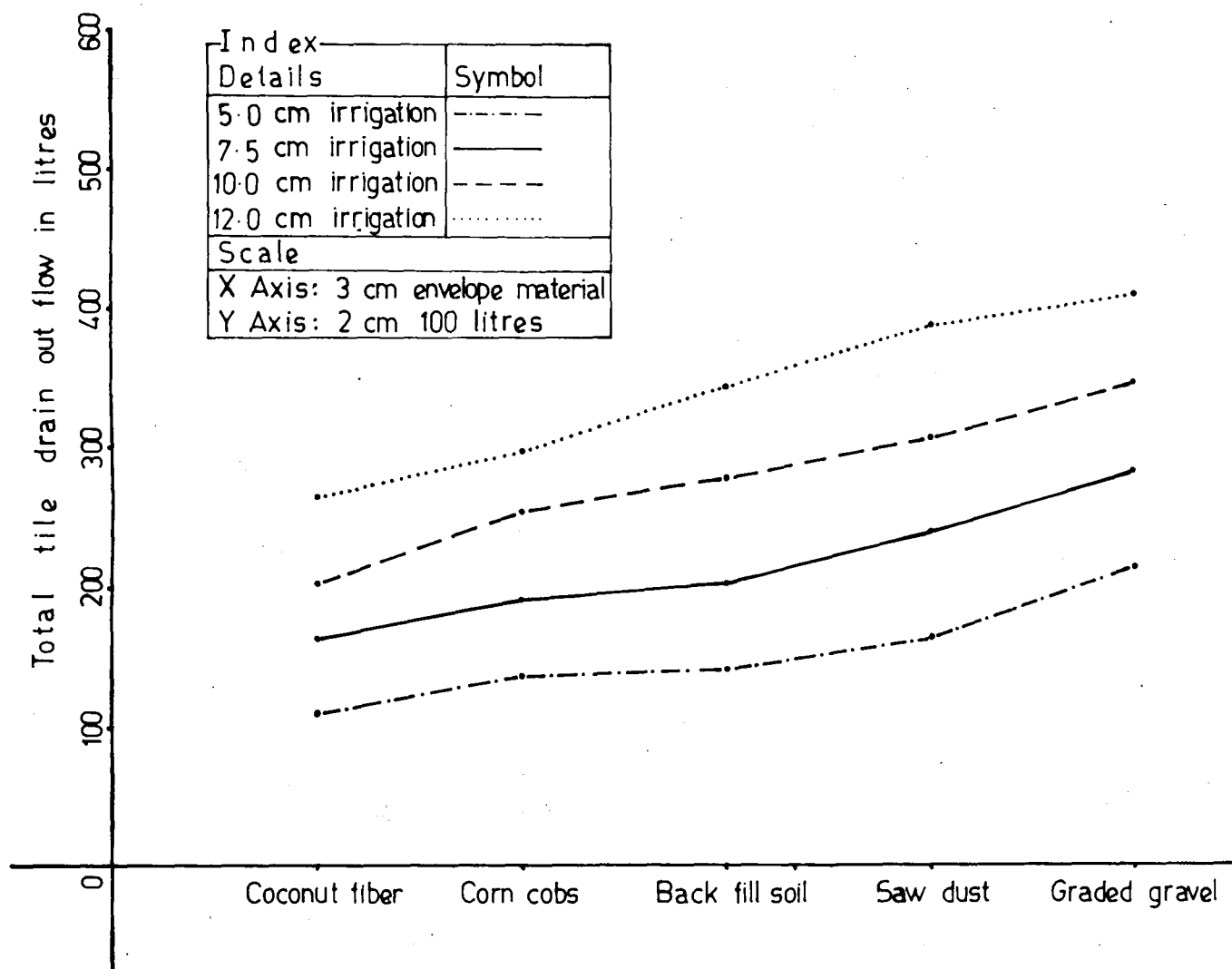


FIG. 26 RELATIONSHIP OF ENVELOPE MATERIALS AND TILE DRAIN OUT FLOW

clay soils causes change of alignment leading to closer of crack space, when tile drain came in contact with the soil. Hence, there is a technical need for envelope material for the clay tile drains. The envelope material so selected would be hydraulically efficient and economically cheap.

Therefore, in order to identify suitable envelope material, locally available for the tile of 10 cm dia and 60 cm long clay tiles, an experiment was conducted in the field. The main treatments used were coconut fibre, corn cobs, saw dust, graded gravel and back-fill soil as envelope materials. The sub-treatments selected were four depths of irrigation above field capacity, namely 5.00, 7.50, 10.00 and 12.50 cm. The parameters measured during the course of experiment were, total tile out-flow, rate of tile out-flow, silt discharged and silt accumulated in drains.

5.9.1. Tile Drain Out-Flow:

The total tile drain out-flow (Fig. 34) was least in coconut fibre and highest in tile drain with graded gravel under all depths of irrigation. The mean tile drain out-flow of 183.30 litres were observed in tile drains with coconut fibre whereas the same mean out-flow of 222.10, 244.80, 282.10 and 319.00 litres were recorded in tile drains with corn-cobs, back-fill soil, saw dust and graded gravel, respectively. Under all depths of irrigation, the increased change in out-flows were significant as compared to tile out-flow in tile drain with coconut fibre.

It could be seen from the Table 80, the total out-flow from various tile drains as compared to tile drain with back-fill soil. Under 5.00 cm depth of irrigation, tile drains with envelope materials coconut fibre and corn-cobs gave 51.30 and 19.70 litres less tile discharge when compared to back-fill soil, whereas tile drains with saw dust and graded gravel gave 26.10, and 68.30 litres more out-flow. Similarly under 7.50, 10.00 and 12.50 cm depth of irrigation, the tile drains with coconut fibre and corn cobs gave consistantly less tile drain out-flow, namely, 69.30, and 24.30 litres under 7.50 cm, 96.40 and 40.30 litres under 10.00 cm and 115.00 and 33.50 litres under 12.50 cm. Hydraulically the saw dust and graded gravel were found to be better as envelope materials for tile drains.

Sission and Jones(1962) found from their studies that straw and saw dust performed well in delivering water. Taylor and Goins(1967) stated from their study that the filter materials, corn-cobs and wheat straw had virtually disappeared leaving 1.25 cm residue around the upper two-thirds of the drain. Hove (1982) reported from laboratory study that the saw dust, fibrous peat and gravel could be used as filter materials for non-submergable tile drains. Burghardt (1983) reported that the decomposed soil material in filter reduced the volume of filter porous by 3-9 per cent per year.

The table 81 gives percentage variation of total tile drain out-flow as compared to tile drain out-flow of tile drain

Table 80. Total Variation of Tile Drain Out-flow in relation to Envelope Materials in litres

Sl. No.	Envelope material	Total variation of tile drain out-flow in litres				Mean total variation (litres)
		----- Depth of irrigation above field capacity in cm				
		5.00	7.50	10.00	12.50	
1.	Back-fill soil (control)	-	-	-	-	-
2.	Coconut fibre	-51.30	-69.30	-96.40	-115.00	-70.18
3.	Corn cobs	-19.90	-24.30	-40.30	- 33.50	-29.45
4.	Saw dust	+26.10	+31.70	+32.90	+ 40.00	+32.08
5.	Graded gravel	+68.30	+68.70	+78.60	+ 82.00	+74.40

Table 81. Total Variation of Tile Drain Out-flow in relation to Envelope Materials (in per cent)

Sl. No.	Envelope materials	Total variation of tile drain out-flow in per cent			Mean total variation in per cent
		5.00	7.50	10.00	
		Depth of irrigation above field capacity (cm)			
		5.00	7.50	10.00	12.50
1.	Back-fill soil (control)	-	-	-	-
2.	Coconut fibre	-33.60	-32.39	-33.98	-33.82
3.	Corn cobs	-12.90	-11.34	-13.83	-9.85
4.	Saw dust	+13.10	+14.80	+11.30	+11.76
5.	Graded gravel	+39.55	+39.00	+26.97	+24.12
					+30.66

with envelope material, back-fill soil (reference). The tile drains with envelope of coconut fibre gave around 33 per cent less out-flow under all depths of irrigation, whereas the tile drains with corn-cobs gave around 9-13 per cent less tile drain out-flow. The tile drains with saw dust gave higher tile drain out-flow ranging between 11 to 14 per cent in all the four depth of irrigation. But the tile drains with graded gravel envelope gave highest total out-flow of 25-40 per cent in all the four depths of irrigation.

The graded gravel and saw dust as envelope material would be preferable for higher hydraulic performance when compared to tile drains without envelope materials. The coconut fibre and corn-cobs were hydraulically less efficient. The graded gravel being uniform in size and shape, and less affected the presence of water and soil, might have provided uniform permeability for the movement of water into tile drains. Similarly, the saw dust being uniform in size and shape might have also given a constant permeability under submerged hydraulic condition. Therefore, by looking into hydraulic performance, the graded gravel could be preferred as envelope material. In case of non-availability of graded gravel, saw dust can be used as envelope material for clay tile drains in Karnataka State.

In the Table 83, the relative variation of tile drain out-flows were compared. The coconut fibre gave less tile drain

Table 82. Relative Variation of Tile Drain Out-flow in relation to Envelope Materials in litres

Sl. No.	Envelope materials	Relative variation of tile drain out-flow in litres				Mean tile drain relative variation (litres)
		Depth of irrigation above field capacity (cm)				
		5.00	7.50	10.00	12.50	
1.	Pack-fill soil (control)	-	-	-	-	-
2.	Coconut fibre	-51.50	-69.30	-96.40	-115.00	-83.05
3.	Corn cobs	+31.80	+45.00	+64.40	+81.50	+55.68
4.	Saw dust	+45.81	+56.00	+65.70	+55.00	+55.50
5.	Graded gravel	+43.20	+37.00	+35.70	+42.00	+39.48

Table 83. Relative Variation of Tile Drain Out-flow in relation to Envelope Materials in per cent

Sl. No.	Envelope materials	Relative variation of tile drain out-flow in per cent				Mean tile drain relative variation(%)

		Depth of irrigation above field capacity in cm				
		5.00	7.50	10.00	12.50	
1.	Back-fill soil (control)	-	-	-	-	-
2.	Coconut fibre	-33.60	-32.39	-33.08	-33.82	-33.10
3.	Corn cobs	31.80	31.03	32.82	36.22	32.97
4.	Saw dust	24.44	29.48	25.16	17.94	24.98
5.	Graded gravel	23.60	15.04	11.20	11.05	15.22

out-flow as compared to back-fill soil and this decrease was around 33 per cent in all the four depth of irrigation. The corn-cobs as compared to coconut fibre gave higher tile out-flow and this increase was around 31-36 per cent under all depths of irrigation. Tile drains with saw-dust as envelope materials had higher hydraulic performance when compared to corn-cobs, and the increase was varying from 17 to 29 per cent under all depth of irrigation. The tile drains with graded gravel as compared to tile drains with saw-dust gave higher hydraulic discharge which was ranging from 11-23 per cent under different depths of irrigation.

From the above discussion one could suggest that the preference for the selection envelope material, depending upon the availability of the material, the hydraulic performance of tile drains are to be considered. In the order of preference, graded gravel, saw-dust, corn-cobs, back-fill soil and coconut fibre are to be selected.

5.9.2. Rate of Tile Drain Out-flow:

From the Table 36, it could be seen that the rate of tile drain out-flow was least in tile drain with coconut fibre, and highest in tile drain with graded gravel. The data had been analysed and presented in Table 84 which indicates total variation as compared to control (without envelope materials). Here also, it could be seen that the tile drains with coconut fibre and corn-cobs gave less rate of discharge as compared to

Table 84. Total variation of Rate of Tile Drain Out-flow in relation to Envelope materials

Sl. No.	Envelope materials	Total variation of tile drain out-flow (l/m)								Mean variation of tile drain out-flow(l/m)
		Depth of irrigation above field capacity(cm)								
		5.00		7.50		10.00		12.50		
		L	%	L	%	L	%	L	%	
1.	Back-fill soil (control)	-	-	-	-	-	-	-	-	-
2.	Coconut fibre	-0.145	-32.80	-0.121	-22.70	-0.143	-23.14	-0.139	-20.38	-0.137
3.	Corn cobs	-0.050	-14.31	-0.043	-8.07	-0.046	-7.44	-0.060	-8.80	-0.050
4.	Saw dust	+0.008	+1.81	+0.011	+2.06	+0.017	+2.75	+0.008	+1.17	+0.011
5.	Graded gravel	-0.053	+12.00	+0.070	+13.13	+0.102	+16.50	+0.101	+14.87	+0.082

back fill soil. The percentage decrease in rate of out-flow was varying from 20-32 in coconut fibre in all the four depth of irrigation. Similarly, the rate of tile out-flow decrease was 7-11 per cent in corn cobs. All these decreased rate of out-flows were compared with rate of out-flow in tile drain with back-fill soil. The tile drain with saw-dust gave 1-2 per cent more rate of discharge as compared to rate of out-flow in tile drains with back-fill soil. Similarly, the higher rate of tile out-flows of 12 to 14 per cent more were observed in tile drains with graded gravel. The rate of tile out-flow was used as another parameter to evaluate the hydraulic performance of envelope materials.

In order to grade the envelope materials for hydraulic performance, the relative variation of rate of tile drain out-flows were used. The analysed data in Table 85 would indicate that the graded gravel gave about 10 to 13 per cent more rate of discharge than the tile drain with saw-dust. The saw-dust gave about 10-14 per cent more rate of discharge than the tile drain with corn-cobs. The tile drains with corn-cobs gave about 20-27 per cent more rate of tile discharge as compared to tile drain with coconut fibre. The coconut fibre as filter material in tile drains gave 20-32 per cent less rate of tile out as compared to back-fill soil, under all four depths of irrigation. In the order of hydraulic performance, the envelope materials graded gravel, saw-dust, corn-cobs, coconut fibre may be selected for adoption to the tile drains. The curves drawn

Table 85. Relative Variation of Rate of Tile Drain in Out-flow in relation to Envelope Materials in litres per minute

Sl. No.	Envelope materials	Relative variation of rate of out-flow in l/m												Mean relative variation out-flow(l/m)
		Depth of irrigation above field capacity(cm)												
		5.00			7.50			10.00			12.50			
		L	%	L	%	L	%	L	%	L	%	L	%	
1.	Back-fill soil (control)	-	-	-	-	-	-	-	-	-	-	-	-	
2.	Coconut fibre	-0.145	-32.80	-0.121	-22.70	-0.143	-23.14	-0.139	-20.38				-0.137	
3.	Corn cobs	+0.085	+27.68	+0.078	+18.93	+0.097	+20.42	+0.079	+14.55				+0.085	
4.	Sa dust	+0.058	+14.80	+0.054	+11.08	+0.063	+11.02	+0.068	+10.93				+0.061	
5.	Graded gravel	+0.045	+10.00	+0.061	+11.21	+0.085	+13.38	+0.093	+13.48				+0.071	

in Figure 26 had also indicated that the same order of preference of envelope materials for adoption.

5.9.3. Silt Discharge in Tile Drains:

The silt discharge in tile drain out-flow was recorded during second and fourth minute after starting discharge in tile drains. The data from the Table 37, indicates that highest silt discharge was in tile drains with back-fill soil as envelope material, and least in tile drains with saw-dust. This trend was same in all fourth depth of irrigation. The mean silt discharge rates were 0.690, 0.825, 0.938, 1.483 and 1.570 grams per litre, respectively in tile drains with envelope materials saw-dust, graded gravel, coconut fibre, corn-cobs and back-fill soil during the second minute of tile discharge.

