Evaluation of hydraulics characteristics and management strategies of subsurface drainage system in Indira Gandhi Canal Command

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Abstract: The present study revealed the performance of subsurface drainage systems for long-term sustainability of irrigated agriculture. The performance of subsurface drainage systems was evaluated on the basis of drain spacing equations for disposal of effluent and hydraulic characteristics of envelop materials, like entrance resistance created by envelop and hydraulic conductivity. Three important synthetic envelopes, HG 22, SAPP 240 and CAN 2 were tested in laboratory using sand tank model and permeability apparatus to compare their performances in terms of entrance resistance and hydraulic conductivity of soil envelope system. The hydraulic conductivity for SAPP 240 filter was found the highest and entrance resistance the lowest. Performance of four unsteady state drain spacing equations viz. Glover-Dumm, Van Schilfgaarde, Integrated Hooghoudt and Modified Glover equations were also tested to evaluate disposal efficiency of excess water. The percentage deviation between predicted drain spacing and actual spacing was -33.31% to -31.55%, 9.40% to 17.07%, 11.84% to 20.83% and 6.10% to 14.62% for Glover-Dumm, Van Schilfgaarde, Integrated Hooghoudt and Modified Glover equations, respectively. Modified Glover equation showed minimum deviation from actual drain spacing due to its versatile applicability. Therefore, the Modified Glover equation with SAPP 240 filter was recommended for subsurface drainage system in sandy soil texture areas.

Keywords: subsurface drainage, unsteady drain spacing equations, evaluation hydraulic characteristics, management strategies

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1 Introduction

Agricultural land drainage is one of the most crucial aspects of water management. For optimal growth of plants, it is necessary to maintain both adequate aeration as well as adequate moisture in their root zone. A prime requirement of sustainable agriculture is the development and maintenance of root zone in which moisture-oxygen-salt balance is favorable for plant growth. The high ground water table and excessive irrigation deposits excess water and consequently results in development of waterlogged soils. In arid and semi arid region, high water table results, salinity. High water table poses a serious threat to optimize long term benefits of irrigation project which were developed with huge investment. Favourable environment for plant growth can be achieved by providing an efficient drainage system which drain out free water and salts to allow good soil aeration and salt balance. There are mainly two types of drainage problems, waterlogging and soil salinity. Waterlogged area poses risks of hydraulic soil properties deterioration, reduce crop productivity and groundwater pollution due to accumulation and leaching of salt. Hydraulic characteristics envelop materials and drain spacing equations are the two most important property of soil that affects the design and performance of subsurface drainage system. The spacing between drains effects the removal of water from effected land. The discharge capacity of drain depends on type of soil, drain depth, envelope material and drain spacing. Envelope materials are used in soils with very high hydraulic conductivity or

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where there is chance of sedimentation of the sub surface drain system. In the area of low hydraulic conductivity, mole type drain works effectively. Envelopes improve the hydraulic conductivity around the drain tube and facilitate the entry of water. In order to understand the surface and subsurface drainage requirements, a number of groundwater regime maps (groundwater table contour map, depth to groundwater table map, groundwater fluctuation map and groundwater quality map) play a significant role to assess long-term groundwater table behavior (Kumar and Singh, 2006 and Kumar et al., 2012).

The envelop material played a significant role in success of any waterlogged soils (Saulmon, 1971; Healy and Long, 1972; Mckeyes and Broughton, 1974; Rapp and Riaz, 1975; Broughton, 1976). The laboratory tests played an important role to evaluate the ability of thin synthetic envelopes to prevent sediment from entering surface drains (Broadhead et al., 1983; Kumar et al., 2009, 2012; Tiligadas, 1988). Sewa Ram and Chauhan (1972) verified the best suitable unsteady drain spacing equation among Glover equation (Dumm 1954), Integrated Hooghoudt equation (Bouwer and Van Schilfgaarde, 1963), and Modified Glover equation (Van Schilfgaarde, 1965) at G.B Pant University of Agriculture and Technology, Pantnagar. They concluded on the basis of field observation that, the Van Schilfgaarde equation was most suitable for sandy loam type soil.

