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Estimation of Hydraulic Conductivity and Drainable Porosity for Irrigated Clay Soils and Prediction of Drain Spacings

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THIS WORK was carried out on irrigated tile drained clay soils at north Nile Delta to compare the methods that used to determaine the soil hydraulic conductivity and drainable porosity. The study aimed also to evaluate the applicability of some drainage design equations to calculate the drain spacings. The results showed that the measured drainage rates were often far less than the design rates, and a close relationship was found between hydraulic head midpoint above drain level (h) and both soil hydraulic conductivity (K) and drain discharge (q). The K-value measured in the field by the auger-hole method during different irrigation cycles were in considerable variability and varied between 1.2 to 72 cm/day with an average value of 25.4 cm/day. The value of soil drainable porosity (f) varied according to the determination method. The average f-value determined from pF-curves was 0.073. While the f-values calculated from the reservoir coefficient increased from 0.014 after irrigation to 0.13 for deep water tables with an average value of 0.058. The f-values calculated by Boussinesq's equation varied between 0.031 and 0.076 with an average value of 0.0608. Whereas the f-value determined by taking the ratio between the change in soil moisture storage and change of water-table depth was found to be 0.104.

According to the steady-state Hooghoudt's equation drain had to be installed at a spacing of 33-41 m for an average depth of 1.40 m below soil surface to achieve a dewatering depth of 1.0 m at the design discharge rate of 1.5-1.0 mm/d. And when the modified Hooghoudt's equation was used, which took the entrance resistance into account, the calculated drain spacings were found to be 29-36m. While the calcalated drain spacing using the un-steady state Glover-Dumm's equation was found to be 24 m when the average f-value of 0.067 was used. A calculated drain spacing of 53 m was obtained when the f-value of 0.014, which was obtained for the 3 days after irrigation under high water table conditions (0-50 cm below soil surface), was used in the calculations. The obtained results showed also that the calculated drain discharge rates using both Boussinesq's equation and Hooghoudt's equation were higher than the measured discharges. The values of the calculated hydraulic conductivity and the calculated depth to the impermeable layer were found to be as much as double the values used for drainage design. As a direct result of the underestimated K and D values the spacing between lateral drains were also understimated. When these high values of K and D had been taken into account a calculated drain spacings of 60-100 m, using Hooghoudt's equation, were obtained, while the using of Glover-Dumm's equation under these conditions gave a calculated drain spacing of 25-135 m.

Keywords: Irrigation, Drainage equations, Hydraulic head, Drain Discharge, Nile Delta.

The soil hydraulic conductivity (K) and drainable porosity (f) are among the most important parameters necessary for the design of efficient drainage system. Most equations related drain spacing principally to the hydraulic conductivity of the soils (Hooghoudt's and Ernst's equations; Van Beers, 1965 and 1976) and drainable porosity (Dumm, 1954 and 1960). Drainable porosity was also implemented in drawdown equations to predict the rate of falling water table levels (Kirkham, 1958). The saturated hydraulic conductivity (K) of the soil is dependent on the soil structure. If K-values are measured on undisturbed core samples, the representativeness of these samples is questionable and the data thus obtained are not applicable directly to the solution of the water flow in the field. Thus, for drainage design, it is essential to obtain a measure of K in field rather than from disturbed samples or soil cores. The drainable porosity respresents the volume of water released from a unit volume of saturated soil under the force of gravity and the inherent soil tensions (U.S. Bureau of Reclamation, 1978). In the design of a drainage system, a very important place is occupied by the calculation of the proper spacing of parallel drains. For this purpose, numerous drainge equations have been developed over the years. In the case of equations based on steady-state flow conditions, the physical soil data requierd are the hydraulic conductivity and the depth to an impermeable layer, whereas in the case of non-steady flow equations it is also necessary to know the drainable porosity (f). Other terms for this are volume fraction of pores drained or drained pore space, specific yield and effective porosity.

There are different methods considered for determining the soil drainable porosity. Some of these methods, which used in this study, are reviewed here as follows:

1- The drainable porosity can be determined from measurements of drain discharge and drowdown of water table. The method is known as reservoir coefficient (J) as defined by Kraijenhoff Van De Leur (1958). In this study the drainable porosity (f) was calculated from the reservoir coefficient equation as described by Dieleman and Trafford (1976). The drainable porosity (f) may be calculated from the following equation (if a, L and Kd are known)

$$a = 1/J = \frac{\Pi^2 K\ d}{fL^2}, \qquad \text{where } a = \frac{2.3\,(\log h_1 - \log h_2)}{(t_2 - t_1)} \qquad (1);$$

or from the equation $q / h = 2\,a\,f / \Pi$ (2);

if a, q and h are known;

where :

a = drainage intensity factor (day^{-1}), J = reservoir coefficient = fL^2 / Π^2 Kd (days),

h_1 = hydraulic head midway between two drains at time t_1 (m),

h_2 = hydraulic head midway between two drains at time t_2 (m),

f = drainable porosity (m^3 / m^3), K = soil hydraulic conductivity (m/day),

L = drain spacing (m), d = thickness of equivalent layer of Hooghoudt (m),

q = drain discharge (m / day),

2- The drainable porosity can be determined using Boussinesq`s equation (Polubarinoa-Kochina, 1962) as follows:

$$f = q / \Delta h\ ; \quad \text{where : } \Delta h = \frac{(h_{t1} + h_{t2})}{2} - \frac{(h_{t2} + h_{t3})}{2} \qquad (3)$$

and h_{t1}, h_{t2} and h_{t3} are the hydraulic heads midway between drains at times t_1 t_2 and t_3, respectively.

3- If no measurements of drainable porosity are available, then in the opinion of Van Beers (1965) it can be estimated in most cases by employing the formula: $f = (K)^{1/2}$, in which f is expressed in ratios by volume and K in cm/day.

4- The drainable porosity may be estimated from the soil water characteristic curves according to FAO (1980). The values of (f) expressed here as the volume of water drained between saturation and 100 cm tension (pF2) as follows:

$$f = \theta_{sat} - \theta_{100}$$

where:

θ_{sat} = moisture content at saturation (zero tension) on volume basis,

θ_{100} = moisture content at 100 cm tension on volume basis.

5- Normally, the volume of water drained between saturation and 100 cm suction is used to estimate the soil drainable porosity but this upper boundary may vary in relation to the type of the soil. Feddes and Stakman (1984) mentioned that, if the groundwater table falls down over a certain depth, then a certain amount of moisture is released from the unsaturated zone. For fluctuation of deeper groundwater tables, *i.e.* deeper than about 150 to 200 cm below soil surface, the moisture content in the upper layers of the soil profile is hardly affected. Then one considers only the change in soil moisture storage over the actual depth of change of the groundwater table. The drainable porosity is expressed as:

$$f = \frac{\text{change in soil moisture storage of the profile (mm)}}{\text{change in groundwater table depth (mm)}}$$

Owing to the importance of hydraulic conductivity and drainable porosity of the soil for drainage design, this work was carried out to compare the methods that used to determine these parameters, which change greatly in the clay soils as a function to time and place. This study aims also to evaluate the using of some drainage equations to compute the proper drain spacings in the irrigated clay soils of the Nile Delta, and to clear the conflict of opinions between the use of the theoretical calculated close drain spacing and the practical used wide drain apacings. Since in spite of a close calculated drain spacings, several examples under Nile Delta conditions had proven that good results can be obtained by using a wide drain spacings in the clay soils.

Material and Methods

This study was conducted during winter season 1998/1999 at an area of about 12 feddans of clay soil which is located near Nosra village, at about 10 km north-east Kafr El-Sheikh city, north Nile Delta. Surface flood irrigation is praticed from Nile water which is distributed on rotational basis. The area was provided with one collector and four cement laterals. The laterals are 305 m long and have a diameter of 10 cm, and installed at an average depth of 1.4 m with a gravel surround, and spaced 40 m apart. The area under study was planted with Egyptian clover (*Trifolium alexandrenum*). To monitor water table heights series of piezometers were installed at 0.4 m from each drain and midway between each two drains at 1/4 , 1/2 and 3/4 drain length as recommended by Dieleman and Trafford (1976). The discharge of every lateral and the hydraulic head between each two drains were monitored daily for five successive irrigation intervals and during winter closure period. The soil hydraulic conductivity (K) was measured in the field in 40 auger-holes during different irrigation cycles, using the auger-hole method according to Van Beers (1970). Undisturbed soil samples were collected along the soil profile every 0.3 m intervals from soil surface till 1.5 m to determine the soil moisture characteristic curve and soil bulk density according to Klute (1986). Disturbed soil samples were collected at the beginning and at the end of an interval of 35 days when no irrigation was applied, from the soil profile up to the water table depth for determining the soil moisture content.

The values of soil drainable porosity were determined using the following methods:

1- Using the reservoir coefficient equation (Kraijenhoff Van De Leur, 1958; Dieleman and Trafford, 1976),

2- Using Boussinesq's equation (Polubarinova-Kochina, 1962),

3- By taking the root of in field measured K-value according to Van Beers (1965),

4- From the soil water characteristic curves as discribed by FAO (1980). The values of (f) were expressed as the volume of water drained between saturation and 100 cm tension,

5- By taking the ratio between the change in soil moisture storage and the change of groundwater table depth according to Feddes and Stakman (1984).