From the table 86, the total variation of rate of silt out-flow during the second minute of discharge was compared, and presented in grams per litre and also in percentage. The silt discharge in tile drain with back-fill soil was taken as reference unit. The analysed data indicates that tile drains with saw dust as envelope materials gave about 54.35 per cent less silt discharge as compared to back-fill soil during the second minute, and the same was true under all depths of irrigation. The second best envelope material was graded gravel which had discharged 46.60 per cent less silt in tile drain water. In the same order the coconut fibre and corn-cobs gave 38.25 and 5.04 per cent less silt discharge as compared to

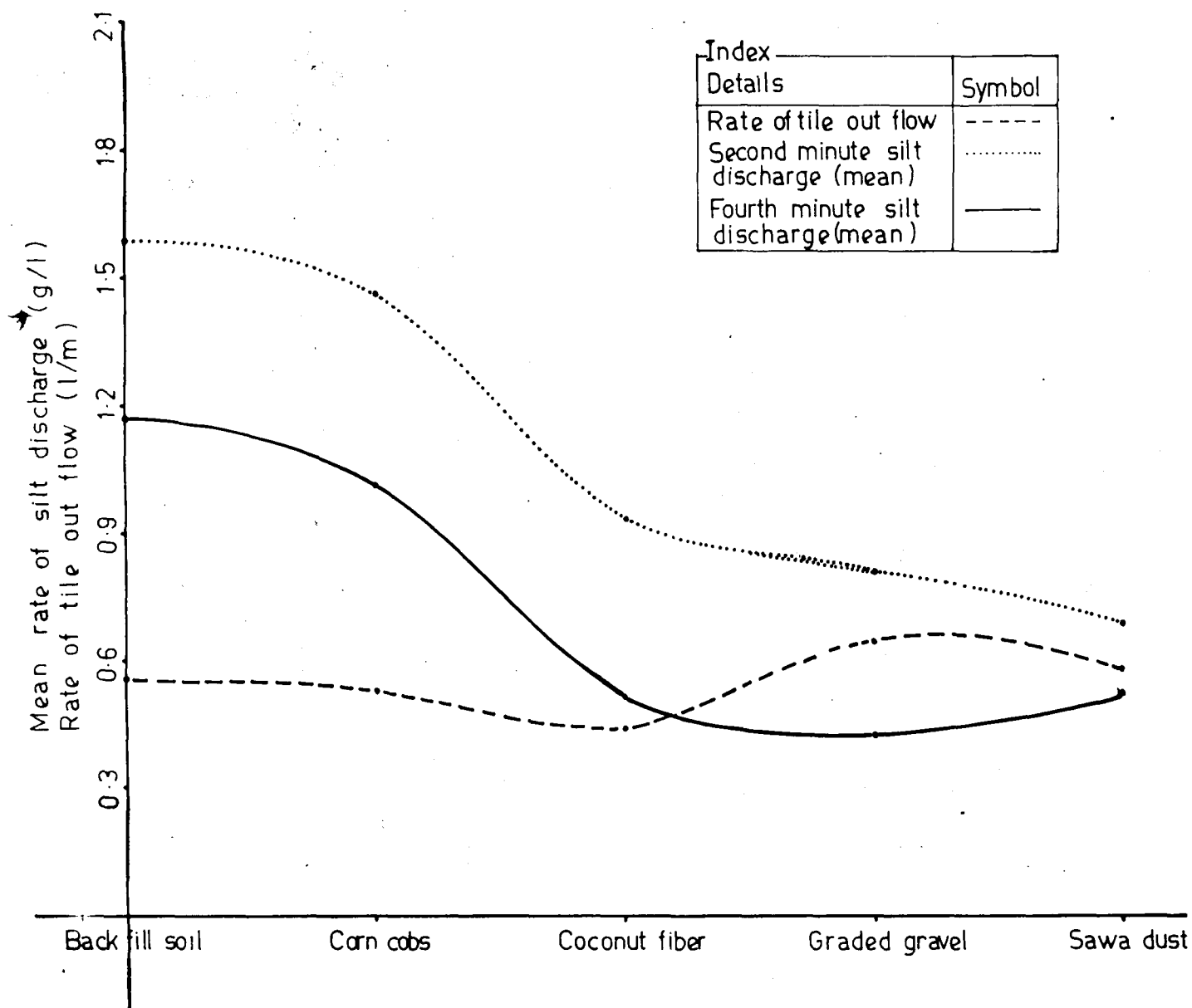


FIG. 27 RELATIONSHIP BETWEEN FILTER MATERIALS AND RATE OF TILE OUT FLOW, SILT DISCHARGE DURING SECOND AND FOURTH MINUTE

Table 86. Total variation of rate of silt out-flow during the
Second minute in relation to envelope materials

Sl. No.	Envelope materials	Total variation of rate of silt out-flow (g/l)						Mean variation of silt out-flow	
		Depth of irrigation above field capacity (cm)							
		g/l	%	g/l	%	g/l	%	g/l	%
		5.0	7.50	10.00	12.50				
1.	Back-fill soil (control)	-	53.63	-	53.25	-	55.40	-	54.05
2.	Saw dust	0.895	44.88	0.700	45.45	0.675	48.56	0.625	46.60
3.	Graded gravel	0.730	37.82	0.550	35.72	0.560	39.93	0.520	38.25
4.	Corn cobs	0.070	3.63	0.890	5.84	0.080	5.76	0.065	5.04
5.	Coconut fibre	0.730	3.78	0.550	35.72	0.560	39.93	0.520	38.25

silt discharge in tile drains with back-fill soil during the second minute of tile out-flow.

The table 87 gives the analysed data on relative variation of silt discharge during second minute in all four depth of irrigation. The saw-dust gave about 54.35 per cent less silt discharge as compared to back-fill soil as envelope material, and the graded gravel gave 16.71 per cent more silt discharge as compared to saw-dust. Relatively, the coconut fibre gave 15.90 per cent more silt discharge than graded gravel, and the tile drains with corn-cobs as envelope materials had discharged 55.48 per cent more silt during the second minute of tile out-flow as compared to coconut fibre. Based on the prevention of silt discharge into drains, the order of preference of envelope materials were saw-dust, graded gravel, coconut fibre and corn-cobs.

The rate of silt discharged during the fourth minute in tile drains with various envelope materials is given in Table 38. The tile drains with graded gravel gave the least silt discharge and back-fill soil of the highest silt discharge. The mean silt discharge of 0.421, 0.500, 0.543, 1.063 and 1.158 grams per litre, respectively in tile drains with graded gravel, coconut fibre, saw-dust, corn-cobs and back-fill soil(control) were recorded during the fourth minute of tile out-flow. The silt discharge rates were statistically significant as per the statistical tests.

Table 87. Relative Variation of Rate of Silt Out-flow during Second Minute in relation to Envelope Materials

Sl. No.	Envelope material	Relative variation of rate of silt out-flow during the second minute(g/l)										Mean silt discharge variation	
		Depth of irrigation above field capacity(cm)											
		5.00		7.50		10.00		12.50		g/l	%	g/l	%
		g/l	%	g/l	%	g/l	%	g/l	%	g/l	%	g/l	%
1.	Back-fill soil (control)	-	-	-	-	-	-	-	-	-	-	-	-
2.	Saw dust	1.035	53.63	0.82	53.25	0.850	55.40	0.725	55.13	0.87	54.35	0.87	54.35
3.	Graded gravel	0.160	17.88	0.12	16.67	0.09	15.32	0.100	16.95	0.12	16.71	0.12	16.71
4.	Coconut fibre	0.145	13.74	0.15	17.86	0.12	16.78	0.165	15.22	0.13	15.90	0.13	15.90
5.	Corn cobs	0.660	55.00	0.49	49.50	0.56	66.47	0.410	50.95	0.53	55.48	0.53	55.48

The total variation of rate of silt discharge during the fourth minute in tile drains with various envelope material are compared with back-fill soil and presented in Table 88. The mean silt discharge reduction in tile drains with graded gravel was 63.64 per cent whereas in tile drains with coconut fibre the reduction was 56.82 per cent. The tile drain with saw-dust and corn-cobs gave 53.12, and 8.21 per cent less silt discharge as compared to silt discharge in tile drains with back-fill soil. The same was true in all the four depth of irrigation. The envelope materials, graded gravel and coconut fibre had shown much better performance during the fourth minute of tile out-flow. Probably, the graded gravel and coconut fibre might have taken more time for stabilization of permeability by readjusting to the flow conditions of grains. The saw-dust had the same effect in preventing the silt entering the drainage water during the fourth minute. Based on the prevention of silt into drainage water, in order of preference, the graded gravel, coconut fibre, saw-dust and corn-cobs could be selected as envelope materials for clay tile drains used in irrigated soils of Karnataka State.

To work out the relative capability to prevent silt entering the drains, the relative rate of silt discharges had been formulated in Table 89 and expressed both in litres per minute and in percentages. Here also, graded gravel was capable of reducing 63-64 per cent less silt discharge in tile out-flow as compared to silt out-flow in tile drains with back-fill soil (control). The coconut fibre as envelope material had discharged

Table 88. Total Variation of Rate of silt Out-flow during the fourth minute of Tile Out-flow in relation to envelope materials

Sl. No.	Envelope materials	Total variation of rate of silt out-flow (g/l)										Mean variation of rate of silt out-flow	
		Depth of irrigation above field capacity (cm)											
		5.00		7.50		10.00		12.50				g/l	%
		g/l	%	g/l	%	g/l	%	g/l	%	g/l	%		
1.	Back-fill soil (control)	-	-	-	-	-	-	-	-	-	-	-	-
2.	Graded gravel	0.905	62.28	0.905	66.78	0.750	65.50	0.740	72.10	0.737	63.64		
3.	Coconut fibre	0.755	52.80	0.795	58.67	0.695	60.70	0.675	56.18	0.658	56.82		
4.	Saw dust	0.725	50.70	0.775	57.20	0.665	58.10	0.608	59.10	0.615	53.12		
5.	Corn cobs	0.190	13.28	0.243	17.93	0.145	12.66	0.145	14.22	0.095	8.21		

Table 89. Relative Variation of Rate of Silt Out-flow during Fourth Minute in Relation to Envelope Materials

Sl. No.	Envelope materials	Relative variation of rate silt out-flow during fourth minute (g/l)											
		Depth of irrigation above field capacity (cm)											
		5.0						7.50					
		10.00						12.50					
		g/l	%	g/l	%	g/l	%	g/l	%	g/l	%	Relative mean variation of rate of silt out-flow g/l	
1.	Back-fill soil (control)	-	-	-	-	-	-	-	-	-	-	-	
2.	Graded gravel	0.905	72.28	0.785	66.75	0.750	65.60	0.740	72.10	0.760	63.64		
3.	Coconut fibre	0.151	28.57	0.060	12.76	0.06	13.92	0.06	21.05	0.080	19.08		
4.	Saw dust	0.030	4.44	0.050	9.43	0.13	28.89	0.10	28.98	0.078	17.94		
5.	Corn cobs	0.535	75.59	0.550	95.17	0.42	72.41	0.43	96.63	0.480	84.95		

19.08 per cent more silt in drainage water as compared to graded gravel. Similarly, saw-dust and corn-cobs could discharge 17.94 and 84.95 per cent more silt, respectively. Even based on the relative performance, in the order of preference, graded gravel, coconut fibre, saw-dust and corn-cobs may be selected for envelope materials.

The studies conducted earlier on these envelope materials did not give any specific recommendation, except giving some merits and demerits of some of the envelope materials. To illustrate the statement, some of the recommendations based on the earlier studies are being stated below.

Lyons et al. (1964) stated that drains installed with safflower straw drained the soil profile nearly 3 times faster than profile laid without envelope materials. Baghott and Houston (1965) found that wheat straw as envelope material was working satisfactorily even after 5 years. Sission and Jones (1962) found from their studies that straw and saw-dust performed well in delivering water while limiting sediment discharge. Browns Combe (1962) found that straw was effective in excluding sediment. Plmes, D.B. and H.P. Jonson (1962) found that corn-cobs and graded inlet produced higher discharge rates than soil and sand in-let. Taylor and Goins (1967) found that the wheat straw and corn-cobs had virtually disappeared and also he found that the crushed stones appear to be un-changed. Broughton et al. (1982) reported from their studies that gravel performed

satisfactory at allowing water entering the drain tubes and in preventing the entry of fine sand.

5.9.4. Effect of Depth of Irrigation:

The total tile drain out-flow due to varied depth of irrigation in tile drain with different envelope materials are given in table 35, and the increased depth of irrigation had positive effect in increasing the tile out-flow. Tile drain with graded gravel envelope had increased its out-flow from 221.00 to 422.50 litres by increasing the depth of irrigation to 12.50 cm from 5.00 cm. Drains with saw-dust increased its out-flow from 178.80 litres to 380.00 litres, corn cobs from 133.0 litres to 306.50 litres, coconut fibre from 157.54 litres to 334.76 litres, and back-fill soil from 153.70 litres to 340.00 litres. The increased depth of irrigation had significant effect on increased tile drain out-flow. In Table 92, the total increased variation of tile out-flow as compared to tile out-flow under 5 cm depth of irrigation is analysed and given. It shows that there was an increased in tile drain out-flow due to increased depth of irrigation. The increased depth of irrigation had more pronounced effect in organic envelope materials than in=organic envelope material. From the Table 90, the relative increase in tile drain out-flow was analysed, and accordingly the increased depth of irrigation had less effect on tile drain out-flow at higher depth of irrigation. This is more so in tile drains with organic envelope materials. In graded gravel, the increased

Table 90. Variation of Total Tile Drain Out-flow in relation to Depth of Irrigation

Sl. No.	Depth of irrigation (cm)	Variation of total tile drain out-flow (litres)					
		Graded gravel	Saw dust	Backfill soil (control)	Corn cobs	Coconut fibre	
		litres	litres	litres	litres	litres	
1.	5.00	-	-	-	-	-	-
2.	7.50	62.00	67.20	60.60	57.00	43.80	43.28
3.	10.00	129.00	135.20	137.70	126.60	93.80	92.68
4.	12.50	201.00	191.20	186.30	173.50	124.10	122.63
Mean		130.70	133.90	128.20	119.00	87.23	86.20

Table 91. Relative Variation of Total Tile Drain Out-flow in relation to Depth of Irrigation

Sl. No.	Depth of irrigation (cm)	Relative variation of total out-flow in litres						Relative variation mean tile drain out-flow (litres)	
		Graded gravel	Saw dust	Back-fill soil	Corn cobs	Coconut fibre		litres	%
		litres	%	litres	%	litres	%	litres	%
1.	5.00	-	-	-	-	-	-	-	-
2.	7.50	62.00	28.05	67.20	37.71	60.60	39.53	57.00	42.86
3.	10.00	67.00	23.67	68.00	27.76	77.10	35.90	69.60	36.63
4.	12.50	72.00	20.67	56.00	17.28	48.60	16.68	46.90	18.07
Mean		67.00	33.45	67.07	28.90	62.10	30.73	57.83	32.52
								41.4	31.4
								59.9	29.3

effect decreased from 28.05 to 20.57 per cent due to increased depth of irrigation from 5 cm to 12.50 cm, whereas in saw-dust, corn-cobs, coconut fibre, the respective decreased effect were 37.71 to 17.28, 42.86 to 18.07 and 43.30 to 15.50 per cent. Even in tile drains with back-fill soil, the decreasing effect was considerable from 39.53 to 15.68 per cent. The increased hydraulic gradient at the interface of soil and envelope material had considerable influence on the permeability. Hence, it could be said that the organic envelope would not be readily permeable at higher hydraulic gradient, but controls the water movement into drain tubes.

The analysed data on total variation of rate of tile drain out-flow when depth of irrigation was varied is presented in Table 92. The increased depth of irrigation had less effect in graded gravel in increasing the rate of out-flow than in organic envelope materials. It could be seen that when depth of irrigation was changed from 7.50 cm to 12.5 cm, the increased rate of tile out-flow was from 34.20 to 76.87 per cent in coconut fibre. The tile drains with other envelope materials, the corresponding rate of increase was 25.00 to 58.60 per cent in corn-cobs, 21.89 to 51.00 per cent in saw-dust, 22.22 to 58.18 per cent in graded gravel and 20.59 to 65.61 per cent in back-fill soil.

The rate of tile drain out-flow relative variation due to increase in depth of irrigation was considerably less (Table 93) in tile drains with graded gravel and saw-dust,

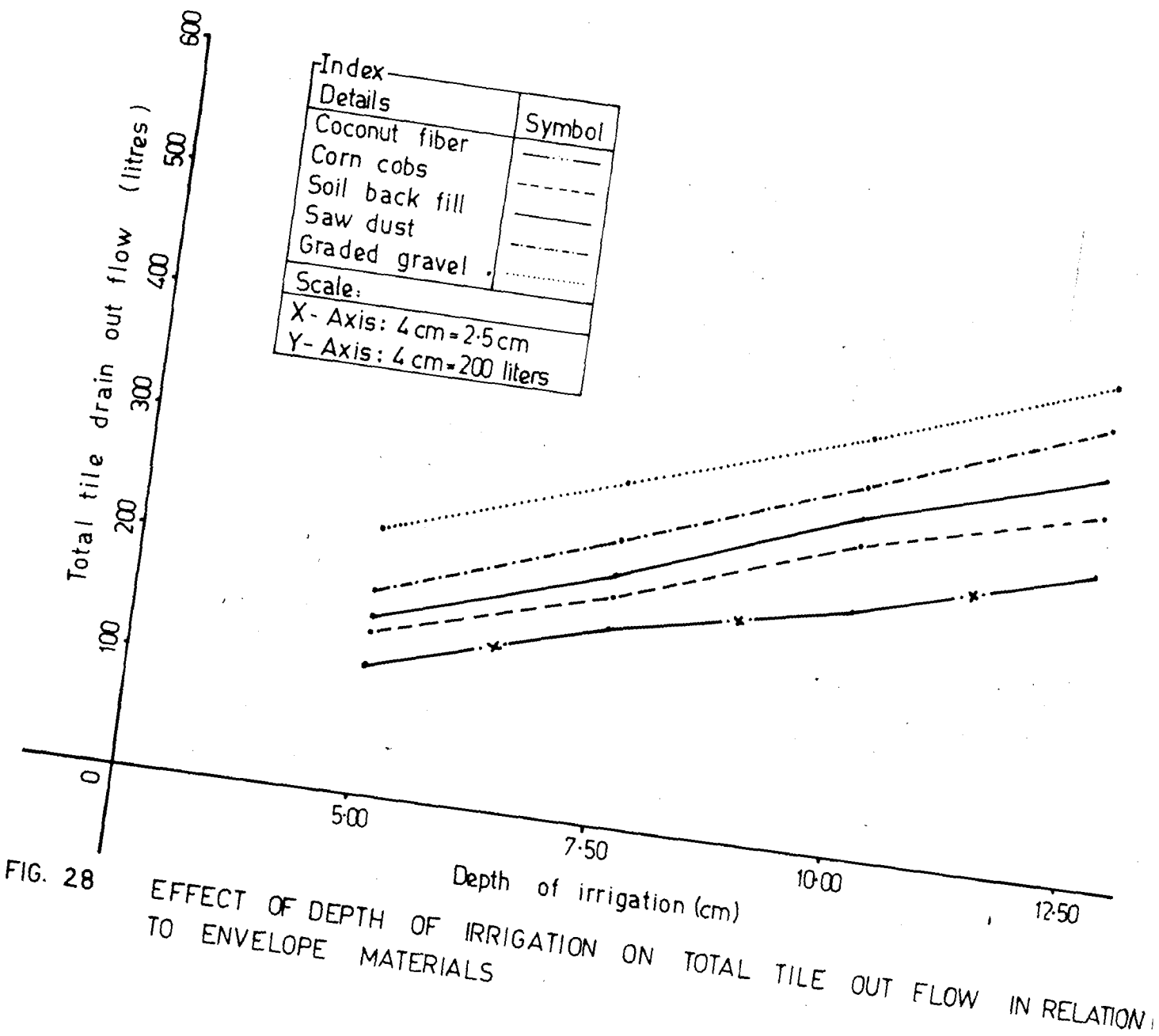


Table 92. Total Variation of Rate of Tile Drain Out-flow in relation to Depth of Irrigation