Kumar and Gupta (2010) studied the decline pattern of groundwater table of two drainage basins in Haryana (India), the upper Yamuna and upper Ghaggar basins. Disposal of drainage effluent is a major issue associated with subsurface drainage system, and without proper disposal of drainage effluent, environmental problems may arise which may nullify the advantages and act as a stumbling block in the expansion of drainage in the country. Datta et al. (2000) documented that construction of evaporation ponds to temporarily store drainage effluent was technically possible while maintaining the financial feasibility of the investments in drainage. A theoretical approach was developed to assess the size of tank and concluded that about 10% of the area was required for a pond where average depth of water in the pond was about 1.7 m (Gupta and Oosterbaan, 1987; Rao and Rao, 1990; Tripathi et al., 2003).

Large numbers of drainage theories are available to design the process of subsurface drainage system and provide equations for a given area. The most important properties of soil which affect the design and performance of subsurface drainage system are hydraulic conductivity, drainable porosity and depth of impermeable barrier. These laboratory evaluations can give a fair deal of idea about the performance of synthetic filters in field conditions. The problems of waterlogging as well as salinity/alkalinity occurred after completion of irrigation network of Indira Gandhi canal project in 1957. By 1976, approximately 20,000 ha showed salinity build up. It was estimated that approximately 180,000 ha became saline or saline sodic because of inadequate drainage measures.

A pilot Indo-Dutch drainage project was initiated in the year 1993 with assistance of Neatherlands Government at Lukhuwali area in Hanumangarh District of Rajasthan with the collaboration of Central Soil Salinity Research Institute (CSSRI), Karnal to control the waterlogging and soil salinity by providing subsurface drainage. Sub-surface drainage is believed to be an answer to overcome the problems of waterlogging and salinity, restore back the productive capacity of soils, and restore the social and economic conditions of the farming community. In view of this, present study focused to evaluate hydraulics characteristics and management strategies of subsurface drainage system in Indira Gandhi Canal Command, India. This study also shows path to identify a number of management strategies that could help for efficient water management. The knowledge generated in this paper would help to design and plan subsurface drainage activities and management strategies which is a base for the food and nutritional security of India and many other developing nations. The salient findings could serve as design guidelines or to operationalize the systems in an effective and eco-friendly manner that have been put together for their application in future.

2 Material and methods

2.1 Study area

The Indira Gandhi Canal Command Area lies between

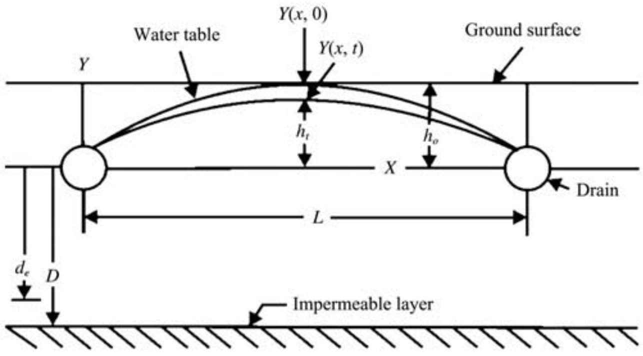
28°30′N and 30°32′N latitude and 73°45′E to 74°46′E longitude in North Western Rajasthan, India. The study was conducted at arid climatic region of Lakhuwali and Lunkarnsar area of Hanumangarh and Bikaner Districts of Rajasthan, India. The command area covers an area of 0.757 million hectares. The maximum temperature goes up to 52℃ in the month of May-June and minimum temperature goes below freezing point in winter. The soil texture is sandy. The land locked areas, evaporation pond could be one of the most appropriate alternatives for the disposal of saline drainage effluent. To analyze the suitability of disposal of drainage effluent, four unsteady drain spacing equations were tested viz. Glover Equation, Van Schilfgaarde, Integrated Hooghoudt Equation and Modified Glover Equation (Table 1). The Lunkarnsar farm is located on National Highway No. 15 at 70 km away from Bikaner comprise 30 ha area. The Lakhuwali area is 25 km from Hanumangarh. The climate of area is arid and average annual rainfall varies between 200 mm to 250 mm. The schematic pattern of ground water table for unsteady state flow is shown in Figure 1.