The drain spacing was calculated by the following equations:

1- Using Hooghoudt's steady-state equation (Van Beers, 1965).

$$L^2 = \frac{8\ K_b\, d\, h}{q} + \frac{4\ K_a\, h^2}{q} \qquad (4)$$

where:

q is the drain discharge in m/day; L is the spacing of drains in m; K_a and K_b are the hydraulic conductivity of the soil layers above and blew the drain level, respectively, in m/day; h is hydraulic head above the drain at the midpoint between two drains in m; d is the equivalent depth from the drain to the impermeable layer in m.

2- Using the modified Hooghoudt's equation (Skaggs, 1978) in the next form:

$$L^2 = \frac{[\,8\ K_b + 4\ K_a\ (h_m - h_n)\,]\,(h_m - h_n)}{q} \qquad (5)$$

It was developed in a very simple way. The hydraulic head midway between two drains is substituted by the difference between head in midway between two drains (h_m) and head nearby the drain pipe (h_n). The other parameters of this equation are the same as in the original Hooghoudt's equation (4)

3- Using Glover-Dumm's formula, transient flow, (Van Beers, 1965):

$$L^2 = \frac{10\ K\ D\ t}{F\ \ln\ (1.16\ h_0 / h_t)}\ ; \ D = D_0 + (h_0 + h_t)/4 \qquad (6)$$

where:

L is spacing of drains in m; K is soil hydraulic conductivity in m/day; D_0 is depth of the impermeable layer below the drain in m; D is average thickness of aquifer (flow depth) in m; h_0 and ht are midpoint water table heights above drain level at biginning and end of drain-out period (in m) ; t is time in days; ln = $\log_e \ldots = 2.3 \log_{10} \ldots$; and f is soil drainable porosity (%).

Comparison was made between the measured water table height midway between two drains and those predicted by two non-steady state equations. These equations were Glover-Dumm's equation (6) and Boussinesq's equation (Polubarinova-Kochina, 1962). The water table height (h_t) midway between drains at any time (t) can be calculated from Boussinesq's equation, which is written as:

$$h_t = \frac{h_0}{1 + 1.115\, K\, h_0\, t / f\, S^2} \quad (7)$$

where h_0 is the initial water table height at time t = 0, and S is half the drain spacing.

The values of drain discharge calculated by Boussinesq's equation (3) and Hooghoudt's equation (4) were compared to drain discharges measured on the field with the 40 m drain spacing. The soil hydraulic conductivity (K) was calculated by Glover-Dumm's equation (6) and using the following two equations according to Dieleman (1972):

$K = q\, L^2 / 2 \prod h\, d$ and $K = a\ f\, L^2 / \prod^2\, d$,
where q, d, a, f and h were obtained as perviously mentioned.

Results and Discussion

The soil of the area is characterized by a clay texture with an average clay content of 51.3% and with fairly uniform profile. The hydraulic conductivity (K) values determined in the field during different irrigation cycles vary from 1.2 to 72 cm/day with an average value of 25.43 cm/day. It is noticed that the values of (K) are in considerable variability. A close positive relationship was found between hydraulic head above drain level at the midpoint between the drains (h) and soil hydraulic conductivity (Fig. 1). The regression equation which expressed the relationship between h and K values is as follows:

$k = 0.7523\, h - 10.2317$ $(r = 0.9386^{**})$

where:

h = hydraulic head midpoint above drain level (cm),

K = soil hydraulic conductivity (cm/day).

Changes in drain discharge with time took the same trend for the four laterals. The drain discharge (q) reached its maximum values after irrigation and decreased with time and reached its minimum values before the next irrigation. The measured drainage rates were often far less than the design rates of 1-1.5 mm/d. The average values of the measured drain discharge ranged between 0.1 and 0.75 mm/d. The discharge values depend on the amount of irrigation water,

