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EFFECT OF TILE DRAINAGE ON SOIL PROPERTIES AND CROP YIELDS AT NORTH OF NILE DELTA

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ABSTRACT: A tile drainage system was carried out in Kafr-El-Sheikh, north of the Nile delta with 30 and 40 m spacing between drains and was evaluated after two years. Cumulative and rate of infiltration were estimated from field data and were calculated using the Philip's model. Measured values (over drains, 30 and 40 m between drains) were 70, 39 and 27% higher than the control. A reasonable fit was obtained between observed and calculated cumulative infiltration (I), but the prediction of infiltration rate (i) was relatively unacceptable, especially shortly after infiltration has commenced. To improve the fit of infiltration rate, an additional constant C was added to compensate the truncated terms in the Philip's equation. Introducing the additional constant C did not change the form of the infiltration rate equation, but dramatically changed the values of sorptivity (S) and final infiltration (A), and significantly improved the fit for both cumulative and rate of infiltration. The best fit parameter was improved by 15 % and 64.3 % of the unmodified form for I and i, respectively. Generally sorptivity was increased with installation of drainage system by 34-42 % between drains, increased to 70 % directly above drains using the unmodified equation. As for the modified equation, the calculated sorptivity increased by 20-28 % between drains and 48 % above drains. The Van Genuchten's model parameters were estimated, for the soil under study, with and without drainage system.

Draw down was significantly higher at the first five days after irrigation than the rest of the period between irrigations, where it was much lower but comparable for all treatments. Hydraulic conductivity measurements showed a wide range values depending

on the location of the measurement. Drainage intensity factor ranged between 0.06 to 0.18 for soil with drainage system compared to 0.04 to 0.11 for soil without drainage. Soil penetrability were lower above drains than between drains. Installation of drainage system resulted in average increase of 40% and 1.7 % for Ca^{++} and SO_4^{-2} and average decrease of 15.3, 40.9, 53.0, 40.0 and 15.5 % for Mg^{++}, Na^+, k^+, Cl^-, and HCO^-_3, relative to the undrained soil respectively. However drainage system installation increased soil productivity by 51–60 % for rice, cotton, wheat and mayze, and by 20% for sugar beet.

Key words: ***Infiltration, sorptivity, penetrability, draw down, Models, productivity.***

INTRODUCTION

Installation of subsurface drainage system in soils leads to disposing of the excess water, reduces soil salinity and soil sodicity (Wesseling, 1983). Also results in improving soil physical, chemical and hydrological properties, such as lowering water table, leading to better structure of top soil, increased infiltration and porosity (Van De Goor, 1979). In addition to increasing soil aeration, drainable porosity, hydraulic conductivity, and reducing bulk density (Naguib, 1987). Maintaining the ground water table at a depth which prevents salinization of soil profile will discharge the excess water and salts, reclaim and conserve land for agriculture, increase crop yields and reduce the costs of crop production (Osterbaan, 1994).

Luthin (1966) reported that position and fluctuation of ground water level is governed by rate of rainfall, application rate of irrigation water, soil hydraulic conductivity, depth to the impermeable layer, and depth and spacing of the drains.

Wesseling (1964) assumed that drainage intensity factor "a" is the ratio between the discharge caused by storage and the amount of water stored. Van beers (1965) indicated that if "1/a" value is large, then transmisivity is small and water table will fall slowly. Mohamedin (1995) obtained values of drainage intensity factor of 0.117, 0.064 and 0.03 mm/day in tile, open and no-drainage soils, respectively.

Singh (1980) stated that, the force required to thrust the penetrometer probe to a certain depth reflects the hardness of the surface crust, soil consistency, soil moisture condition and compactness of the soil. Skaggs (1987); Zaidelman and Belichenko (1999) recognized compaction of heavy soils as a serious problem in poorly drained soils.

El-Gohary *et al.* (1989), indicated that the rate of infiltration above tile drains is about 2-3 times that between drains. Also infiltration decreased with increasing drain spacing (Ramadan *et al.*, 1994). Ochs and Bishay (1992) reported that the hydraulic conductivity is one of the most important soil properties which is related to drainage improvement. Soil drainability is characterized by the hydraulic conductivity and the thickness of the soil layers and by their position relative to the drained level.