Sl. No.	Depth of irrigation (cm)	Total variation of rate of tile drain out-flow in (l/m)					
		Coconut fibre	Corn cobs	Backfill soil	Saw dust	Graded gravel	
		l/m	l/m	l/m	l/m	l/m	l/m
1.	5.00	-	-	-	-	-	-
2.	7.50	0.105	0.198	0.091	0.094	0.110	22.22
3.	10.00	0.158	0.180	0.172	0.185	0.115	23.23
4.	12.50	0.236	0.230	0.290	0.240	0.290	58.18
Mean		0.170	0.169	0.184	0.173	0.172	34.54

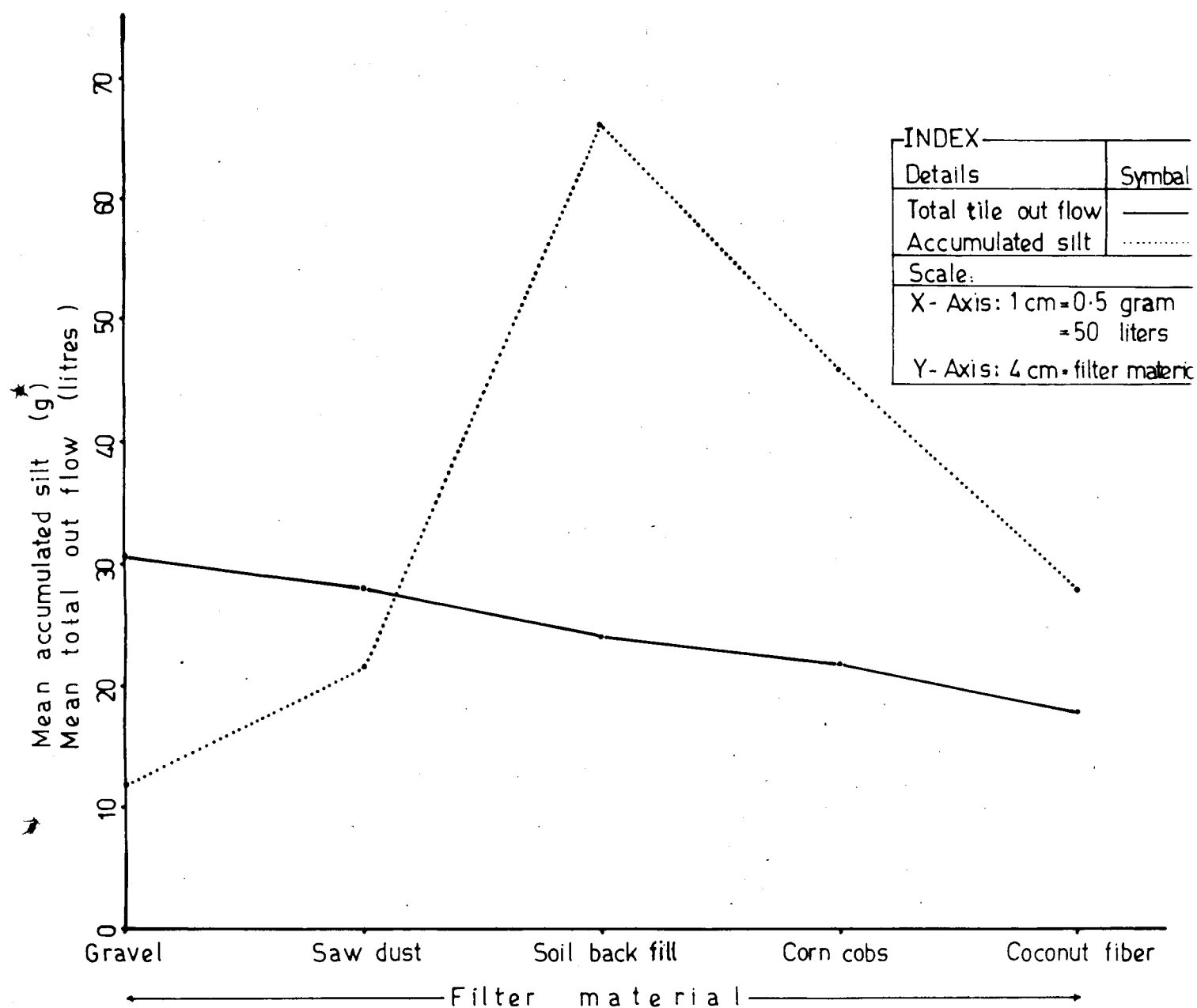


FIG. 30 RELATIONSHIP BETWEEN FILTER MATERIALS AND TOTAL TILE DRAIN OUT FLOW (mean) AND SILT ACCUMULATION (mean)

whereas in tile drains with coconut fibre, corn-cobs and in back-fill soil, the rate of relative variation of tile drain out-flow was more. Probably the graded gravel and saw-dust might have attained a stable permeability due to structure of the materials. The curves drawn in relation to depth of irrigation (fig. 26 and 27) indicates that the rate^{of}/out-flow in tile drains with different envelope materials did not differ significantly, but graded gravel and saw-dust gave higher rate of tile out-flow in all the four depth of irrigation.

From the Table 94, the data indicates that the rate of silt out-flow was decreasing as the depth of irrigation increased in all types of envelope materials. The rate of silt out-flow was significantly less in tile drains with envelope materials saw-dust, graded gravel and coconut fibre, whereas in tile drains with corn-cobs and back-fill soil, it was considerably more due to increased depth of irrigation. Probably the hydraulic gradient at soil envelope interface had significant effect in carrying the silt particles into drain tubes. In tile drains with corn cobs and back-fill soil, the silt particles availability was much more than in other envelope materials. The same was true during the second and fourth minute of tile out-flow.

The total variation of the rate of silt discharge during the second and fourth minute of tile out-flows were given in Table 94 and 95 due to increased depth of irrigation.

Table 94. Total Variation of Rate of Silt Out-flow during Second Minute in relation to Depth of Irrigation

Sl. No.	Depth of irrigation (cm)	Total variation of rate of silt out-flow during second minute (g/l)									
		Saw dust		Graded gravel		Coconut fibre		Corn cobs		Backfill soil	
		g/l	%	g/l	%	g/l	%	g/l	%	g/l	%
1.	5.00	-	-	-	-	-	-	-	-	-	-
2.	7.50	0.175	19.55	0.125	20.38	0.210	17.50	0.380	20.43	0.390	20.21
3.	10.00	0.275	30.73	0.340	32.23	0.365	30.42	0.470	25.27	0.460	23.83
4.	12.50	0.305	34.10	0.365	34.60	0.405	33.75	0.660	35.48	0.615	31.87
Mean		0.252	28.13	0.307	29.07	0.327	27.22	0.510	27.06	0.488	25.30

Table 95. Total Variation of Rate of Silt Out-flow during the fourth minute in relation to Depth of Irrigation

Sl. No.	Depth of irrigation (cm)	Total variation of rate of silt out-flow during the fourth minute (g/l)							
		Graded gravel		Coconut fibre		Saw dust		Corn cobs	
		g/l	%	g/l	%	g/l	%	g/l	%
1	5.00	-	-	-	-	-	-	-	-
2	7.50	0.075	14.28	0.145	17.48	0.125	17.73	0.128	10.32
3	10.00	0.130	24.76	0.225	33.33	0.225	31.31	0.240	19.35
4	12.50	0.240	45.71	0.330	48.88	0.263	37.30	0.365	29.44
Mean		0.148	28.25	0.220	33.23	0.204	28.78	0.244	19.70
								0.297	20.75

The increased depth of irrigation did not give the same proportion of higher silt out-flow. During the second minute of tile out-flow, the percentage change in silt out-flows were 19.55 to 34.10, 20.38 to 34.60, 17.50 to 33.75, 20.43 to 35.48 and 20.21 to 31.87, respectively in tile drains with envelope material saw-dust, graded gravel, coconut fibre, corn-cobs and back-fill soil when the depth of irrigation increased to 12.50 cm from 7.50 cm. Similarly during the fourth minute of tile out-flow, the rate of silt out-flow changes were 14.28 to 45.71, 17.48 to 48.88, 17.13 to 37.30, 10.32 to 29.44 and 13.64 to 28.67 per cent. The above data indicates that there was increase in silt out-flow in all envelope materials, but was not significant enough.

The relative increase in rate of silt out-flows were presented in Table 96 and 97 and the data indicates that the increased depth of irrigation had less effect in increasing the silt out-flow. When the depth of irrigation was increased from 5.00 to 7.50 cm, the corresponding rate of silt out-flow increased to 19.50, 20.38, 17.50, 20.43 and 20.21 per cent, respectively in tile drain with envelope materials saw-dust, graded gravel, coconut fibre, corn-cobs and back-fill soil. Similarly, when depth of irrigation was increased to 10.00 cm, the corresponding rate of silt out-flows were 13.89, 14.88, 15.66, 11.45 and 9.74 per cent. This increase was significantly less when the irrigation was increased to 12.50 cm and the rate of silt out-flow was around 4 per cent in almost all envelope materials during the second minute of the tile out-flow. During the fourth minute of tile out-flow,

Table 96. Relative Variation of Rate of Silt Out-flow during second minute in relation to Depth of Irrigation

Sl. No.	Depth of irrigation (cm)	Relative variation of rate of out-flow from drain in g/l							
		Saw dust	Graded gravel	Coconut fibre	Corn cobs	Backfill soil			
		g/l	%	g/l	%	g/l	%	g/l	%
1	5.00	-	-	-	-	-	-	-	-
2	7.50	0.175	19.55	0.215	20.38	0.210	17.50	0.380	20.43
3	10.00	0.100	13.89	0.125	14.88	0.155	15.66	0.170	11.49
4	12.50	0.030	4.85	0.025	3.50	0.040	4.80	0.060	4.58
Mean		0.102	12.76	0.122	12.92	0.135	12.65	0.210	18.88
								0.205	11.78

Table 97. Relative Variation of Rate of Silt Out-flow during the Fourth Minute
in relation to Depth of Irrigation

Sl. No.	Depth of irrigation (cm)	Relative variation of rate of silt out-flow from drains (g/l)									
		Graded gravel		Coconut fibre		Saw dust		Corn cobs		Back-fill soil	
		g/l	%	g/l	%	g/l	%	g/l	%	g/l	%
1.	5.00	-	-	-	-	-	-	-	-	-	-
2.	7.50	0.095	14.29	0.015	17.04	0.125	17.73	0.128	10.32	0.165	11.64
3.	10.00	0.055	12.22	0.110	19.64	0.100	17.24	0.112	10.07	0.115	8.09
4.	12.50	0.110	27.85	0.105	23.33	0.068	14.17	0.125	12.50	0.125	10.92
Mean		0.080	18.12	0.110	20.00	0.088	16.38	0.122	10.96	0.127	10.22

the increased depth of irrigation gave uniform rate of silt out-flow at all increased depth of irrigation. This could be seen from the Table 97, the increased depth of irrigation from 5 to 7.50, 7.50 to 10.00 and 10.00 to 12.50 cm did have uniform effect on rate of silt out-flow. Probably, the envelope materials might have stabilized the permeability at the interface of envelope material and soil. The curve (Fig. 27) drawn between envelope material and rate of silt out-flow during second and fourth minute of out-flow indicates that the rate of silt out-flow became uniform at fourth minute and does not follow the curve drawn for rate of tile out-flow, since the nature of two curves were not the same.

The literature cited in Review, indicates that the work done in this direction to draw any specific conclusion based on depth of irrigation was considerably less or negligible. Hence the item had been discussed in depth. Based on analysis of data obtained, it could be concluded that the increased depth of irrigation did not significantly respond for tile drain out-flow in all envelope material. But it did had some effect on the out-flow from tile drains with organic envelope materials. The graded gravel, saw-dust and coconut fibre as envelope material were better in preventing silt entering the tile drains.

5.9.5. Silt Accumulated in Tile Drains:

From the Table 98, it could be seen that the silt accumulated was higher in tile drains with back-fill soil and lower in

Table 98. Total Accumulated Silt in Tile Drains at the end of the Experiment

Sl. No.	Envelope materials	Mean silt accumulated in drains(g)	Total variation		Relative variation	
			Weight in gms	Percent	Weight in gms	Percent
1.	Back-fill soil (control)	6.84	-	-	-	-
2.	Corn cobs	4.68	2.24	32.75	2.24	32.75
3.	Coconut fibre	2.84	4.00	58.48	1.84	39.32
4.	Saw dust	2.18	4.66	68.13	0.66	23.24
5.	Graded gravel	1.20	5.66	82.46	0.98	44.95
	1. For comparison of envelope materials		S.Em _t	CD(5%)	F Test	
			0.9356	1.652	NS	
	2. For comparison of depth of irrigation		0.4154	0.187	Significant	
	3. For comparison of depth of irrigation at same or different envelope materials		0.9511	2.254	NS*	

* NS = Not Significant

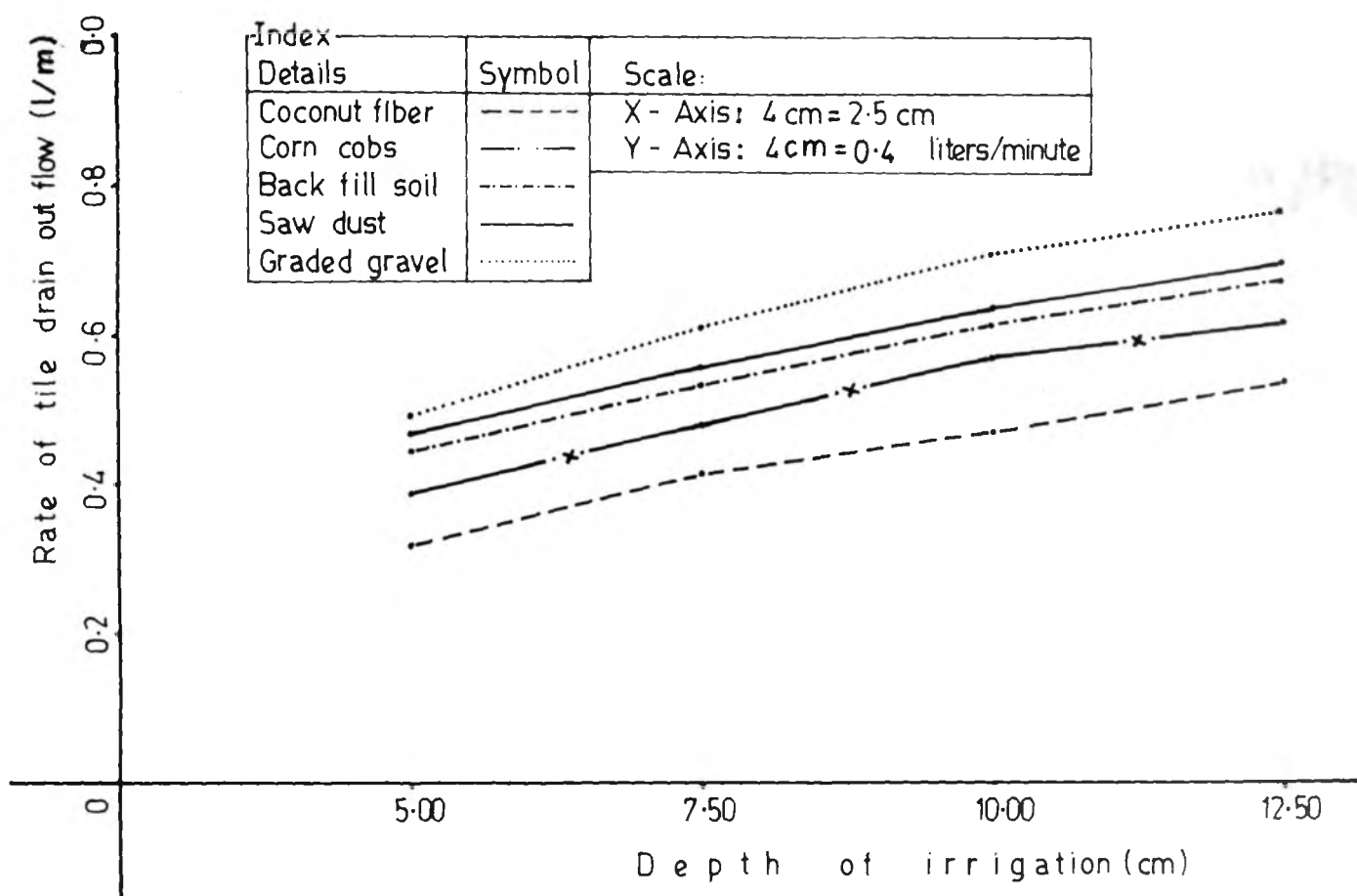


FIG. 29 EFFECT OF DEPTH OF IRRIGATION ON RATE OF TILE DRAIN OUT FLOW IN RELATION TO ENVELOPE MATERIALS

graded gravel. The accumulated silt was 6.84, 4.68, 2.84, 2.18 and 1.20 grams, respectively in tile drains with back-fill soil, corn-cobs, coconut fibre, saw-dust and graded gravel. The total decrease in silt accumulation was 82.46 per cent less in tile drains with graded gravel as compared to silt accumulated in tile drains with back-fill soil. Similarly, in tile drains with saw-dust, coconut fibre, and corn-cobs, the percentage silt accumulations were respectively 68.13, 58.48 and 32.75.

The relative variation of silt accumulation in tile drains with corn-cobs, coconut fibre, saw-dust and graded gravel were 32.75, 39.32, 23.24 and 44.95 per cent. From the Fig. 30, the curve also indicates that there was no relationship between silt accumulation and total tile out-flow.

By looking into hydraulic performance and silt prevention in tile drains, the graded gravel considered to be the most ideal for adoptation as envelope material. Among the organic envelope materials, saw-dust found to be more efficient hydraulically and also to prevent silt entering the tile drains.