Table 1 Unsteady drain spacing equations

Name of Equation	Unsteady drain spacing equation	References
Glover – Dumm	$L=\pi\left[\frac{K(d_e+\frac{h_o}{2})}{f\ \ln(\frac{4h_o}{\pi h_t})}\right]^{1/2}$ $(d > h_o)$	Dumm (1954)
Van Schilfgaarde	$L=3A\left[\frac{k\,(d_e+h_o)\,(d_e+h_t)\,t}{2f\,(h_o-h_t)}\right]^{1/2}$ $A=\left[1-(\frac{d_e}{d_e+h_o})^2\right]^{1/2}$	Van Schilfgaarde (1963)
Integrated Hooghoudt	$L=\left[\frac{8\,k\,d_e\,t}{C\ f\ \ln\frac{ho(h_t+2d_e)}{ht(h_o+2d_e)}}\right]^{1/2}$	Bouwer and Van Schilgaarde (1963)
Modify Glover	$L=\left[\frac{9\,k\,d_e\,t}{f\ \ln\frac{ho\,(2d_e+h_t)}{h_t\,(2d_e+h_o)}}\right]^{1/2}$	Van Schilfgaarde (1964)

2.2 Drainage experimental plot

The subsurface drainage system was installed to drain the deep percolation losses resulting from applied irrigation water so as to maintain a safe water table depth. A drainage coefficient of 1.0 mm/d was adopted for the design of subsurface drainage system. Laterals were



where, L is drain spacing, m; K is hydraulic conductivity, m/d; d_e is equivalent depth, m; t is change in time from beginning for the period considered, d; f is drainable porosity, fraction; h_o is initial height of water table above drain axis at midpoint between drain axis at time to, m; h_t is height of water table above drain axis at time t, m

Figure 1 Definition Sketch for the unsteady state drainage study

placed at a depth of 1.6m with a drain spacing of 125 m and depth of collector drain was 2 m. The difference between depth of lateral and collector drain at their junction facilitated monitoring of the drain discharge and quality of water from individual lateral. Drainable porosity of 0.12 was used for this site. The average hydraulic conductivity was measured using Smedma and Rycroft (1983) curve method and its value was recorded as 1.36 m/d using field observed data of hydraulic head and discharge. Based on large number of studies conducted at CSSRI and elsewhere in India, guidelines were prepared to design a subsurface drainage system under different agro-climatic conditions of India (Gupta, 2002). Drainage coefficient is the most important parameter (Gupta, 2002) because that decides the lateral drain spacing, size of the laterals and collectors and capacity of the pump to dispose off the drainage effluent. The guide lines suggested (Gupta, 2002) the capacity of evaporation pond and importance of envelop materials. Hydraulic head and drain discharge data were collected from Indo–Dutch Network Project Sub-centre, Hanumangarh and Lunkarnsar farm, Rajasthan.

There is a need to strengthen the capacity of the sub-surface drainage network, like installation of subsurface drainage and proper removal of excess water in the study area. Three synthetic envelopes viz. HG 22, SAPP 240 and CAN 2 were used in the sub surface drainage system to strengthen the drainage network. The physical properties of all the three synthetic envelops are given in Table 2. Performance of synthetic envelopes significantly depends upon the entrance resistance created by it and pattern of permeability behaviour. The laboratory tests were conducted for the performance evaluation of the three different envelopes at Irrigation Water Management (IWM) Lab, College of Technology and Engineering (CTAE) Udaipur (Rajasthan), India.