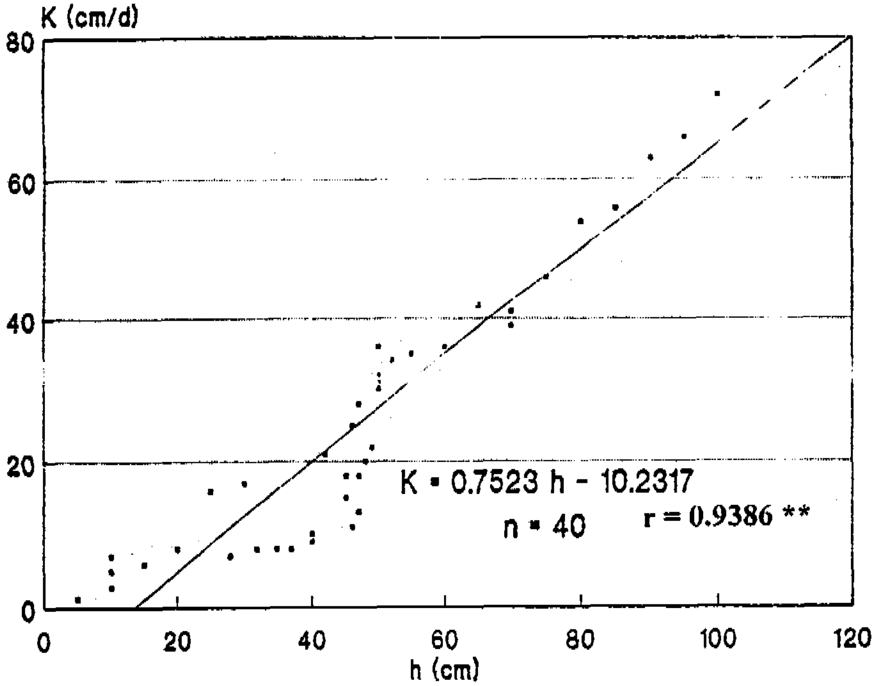

Fig. 1. The relationship between hydraulic head (h) and hydraulic conductivity (K).

soil effective porosity and hydraulic head. The relationship between lateral discharge (q) and hydraulic head (h) midpoint above drain level is shown in Fig. 2. Positive and highly significant correlation coefficient was found between drain discharge and hydraulic head . The regression equation obtained between (q) and (h) is as follows:

$$q = 0.0265\,h + 0.0651 \quad (r = 0.9437^{**})$$

where q in mm/day and h in cm.

This means that the laterals are in good situation and the amount of discharge depend on the height of measured hydraulic head . These results are coincided with those reported by Beltran (1978) and Talha *et al.* (1993 a), who obtained a straight line relationship between (q) and (h) and mentioned that if q and h relationship is represented by a straight line, this means that the unsteady flow equation is suitable for application.

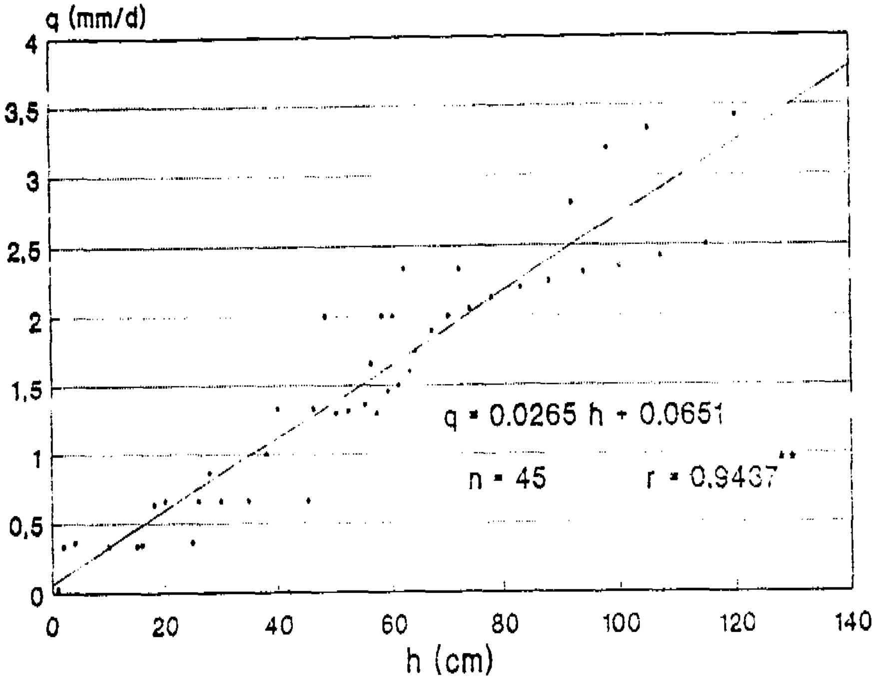

Fig. 2. The relationship between hydraulic head (h) and drain discharge (q).