CHAPTER 6

CONCLUSIONS AND SUGGESTIONS

CHAPTER 6

CONCLUSIONS AND SUGGESTIONS

6.1. Conclusions:

Four experiments were conducted to find out the optimum size and number of perforations, the ideal placement of perforations of tile for easy entry of drainage water and to identify suitable locally available envelope materials, for 10 cm dia and 60 cm long clay tile drains used in irrigated areas of Karnataka. From the results presented in Chapter IV and discussion from the Chapter V, the following conclusions were drawn.

6.1.1. Size of perforations:

1. Tile drain out-flow from various treatments indicated that the decrease in size of perforations below 1 cm diameter of perforations does not increase the relative hydraulic efficiency of tiles.
2. The rate of increase of rate of tile out-flow was significant in tile drains with 1.50, 1.25, and 1.00 cm diameter, but not in tile drains with 0.75 and 0.50 cm dia perforations.
3. The reduction in size of perforations less than 1 cm dia would have considerable effect on the process and cost of manufacture of tiles.

4. The decrease in size of perforations below 1 cm dia had resulted in increased number of perforations of 420 per cent and the corresponding reduction in bearing strength tiles was 44.35 per cent.

5. The perforations size of 1 cm dia were logically ideal for 10 cm(dia) by 60 cm (long) clay tiles used in irrigated areas of Karnataka.

6. The silt discharge in tile drains did not give any specific indication which could be used for the selection of size of perforations.

7. According to silt accumulation factor, the 1.00 cm dia perforations were ideal for clay tiles.

6.1.2. Number of perforations:

1. The change in total out-flow in increasing order was significant in tile drains upto 24 perforations per tile and became less significant in tile drain with 36, 48 and 60 perforations per tile.

2. The relative increase of total tile drain out-flow decreased as the number of perforations per tile increased and providing more number of perforations per tile does not give higher hydraulic efficiency.

3. The increased rate of out-flow decreased substantially in tile drains with more than 24 perforations per tile.

4. In tile drain with 24 perforations per tile gave relative increase of 28.00 per cent silt discharge, which was relatively less as compared to the tile drains with higher number of perforations per tile.

5. The tile drains with 24 perforations per tile had 16.00 per cent relative increase of silt accumulation as compared to 19.15, 21.70 and 22.55 per cent in tile drains with 36, 48 and 60 perforation per tile.

6. The rate of silt discharged was increased after 36 perforations per tile, and it was more significant in tile drain with more than 24 perforation per tile.

7. The relative decrease of bearing strength upto 24 perforations was around 30 per cent and in tiles with more than 24 perforations per tile the decreasing rate increased more significantly.

6.1.3. Orientation of Tile Perforations:

1. Based on the total and rate of tile drain out-flow, bottom orientation of perforations of tiles was more suitable for higher hydraulic efficiency.

2. The mean silt discharges were 4.54, 3.54 and 3.41 grams per litre in top, lateral and bottom orientation of tile perforations, respectively.

3. The top orientation of tile perforations was more prone to silt accumulation than lateral and bottom orientation.

4. The orientation of tile perforations did not respond significantly for higher depth of irrigation.

6.1.4. Envelope Materials for Clay Tile Drains:

1. Hydraulically the saw-dust and graded gravel were found to be better as envelope materials for clay tile drains.

2. The tile drain with graded gravel envelope gave higher total tile drain out-flow of 25.40 per cent under all depth of irrigation.

3. In the order of preference graded gravel, saw-dust, corn-cobs, back-fill soil and coconut fibre could be used as envelope materials for clay tile drains.

4. Based on the prevention of silt discharge into drains, in the order of preference of envelope materials, saw-dust, graded gravel, coconut fibre and corn-cobs could be selected.

5. The increased depth of irrigation had more pronounced effect on organic envelope materials than on in-organic envelope materials.

6. By looking into hydraulic performance and silt prevention into tile drains, the graded gravel was considered to be the most ideal for adoption as envelope materials. Among the organic materials, saw-dust found to be more efficient hydraulically and also to prevent silt entering into tile drains.

6.2.0. Suggestions for future line of work:

The tiles of 10 cm (dia) by 60 cm (long) have been evaluated in the field experimental plots to standardise the technical information such as size of perforations per tile, number of perforations of optimum size per tile, proper placement of perforated face of the tile in trenches for easy entry of drainage water into tile drains and for identification of locally available envelope materials for clay tile drains.

The above information has been identified by conducting four experiments, one each every year from 1981 to 1984. In the experimental plots, field scale parameters such as number of main and lateral lines, varied grades of lateral tile drains, cumulative involvement of man-holes for silt movement, soil heterogeneity and their chemical and mineralogical effect on tiles for longer life, structural stability of envelope materials, especially organic ones, for longer hydraulic performance could not be adopted in the present study. In any experiment of the present nature, it is not possible to involve all the above mentioned long range parameters for the known reasons of experimental limitations.

Therefore, as the first phase of the study the information obtained from the present investigation is highly scientific and systematic, and it can be recommended for larger scale adoption in the field. To involve all the parameters, including sociological and economic factors of the farmers and Government

agencies, in the field scale, an operational research on adoption of clay tile drains may be undertaken to evaluate the standardised techniques of clay tiles used in irrigated area of Karnataka State.

CHAPTER 7

SUMMARY

CHAPTER 7

SUMMARY

7.0. Summary

The effects of excess irrigation water are of many fold. Water in excess of field capacity remain unavailable for plants. Moreover, this water blocks aeration space of root zone of plants, thereby reducing beneficial activities of soil fauna. Apart from this, excess water influences the accumulation of salts at root zone, which in turn creates toxicity in the soil and unfavourable conditions for tillage and other operation.

Wherever topography of sub-soil conditions obstruct the natural movement of water from the root zone, artificial sub-surface drainage becomes inevitable to maintain high productivity of soil. In sub-surface drainage, drain tiles and envelope materials play important role in keeping the system efficient and also in the economy of the tile drainage system.

In irrigated command areas of Karnataka the tile drains of 10 cm (diameter) by 60 cm (long) are being used. They have been provided with perforations or slits on the body for entry of drainage water. The sub-surface drainage systems with these clay tiles often failed immediately after laying or within a year or two. After thorough investigation, it was found that there was inadequate technological know-how for adoption of such tiles for sub-surface drainage system.

The main deficiencies noticed were lack of knowledge on number and size of perforations required per tile, orientation of perforated area of tiles in trenches for drainage water entry, right type of envelope materials to prevent silting and clogging of tile drains and optimum bearing strength of tiles to take load when provided with number of perforations. In order to know the required technological information for the above mentioned problems, four field experiments of perforated clay tiles were conducted in Agricultural College Farm. The soils in which experiment conducted, were porous enough for such field studies.

7.1. Summary of Experiments:

The experiments were conducted in water logged soils in plot number 177 of 'G' Block at Agricultural College (Fig. 1) Farm, Dharwad, during the years 1980-81, 1981-82, 1982-83 and 1983-84, to understand the effect of size of perforations of tiles, number of circumferential perforations per tile, orientation of perforated face of tile in the trenches and the nature and type of envelope materials required for the clay tile drains. The parameters measured were the drainage out-flow, silt accumulated in tile drains and on load bearing strength of clay tiles of 10 cm dia and 60 cm long, which are widely used in irrigated areas of Karnataka State.

The first experiment conducted was for optimum size of circumferential perforations and the main treatments were plain clay tiles without perforations and clay tile with 0.5, 0.75, 1.00, 1.25 and 1.50 cm dia perforations. The sub-treatments were four depths of irrigation, namely, 8, 10, 12 and 14 cm above field capacity of soil profile to a depth of 90 cm.

The second experiment conducted was on optimum number of circumferential perforations and the main treatments were plain clay tiles without perforations and clay tiles with 6, 12, 24, 36, 48 and 60 perforations of 1 cm dia per tile. The sub-treatments were 2.5, 5.0, 7.5 and 10.0 cm depth of irrigation above field capacity of soil profile to a depth of 90 cm.

The third experiment was on the effect of orientation of circumferential perforations of tile to the direction of drainage water entry. The main treatment were placement of perforated area of the tiles facing upward, downward and sideward. The sub-treatments were 5, 10, 15 and 20 cm depth of irrigation above field capacity of soil profile to a depth of 90 cm.

The fourth experiment was on the identification of suitable locally available envelope materials for the circumferentially perforated clay tile drains which could be used in irrigated areas of Karnataka State. The main treatments were top-soil, coconut fibre, saw-dust, corn cobs and graded gravel, and sub-treatments were 2.5, 5.0, 7.5 and 10.0 cm depth of irrigation above field capacity of soil profile under study.

7.2. Summary of Results:

In order to find optimum size of perforations, the tiles with 1.50, 1.25, 1.00, 0.75 and 0.50 cm dia perforations were provided with respective number of perforations of 11, 15, 24, 42 and 96 per tile to maintain constant water entry of 18.85 sq.cm. The plain tile without perforations was taken as reference. The mean total tile drain out-flows were 263.00, 505.00, 576.00, 686.00, 716.00 and 750.00 litres (without perforations) in tile drains with 0.0, 1.50, 1.25, 1.00, 0.75 and 0.50 cm dia perforations, respectively. The corresponding tile drain discharge rates were 0.033, 0.063, 0.098, 0.132, 0.152 and 0.165 litres per minute. The mean silt discharged through drainage water correspondingly were 0.270, 2.020, 1.370, 0.960, 0.694 and 0.460 grams per litre. In the same order, the silt accumulated in each tile drains were 2.65, 7.86, 6.53, 6.00, 5.61 and 5.04 grams. The bearing strength of corresponding tiles with zero, 1.50, 1.25, 1.00, 0.75 and 0.50 cm dia perforations were 12.13, 9.86, 9.25, 8.67, 6.75 and 5.68 kg/cm².

To find out the optimum number of perforations of 1 cm dia, the number of perforations per tile adopted were 6, 12, 24, 36, 48 and 60 and plain tile without perforation as reference. The mean drain discharges recorded were 105.85, 155.13, 183.63, 248.87, 308.38, 336.25 and 356.38 litres in tile drains with zero, 6, 12, 24, 36, 48 and 60 perforations per tile, respectively. The mean rate of tile drain out-flows corresponding were 0.071, 0.108, 0.128, 0.173, 0.213, 0.238 and 0.247 litres per minute. The respective silt discharge

rates were 0.586, 0.744, 0.925, 1.184, 1.562, 2.124 and 2.863 grams per litres. The mean accumulated silt in tile drains were 5.68, 8.76, 10.46, 12.23, 16.65, 20.54 and 25.00 grams, respectively. The corresponding salt discharges were 136.43, 171.45, 204.23, 260.61, 281.28, 287.33 and 292.38 kg/ha. The bearing strength of tiles in the same order were 12.15, 10.68, 9.50, 8.67, 7.28, 6.12 and 5.03 kg/ cm².

To identify suitable placement of perforated tiles in trenches the lateral, top and bottom orientation were adopted and mean tile drains out-flows were 211.24, 247.34 and 428.84 litres, respectively. The corresponding rate of tile drain out-flows were 0.340, 0.393 and 0.604 litres per minute. The rate of silt discharges were 3.54, 4.54, and 3.41 grams per litres in lateral, top and bottom orientation of tile drains, respectively and the corresponding silt accumulation in tiles were 5.6, 10.3 and 3.5 grams.

To evaluate envelope materials for their hydraulic performance five locally available envelope materials, namely, coconut fibre, corn cobs, saw-dust, graded gravel and back-fill soil were used. The mean total tile drain out-flows of 183.30, 222.10, 244.80, 282.00 and 319.00 litres were recorded in tile drains with envelope materials coconut fibre, corn cobs, back-fill soil (reference), saw-dust and graded gravel respectively. The corresponding mean rate of tile drain out-flows were 0.443, 0.522, 0.564, 0.570 and 0.620 litres per minute. The rate of silt

discharges were 0.938, 1.483, 1.570, 0.690 and 0.825 grams per litre and the corresponding silt accumulation in tile drains were 2.84, 4.64, 2.18, 1.20 and 6.85 grams.

7.3. Summary of Discussions:

To find out the optimum size of perforation for clay tiles, the parameters such as total tile drain out-flow, rate of tile drain out-flow, rate of silt discharge in drainage water, total silt accumulated in tile drains and bearing strength of tiles, were used. According to total tile drain out-flow, the hydraulic performance of tiles becomes less significant when the size of perforation decreased less than 1.00 cm dia and the corresponding relative increase in out-flows were 4.53 and 4.20 per cent in tile drains with 0.75 and 0.50 cm dia perforation. The rate of relative increase of tile out-flows were 15.15 and 8.55 per cent in tile drain with 0.75 and 0.50 cm dia perforation, which were less significant as compared to 69.23, 55.96 and 90.90 per cent in tile drain with 1.00, 1.25 and 1.50 cm dia perforations. The rate of silt discharge in drainage water was almost uniform in all tile drains, namely 35.45, 38.21, 37.68, 37.12 and 640.8 per cent in tile drains with 0.50, 0.75, 1.00, 1.25 and 1.50 cm dia perforations. The silt accumulated in tile drains were 2.33, 6.18, 15.77, 17.13 and 197.36 per cent in the same order as said above. The reduction in bearing strength of tiles were 53.77, 44.35, 28.52, 23.74 and 18.71 per cent in tile with 0.50, 0.75, 1.00, 1.25 and 1.50 cm dia perforations and the reduced bearing

strength of tile was less than 30 per cent upto tiles with 1.00 cm dia perforations which was within the permissible limit. Therefore, by looking into hydraulic performance, silt discharge, silt accumulation in tile drains and bearing strength of tiles, perforations of 1 cm dia would be more ideal for clay tiles which are being used in irrigated areas of Karnataka State.

To find out optimum number of perforations of 1 cm dia per tile, the parameter such as total tile drain outflow, rate of tile drain out-flow, rate of silt discharge in drainage water, total accumulated silt in tile drains and bearing strength of tiles were used. The relative increase of total water entry area per tile consequent to the increase of number of perforations per tile were 74.50, 42.78, 59.92, 37.47, 27.26 and 21.14 per cent when the perforations per tile increased in the order of 0, 6, 12, 24, 36, 48 and 60 number. The corresponding relative mean increase in tile drain out-flows were 44.18, 26.46, 28.95, 23.66, 9.10 and 5.98 per cent. Similarly the respective increase in silt discharges were 26.96, 24.33, 28.00, 31.93, 35.98 and 34.50 per cent. Consequent to the increase of number of perforations, the relative decrease in bearings were 12.10, 11.05, 11.42, 16.03, 15.93, 17.81 per cent. The mean relative increase in salt discharge in drainage water were 25.70, 23.19, 24.73, 9.79, 3.44 and 1.89 per cent, respectively. From the above analysed data, it could be concluded that 24 perforations of 1 cm dia were most ideal for higher hydrological efficiency and structural stability of clay tiles of 10 cm (dia) by 60 cm (long) in irrigated areas of Karnataka State.

To understand suitable placement of perforated face of clay tiles in trenches for higher hydrological efficiency and for long life, the lateral, top and bottom orientation of perforated face were adopted. The increased total tile drain out-flow in top and bottom perforations oriented tile drains were 18.60 and 100.27 per cent as compared to tile drain out-flow in lateral orientation. Similarly, the rate of tile drain out-flows were 13.78 and 57.42 per cent. The mean relative decrease in silt discharge in tile drain with lateral and bottom orientation as compared to top orientation were 10.34 and 9.34 per cent. The mean increase of silt accumulation in tile drains as compared to bottom orientation of perforations were 2.20 and 4.74 grams as the bottom orientation gave the least silt accumulation. From the analysed data, the bottom orientation of perforated face of the tile drains gave the highest hydrological efficiency by preventing silt accumulation. The next best way of placing of tiles would be lateral orientation of perforations. The last preference would be top orientation under inevitable situation.

In order to identify suitable envelope material for clay tile of 10 cm (dia) by 60 cm(long), five locally available envelope materials, namely, coconut fibre, corn-cobs, saw-dust, graded gravel and back-fill soil were evaluated in the field. The parameters such as total tile drain out-flow, rate of tile drain discharge, rate of silt discharged in drainage water and silt accumulated in tile drains, were used for evaluation. The back-

fill soil was considered as reference and relative variation of tile drain out-flow in tile drain with envelope material, coconut fibre, corn-cobs, saw-dust and graded gravel were -33.10, +32.97, +24.98 and +15.22 per cent. Similarly, the respective mean relative rate of tile drain out-flows were -0.137, +0.085, +0.061 and +0.071 litres per minute. The total decrease in variation of rate of silt discharge in saw-dust, graded gravel, coconut fibre and corn-cobs, keeping back-fill soil as reference were 46.60, 38.25, 5.04 and 38.50 per cent, during second and fourth minute of tile out-flow. The respective rate of silt discharges were 63.64, 56.82, 53.12 and 8.21 per cent. The decreased accumulated silt in tile drains were 32.75, 58.48, 68.13 and 82.46 per cent as compared to tile drains with back-fill soil, in order of corn-cobs, coconut fibre, saw-dust and graded gravel. From the above information, the graded gravel is more hydrologically efficient than saw-dust, coconut fibre, and corn-cobs in the order of their total performance as envelope material for clay tile drains used in irrigated areas of Karnataka State.

7.4. Summary of Conclusions:

By considering the hydraulic performance, silt discharge and silt accumulation in tiles, and load bearing strength of tiles, the perforations of 1 cm dia would be more ideal for clay tiles of 10 cm (dia) by 60 cm(long) used in irrigated soils.

The clay tiles with 24 perforations of 1 cm dia gave higher hydrological efficiency and structural stability to use as tile drains to control water table in irrigated soils.

The bottom orientation of perforated face of tile drains would give higher hydraulic efficiency and long life by preventing of silt entering drains. The next best way of placing of tiles would be the lateral orientation of perforations.

The graded gravel is more hydrologically efficient than saw-dust, coconut fibre, and corn-cobs in the order of their total performance as envelope materials for clay tile drains of 10 cm(dia) by 60 cm(long) used in irrigated areas of Karnataka State.