Table 2 Physical properties of synthetic envelopes

No.	Properties	Geo-textiles		
		HG 22	SAPP 240	CAN 2
1.	Filtration opening 095 size/mm	99.5	111.00	175.0
2.	Mass per unit area/gm m^{-2}	236.8	226.9	180.0
3.	Thickness/mm	2.33	2.83	1.9
4.	Tear strength/N	221.9	195.5	90.0
5.	Breaking strength of seams/N	307.4	743.90	Not available
6.	Polyester/%	100	97.1	100.0
7.	Cotton/%	Not available	2.9	0

The soil samples were collected from the study area for measuring the entrance resistance using Equation (1) of measured observation in sand tank model in three different types of synthetic envelopes viz. HG 22, SAPP 240 and CAN 2. The permeability behaviors of soil envelop system was measured by using permeability behavior apparatus. The schematic diagram of sand tank model is shown in Figure 2. In the experimental set up of sand tank model, all outlets of external tank were closed and a constant water level of 60 cm of water was maintained. During the first set up, one of the envelopes to be evaluated was wrapped over the drain tube. After ensuring stabilized state, reading of all the piezometers was taken. Then, by opening the outlet 1 the water table in external tank was maintained up to 50 cm and all the readings of steady discharge and piezometers were taken. Similar procedures were repeated for the head of 40 cm, 30 cm, 20 cm and 10 cm. The same procedure was repeated for all the three envelopes.

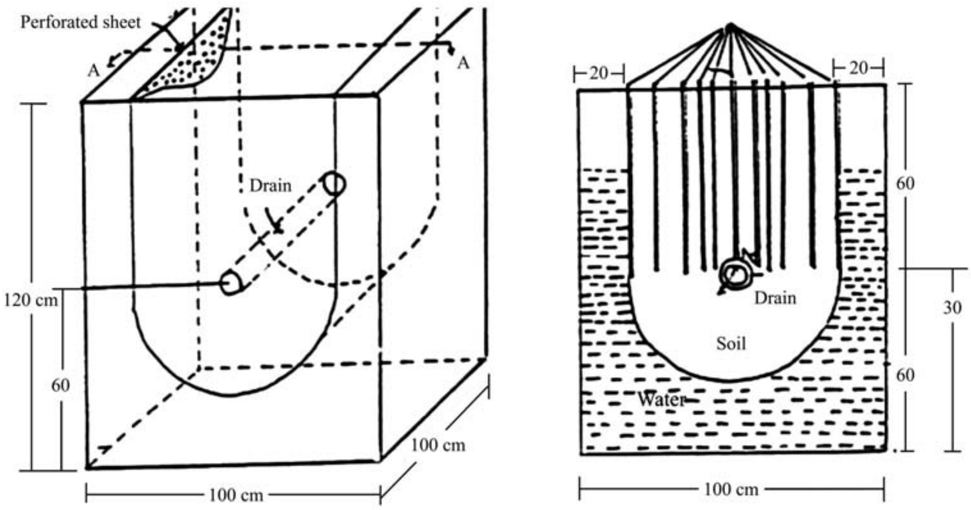


Figure 2 Schematic representation of the sand tank model

The piezometer readings on both ends of the tank simulated the height of water table of the mid plane. Several readings were taken at each head. Entrance resistance (W_e) was determined by using following equation

$$We = \frac{he}{q_u} = \frac{he.L}{Q} \quad (1)$$

where, W_e is entrance resistance, d/m; h_e is entrance head loss, m; L is length of drain, m; q_u is flow rate per unit length of drain, m^3/d; Q is total drain discharge, m^3/d.