The soil drainable porosity (f) is an important parameter in drainage design. It represents the amount of water that discharge to drains. The f-values calculated using Boussinesq's equation ranged between 0.031 to 0.076 with an average value of 0.0608. The f-values determined by taking the root of in field measured K-values varied between 0.02 and 0.0848 with an average value of 0.052. Table 1 shows the fraction of the drainable porosity (f) as determined from moisture characteristic curves according to FAO (1980) for different soil layers. The f-value ranged between 0.0589 and 0.0868 with an average value of 0.073.

TABLE 1. Drainable porosity (f) as determined from pF-curves.

Soil depth (cm)	Fraction of drainable porosity (f)
0-30	0.0589
30-60	0.0791
60-90	0.0868
90-120	0.0636
120-150	0.0767
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average	0.073

Table 2 shows the values of (f) as calculated from reservoir coefficient for different irrigation cycles. The drainable porosity increased from very small values (0.01) when the water table is close to soil surface (after irrigation) and reached higher values (up to 0.13) for deep water tables. In other words, the values of (f) decreased with increasing the values of hydraulic head. These results confirm that the clay soils have high f-values when the water table is deep. The values of (f) calculated from (q) ranged between 0.012 and 0.121 with average values of 0.031 - 0.085. While the values of (f) which calculated from (h) varied between 0.013 and 0.132 with average values of 0.037- 0.094 for the same irrigatation cycles.

TABLE 2. Drainable porosity (f) as calculated from reservoir coefficient at different irrigation cycles.

Irrigation cycle (No.)	Fraction of drainable porosity (f) as calculated from:	
	q	h
1	0.041 (0.013-0.076)	0.044 (0.013-0.096)
2	0.064 (0.014-0.110)	0.072 (0.015-0.121)
3	0.048 (0.013-0.072)	0.059 (0.014-0.075)
4	0.031 (0.012-0.065)	0.037 (0.013-0.068)
5	0.085 (0.015-0.121)	0.094 (0.021-0.132)
average	0.054 (0.013-0.089)	0.061 (0.015-0.098)

The variation in f-values may be due to the variation in the period between every irrigation cycle and the amount of irrigation water gifted for every cycle. In this concern, Youngs (1992) reported that, thus the drainable porosity is the air content at the soil surface, which increases from zero when the water table is close to it and approaches a constant large value for deep water tables; this latter value is often taken to be the specific yield. The average of this value for the studied field is about 0.094. The disadvantage of reservoir coefficient method is the water seepage from the neighbor irrigated fields and the natural drainage through the soil cracks which are not considered through the reservoir coefficient equation. This leads to find a method that depend on the receding of water table for a long period without any interference with seepage from any sources.

Therefore, the method suggested by Feddes and Stakman (1984) was used. Data in Table 3 represent the receding of water table and the change in soil moisture storage during the irrigation closure period to be sure that there is no effect for seepage on the water table. The average value of (f) for the soil profile (up to 150 cm) was 0.104. This method for determination of soil drainable porosity considered from the preferable methods, but it must be used in the areas that are not subjected to water seepage. The high f-values calculated by this method (10.4%) and using the reservoir coefficient method (up to 13.2%) when the water table is deep. show that the clay soils have a higher drainable porosity when the water tables are deep. The f-values measured in the field using both the reservoir coefficient method and Feddes and Stakman's method were higher than those had been predicted from water retention curves. Possible reason for this differences is the swelling of the samples during the pF-studies which increased the calculated volumetric water content and resulted in lower f-values.

TABLE 3. Calculation of drainable porosity (f) when the groundwater table lowered from 22 cm down to 145 cm

Depth below soil surface (cm)	Height above water table $z = -h_1$ (cm)	θ_1*(z)	Height above water table $z = -h_2$ (cm)	θ_2*(z)	$\Delta\theta=\theta_1-\theta_2$	$\Delta\theta.100$ (mm)
0	22	0.5220	145	0.3533	0.1687	15.99
10	12	0.5120	135	0.3608	0.1512	14.61
20	2	0.5035	125	0.3626	0.1409	13.59
30	0	0.4985	115	0.3675	0.1310	12.87
40		0.4985	105	0.3721	0.1264	11.93
50		0.4985	95	0.3863	0.1122	10.98
60		0.4985	85	0.3912	0.1073	10.17
70		0.4985	75	0.4025	0.0960	8.82
80		0.4985	65	0.4182	0.0803	7.53
90		0.4985	55	0.4283	0.0702	6.83
100		0.4985	45	0.4321	0.0664	5.84
110		0.4985	35	0.4482	0.0503	4.32
120		0.4985	25	0.4625	0.0360	2.69
130		0.4985	15	0.4808	0.0177	1.30
140		0.4985	5	0.4902	0.0083	0.42
150		0.4985	0	0.4984	0.0001	