REFERENCES

REFERENCES

- Aldabagh, A.S.Y. and C.E. Bear, 1972. Field measurement of hydraulic conductivity above a Water table with air entry parameter. Amer. Soc. Agr. Eng. Trans, 14: 29-32.
- American Society for Testing Materials, 1959. Tentative specifications for clay drain tile. ASTM, C4-59T.
- American Society for Testing Materials, 1960. Standard Specification for concrete drain tile. ASTM, C412-60.
- American Society of Agricultural Engineers, 1967. Report on Drainage Material; Soil and Water Div, St. Joseph, Michigan, 48 p(Special Publication).
- Ami, S.R., Broughton, R.S. and Shady, A.M., 1978. Designing and installing sub-surface drainage laterals Less than 100 mm in diameter. Canadian Agricultural Engineering, 20(1): 16-19, Canada.
- Anonymous, 1974. Consolidated Report of fourth plan period. All India Coordinated Scheme for Research on Water Management and Soil Salinity, R.R.S., Dharwad, UAS, Bangalore.
- Anderson, S.A., 1983. Experiments and Experiences with drainage methods (Drainage Materials in Denmark) Zaitichriff fur Kulturtechnik und Flurbereinigung, 24(4): 223-239.
- Anandakrishna, M. and G.H.Varadarajulu, 1963, Laminer and Turbulent flow of water through sand. Amer.Soc.Civil Eng. Proc. 89(SMS) p. 1-15.

- Ansari, M.Y. and Babi, S.S., 1966. Irrigation engineering. Pub. Geeta Prakashan, Allahabad.
- Ayers, A.D., J.W.Brown. and C.H.Wadleigh, 1952. Salt tolerance of barley and wheat in soil plots receiving several salinization regimes. Agron. J., 44: 307-310.
- Ayres, C. and Scoates, D. 1939. Land drainage and reclamation. McGraw Hill Book Co. Inc. New York, pp. 392-454.
- Baghott, K.G. and C.E.Houston, 1965. Tile drainage solves salinity problems in tulelake basin. Calif. Agr. 19(8): 6-7.
- Baker, J.L. and H.P.Hohnson, 1977. Impact of sub-surface drainage on water quality. Proceedings of the Third National Drainage symposium. A.S.A.E. pp. 1-7.
- Basu, J.K., 1950. Problems of saline soils in Bombay State. India. Trans. IV. Int. Congr. Sci., 3:169-172.
- Belgaumi, M.I., Channabasaiah, H.S.M. and Seshagiri Rao, T. 1976. Leaching requirement and technique of leaching excess soluble silts from salt affected soil in Tungabhadra project area. Curr. Res. 5: 135-137.
- Belgaumi, M.I., 1978. Extent of circular openings of tile on the efficiency of tile drainage system. Unpublished. M.Sc Thesis, submitted to U.A.S. Bangalore.
- Bears, W.F.J., 1968. Some Nomograph for the calculation of drain spacing. Bulletin No.8, International Institute of Land Reclamation and Improvement, Wagenigen, Netherland.

- Bellin, K., 1979, Accuracy of drain pipe installation experiments, principles, requirements. Wasser und Boden 31(1): 10-14. German Federal Republic.
- Beltram, J.M., 1978. Study of drainage and filter materials in saline silty-clay soil of the Bardenas Area. Spain. In Tenth Congress on Irrigation and Drainage, Athens. Transactions Vol. IV. New Delhi. India.
- Beng; K.C., Doering, E.J., Reichman, G.A. and Follett, R.F. 1980. Evaluation of some sub-surface Drainage Envelope. In Proceedings, Third National Drainage Symposium. Chicago, USA, ASAE, 31-33.
- Bengton, R.L., 1982. Reducing Water pollution with sub-surface drainage, Ame. Soc. Agr. Engineers. No.82: 2554- 15 pp.
- Bennett. D.R., Webster, G.R., Paterson, B.A. and Harker, D.B., 1982. Drainage of irrigated saline soil in Alberta. Canadian Journal of Soil Science, 62(2):387-396.
- Bertram, C.E. 1940. An experimental investigation of protective filters, Pierce Hall, Harvard Univ. Harvard Soil Mechanics Series, 7: 21 p.
- Bhattacharya, A.K. and Broughton, R.S., 1979. Spacings of drains to minimize revenue increases. Transation of the ASAE, 22(2): 351-356.
- Bigger, J.W. and Nelsen, D.R., 1967. Miscible displacement and leaching phenomenon. In: R.M.Hagon et al. (Ed). Irrigation of Agricultural lands, Agronomy, 11: 254-274.
- Black; R.D., M.F.Walter, and F.N.Swadax, 1977. Apparent effects of sub-surface drainage on soil physical properties. Proceedings of the Third National Drainage Symposium, ASAE, pp. 1-77.

- Bliesnar, R.D., Hanks, R.J., Kong, L.B. and Willardson, L.S., 1977. Effect of irrigation management on the quality of irrigation return flow in Ashley Valley. Utah Soil Sci. Soc. Amer. J., 41(2): 424-428.
- Blinder, V., Nicolau, A., Nitiesco, E. and Cojocaru, I. 1978. Model study of drain filter for establishing their hydraulic and functional efficiency. Report in Tenth Congress on Irrigation and Drainage. Athens. Transaction Vol.IV, New Delhi, India.
- Blishay, B.G., Dierickx, W. and Boodt, M.D.DE. 1975. Conditioned sandy soil as an envelope to prevent silting-up in drain tube. Journal of Ag.Engg. Res. 20(2): 139-148.
- Bodman, G.B. and F.F.Harradine, 1939. Mean effective pore size and clay migration during water percolation in soil. Soil Sci. Soc. Am. Proc., 3: 44-51.
- Bools, D., 1979. A method to predict changes in hydraulic conductivity caused by drainage plows and back-filling of Trenches. Agricultural Water Management, 2(1): 11-24, Wageningen, Netherlands.
- Boost, C.W. and Don Kirkharm. 1971. Auger-Hole Seepage Theory. Soil Sci. Soc. Amer. Proc. 35: 365-374.
- Bornskein, J. 1964. Ground Water movement in poorly drained glacial tilth soil, Tran. ASAE, 7: 38-45.
- Bottcher; A.B., Monke, E.J. and Huggins, L.F., 1980. Sub-surface drainage and Sediment transport model. Transaction of the ASAE, 23(4): 870-876.

- Bottcher, A.B., Monke, E.J. and Huggins, L.F., 1981.
Nutrient and Sediment loadings from a sub-surface
drainage system. Tran. ASAE, 24(5): 1221-1226.
- Bouma, J. and F.D.Hole, 1971. Soil structure and hydraulic
conductivity above a water table with the double-tube
method. Soil Sci. Soc. Amer. Proc. 26: 330-335.
- Bouma, J., Dekkar, L., Verlinder, H.L., 1975. Drainage and
vertical hydraulic conductivity of some dutch 'Kmik'
clay soil. Agricultural Water Management. (1) 167-68,
Wegemington, Netherlands.
- Bouwer, Horman, 1962. Field Determination of hydraulic
conductivity above a water table with the double tube
method. Soil Sci. Soc. Amer. Proc. 26: 330-335.
- Bouwer, Herman, 1961. A double-tube method for measuring
hydraulic conductivity of soil in situ above a water table.
Soil Sci. Soc. Amer. Proc. 25: 334-339.
- Bouwer, Herman, 1964. Measuring horizontal and vertical
hydraulic conductivity of soil with the double-tube
method. Soil Sci. Soc. Amer. Proc. 28: 19-23.
- Bouwer, Herman. 1966. Rapid Field Measurement of air-entry
value and hydraulic conductivity of Soil as significant
parameters in slow system analysis. Water Resour.Res.
21: 729-738.
- Bouwer, Herman and R.C.Rice, 1967. Modified tube diameters
for the double-tube apparatus. Soil Sci.Soc. Amer.
Proc. 31: 437-439.

- Bouwer, H. and Rice, R.C., 1983. The put bailing method for hydraulic conductivity measurement of Isotopic or anisotropic soil. Paper. ASAE. No.83-2039, 27 pp.
- Bravo, N.M. and G.O.Schwab., 1978. Effect of openings on inflow into corrugated Drains. Tran. ASAE. 20(1): 100-110.
- Broadhead, R.G., Schwab, G.D., Reeve, R.C., 1980. The evaluation of synthetic envelopes for sub-surface drains. ASAE. Paper No.2541, 5 pp.
- Broadhead, R.G., Schwab, G.D. and Reeve, R.C., 1983. Synthetic Drain Envelopes and Soil particle size distribution. ASAE pp. 157-160.
- Broughton, R.S., English, B., Damanet, C., Anil, S., Mekyer, E. and Brasseur, J., 1976. Tests of filter materials for plastic drain tubes. Amer. Soc. Agri. Eng., 34-39.
- Broughton, R.S., Gameda, S. and Gibson, N., 1982. Field tests of some drain tube envelope materials. ASAE, 69-78.
- Bro, P.B. and Geoharing, L.D., 1983. Transient Reverse Auger Hole Measurement of hydraulic conductivity. Paper ASAE No.93-204 12 pp.
- Brown, Charles, F., 1915. Drainage of irrigated lands. U.S. Dep.Agr. Farmers Bull., 371, 52 p.
- Brownscombe, R.H., 1962. Field evaluation of tile drains laid with organic blinding materials. ASAE, 5(1): 61-63, 67.

- Buras, Nathan and Arthur, F., Fillsbury, 1963. Lateral movement of water along a glass fiber sheet utilized as a filter for drain tile. Amer. Soc. Agr.Eng. Trans. 6(2): 173-174.
- Bureau of Reclamation, 1966. Land drainage technique and standards. Reclamation. Institute Series, 520. Denvar Col. p. 526-2; 7-526. 2.15.
- Burgess, P.A., 1928. Alkali soil studies and methods of reclamation. Ariz Agr.Expt. Sta. Bul. 123.
- Burghardt, W., Foerster, P., Scheffer, B., 1979. Influence of some soil properties on the decomposition of drain filter made of coconut fibers. Part I. Zeilschriff fur Kulturfechon K und Flurbereimigings 19: 363-370.
- Burghardt, W., Foerster, P. and Scheffer, B., 1979. The effect of Land Use, management and installation technique on the durability of drain filters made from coconut fiber, Report. Zeilohriff fur Kulturfeehon K und Flurabereinings 20(1): 11-19.
- Burghardt, W., 1979, Development of plastic fiber drain filter Die Entwickling Von Dran Vollfibtern aus Kunststofffasen Wasser Und Boden 31(1): 14-17. German Fedral Republic.
- Burghardt, W., 1983. Investigation on the Decomposition of coconut fibre filters in Marsh soils. Zeitschriff fur Kulturtechnik Und Flurbereinigung 24(1): 43-49. G.O.R.
- Burch, C.D., 1958. Low cost subsurface drainage. Agr.Eng. 39(2): 92-93, 97, 103.

- Cade E. Carfer, W.W. Donnan, L.G. Kind and G.O. Schwab, 1975, Agricultural drainage needs and priorities, Transaction of ASAE 18: 529-534.
- Cannel, R.Q. and Belford, R.K., 1982. Crop growth after transient Water logging, Advances in Drainage, ASAE, 163-170.
- Carter, C.E., Wretten, F.T. and Halverson, B., 1983, Hydraulic Conductivity measured electrically in an auger-hole. Paper, ASAE No. 83 - 2040 14 pp.
- Carter, C.E. and Camp, C.R., 1983. Subsurface Drainage of an alluvial Soil increased sugarcane yield. Transaction of the ASAE, 26(2): 426-429.
- Cavelaars, T.C., 1966. Hydrological aspects of the plastic drain pipes and filter materials. Czechosllovak. Scientific and Technical Soc. Agr. and Forestry Section, Prahal, Siroka, 5: 17 pp.
- Childs, E.C., 1952. The measurement of the hydraulic permeability of saturated soil in situ. I. Principles of a proposed method. Roy. Soc(London), Proc. A 215: 525-535.
- Childs, E.C., A.H. Cole. and D.H. Edwards, 1953. The measurement of the hydraulic conductivity of saturated soil in situ, II Roy. Soc(London), Proc 216: 72-89.
- Childs, E.C. and Yong, E.G., 1958. The Nature of the drain Channel in the design of an land drainage system. Journal of Soil Sci. (9): 316-331.
- Childs, E.C., 1960. A treatment of the capillary fringe in drainage theory. Journal of Soil Sci. (10): 83-100.

- Childs, E.C., 1960. The non-steady state of the water table in drained land. *Journal of Geophysical Research* (68): 479-481.
- Childs, E.C., 1968. The achievement of drainage theory in relation to practical need. Taking stock. *Int.Congr. Soil Sci. Proc. of 9th (Adelaide, Australia)*, 1:349-356.
- Clark, F.E. and W.D.Kemper, 1967. Microbiological activity in relation to soil water and soil aeration in R.M.Hagen et al.(ed). *Irrigation of Agricultural Lands, Agronomy*, 11: 472-480.
- Creager, W.P., Justin, J.D. and Hinds, J., 1968. Engineering for dams. *Wiley Eastern Pvt.Ltd. New Delhi*. pp.682-688.
- Christopher. and J.N.Tekrony, R.G., 1982. Benefits related to water table and salinity control. *Paper ASAE No.82-2077*, 13 pp.
- Dakshinamurthy, C., Michael, A.M. and Shrimohan, 1973. Water resources of India and their utilization in agriculture. *Water Technology Centre, IARI, New Delhi* pp 335-348.
- Deboer, D.W. and Johnson, N.P., 1965. Investigating of flow into tile at joints. *Agri.Engg.* 46(9): 494.
- Dejager, A.W., 1960. Review of plastic drainage in the Netherlands, *Netherlands J.Agric.Sci.* 8(4): 261-270.
- Dennis, C.W. and B.C. Trafford, 1975. The effect of permeable surrounds on the performance of clay field drainage pipes. *Journal of Hydrology*, 23: 239-249.

- Dennis, C.W., 1978. The failure of a pipe drainage system in an organic and subsequent remedial measures. Technical Report. Field Drainage Experimental No.78/3, 11 p.
- Dennis, C.W. 1982. Field Drainage - a specification for permeable back-fill. Journal of Agricultural Engineering Research, 27(6): 529-535, UK.
- Dierick W., Bishey, B.G. and Maton, A., 1975. Aspects of silting up of drainage pipes. J.Agr.Engg. Res. 20: 123-137.
- Dierickx, W., Molen, and W.H.Vander, 1981. Effect of perforation shape and pattern on the performance of drain pipes. Agricultural Water Management, 4(4): 420-443.
- Dierickx, W., 1982. Hydraulic gradient near sub-surface drains and soil erosion. Paper ASAE No.82 - 2565.
- Dierickx, W., 1982. Structural stability of soil and need for drainage envelopes. In Advance in Drainage. ASAE Pub. 12-82, Belgium.
- Diserens, E., 1934. Beistrag zur Bestimmung der Durchlassigkeit des Bodens in natuerlicher Bodenlagerung. Schweizerische Landow. Monatshafte. XII: 1 and following.
- Donate, J., 1935. Die Sangstrangent fering bei Dranngen in Mineralhoden Wasser-Wirshaft and Technik; 207.
- Donnan, W.W. and V.S.Aronovice, 1961. Field measurement of hydraulic Conductivity. J. Irrig. & Drain.Div. Amer.Soc.Civil Eng., 87(IR-2): 1-13.
- Dorsey, C.W., 1906. Alkali soils of the United State, USDA Bur.Soils, Bul. 35.

Doty, C.W., Currin, S.T. and Mohn, R.E. 1975. Controlled Sub-surface drainage for southern coastal plains soil. *Journal of Soil and Water Conservation*, 30(2): 82-84.

Drainage Manual, 1972. Irrigation and Drainage paper. Food and Agricultural Organisation of the United States (9): 1-20.

Drainage Manual, 1978. A water resources technical publication. Bureau of reclamation. Department of the interior. 191 pp.

Dutz, H.G., 1950. Flow of ponded water into drains as affected by space between individual tiles. M.S. Thesis. Iowa State Uni. Library, Amer.

Dylla, A.S. and J.C.Guitgens. 1970. Hydraulic Conductivity sampling for confidence. *Amer. Soc.Agr.Eng. Trans*, 13: 485-488.

Earnst, L.F., 1962. Ground water flow in the saturated zone and its calculation when parallel horizontal open conducts are present. *Versl.Landh* and 67: 15-189.

Edminster, T.W., 1965. The challenge of new technology in drainage, P.43-45. In drainage for efficient crop production conf.(Chicago). *Amer. Soc. Agr. Eng.* St.Joseph, Mich.

Ede, A.N., 1957. Continuously formed concrete tube for drainage. *Agro.Eng.*, 38(12): 864-866.

EL-Mowelhi, N.W. and Schilfgaard, J. Van, 1982. Computation of soil hydrological constants from field drainage experiments in some soils of Egypt. *Trans. ASAE*, 25(4): 984-986.

- Engelund, F., 1953, Mathematical discussion of drainage problems, Danish Academy of Sciences, No.3.
- Engelund, F., 1953. On the Laminar and Turbulent flows of ground water through homogeneous sand. Transactions, Danish Aca. Tech. Sci. No.3.
- Engineering Standard for sub-surface Drains, 1977. Sub-surface drain specifications: Materials, National hand book of conservation practices. Soil Conservation Service. United States Department of Agriculture, 606.
- Ernst, L.F., 1978. Drainage of undulating sandy soil with high ground water table 1. A drainage formula based on a constant hydraulic head ratio, 11. The variable hydraulic head Technical Bulletin. Institute of Land Water Management Research, No.106: 50 pp.
- Falcial, M., Bruno, V., 1982. Drainage trails for salinity control. Rivista di Agricoltura Subtropicalee Tropicale, 76(3-4): 261-285.
- FAO/UNESCO: 1971-1979. Soil map of the world volume 1-X UNESCO, Paris.
- Food and Agricultural Organisation, United Nations, 1976. Drainage Materials, FAO, Irrigation and Drainage Paper No.9, 122 pp.
- Fausy, N.R. and S.S.Hundal, 1980. Role of trench back-fill in sub-surface drainage. A Review. Trans. of the ASAE, 1197-1200.
- Fausy, N.R., Taylor, G.S. and Schwab, G.O., 1983. Tillage related effects on sub-surface drain flow rate in a clay soil with impaired permeability. Paper ASAE, No.83-2149, 18 pp. USDA-ARS, Columbus, OH.USA.