The permeability behavior of soil envelope system for all the synthetic envelopes was conducted for the soil by using permeability behavior apparatus as shown in Figure 3. Four piezometers were installed with two PVC pipes of 1 m length by inserting first at the bottom side of the pipe and remaining at a vertical spacing of 20 cm each. The bottom of pipes were closed by three synthetic envelopes to be tested, giving support of round shaped wire mesh and a cap providing sufficient clearance between wire mesh and cap by using the ring shaped PVC piece 1.5 cm height. The upper end was also closed by the PVC cap after filling the pipes with soil. In order to maintain the same density of the soil in the pipe, alternate drying and wetting process was conducted every time with the change of envelope. The set up was fixed with the wall through clamps in the IWM laboratory of CTAE, Udaipur, by putting a water tank on a table of adjustable height. A constant head of 60 cm was maintained. By using the PVC flexible pipes of equal diameter a divider was connected to supply water to both the pipe fixed on the wall. A scale was attached with the piezometer pipes to observe the pressure head.

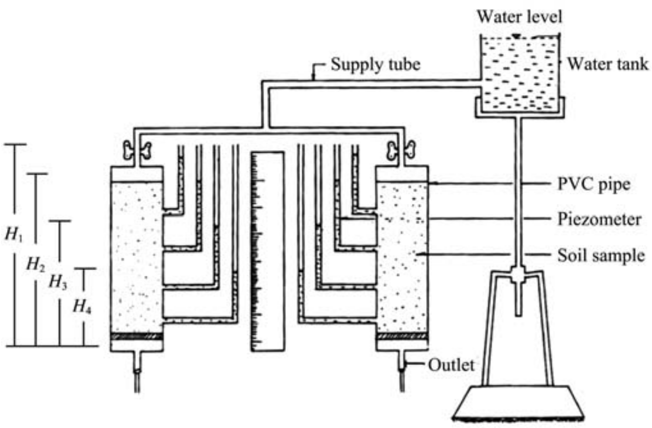


Figure 3 Schematic diagram of apparatus used to study permeability behavior of soil envelope system

After setting the whole set up, water supply was opened from the water tank and a constant head was maintained. During the first 12 h, reading of each piezometer was taken with the help of vertical scale attached with the piezometer. By placing all the three envelopes in the lower cap of the apparatus the readings of piezometers and discharge were taken with respect to time. This experiment was continued with each envelope until the piezometer readings reached stabilized state with outflow through the soil envelope system per unit time.

The study implies that the evaluation of hydraulics characteristics and management strategies are based on envelope material and field observed data. The required data are; drainage coefficient, entrance resistance of envelop material, drainable porosity, hydraulic conductivity and soil properties. The data collected from field an laboratory were further, used to analyze the evaluation of hydraulics characteristics

3 Results and discussion

This study evaluated the hydraulic characteristics and performance of different synthetic envelopes by measuring entrance resistance at the drain pipe in a sand tank model. The entrance head losses, corresponding to discharge rates and computed entrance resistance for the soil under the lab conditions are shown in the Table 3. The graphs between the entrance resistance and the entrance head loss for three different envelope materials are given in Figures 4-6. The graphs clearly show the linear relationship between the entrance head loss and entrance resistance. The Figures 4-6 illustrated that entrance head loss rapid increases near the drain pipe with increase in discharge. The entrance resistance of the drain envelopes HG 22, SAPP 240 and CAN 2 were computed by using Equation (1) and value varied from 2.0 to 1.56 d/m; 2.002 to 1.030 d/m; and 2.07 to 1.05 d/m, respectively. The reason of such variations in the entrance resistance may be the converging nature of flow towards the drain. The average values of entrance resistance for HG 22, SAPP 240 and CAN 2 were found to be 1.72 d/m, 1.41 d/m and 1.54 d/m, respectively. The entrance resistance of SAPP 240 filter was found lowest among the three envelopes.