* θ_1, θ_2 = soil moisture contents (cm^3/cm^3) at time t_1,t_2 respectively Σ 127.89

$$f = \frac{127.89}{1450-220} = \frac{127.89}{1230} = 0.104$$

The Hooghoudt's formula (4) was used for calculating drain spacings. The soil hydraulic conductivity (K) used for these calculations was 0.254 m/day, the design water table depth midway between drains was 1.0 m, and the average drain depth was 1.4 m. The drainage coefficient (q) was taken as 1.0 mm/d. The depth to the impermeable layer was 4.0 m below the soil surface. Under these conditions the calculated drain spacing was found to be 41 m. Although under the Nile Delta conditions, drainage coefficient of 1.25-1.50 mm/d may be more appropriate to control the water table below the design water table depth (ISAWIP, 1994). Calculated drain spacings of 37 m and 33 m would be obtained if drain discharge rates of 1.25 and 1.5 mm/d were used, respectively. For economic design capacity of tile drainge under water table conditions in the irrigated lands one may ignore the unusual and unfrequent high rates, as a water table in the root zone can be tolerated for short periods.

One of the main assumptions of Hooghudt's equation is that the entrance resistance is negligibly small. Measurements of groundwater level between two drains show that water elevation in the piezometer nearby the drain pipe is rather high . So, an assumption of no entrance can make a considerable error and the modified Hooghoudt's equation (5), which takes into account the entrance resistance, have been applied. The calculated drain spacing using this equation was 36 m if the drain discharge was 1.0 mm/d, and when q-values of 1.25 and 1.50 mm/d were used, the calculated drain spacings were found to be 32 and 29 m, respectively.

In areas with periodic irrigation the assumption of steady state recharge is no longer justified. Under these conditions the non-steady state criterion (falling watertable condition) is more nearly approached the actual situation occurring during drainage (Hiler, 1969). The drain spacings computation using the non-steady flow equation of Glover-Dumm's (6) was based on the consideration that water table rises to the soil surface after irrigation and the requirement is to lower it to a depth of 50 cm after 3 days. These conditions are assumed reasonable to satisfy the water table depth control requirements in the irrigated fields of Nile Delta (Abdel Dayem *et al.*, 1998). The depth of impermeable layer below drain depth is 2.6 m and the drain depth is 1.4 m. The average soil drainable porosity (f) is 0.067. Under these conditions, the calculated drain spacing was 24.4 m. Calculated drain spacing of 53.3 m would be obtained if the drainable porosity of 0.014 was used. This value was obtained using the reservoir coefficient method for the 3 days after irrigation. It is interesting to notice that in the studied area the drains were installed with a gravel surround. It is well known that drain surround minimize entrance resistance, improves the capacity for water removal from the soil matrix and allows a wider drain spacing. Dieleman and Trafford (1976) showed that, for clayware pipes it is theoretically possible to double the drain spacings using a gravel surround for deep and good permeable soil (K = 1 m/d).

The measured and calculated hydraulic heads as a function of time during one irrigation interval are plotted in Fig. 3. Water table recession was calculated using both Boussinesq's equation (3) and Glover-Dumm's equation (6). The water table height 24 hr after the irrigation was considered to be the initial water table height and was used as such in all calculations. The calculated hydraulic head using Boussinesq's equation is higher than the measured one, this equation assumed that the drains are resting on the impermeable bed. While the predicition of water table height using Glover-Dumm's equation gives better results with an overestimation at the first days and it is followed by an underestimation for the rest of the observation period. It can be concluded from these results that Glover-Dumm's equation is suitable to predict the hydraulic head and calculating the spacing between lateral drains in the irrigated clay soils at the Nile Delta. Similar results were reported by Talha *et al.* (1993a). In this concern, Marei *et al.* (1989) mentioned that the calculated water table height using Glover-Dumm's equation deviates from measured data with increase in the depth of the impermeable bed.