Fisher, L.S. and A.R.Jarrett, 1984. Sediment retention efficiency of synthetic filter fabrics, Transaction of the ASAE, Vol.27(2):429-436.

Ford, H.W., 1970, Sludge and associated problems involving agricultural drains in Florida wet lands. Special symposium, ASAE and ASCE. In Social and Ecological Aspects of Irrigation and Drainage of ASCE.

Ford, H.W., 1970. Methods of drains installation to control sediment and chemical deposits in Florida wet lands. Amer.Soc.Agric. Eng. Minneaplis, 70-211.

Ford, H.W., 1974. Low pressure jet cleaning of plastic drains in sandy soil. Transactions of the ASAE, 17(5): 895-897.

Ford, H.W., 1979. Characteristics of aslimes and Ochre in drainage and irrigation systems. Transactions of the ASAE, 25(5): 1093-1096.

Ford, H.W., 1982. Estimating the potential for Ochre clogging before installing drains. Transaction of the ASAE, 25(6): 1597-1600.

Foround, N. and R.S.Broughton, 1978. Effect of different drainage rates on the duration of high water tables in South-western Quibbee, Canadian Agr.Eng. 20(2): 71-75, Canada.

Fortier, S. and Cona, V.M., 1909. Drainage of irrigated lands in the Sanjonquin Valley. California, USDA. OES Bul: 217.

- Fouss, J.L. and W.W. Donnan, 1962. Plastic-lined mole drains. Agr.Eng. 43(9): 512-515.
- Fouss, J.L., 1965. Plastic drains and their installation, p. 55-57. In drainage for efficient crop production. Comb(Chicago). Amer. Soc. Agr.Eng, St.Joseph. Mich.
- Fouss, J.L. and N.R.Fausy, 1967. Laser beam depth control drainage machine. Ohio Report, 52(4). 51-53.
- Fouss, J.L., 1968. Corrugated plastic drains plowed in automatically. Amer. Soc. Agr.Engg: Trans, 11: 804-808.
- Fouss, J.L., 1971. Status of specifications for corrugated plastic drain tubing. Amer. Soc. Agr.Eng, Conf. Proc. National Drainage Symp. p. 32-33, 36.
- French, H.F., 1959. Farm drainage. A.O., Moore and Co. New York, 400 p.
- French, B.E. and J.R.O. Callghan, 1966. A field test of drain spacing equations for Agricultural Land. J.Agr.Engg.Res. 11: 282-295.
- Frevert, R.K. and Don Kirkham. 1948. A field method for measuring the permeability of soil below the water table. Highw. Res. Bd. Proc. 28: 433-442.
- Fukunaka, A., 1980, Sub-surface drainage by plastic drains. Construction methods and drainage effects. Research Bulletin of the Honkaido, National Agricultural Experiment Station, 127: 109-122, Japan.
- Fukunaka, H., 1980. Sub-surface drainage by plastic drains working efficiency and drainage effect of different types of sub-surface drains in peat Bog Research Bulletin of the Hokkaido, National Agri.Experiment Station, 127: 123-13

- Ganeda, S., P.J.Jwtras, and R.S.Broughton, 1983. Ochre in sub-surface drains in a quebec fine sandy soil. Canadian Agricultural Eng., 25(2): 209-213.
- George, S. Taylor and Trumen Goins, 1957. Characteristics of water removal in a tile drained humic clay soil. Soil Sci.Soc. Proceedings, P. 575-579, 580.
- Goettelman, R.C., Grass, L.B., Millard, J.P. and Nixon, P.R., 1983. Comparison of multispectral remote-sensing techniques for monitoring sub-surface drain conditions. NASA, Technical Memorandum, No.84317, 16 pp. California, USA.
- Gold, A.J. and Loudon, J.L., 1982. Nutrient, sediment and herbicide losses in tile drainage under conservation and conventional tillage. ASAE, No.82, 2549, 14 pp.
- Grass, L.B., 1969. Tile clogging by iron and manganese in Imperial valley, C.A. Jour.Soil and Water Conservation, 24(4): 135-138.
- Grass, L.B. and A.J.Mackenzie, 1972. Restoring sub-surface drain performance. J.Irri. and Drai. Div. ASCE, 98: 97-106.
- Grass, L.B. and L.S.Willardson, 1974. High pressure jet cleaning of sub-surfade drains. Trans. of the ASAE, 17(5): 886-888, 891.
- Grass, L.B., A.J.Mackenzie, and L.S.Willardson, 1975. Inspecting and cleaning sub-surface drain system. USDA Farmers' Bul. 2258.
- Grass, L.B., L.S.Williardson and R.A.Lemert. 1979. Sediment deposits in sub-surface drains. Trans.of the ASAE, 22(5):1054-1057. USDA-SEA. Brawlegien, USA.

- Gulati, O.P., G.O.Schwab and R.C.Reeve, 1970. Control of sediment flow into sub-surface drains. ASCE Proc. 96(IR 4): 437-449.
- Gulati, O.P., 1977. Evaluation of filter design practices as related to sub-surface drain sedimentation. Journal of the Institution of Engineers (India), 54: 41-46.
- Habib, I.M., 1974. Leaching of saline soils in monoliths of Iraq. Egyptian J. Soil Sci. 14(2): 149-155.
- Hansan, Robert, L., 1963. Filter materials for sub-surface drains. Varmount Agr.Exp. Sta: Misc. Publ. 25: 7 pp.
- Harker, D.B., 1983. Characteristics trends and surface water quality implications of saline tile effluent. Paper, ASAE.No. 83-2107-10 pp. Alberta, Canada.
- Hart, R.A., 1917. The drainage of irrigated lands. U.S. Dep. Agr.Farmers Bull. 371: 52.
- Harris, F.S., 1920. Soil-alkali soils of the United States. USDA. Bur. Soil Bul. 35.
- Hautala, E. and Menefee, E., 1981. Artificial gravel produced by sintering. Soil Journal of the Science of Food and Agriculture, 32(5): 508-512.
- Hayward, H.E. and Magistard, O.C., 1946. The salt problem in irrigated agriculture. USDA, Misc. Pub. 607.
- Herman Houwer, M., 1969. Salt balance. Irrigation efficiency and drainage design. J.Irri. and Drain. Div. ASCE, 95 (IRI): 153-169.

- Hermesmeir, L.F. and L.S. Willardson, 1970. Friction factor for corrugated plastic tubing. J. Irri. Drain. Div. ASCE, 96(IR3): 265-271.
- Hermesmeier, L.F., 1973, Shallow drain performance in a heavy soils. ASAE, 92-94(P).
- Hermesmeier, L.F., 1976. Economical envelope for sub-surface drains in irrigated lands, ASAE, Third Nat. Drain Symp. Proc. 18-21.
- Hoffman, G.J. and G.O. Schwab, 1964. Tile spacing prediction based on drain out-flow. Amer. Soc. Agr. Eng. Trans. 7: 444-447.
- Holsambre, D.G., Varade, S.B., Acharya, H.S. and Rapte, 1982. Drainage characteristics of vertisols. Journal of the Indian Soc. Soil Sci. 30(2): 116-121.
- Hooghoudts, S.B., 1936. Bijdragen tot de Kennis van de natuurkundige grootheden van de grond, versl. Landb. Ordery, 42(13B): B 69-B 161.
- Hooghoudts, S.B. 1952. Tile drainage and sub-irrigation. Soil Sci. 74(1): 35-48.
- Hove, F.R. and R.W. Irwin, B.C. Mathews and F.J. Parush, 1960. Ontario. Agr. College, Pub. 29: 24 p.
- Hove, P. 1982. Filter materials for drains - experience in Norway. Zeitschrift für Kultur Technik Und Flurbereinigung, 23(2): 104-109, Norway.
-

- Hundal, S.S., G.S.Taylor and G.O.Schwab, 1977. Ochre and sub-surface drainage in cultivated organic soils on Willard Marsh, OH. Transaction of the ASAE, 20(3): 489-492.
- Hundal, S.S., Taylor, G.S. and Fausy, N.R., 1980. Back-fills effect on sub-surface drainage of Toledo soils with Grass-legume cover. Research circular. Ohio Agricultural Research and Development Centre, No.257, 14 pp. Ohio. USA.
- Ireland, W., 1980. An investigation of back-hoe installed tubing. ASAE, Paper No.80: 2057. Soil Conservation Service, Somerset NJ. USA.
- Irwin, R.W., 1960. Farm drainage. Dept. Sci. Ontario Agr. College Pub. 29-24 p.
- Irwin, R.W. and G.Tsang, 1972. Hydraulic roughness of corrugated plastic tubing. Trans. ASAE, 15: 290-292.
- Israelsen, O.W., 1935. Drainage and Irrigation, Soil economic and social conditions. Delta Area, Utah. Utah Agr.Expt. Sta. Bul. 255.
- Isherwood, J.D., 1959. Water table recession in tile drained land. J.Geophysical Res. 64: 795-804.
- Ivarson, K.C. and M.Sotak, 1980. Plugging of soil drains by Microorganisms. Canada Agriculture 25(4): 19-21.
- Janert, H., 1952. Die Mechanisierung der Dranarbuiten. Wasserwirt chaff wasser technik, 2: 392-397.
- Janert, H., 1950. Der Greifswalder Rochrpflug Und Seine Arbeit Weise Wasserwirts craff Wassertechnik, 2: 123-150.

- Jensen, M.E. and Hanks, R.J., 1967. Non-steady state water table. Journal of the Irrigation and Drainage Division, ASCE, 93(IR3): 209-231.
- Jones, B.A., Jr. 1960, Effect of crack width at tile joints on soil movement into drain tile lines. Trans. ASAE. 3(1): 33-35, 44, 54.
- Johnson, H.P., R.F. Frevert and D.D. Evans, 1952. Simplified procedure for measurement and computation of soil permeability below the water table. Agr. Eng. 33: 283-286.
- Johnson, Edward, E., Co. 1966. Ground water and wells. St. Paul. Minn. P.201.
- Johnston, W.R., J. Letey and A.F. Pellsbury, 1963. Hydraulic conductivity values using (1) ponded water theory and (2) Auger hole method. Amer. Soc. Trans. 6: 249-250.
- Joshi, N.C., 1968. Water logging and land drainage. Proc. Seminar on Soil and Water management. Inst. of Engineers (India). Bangalore pp. 249-254.
- Juusela, T., 1958. On method of protecting drain pipes and on the use of gravel as a protective filters. Amer. Soc. Test. Mater. 55: 183-198.
- Kanwar, R.S., H.P. Johnson and J.L. Baker, 1983. Comparison of simulated and measurement nitrate losses in tile effluent. Trans. ASAE, 26(5): 1451-1457.
- Karpoooff, K.P., 1955. The use of laboratory tests to develop design criteria for protective filters. Amer. Soc. Test. Mater, 55: 1183-1198.

- Kidder, E.H. and W.F. Lytle, 1949. Drainage investigations in the plastic till soils of North-Eastern Illinois. Ag.Eng. 30: 384-386, 389.
- Kirkham, Don and C.H.M. Van Bavel, 1948. Theory of seepage into auger-holes. Soil Sci. Soc. Amer. Proc. 13: 75-81.
- Kirkham, Don, 1949, Flow of ponded water into drain tiles in soil over-laying an impervious layer. Trans. Am. Geophys. Union, 30: 369-385.
- Kirkham, Don, 1950. Potential of flow into circumferential openings in drain tubes. J.Appl. Phys. 21: 655-660.
- Kirkham, Don. 1950b, Seepage into ditches in the case of a plane water table and an impervious substrata. Trans. Amer. Geophys Un. 31: 425-430.
- Kirkham, Don. and Schwab, G.O., 1951. The effect of circular perforation on flow into sub-surface drain tubes. Agr.Eng. 32: 211-214.
- Kirkham, Don. and J.W. Dezeew, 1952. Field measurement for tests of Soil drainage theory. Soil Sci. Soc. Amer. Proc. 16: 286-293.
- Kirkham, Don. 1954. Seepage of artesion and surface water into drain tube in stratified soil. Trans. Amer. Geophys. Un. 35: 775-790
- Kirkham, Don., 1954. Measurement of the hydraulic conductivity in place. Symposium on permeability of soil. Amer. Soc. Test Mater, Spec. Tech. Pub. 163: 89-97.

- Kirkham, Don, 1958. Seepage of steady rainfall through soil into drains. Trans. Amer. Geophys Union, 39: 892-908.
- Kirkham, Don, 1965. Saturated conductivity as a characterizer of soil for drainage design, p. 24-31. In Drainage for efficient crop production, Conf (Chicago) Amer.Soc.Agr.Eng. St.Joseph, Mich.
- Klimko, A.E. and Passinskie. V.M., 1966. Perforations in plastic drain tubes. Journal of hydrology and land reclamation, Vol. 3 (Translated from Russian to English by E.E.Merva).
- Kontze, H., 1982. Iron clogging in soil and pipes analysis and treatment. Pitman Book Ltd., Bulletin. German association for water resources and Improvement (DWWK) (10): 147.
- Kovda, V.A., 1957. Drainage in the struggle against the salinisation of irrigated soil. Rept. of III Congress of irrigation and drainage in San Francisco and Intern Gon on Irrig. and Drainage.
- Knight, E.H., 1932. Agricultural investigations of the New Lands (Naveda). Reclamation Projects, USDA. Tech.Bull. 464.
- Kruse, E. Gardon, 1962. Design of gravel packs for wells. Amer. Soc. Agr. Eng. Trans. 5(2): 197-199.
- Lea, F.H. and Desch, C.H., 1935. The Chemistry of Cement and Concrete. Longmans Green & Co. Inc. New York.
- Lembke, Walter, D., 1967. Observed and predicted tile flow on a lake Plain soil. Trans. ASAE, 10: 142-144.

- Lembke, Walter D. and D.A.Bucks. 1970. A model study of drain envelopes in a coarse silt material. Amer. Soc. Agr. Eng. Trans. 13(5): 669-671-675.
- Lidster, W.A. and H.W.Ford, 1981. Rehabilitation of Ochre (iron) clogged Agricultural drains. In Eleventh Congress on Irrigated and Drainage. Part I. 451-463. New Delhi, India.
- Linder, H. and Schaffer, E., 1980. Effect of drain pipes with different parameters in a fine-grained sandy soil. Zur Wirksamkeit Von Dranrwhren nit Verse hiedemen parameter in civen fainhoriyan sandboden Arch fur Acker- Und Pblanzenban Und Bodenkunde. 24(9): 577-583.
- Linder, H. and Schaffer, E. 1981. Prevention of drain siltation in medium to fine sandy soil. Archiv. fur Acker Und Pblenzenban Und Bodenkunde, 25(12); 727-733. GDR.
- Linder, G. and Schaffer, E., 1984. Model experiments on the efficiency of smooth walled and grooved ceramic drain pipes. Archiv fur. Acker-Und Pblanzenbau Und Bodenkunde, 28(3): 153-156.
- Logan, T.J. and G.O. Schwab, 1976. Nutrient and Sediment characteristic of tile effluent in Ohio. Journal of soil and water conservation, 31(1): 24-27.
- Luthin, J.N. and Don Kirkham, 1949. A Piezometerie method for measuring permeability of soil in situ below a water table. Soil Sci. 68: 349-358.
- Luthin, J.N., 1957. Drainage of agricultural land. Edited by J.N.Luthin. Amer. Soc.of Agron. Madison, Wisco. pp. 155-169.

- Luthin, J.N., 1957. Measurement of hydraulic conductivity in situ. In J.N. Luthin (Ed). Drainage of Agricultural lands. Agronomy, 7: 420-439. Amer. Soc. Agron. Madison, Wisco.
- Luthin, J.N., G.S.Taylor and C.Prieto, 1968. Exist gradients into sub-surface drains. Hilgardia 39(15): 419-428.
- Luthin, J.N. and Haig, A., 1972. Some factors affecting flow into drain pipes. Hilgardia, 41(10): 235-245.
- Lyons, T, L. Werenfels and C.H.Honston, 1964. Filter envelopes aid tile drainage in Sacramento-san Joaquin Delt. Test-Calif. Agr. 18(3): 14-16.
- Lyman, S.M. Willardson, L.James, Focuss C., Ronald Reeue. M., and R.Norman, R.Fauscy, 1970. Entry velocity control limits drain sedimentation. Journal of Irri. and Dra. Div. Proc. ASCE(94): 455-463.
- Lyman, S., Willardson, 1982. Drainage coefficient. Trans. ASAE, 25(3): 1256-1257.
- Maasland, M. and H.C.Haskew, 1957. The Auger-hole method of measuring the hydraulic conductivity of soil and its application to tile drainage problems. Inst. Congr. Comm. Irrig. and Drain. Trans. 3rd R-5. 8: 8.6.
- Massland, M. and Kirkham, D. 1959. Measurement of the permeability of tri-axially anistropic soil. Journal of the Soil Mechanics and Foundations Division, ASCE 5(3): 25-34.