Table 3 Discharge rate, entrance head loss and entrance resistance for different envelope materials of soil under lab conditions

HG 22			SAPP 240			CAN 2		
h_e/m	q/m^3 d^{-1}	W_e/d m^{-1}	h_e/m	q/m^3 d^{-1}	W_e/d m^{-1}	h_e/m	q/m^3 d^{-1}	W_e/d m^{-1}
0.275	0.1375	2.00	0.283	0.1405	2.002	0.290	0.140	2.07
0.230	0.1195	1.928	0.248	0.1285	1.931	0.2325	0.134	1.87
0.170	0.0975	1.743	0.181	0.1055	1.722	0.1705	0.104	1.63
0.123	0.0765	1.607	0.143	0.0885	1.615	0.1230	0.087	1.41
0.078	0.050	1.564	0.082	0.0595	1.390	0.0822	0.0665	1.23
0.038	0.025	1.520	0.038	0.036	1.030	0.0342	0.0325	1.05

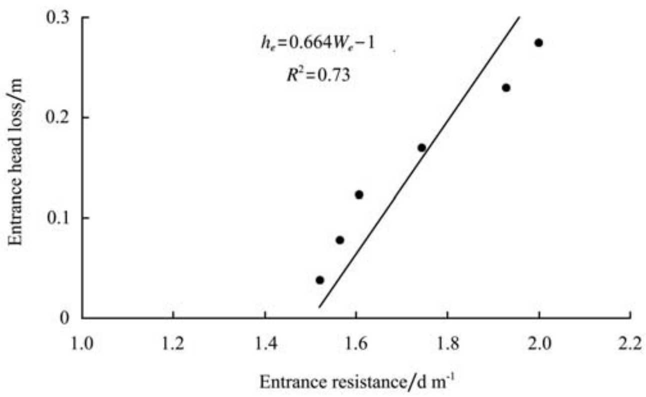


Figure 4 Entrance resistance versus entrance head loss of soil for HG 22

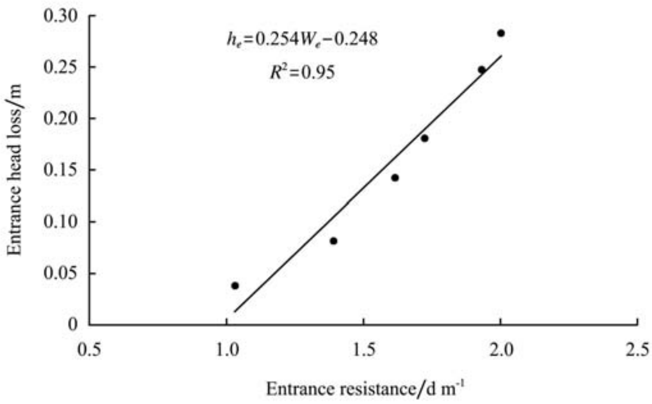


Figure 5 Entrance resistance versus entrance head loss of soil for SAPP 240

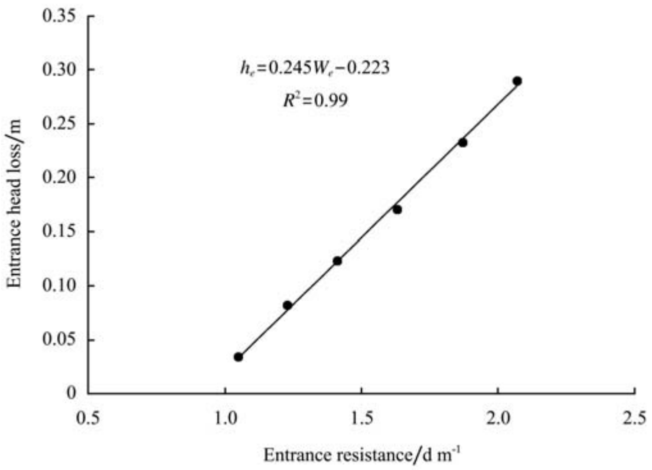


Figure 6 Entrance resistance versus entrance head loss of soil for CAN 2

In order to determine the filtration performance of envelopes in drainage system, the permeability behavior of synthetic envelope soil system for different synthetic envelopes was also studied. The experiment was performed in the CTAE laboratory by observing the piezometric heads and discharge through soil column. The graphs between time and hydraulic conductivity were plotted for all the three different envelopes. The permeability of soil - envelope systems for the total thickness and contact layer between filtration time of all the three envelopes are illustrated in Figures 7-9. These graphs indicate rapid decrease in hydraulic conductivity for initial 12 h. The distribution of soil particles in layers is a function of the tendency of the soil for clogging. A decrease of hydraulic conductivity was observed for layer adjacent to the envelope. It was also observed with the soil envelope system that initially hydraulic conductivity in the layer varied while it became constant after longer duration of filtration. The hydraulic conductivity of total thickness decreased right from the beginning and attained a constant value after 72 h. However, increasing value of the hydraulic conductivity was observed during first 12 h with respect to the initial value. Later after 60-70 h it decreased and stabilized.