The values of measured and calculated drain discharge, for one of the middle two laterals, as a function of time after irrigation are illustrated in Fig. 4. The measured discharge rate decreased with time and varied between 0.76 and 2.5 mm/day. The calculated drain discharge using Boussinesq's equation varied between 0.9 and 3.15 mm/day, which is about 20% greater than the measured discharge rate. While the calculated drain discharge using Hooghoudt's equation

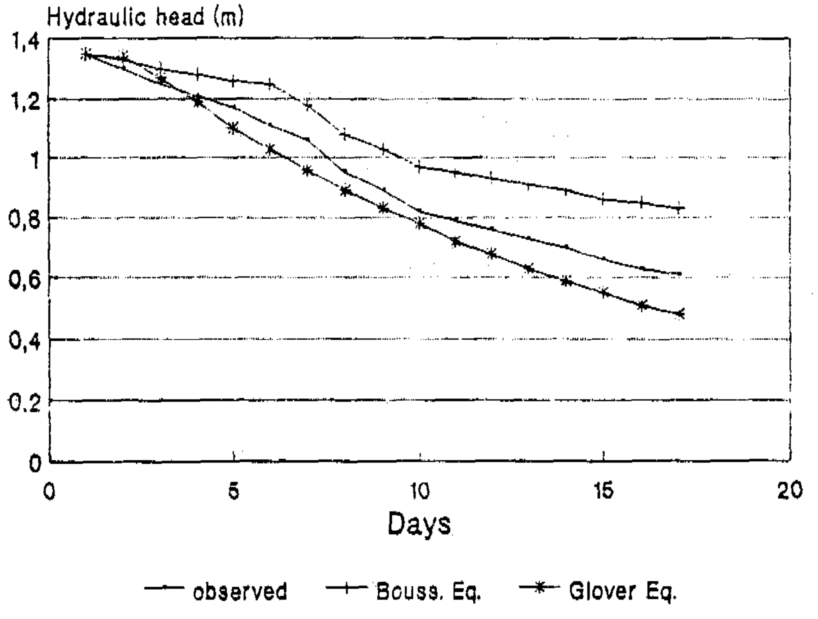

Fig. 3. Observed and calculated hydraulic head (h).

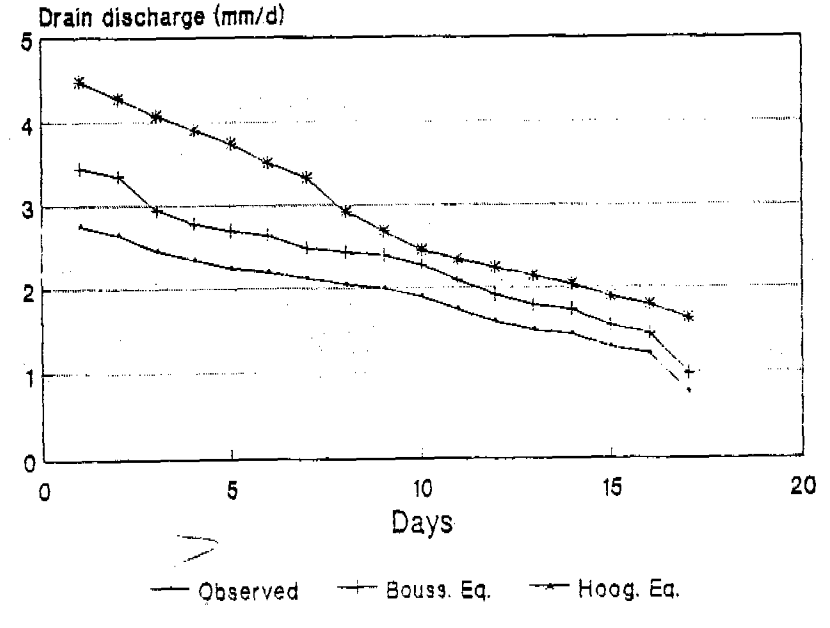

Fig. 4. Observed and calculated drain discharge (q).

varied between 1.74 and 4.49 mm/day, which is about 55% greater than the measured discharge rate. Possible reasons for the higher calculated discharge rates are either higher than measured soil hydraulic conductivity or a deeper impermeable layer than assumed. In this concern, Talha *et al.* (1993b) showed that the natural drainage through the growth season of clover plants cultivated in Nile Delta clay soils was equal to 93 mm (about 60% of the measured drain discharge of 154.8 mm). And they concluded that the natural drainge must be taken into consideration for calculation of drain spacings.

Reversing the process to calculate the hydraluic conductivity (K) corresponding to the measured discharge rates, the average values of the calculated hydraulic conductivity varied between 40 and 55 cm/day, they were 55 to 116% greater than those measured by the auger-hole method. Similarly, the depth to the impermeable layer was calculated for the measured discharge rates and the measured K-values, and it was found to be about 10 m. Also, it was much higher than the used design depth of 4.0 m below the soil surface. These results show that the actual soil transmissivity (Kd - value) is much higher than the value used for the drainage design. The calculated drain spacings under these conditions using Hooghoudt's equation were found to be 80-100, 70-75 and 60-75 m when drainage coefficient values of 1.0, 1.25 and 1.5 mm/d, respectively were used in the calculations. Also, they are as much as double the drain spacings calculated on the basis of steady-state water table depth, auger - hole measurements of K-value, shallow impermeable layer. Using Glover - Dumm's equation, assumed a depth of the impermeable layer of 10.0 m below soil surface, drain depth of 1.40 m, K-value of 0.40 - 0.55 m/d and f - value of 0.014 gave a drain spacing of 115-135 m. And when the average f-value of 0.067 was used the calculated drain spcings were found to be 52 - 62 m.