Zaslavsky (1979) stated that, reclamation of salt-affected soils is achieved by leaching of soluble salts through adequate drainage. Water movement during leaching, enables for redistribution of both soluble and scarcely soluble colloidal materials through out the soil profile. Abu Sinna (1991) indicated that soil desalinization is associated with the decrease in "SAR" and "ESP" values due to the high leachability of Na^+ compared to that of Ca^{++} and Mg^{++}. Rao and Leeds Harrison (1991) found that salintiy of the drained soil was higher in the mid-portion between drains and gradually decreased towards the drains because of more leaching of salts near the drains. Average soil salinity decreased after three months of leaching and cropping. The decrease in profile salinity was more in 25 and 50 m. drain spacings as compared with 75 m. drain spacing (Sharma *et al.*, 1992).

Abd El-Dayem and Ritzema (1990); Abu-Sinna (1991); Faltas *et al.* (1991) and Abd El-Dayem and EL-Safty (1992) showed that crop yields increased significantly after installation of subsurface drainage system. The increase was 10-21 % for rice, 35-48 % for berseem, 24-75 % for maize and 27-130 % for wheat. Part of the yield increase was attributed to the decrease in soil salinity, the other part was due to the improved water and air conditions in the root zone and other improved agricultural inputs. Sharma *et al.* (1992) found that grain and straw yields decreased with increasing drain spacings from 25 to 75 m. Grain yields was higher near the drains and decreased as the distance from the drains increased.

The objectives of this work are to evaluate the importance and effect of tile drainage system on some properties of the heavy clay soils, north at Nile Delta. Also to estimate the best values of some soil parameters, such as soil sorptivity, final infiltration rate and Van Genuchten's model parameters for easy predictions of cumulative and rate of infiltration as well as pressure head values from moisture content data.

MATERIALS AND METHODS

A field experiment was conducted on the salt affected soils (clay), north-east of the Nile Delta at the Fuwa area, Kafr El-Sheikh Governorate, Egypt. A tile drainage system was installed in October 1995, using plastic pipes with 30 and 40 m spacing between drains and a depth of 140 cm below the soil surface. Tile drainage system with 30 m spacing was carried out in EL-Atala Village while the 40 m spacing was installed in Adeoun and Drosely Villages. An area located near the second location was not served by drainage and was considered as the control area for the study.

Soil samples from the studied locations (30 m, 40 m and without drainage) were taken in summer, 1996 and was repeated in summer 1997. The sampling was carried out, two days before irrigation. Samples were taken in the parallel direction of drains, above and midway between drains. The samples were taken from six depths namely 0-15, 15-30, 30-60, 60-90, 90-120 and 120-150 cm. At each depth of the treatments under study, moisture content was estimated, disturbed and undisturbed soil samples were taken. The disturbed samples were air dried, gently crushed, and sieved through a 2 mm sieve. Fractions below 2 mm were subjected to physical and chemical analysis. Soil samples were analysed for total soluble salts (EC), soluble cations (Ca^{++}, Mg^{++}, Na^{+}, K^{+}) and soluble anions (CO_3^{--}, HCO_3^{-}, SO_4^{-2}, Cl^{-}) according to Jackson (1973).

Productivity data were collected from farmers and agricultural societies of the studied areas through out two seasons for wheat, sugar beet, rice, cotton and maize crops.

Hydraulic conductivity (K) was measured in situe by auger hole method according to Van Beers (1965). The depth of the hole was 150 cm from soil surface with 10 cm diameter, hydraulic conductivity K was then calculated by the following equation:

$$K = \frac{4000r^2}{(H+20r)(2-Y/H)Y} x \frac{\Delta Y}{\Delta t}$$

Where, K = hydraulic conductivity (m/day), $Y = Y_0 - ½ \Delta Y$, Y_0 = water table at zero time minus water table at equilibrium (cm), r = radius of Auger hole (cm), Δt = change in time (sec.), H = height of water in hole at equilibrium (cm), ΔY = change in height of water in hole (cm) after Δt.