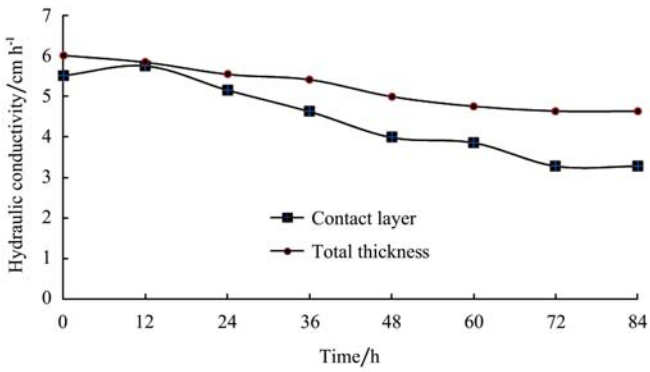


Figure 7 Permeability behavior of soil for HG 22

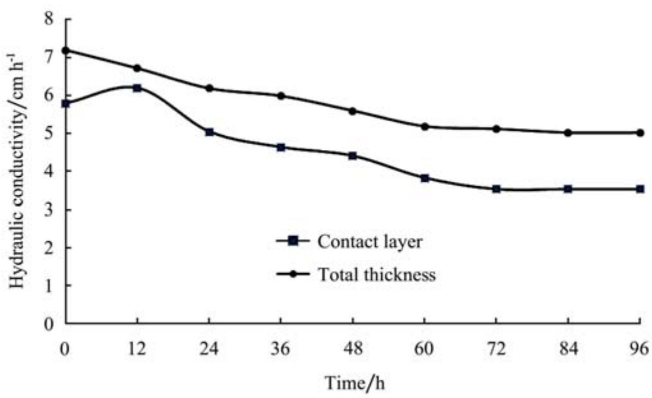


Figure 8 Permeability behavior of soil for SAPP 240

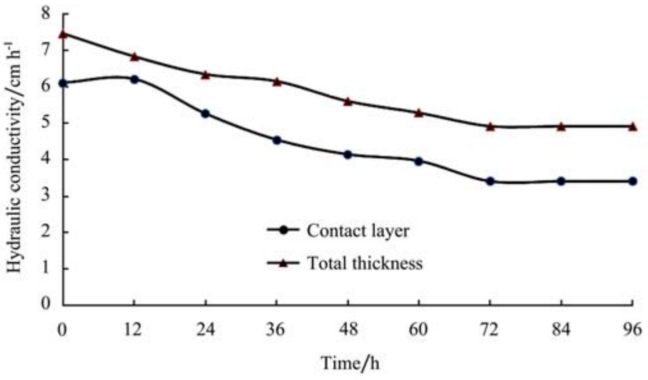


Figure 9 Permeability behavior of soil for CAN 2

Increase in hydraulic conductivity of contact layer may be attributed to the excessive loss of soil particles which results in an increasing permeability (Kumar et al., 2009). The overall decreases in hydraulic conductivity were due to the cake formation at the interface of soil and envelope resulting stabilization. The hydraulic conductivities of total thickness were found to be 4.64, 5.01 and 4.90 cm/h and that of contact layer to be 3.28, 3.52 and 3.39 cm/h for the HG 22, SAPP 240 and CAN 2, respectively. The hydraulic conductivity of SAPP 240 filter was more than HG 22 and CAN 2 filters. Relationships between entrance resistance versus entrance head loss, hydraulic head versus discharge and hydraulic conductivity versus time shows the similar trend for the area. The SAPP 240 filter shows more hydraulic conductivity and minimum entrance resistance than HG 22 and CAN 2 filters. Therefore, these two properties proved that the performance of SAPP 240 was the best among the three envelopes and it is suitable synthetic envelop for Indira Gandhi Canal Command area and it could be used for subsurface drainage system in order to provide adequate drainage solution of water logging problems.