These results confirm that the actual field scale K and D values are much larger than the values used for the drainage designs. Meanwhile, the non-uniform irrigation conditions accelerates the drawdown of the water table, possibly due lateral flow to the surrounding non-irrigated fields. Volume changes and resulting shrinkage cracks are of great importance for water transport in clay soils (Wilkinson *et al.*, 1986). Therefore these processes should be taken into account when applying drainage equations to these soils. In spite of a close calculated drain spacings, several examples in clay soils had shown that good results can be obtained by using wide drain spacings without severe effects on soil properties and crop production (Abdel Dayem *et al.*, 1998 and Gupta *et al.*, 1998). Especially in the case of high-intensity rain or irrigation on dry clay soils, a large part of the infiltrating water is transported quickly to the groundwater table. Bronswijk (1988) reported that water transport in clay soils takes place both through soil matrix and through shrinkage cracks. He showed also that the bypass flow amounted to 28% of the total infiltration, which results in a very rapid response after percipitation events and a higher drain outflow. Clark *et al.* (1987) reported that once routeway has been established, water travels most rapidly in the heavy clay soils compared with the light soils. In this concern, Abdel Dayme *et al.* (1998) reported that the actual hydraulic conductivities of the Nile Delta clay soils can be as much as double the values obtained by the aguer-hole method.

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التوصيل الهيدروليكي ومسامية الصرف للأراضي الطينية وحساب المسافة بين المصارف

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أجريت هذه الدراسة في الأراضي الطينية المروية تحت نظام الصرف المغطى بشمال دلتا النيل ، بهدف تقدير التوصيل الهيدروليكي ومسامية الصرف لهذه الأراضي وتقييم معادلات الصرف المستعملة لتحديد المسافة بين المصارف . ولقد أوضحت نتائج الدراسة أن معدل الصرف المقاس أقل بكثير من معدل الصرف المستعمل لتصميم نظام الصرف ، وأن هناك علاقة واضحةبين الضاغط الهيدروليكي (h) وكل من معامل التوصيل الهيدروليكي للأرض (K) ومعدل تصرف المصارف (q) . ولقد وجد أن قيم التوصيل الهيدروليكي المقدرة في الحقل بطريقة الحفرة أثناء دورات الرى المختلفة تتراوح بين ١,٢ - ٧٢ سم / يوم بمتوسط قدره ٢٥,٤ سم / يوم . وتختلف قيمة مسامية الصرف (f) باختلاف الطرق المستعملة في القياس والموضحة في البحث وتتراوح بين ١٤,٠٠ - ١٣,٠ .

ولقد وجد أن المسافة المحسوبة بين المصارف باستعمال معادلة هوخ أوت تعادل ٢٩ - ٤١ متراً عندما يكون عمق المصارف ١٤٠ سم ومعدل التصرف ١,٥ - ١ مم / يوم وذلك باستعمال القيمة المتوسطة للتوصيل الهيدروليكي للتربة . بينما أبعاد المصارف المحسوبة باستعمال معادلة جلوفر - دوم تختلف باختلاف قيمة المسامية الصرفية المستعملة في الحساب وتتراوح بين ٢٤ - ٥٣ متراً . أوضحت نتائج الدراسة أيضاً أن القيم المحسوبة لمعدل تصرف المصارف باستعمال معادلة **Hooghoudt** ومعادلة **Boussinesq** كانت أعلى من القيم المقاسة . وأن القيم المحسوبة لكل من التوصيل الهيدروليكي وعمق الطبقة الصماء كانت أعلى بكثير من تلك القيم المستعملة لتصميم نظام الصرف ، وهذا يعني أن أبعاد المصارف المقدرة عند التنفيذ أقل من الواقع . وأنه عند أخذ هذه القيم المرتفعة لكل من التوصيل الهيدروليكي وعمق الطبقة الصماء في الأعتبار فسوف نحصل على قيم أكبر للمسافة بين المصارف الحقلية بحيث تكون المسافة المناسبةبين المصارف أعلى دائماً من ٥٠ متر .