- Mackenzie, A.J., 1962. Chemical treatments of mineral deposit in drain tile. J. Soil and Water Conservation, 17: 124-125
- Manson, P.W. and D.G. Miller, 1948. Essential characteristics of durable concrete drain tile for alkali soils. Agr. Eng. 29(11): 485-487.
- Manson, P.W. and D.G. Miller, 1954. Making durable concrete drain tile in packer head machines. Minnesota. Agr. Exp. Sta. Bull. 426.
- Manson, P.W. and F.W. Blaisdell. 1966. Computing energy losses at drain-tile junctions. Trans. ASAE, 9: 445-448.
- Marston, A., 1930. The Theory of external lands on closed conduits in the light of the latest experiments. Iowa Eng. Expt. St. Bull. 96.
- McLean, J.J.P. and G.O. Schwab, 1982. Flood peak flows and sub-surface drainage. Paper ASAE, No. 82-2053, 13 pp.
- Mehta, M.L., 1954. The behaviour of sub-soil water table under the Punjab Canals. Second Congress on Irrig. and Dra. R. 57-210.
- Meyerhof, G.G., and L.D. Baikie, 1963. Strength of steel culvert sheets bearing against compacted sand back-fill. High Res. Bul. Proc. Vol. 42.
- Michael, A.M. and Ojha, T.P., 1978. Principles of agricultural Engineering. Second Edition, Volume II. Jain Brothers, Jodhpur.

- Miller, D.G., 1916. The seepage and alkali problems in the Grand Valley. Colorado. Report of the U.S. Dept. Agri.
- Miller, D.G., 1921. Report of Concrete alkali investigations in Minnesota. Minnesota Department of Drainage and Waters, pp. 1-74.
- Miller, D.G. and P.W. Manson, 1933. Laboratory and field tests of concrete exposed to the action of sulphate waters. USDA Tech.Bul. 358, pp. 1-80.
- Miller, D.G. and G.G.Snyder, 1944. Expansion of clay and concrete drain tile due to increase of temperature and moisture content. Agr. Engg. 25: 179-180.
- Miller, D.G. and P.W.Manson, 1948a. Durability of concrete and mortars in soils with particular reference to drain tile. Minn. Agr.Expt. Sta. Tech. Bul. 180.
- Miller, D.G. and P.W.Manson, 1948b. Essential characteristics of durable concrete drain tile for acid soils. Agr.Eng. 20(10: 437-441.
- Miller, D.G. and P.W.Manson, 1951. Long-Time tests of concrete and mortars exposed to sulphate waters. Minn.Agr.Expt. Sta. Tech.Bul. 194.
- Miller, D.G. and P.W.Manson, 1951. Long-time performance of some clay drain-tile, Agr.Eng. 32(2): 95-97. 100-101.
- Miller, R.J., J.W.Bigger. and O.R.Nielson, 1965. Chloride displacement in panochre clay loam in relation to water movement and distribution. Water Resources Res. 1: 63-73.

- Miller, E.R. and E.J.Monke, 1980. Sediment movement into sub-surface drain from back-fill profiles. ASAE Paper No.80-2047, Purdue Univ. USA.
- Miller, D.G. and L.S.Willardson, 1983. Head loss at soil drain envelope interfaces. J.Irri. and Drain. ASCE, 109(2): 211-222.
- Misra, M.K. and R.P. Bearleg, 1975. Corrugated plastic drain tubing used as Underground conduct, ASAE, p.20.
- Mohammed, F.S. and R.W.Skaggs, 1983. Drain tube opening. Effects of drain inflow. Journal of irrigation engineering. 109(4): 393-404. Iraq.
- Mohammed, F.S. and R.W.Skaggs, 1983. Experimental determination of drain openings effects on drain rates. Paper, ASAE No.83-2147.
- Moran, K.L., 1971. The use of corrugated plastic tubing for sub-surface drainage. ASAE, Paper No.71-243.
- Myers, V.I., R.J.Rektorik. and C.A.Wolfe, Jr. 1967. Deflection tests and trench conditions for plastic drain pipe. ASAE, 10: 454-456.
- Myers, V.I.(Editor), 1967. Report of Drainage materials prepared by the committee on drainage materials and materials handling, Amer. Soc. Agr.Eng.
- Narayana, V.V. and S.K.Kamra, 1982. Sub-surface drainage for saline soil reclamation in polders of the world. Vol. III. Late Paper Wageningen. Netherlands. International Inst. for Land Reclamation and Improvement.

- Neal, J.H., 1934. Proper spacing and depth of tile drains determined by the physical properties of the soil. Minnesota Agr.Exp.Sta. Tech. Bull. 101.
- Nelson, R.W. 1960. Fiber-glass as a filter for closed drains. Agr. Eng. 41(10: 690-693-700.
- Nielson, D.R., Bigger, J.W. and Luthin, J.W., 1965. Desalination of soils under controlled unsaturated flow conditions. Int.Comm. Irri. and Drai. 6th Congress, New Delhi. India. pp. 15-24.
- Nieuwenhuis, G.J.A. and J.Wesseling, 1979. Effect of perforation and filter materials on entrance resistance and effective diameter of plastic pipes. Agri.Water Management (2): 1-9.
- Nwa, E.U., 1981. Using the Bamboo(*Bambus vulgaris*) as field drainage materials. Trans. ASAE, 24(4): 974-976.
- Olbertz, M.H. and G.Wertz. 1962. Hydraulische versucha Zur Bestimmung des Leistungs vermogen von plast folien-rohren zeitechrift fur Landeskultur Bul. 3: 97-111.
- O'Neal, A.M., 1949. Soil characteristics significant in evaluating permeability. Soil Sci. 67: 403-409.
- Overholt, Vigil, 1959. Fiberglass filter for tile drains. Agr.Engg 40: 604-607.
- Paterson, E. and Mitechall. B.D., 1978. Erosion deposits in tile drains. Agricultural Water management. 1(4): 311-317. The Macauley Institute of Soil Research, UK.

- Pillusbury, A.F., R.E. Pelishek., and N. Bures, 1960.
Wetting expansion of drain tile and its effect on water entry. Trans. ASAE, 3(1): 88-89.
- Pillusbury, E.H., Taylor, M., R.W. Pelishek. and J.F. Osborn, 1964. An experiment on flow through smooth joints. ASCE, 34(30): 69.
- Pillsbury, A.F., 1967. Observations on tile drainage performance. Amer. Soc. Civil. Eng. Proc. 93(IR3): 233-241.
- Piper, C.S., 1966. Soil and plant analysis. Hans Publishers, Bombay.
- Plames, D.B. and H.P. Johnson, 1962. Field evaluation of flow through blind inlets. Amer. Soc. Agr. Eng. p. 58-60.
- Plamenea, N., 1982. Some properties of drainage filters used in agriculture. In proceedings of the 9th Conference of the Soil Tillage Research Organisation, 33-44, Yugoslavia.
- Polubarinova-Kochina, P.Y., 1962. Theory of ground water movement (translated from the Russian by J.M. Koger De Wiest). Princeton University Press, Princeton, N.J., 613 p.
- Ponu, U.S. and W.N. Stammers, 1976. Effect of drain boundary and sub-surface drain design. Proc. 3rd National Drainage symposium, ASAE, MI. 49085 pp. 22-26.
- Porcella, D.B., 1970. Biological effects on sediment water nutrients interchange. Proc. ASCE, 911-927.

- Powers, W.L., 1919. The improvement of marsh lands in Western Oregon. Oreg. Agr. Exp. Sta. Bul. 157.
- Ransch, D.L. and J.D.Schreiber, 1977. Callaghan reservoir sediment and nutrient trap. Efficiency. Trans. ASAE, 29(2): 231.
- Rapp, E. and Ashraf, M., 1966. Deformation of corrugated plastic drains by soil surface loads. Canadian Agricultural Engineering, 18(1): 7-9, Canada.
- Reeve, R.C., Allison, L.E. and Peterson, Jr. D.F., 1948. Reclamation of saline-alkali soils by leaching. Utah Agri.Expt. Sta. Bul. 336.
- Reeve, R.C., 1953. Factors influencing drainage designs in irrigated areas. Agr. Eng. 34: 88-90.
- Rektorik, R.J. and M.V.Myers, 1967. Polyethylene drainage pipe installation techniques and field performance. Amer. Soc. Agr. Eng. Trans. 10: 458-459, 461.
- Richards, L.A.(Edited). 1954. Diagnosis and Improvement of saline and alkali soils. USDA Hand Book No.60.
- Rice, R.C., 1969. Dynamic Response of small piezometers. Amer.Soc.Agr.Eng. Trans. 10: 80-83.
- Roe, H.B. and Q.C. Ayres, 1954. Engineering for agriculture drainage. Agr. Eng. 36: 86-89.
- Royowski, A.S. and W.D. Shorader, H.P.Johnson and Don Kirkham, 1966. Tile drainage experimentation on Webster soils. Results of years, 1954-63. Iowa State J.Sci. 41: 25-40.

- Sack, H., 1933. Apparatus for laying drain pipes or cables. U.S. Patent, 904, 666, Official Gazette U.S. Patent Office, 427-429, Agril. 1933.
- Samani, Z.A. and Willardson, 1981. Soil hydraulic stability in a sub-surface drainage system. Trans. ASAE, 24(3): 666-669.
- Schwab, G.O. and D.Kirkham, 1951. The effect of circular perforation on flow into sub-surface drain tubes. Part II. Experiments and Results. Agr.Eng. 32: 270-274.
- Schwab, G.O., 1955. Plastic tubing for sub-surface drainage. Agr.Eng. 36(2): 86-89, 92.
- Schwab, G.O., J.L.Fouss and D.P.Leach, 1961. Rate, duration and frequency of tile flow. Agri.Eng. ASAE, 42: 546-549.
- Schwab, G.O. and T.J.Thiel, 1963, Hydrological characteristics of tile and surface drainage systems with grass covers. Trans. ASAE, 6: 89-91.
- Schwab, G.O., 1965. Plastic tubing for subsurface drainage. Agr. Eng. 56: 86-89.
- Schwab, G.O. and J.L.Fourss, 1967. Tile flow and surface run-off from drainage system with corn and grass covers. Trans. ASAE, 10: 492-496.
- Schwab, G.O., Darrell. W. Deboer and Howard, P. Johnson, 1969. Effect of openings on design of sub-surface drains. Proc. ASCE, Irr. and Drai. Div. 95(IRI): 199-209.

- Schwab, G.O., 1969. Procedure for determining hydraulic capacity of tile drains in humid areas. Amer. Soc. Agr. Eng. Tran. 12: 766-768.
- Schwab, G.O., E.O. Melean, A.C., Waldron., R.K. White and D.W. Michever, 1973. Quality of drainage water from heavy textured soil. Trans of ASAE, 16(6): 1104-1107.
- Schwab, G.O., 1974. Proportional sampler for tile or surface flow. Instrument news, Agricultural Engineering, 55(3): 22.
- Schwab, G.O., B.H.Nolte and R.D. Brehim, 1977. Sediment from drainage system for clay soils. Trans of ASAE, 20(5): 866.868, 872.
- Schwab, G.O., N.R. Fausey, and D.E. Kopact, 1980. Sediment and chemical content of agricultural drainage water. Trans. of ASAE, pp. 1446-1449.
- Schwab, G.O., E.D.Desmond. and W.J.Ochs, 1982. Ultraviolet standard for corrugated plastic tubing. In Advances in drainage. ASAE Publication St.Joseph Michigan, USA, 87-92.
- Schwab, G.O. and T.J.Logan, 1982. Sediment and nutrient in effluent from sub-surface drains. ASAE. No. 522-550 pp
- Schaffer, E., 1976. Use of plastic materials for drainage and ground water control by sub-surface system. Fertis-chritts berichite fur die land weirtscheft und Vahrungs guterneirtrohiff, 14(14): 55-40 R.

- Scheffer, B. and G.Kuntze, 1979. Organic drain filter to prevent clogging with ochore. Part 3. drain sludge and filter quality, Zeitschrift fur Kutturtechnik Und Flurbereimgurif, 20(3): 146-151. G.D.R.
- Scheffer, B., 1982. Drain flushing in field tests in brokesn zeistscheift fur kultur technik Und Flubereinigung, 23(2): 110-114.
- Sekendar, M.A., 1984. Entrance resistance of enveloped drainage pipes. Agricultural water management. 8(4): 351-360.
- Shull, Hollis, 1964. Hydraulic characteristics of glass fiber materials. Trans. of ASAE, 7(2): 120-122.
- Shull, Hollis, 1967. Soil filtering properties of glass-fiber Mat. Soc. Agr. Eng. Trans. 10(5): 655-657.
- Sing, B. and Michael, A.M., 1974. Predicting discharge from tile drains. J.Agr. Eng. 22-26.
- Sission, D.R. and B.A.Jones, Jr. 1962. Filter materials for tile drain in a medium sand - A laboratory comparison. Amer. Soc. Agr.Eng. Trans. 5(1): 50-54.
- Sission, D.R., 1965. Envelope materials - Their use in drainage. p. 51-54. In Com Proc. Drainage for effective crop production. Amer. Agr. Eng. St. Joseph, Michigan.
- Skaggs, R.W., 1978. Effect of drain tube openings on water table draw-down. Journal of Irri. and Drai. ASCE, 104(IR1): 13-21.
- Skaggs, R.W. and Y.K. Tang. 1979. Effect of drain diameter Openings and envelops on Water draw-down. Trans. ASAE, 27: 326-333.

- Skaggs, R.W., 1979. Factors affecting hydraulic conductivity determination from draw-down measurement. ASAE, Paper No.79-2675, 22 pp.
- Skempton, A.W., 1960. Terzaghi's Discovery of effective stress from theory to practice. Soil Mechanics. John Wiley and Sons, N.Y. pp. 42-53.
- Smiles, D.E. and E.C. Yongs, 1965. Hydraulic Conductivity determination by several field methods in a sand tank. Soil Sci. 99: 83-87.
- Snell, A.W. and J.Van Schilfgaarde, 1964. Four-Well method of measuring hydraulic Conductivity in saturated soils. Amer. Soc. Agr.Eng. Trans. 7: 83-87, 91.
- Sneyd, A.D. and Hosking, R.J., 1976. Seepage flow through homogeneous soil into a row of drain pipes. Journal of hydrology, 30: 127-146.
- Sommerfieldt, T.G., 1975. Out-flow from various subsurface drainage materials. Trans. ASAE, 18(1): 85-88.
- Soil Conservation Service, 1971. Drainage of agricultural lands. U.S. Agr. Sea-Nat.Eng. Hand book. Sect. 16. 46 p.
- Soil Survey Staff, 1975. Soil Taxonomy, A basic system of soil classification for making and interpreting soil survey. U.S. Dept. of Agri. Soil Conservation Service, Agri.Hand Book No.436.
- Spencer, W.F., R.Patrick and H.W. Ford, 1963. The occurrence and cause of iron oxide deposits in tile drains. Soil Sci. Soc. Proc. 27: 134-137.

- Studebaker, D.C., 1971. The laser-plane system.
Agri. Eng. 53(8): 418-419.
- Stojacic, M. and D. Sevie, 1978. Hydraulic characteristics of PVC corrugated pipes. In Tenth Congress on Irri. and Drain. Trans. Vol. IV. New Delhi. 34/1 285-34/1/293.
- Stuyt, L.C.P.M., 1981. Development in research on drainage filter materials in the Netherlands. Soil and Water, 9(2): 31-33. Inst. for Land water Management, Wageningen, Netherlands.
- Susser, P. and Schwertmann. 1983. Iron oxide minerology of ochreous deposits in drain pipes and ditches. Zeitschrift für Katturtechnik und Flubereinigung. 24(6): 386-395: GDR.
- Svobodova, V. and Vinsoua, 1979. The decomposition of filter materials in soil. A model experiment. Veruchivstat: fur Meliorationen Prague Zbralar czechoslovak, 20(1): pp. 42-50.
- Swartzendraber, Dale, 1962. Approximate water flow rate for tube drains in stratified soil. J. Geoph. Res. 67: 2390-2402.
- Tabolt, R.J. and I.J. Bruce, 1974. Effect of leaching on salinity levels and other soil properties of a clay soil in the Lookyer Valley, Queensland. J. Agri. and Amer. Sci. 31(2): 175-183.
- Talman, A.J., 1978. Interactions between iron ochre and pipe slots. An experimental study. Technical Report. Field Drainage Experimental Unit. No. 78/2 13 p.

- Talsma, T. and S.E. Flint, 1958. Some factors determining the hydraulic conductivity of sub-soils with special reference to tile drainage problem. Soil Sci. 85: 198-206.
- Talsma, T. 1960b. Comparison of field methods of measuring hydraulic conductivity. Int. Congr. Conf. on Irri. Drain.Proc. 4th C. 146-156.
- Tang, Y.K. and R.W. Skaggs, 1978. Sub-surface drainage in soils with high hydraulic conductivity layers. Trans. ASAE, 21(8): 515-521.
- Taylor, G.S. and Goins, J. 1967. Field evaluation of the tile drain filters in a humid region. Soil Res. Circular. 154, As quoted in Agronomy Monograph No.17.
- Taylor, G.S., Hundal, S.S., Fausey, N.R. and Schwab, G.O., 1981. Back-fill alteration effect on pipe drainage of clay soil. Soil Sci. Soc. Amer. Journal. 45(3): 611-616.
- Telati, N.R., 1975. Effect of amendments on flood plain soil at Anupgarh Sheka affected with saline sodic problem. J.Indian Soc.Soil Sci. 23(1): 135-137.
- Thomas, A.W. and A.W. Snell, 1967. Measuring hydraulic conductivity by the four well method. Amer. Soc. Agr.Eng. Trans. 10: 672-679.
- Thorne, D.W. and Peterson, H.B., 1954. Irrigated soils. Second Edition, Blakiston, New York.
- Theron, G. Summerfieldt, 1975. Out-flow from various sub-surface drainage materials. Trans. ASAE 18: 85-88.