Glover Dumm, Van Schilfgaarde, Integrated Hooghoudt and Modified Glover equations summarized in Table 1 were used to predicting the drain spacing for disposal of effluent. A time interval 7d was taken between two consecutive irrigations. Different values of spacing were obtained and compared with existing actual spacing for drainage period. The average predicted drain spacing after 7 d interval and their percentage deviation from actual spacing are shown in Table 4. It is evident that Modified Glover Equation has predicted spacing closer to the actual spacing than other equations. Modified Glover Equation resulted 6.1% to 14.62% deviation from the actual spacing, whereas predicted spacing deviation from actual spacing was -33.31% to -31.55%, 9.40% to 17.07% and 11.84% to 20.83% by using Glover-Dumm equation, Van Schilfgraade equation and Integrated Hooghoudt equation, respectively. Modified Glover Equation has minimum deviation than actual spacing. On the basis of low percentage deviation of drain spacing between field observed data and equations predicted, Modified Glover equation was found appropriate to assess the hydraulic heads and the drain discharge. Therefore, this equation is suggested for use to predict drain spacing and drain discharge on daily basis for the design of drainage structures including evaporation ponds for the disposal of drainage effluents (Kumar et al., 2012).

Table 4 Average predicted drain spacing after 7d and their percentage deviation from actual spacing

Plot No.	Actual spacing Equation/m	Glover-Dumm Equation		Van Schifgraade Equation		Integrates Hooghoudt Equation		Modified Glover Equation	
		Spacing/m	Dev./%	Spacing/m	Dev. /%	Spacing/m	Dev. /%	Spacing/m	Dev./%
11	125	83.35	-33.31	136.75	9.4	139.8	11.84	132.62	6.1
23	125	83.95	-32.83	138.62	10.9	142.7	14.16	135.34	8.27
28	125	84.41	-32.46	140.25	12.2	144.45	15.56	137.04	9.63
38	125	85.53	-31.55	146.34	17.07	151.04	20.83	143.28	14.62
42	125	84.73	-32.31	141.37	13.1	145. 69	16.55	138.2	10.56

4 Conclusions

The performance of subsurface drainage systems in terms of long-term sustainability of irrigated agriculture, based on the hydraulic characteristics of envelop materials and evaluation of drain spacing equations play a very important role. The study implies the evaluation of hydraulics characteristics and management strategies based on envelope material and field observed data. The required data are; drainage coefficient, entrance resistance of envelops material, drainable porosity, hydraulic conductivity and soil properties. The data collected from field and laboratory was further, used to analyze the evaluation of hydraulics characteristics. The water logging problem has adversely affected the crop yields in the study area. In order to estimate the quantity of drainage effluent the Modified Glover equation was found to be the most appropriate. The following conclusions are drawn from the present study.

1) Three different synthetic envelopes viz. HG 22, SAPP 240 and CAN 2 were evaluated to compare their performances in terms of entrance resistance and hydraulic conductivity of soil envelope system. The Hydraulic conductivity for SAPP 240 filter was found highest and entrance resistance was the lowest.

2) Applicability of unsteady state drain spacing equations viz. Glover-Dumm, Van Schilfgaarde, Integrated Hooghoudt and Modified Glover equations were evaluated. Modified Glover equation has minimum deviation from actual drain spacing than observed value to estimate the quantity of drainage effluent.

3) The Modified Glover equation with SAPP 240 filter is recommended for sub surface drainage system in the Indira Gandhi Canal command, India.

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