- Theriault, R.U. Delisle, M. Brouillette and Asscun, R., 1982. Efficiency of drains with small perforations in sandy soil. Paper ASAE No.82-2566, 23 pp.
- Todd, D.K., 1959. Ground water hydrology. John Wiley & Sons. Inc. New York. N.Y.
- Topp, G.C. and S.Sattlocker. 1983. A rapid measurement of horizontal and vertical components of hydraulic conductivity. Canadian Agricultural Engineering, 25(2): 193-197.
- Truman, Coins, 1956. Tile flow characteristics in Agriculture. Agr. Eng. ASAE, 37: 30-33.
- Trafford, B.D.C, Bloomfield, W.I., Kelso. and C.Pruden, 1973. Ochre formation in field drain in pyrite soils. J.Soil Sci. 24: 453-460.
- U.S.D.A. (Soil Conservation Service), 1973. Drainage of Agriculture land. Water Information centre Inc. New York
- U.S.Army Eng. Water Ways Exp. Sta. Corps of Engineers, 1941. Investigation of filter requirements for under drains. Tech. Memo, No.183-1, 35 pp.
- U.S. Salinity Laboratory Staff, 1954. Diagnosis and Improvement of saline and alkanin soils. USDA. Hand Book No.60: 160(
- University of California, 1965. Drainage of recreational areas. s. Agri. Expt. Sor. Danis, 78.
- Van Bavel, C.H.M. and Don Kirkham, 1948. Field measurement of soil permeability using auger holes. Soil Sci. Soc. Amer. Proc. 13: 90-96.

- Van Bavel, C.H.M., K.T. Brust and G.B.Stirk, 1968.
Hydraulic properties of a clay loam soil and the
field measurement of water uptake by roots. The
Water Balance of the Root Zone. Proc. Soil Sci. Soc.
Amer. 32: 317-340.
- Van Bears, 1958. The Auger-hole method. Int. Inst. Land
Reclaim and Improve Bull. No.1 Weginingen.
The Netherlands, 32 p.
- Vander Molen, W.H. 1953. Depaling Vande Drainafstandon door
een monfologische beoordeling van het bodemprofile
Land Bouwk, Tildschr, 65: 105-113.
- Van Somern, C.L., 1964. Het drainage onderzock in Nederland,
Rapport, Cuttuurtee anischa Danish. 51 p.
- Van Schilfgaarde, J., R.K. Prevert. and W.J.Schlick, 1951.
Effect of present installation practices on drain
tile loading. Agr. Eng. 32: 371-374, 378.
- Van Schiffgaarde, J. 1974. Non steady flow to drainage,
Drainage for agriculture. J. Van Schilfgaarde,
Ed. American Society of Agronomy, Madison, Wiscos.
pp. 245-270.
- Vaughan, D., Wheatley, F.E. and B.G. Ord, 1984. Journal of
Soil Science, 35(1): 149-153, U.K.
- Visser, W.C., 1954. Tile drainage in the Netherlands.
Neth. J. Agr. Sci. 2: 69-87.
- Wallan, N.L., 1931. The Poppelrdorf Mole- tile drainage system.
Agr. Eng.12(1): 419-420.

- Waite, P.J., 1981. Soil Salinity, Water table modelling. Report. Hydraulic research Station No. OD.3610. Hydraulic research station. Wallingford, Oxen Ox10 8BA.
- Walter, M.F., R.D.Black. and P.J.Zwerman, 1979. Tile flow response in a Layered soil. Trans. ASAE, 22: 577-581.
- Walker, P.N. and C.L. Armstrong, 1980. Hydraulic characteristics of deflected corrugated plastic drainage. Trans. ASAE, 23(6): 1440-1445.
- Watts, D.G. and J.N. Luthin, 1963. Tests of thick fiber glass filter for sub-surface drains. Hilgardia, 35(3): 33-46.
- Watkins, R.K. and F.D. Nielson, 1964. Development and use of the Modpares, device. Journal of pipe line division. Proc. ASAE, 90(HL): 55-78.
- Weaver, M.H., 1964. History of tile drainage. Private Publication. M.M.Weaver, Waterloo, N.Y. 343, p.
- Weir, Walter, W., 1949. Land Drainage, Calif. Agr. Exp. Sta. Cir. 391.
- Wells, L.C. and R.W.Skaggs, 1976. Upward water movement in field cores. Trans. ASAE, 19(2): 275-283.
- Wesseling, J. and Homma, F., 1960. Entrance resistance of plastic drain, tubes. Technical Bulletin, 51. Institution of Land and Water Management Resources, Wageningen. The Netherlands.
- Willardson, L.S. and R.L. Hurst, 1965. Sample size estimate in permeability studies. J.Irri. Drai. Div. Amer. Soc. Agr. Eng. 91(IR1): 1-11.

- Willardson, L.S., Avellano, M.F. and Becker, E.R., 1966.
Comparatory laboratory tests of New drainage,
conducts. Trans. ASAE, 9(3): 362-354.
- Willardson, Lyman, S., James, Fouss, C. Ronald, Reeve. and
Norman, R. Fausy, 1968. Entry velocity control limits.
Drain sedimentation, Amer. Soc. Civil. Eng. Proc.
94(IR 4): 455-463.
- Willardson, Lyman, S.L., James, Fouss, C.R. Ronald, Reeve,
and Norman, R. Fausy, 1970. Entry velocity control
limits drain sedimentation. Closure. Amer. Soc. Civil.
Eng. Proc. 96(IR 3): 339-343.
- Willardson, L.S., Devis, D., Mulder, D. and Spencer, J.R., 1978.
Drain envelope response to field treatments. Trans.
ASAE, 18(1): 134-366.
- Willardson, L.S. and R.E.Waker, 1979. Synthetic drain envelope
soil interaction. Jour. Irri. and Drai. Divi. ASCE.
105(IRA): 367-373.
- Willardson, L.S., 1979. (Compiler). Factors influencing water
and particle movement into drain. U.S. Dept. Agr.
Science and Education Administration. Agri.Res.
Results. ARR-4-8, 70 pp.
- Wilson, L.G., J.N.Luthin. and J.W. Bigger, 1961. Drainage
salinity investigation of the Tule lake lease lands.
California. Agri.Expt. Sta. Bull. 799, Berkeley,
California.
- Winger, R.J. Jr. 1960. In place permeability tests and their
use in sub-surface drainage. Int. Congr. Comm. Irri.
and Drai. 4th Madrib, Spain. 48 p.

- Withers, B. and Vipond, S., 1974. Irrigation design and practices. B.T. Ratisford Ltd., London, pp. 156-170.
- Youngs, E.G., 1963. An infiltration method of measuring the hydraulic conductivity of unsaturated porous materials. Soil Sci. 97: 307-311.
- Youngs, E.G., 1965. A comparison of the performance of some plastic and tile-drains. Trans. ASAE, (3): 27-35.
- Youngs, E.G., 1968. Shape factors for Kirkham's piezometer method for determining the hydraulic conductivity of soil in situ for soils overlaying an impermeable floor or infinitely permeable stratum. Soil Sci. 106: 235-237.
- Youngs, E.G., 1976. Determination of the variation of hydraulic conductivity with depth in drained land and the design of drainage installation. Agricultural Water Management 1(1): 57-66(En). ARC. Unit Soil Physics, UK.
- Youngs, E.G.M., 1980. The hydraulic effect of filter material around gappy non-ideal field drains. Agricultural Water management (3): 77-34.
- Yunghaichen, Simons, D.B. and Demery, D.M., 1981. Hydraulic testing of plastic filter fabrics. Jour. Irri.Drai. Div. Amer. Soc. Civ. Eng., 107(IR3): 307-324.

APPENDIX

Appendix I. Computation of Static Load of Soil on Tile Drain under Ditch and Projecting conditions

Unit weight of saturated clay (back fill material) = $w = 0.00202 \text{ kg/cm}^3$

Depth to bottom of tile = $d = 90 \text{ cm.}$

Depth of top of tile = $H = 77 \text{ cm.}$

Outside diameter of tile = $D_o = 13 \text{ cm.}$

Width of ditch at top of tile = $B_d = 25 \text{ cm.}$

Total load on the tile per unit length (kg/lin. cm) = $W_o.$

Load coefficient (d and C_e , are obtained from Fig-7, for the values of $\frac{H}{B_d}$ and $\frac{H}{B_c}$, respectively, ditch and projecting conduit condition.

Ditch conduit conditions

$$W_c = C_d w B_d^2$$

$$C_d = \frac{H}{B_d} = \frac{77}{25} = 3.08 \text{ (Read from Fig.7)}$$

$$W_c = 2 \times 0.00203 \times 25 \times 25 = 2.54 \text{ kg/lin.cm}$$

$$W_o = 2.54 \text{ kg/lin.cm}$$

Projecting conduit conditions

$$W_e = C_e w B_e^2$$

$$C_e = \frac{H}{B_o} = \frac{77}{12} = 6.43 = 9.5 \text{ (Read from Fig-7)}$$

$$W_o = 9.5 \times 0.00203 \times 12 \times 12 = 2.76 \text{ kg/lin cm}$$

$$W_o = 2.76 \text{ kg/lin.cm.}$$

Appendix II. Extract of the Analysis of variance (size of perforation)
for load bearing capacity and accumulated silt

Sources of Variance	D.F.	Sum of squares		Mean sum of squares		Calculated 'F'	
		Accumula- ted Silt	Load bear- ing capa- city	Accumula- ted silt	Load bear- ing capa- city	Accumula- ted silt	Load bearing capacity
Replication	4-1=3	0.40	-	0.133	-	-	-
Treatment	6-1=5	17.42	146.14	0.435	36.53	4.35	274.66
Error	12	1.21	0.665	0.100	0.133		
Total	19	19.03	146.80	1.00	0.772		
For tile drain out-flow							
Replication	4-1=3	. . .	7.73		2.58		
Treatments	6-1=5	. . .	31.24		10.31		
Errors	12	. . .	15.33		1.78		5.79
Total	19	. . .	54.30		14.67		

Appendix III. Abstracts of Analysis of Variance Table (Number of perforations)

Source of variation	D.F.	Sum of squares			
		Tile drain out-flow in litres	Drainage coefficient	Salts removed through drainage water in kg/ha.	Bearing strength of tile
Blocks	1	28.3	0.0004	1273.04	-
Irrigation levels	3	456765.4	7.0567	182438.58	-
Errors (a)	3	46.1	0.0008	29656.93	-
Tile openings(B)	6	570197.4	8.9867	129881.56	-
Interaction(AB)	18	78678.4	1.2126	52971.43	-
Grand Total	55				
Replication ..	2				0.07
Treatments ..	6				87.16
Errors ..	12				0.81
	20				-

Appendix IV. Extract of the Analysis of variance (orientation of perforation)
For tile drain out-flow

Source of variance	D.F.	Sum of squares	Mean sum of squares	Calculated 'F'
Replication	2	0.402	0.201	
Treatments	3	81.687	27.229	299.23
Errors	16	9.220	0.576	
Total	21	91.309	27.996	
<u>For accumulated silt</u>				
Treatments	2	92.152	46.076	4.826
Errors	6	57.280	9.546	
Total	8	149.439		

Appendix V Extract of the Analysis of variance (Envelope Materials)

Tile drain out-flow

Source of variance	D.F.	Sum of squares	Mean sum of squares	Calculated 'F'
Replication	2	0.15	0.150	-
Treatments	5	1135.68	378.860	163.17
Errors	16	13.26	0.828	-
Total	23	1149.09	379.838	
<u>For accumulated silt</u>				
Treatments	5	35.15	8.78	7.44
Errors	4	5.88	1.17	
Total	9	41.03	4.55	

RESEARCH PUBLICATIONS

Papers published

1. Ramaiah, R. and Satyanarayana, T. 1973. Investigation on Vertical movement of water in a soil column under different depth of submergence and surface compaction. Journal. Harvester, IIT, Kharagpur, India.
2. Ramaiah, R. and Satyanarayana, T. 1973. Effect of submergence and surface compaction on hydraulic head in a soil profile. Mysore Journal of Agricultural Sciences, UAS, Bangalore, India.
3. Ramaiah, R. 1973. Dimensional Analysis applied to seepage studies. Mysore Journal of Agricultural Sciences, UAS, Bangalore, India.
4. Ramaiah, R. 1975. Investigation of Drought using monthly rainfall as parameter of Bangalore Agro-climatic region. Mysore Journal of Agricultural Sciences, U.A.S., Bangalore, India.
5. Ramaiah, R. 1975. Erosion Index of Bangalore Agro-climatic Region. Mysore Journal of Agricultural Sciences, UAS, Bangalore, India.
6. Chowde Gowda, M and Ramaiah, R. 1980. New Interculture implement for groundnut crop. Current Research, UAS, Bangalore.
7. Chowde Gowda, M. and R.Ramaiah, H.Jayaramaiah and R.F.Patil, 1981. A case study of bullock drawn potato digger. Current Research, UAS, Bangalore.

Continued

8. Chowde Gowda, M., R.Ramaiah and S.F.I. Raj, 1981.
A machine for Threshing safflower crop.
Current Research, U.A.S., Bangalore.
9. Chowde Gowda, M. and R.Ramaiah, 1979. Post Harvest
Aspects of food production. Paper presented in
Seminar on "Food for Millions" at the Institution
of Engineers, Dharwad.
10. Chowde Gowda, M., R.Ramaiah and S.F.I. Raj, 1984.
A study on size frequency distribution of safflower seeds, Mysore Journal of Agricultural Sciences, U.A.S., Bangalore.
11. Chowde Gowda, M., R.Ramaiah and P.Ranganath, 1984.
A study of some of the physical properties of safflower seeds. Mysore Journal of Agricultural Sciences, U.A.S., Bangalore.
12. Chowde Gowda, M., R.Ramaiah and S.S.Kumathe, 1986.
Correlation studies of physical dimensions of safflower seeds. Mysore Journal of Agricultural Sciences, U.A.S., Bangalore.

Research Projects Guided under Post-graduate programme
in Soil and Water Conservation

1. A study on the use of different lining materials in field channels to prevent seepage losses, 1977.
2. Study on the effect of crops and crop canopies on run-off and soil loss under natural conditions in red sandy loam soils of Dharwad, 1977.
3. A study on drip irrigation under Dharwad Agro-climatic condition, 1977.
4. A study on the use of saline water through drip irrigation system, 1978
5. Study of the drainage status of affected lands of Munoli village due to irrigation, 1978.
6. A study of farm ponds in low rainfall areas of Northern Karnataka, 1978.
7. Land development methods for irrigated black soils of Karnataka, 1979.
8. Extent of circular openings of tiles on the efficiency of tile drainage system, 1979.
9. A study on drip irrigation for grapes under the Agro-climatic condition of Dharwad, 1980.
10. A study of sprinkler and surface (check basin) method of irrigation using sorghum as test crop, 1980.
11. A study of the seepage losses through different lining materials under flowing conditions of water, 1980.
12. Evaluation of filter materials used for tile drains in black soils of Dharwad, 1981.

Continued.

13. Evaluation of check basin method of irrigation in black soils of Dharwad, 1981.
14. Drip system of irrigation for the use of saline water for cabbage crop, 1981.
15. A study on the suitability of sprinkler method of irrigation under Dharwad Agro-climatic condition, 1981.
16. Drip irrigation system for application of fertilizer, 1981.
17. Investigation on the size of the perforations of burnt clay tiles used in black soils of Karnataka, 1982.
18. Evaluation of the length of graded furrows used in red soils of Dharwad region, 1982.
19. Orientation of tile openings as related to drainage efficiency, 1982.
20. Effect of irrigation frequency on crop growth and yield of cabbage by drip method of irrigation, 1982.
21. Evaluation of check basin method of irrigation in soils of Dharwad, 1982.
22. A study on the performance of contour bunds in Athani Taluk of Belgaum District, Karnataka State, 1983.
23. Investigation on alternate furrow system of irrigation for optimum spacing for hybrid maize in fine textured soils of Dharwad, 1982.

Continued.

24. Investigation for standardising of mini-borders used for groundnut cultivation in light soils of Dharwad, 1983.
 25. Evaluation of furrow dimensions in skip furrow method of irrigation in black soil for maize, 1983.
 26. Standardisation of stream size for check basin method of irrigation in red soils of Dharwad, 1983.
 27. Effect of filter material thickness on tile drainage discharge, 1983.
 28. Efficiency of envelope materials and their effect on tile drainage system, 1984.
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V I T A

Reddihalli Ramaiah was born on 14th May 1937, at Reddihalli, Devanahalli Taluk, Bangalore District, Karnataka, INDIA. He received his matriculation education at Municipal High School, Devanahalli in the year 1956 and completed the Intermediate education at Basappa College, Bangalore, during the year 1958. He studied in Agricultural College, Hebbal, Bangalore and received Bachelor of Agricultural Sciences Degree from Mysore University in 1962. Also received Bachelor of Civil Engineering Degree from the University Visvesvaraya College of Engineering, Bangalore, Bangalore University during the year 1966.

He joined the Department of Agriculture, Karnataka State, as Assistant Agricultural Officer, Soil Conservation, on 25th April 1966. After serving nearly 11 months, he joined the University of Agricultural Sciences, Bangalore, as Instructor in Agricultural Engineering at Agricultural College, Hebbal, Bangalore. He was selected as Assistant Professor of Agricultural Engineering in the University of Agricultural Sciences, Bangalore, and reported for duty on 29th December 1969.

During 1971, he joined the Indian Institute of Technology, Kharagpur, for his Post-graduate degree in Agricultural Engineering, specialised in Soil and Water Conservation Engineering and completed the degree programme in 1972, successfully.

After the Post-graduation, he rejoined the University of Agricultural Sciences, as Assistant Professor of Agricultural Engineering. Later on selected to Associate Professor Cadre and reported as Agricultural Engineer, Dry Land Agriculture Project on 17th July 1974. After serving two years in Dry Land Agricultural Project, he was selected as Professor of Agricultural Engineering and reported to duty at the Agricultural College, Dharwad, on 3rd September 1976. Since then he has been working as Professor and Head of the Department of Agricultural Engineering, University of Agricultural Sciences, Bangalore.

He has published many papers in National and International Journals, and participated in symposiums and conferences of National and International level. He has guided 28 students leading to Master's Degree in Agricultural Sciences, specialising in Soil and Water Conservation Engineering, in the University of Agricultural Sciences, Bangalore.

He is actively engaged in teaching, research and extension work in the field of Soil and Water Conservation Engineering.

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He is married to Smt. Uma and Father of two daughters, Divyalakshmi and Madhuvanthi.

He is a citizen of INDIA.

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