A group of field piezometers were installed to the drain depth above and midway between laterals in each treatment for recording the depth and fluctuation of water table. The measurements were carried out daily, directly from the day after irrigation to the next irrigation.

Drainage intensity factor (a) was calculated according to Dieleman and Trafford (1976), as $a = \ln (h_o/h_t) / t$, where, a = the drainage intensity factor (mm/day), h_o = the hydraulic head in mm at zero time, h_t = the hydraulic head in mm/day.

Rate of water table draw down was calculated as $(h_t - h_o) / t$, where h_t = water table depth at time t, h_o = water table depth directly after irrigation, and t = time from irrigation (days).

Soil penetrability was measured using a hand penetrometer apparatus. A uniform pressure was applied to the handgrips to push the cone into the soil at a constant rate of 2 cm/sec.

Infiltration rate (IR) was measured using a double ring infiltrometer, as the rate of water intake was recorded over 3.25 hours period. The (IR) measurements were carried out in September 1996 at the three locations and were repeated in September 1997. The infiltration rate was calculated according to Garcia (1978).

Soil moisture retention data were determined using the pressure plate extractor (Garcia, 1978).

RESULTS AND DISCUSSION

Philip (1957), indicated that cumulative infiltration (I) can be expressed as a series that converges rapidly for times not too large. The series that can describe infiltration over the period of interest from the initial stage out to a long time after infiltration has begun is $I = S\,t^{1/2} + A\,t + B\,t^{3/2} + \ldots$, which is usually truncated after the first two terms. The coefficients S, A, B, .. are constants depending on the soil properties and soil moisture content (surface and initial water contents) and can be evaluated by numerical analysis techniques. The coefficient S, called the sorptivity, has a wide applicability in the soil water theory. Sorptivity is a measure for the capacity of a soil to absorb water and is also known as the coefficient of the square root of time term in infiltration. The Philip model has recently been applied in the field by measuring cumulative infiltration at numerous times, using for example a double ring infiltrometer, and fitting the resulting data to find the best values of S and A. The early stage of infiltration is effectively described by the truncated equation and the infiltration rate (i) is derived by differentiating with respect to time (t) to obtain $i = \frac{1}{2}\,S\,t^{-1/2} + A$. The infiltration rate decreases as a function of time. Sorptivity is the dominant parameter in the early stage of infiltration. As time progresses, the first term becomes negligible and the importance of A, which represents the main part of the gravitational influence, increases. Cumulative and rate of infiltration were estimated from field data and were plotted for different drainage treatments in Fig. (1). Data showed that measured values over drains were significantly higher than between drains or the control. The over drains treatment produced values 70% higher than the control, while the 30m treatment produced relatively higher values than the 40m treatment, the values were ~39 and 27% higher than the control, respectively. These results are in agreement with that of El-Gohary *et al.* (1989), Ramadan *et al.* (1994).

Results showed a reasonable fit between observed and calculated cumulative infiltration but prediction of the infiltration rate i was relatively unacceptable especially shortly after infiltration has commenced. Calculated values of S and A are presented in Table (1) along with the best fit parameter SER (summation of error ratios, Aly, 2001) and correlation between measured and calculated values for cumulative and rate of infiltration using the commercial computer program MATHcad.

Table 1. Measured and calculated cumulative and rate of infiltration data using modified and unmodified forms of Philip's equation, with their best fit parameter values and sorptivity.

Drainage			Cumulative infiltration		Infiltration rate		
Treatment	sorptivity	final-k	SER (I)	r^2 (I)	SER (i)	r^2 (i)	c-value
Without correction							
No	0.99076	-0.011672	0.87824	0.98891	2.4465	0.98998	
40m	1.3314	-0.022372	0.67303	0.99202	1.8938	0.99167	
30m	1.411	-0.019917	0.66264	0.99269	1.9171	0.99323	
Over	1.6836	-0.021854	0.57095	0.99423	1.9646	0.99665	
With correction factor c							
No	1.7115	-0.0509	0.14554	0.99949	1.3291	0.98998	-2.904
40m	2.0599	-0.062024	0.10319	0.99942	1.4559	0.99167	-2.935
30m	2.1882	-0.062215	0.10293	0.99952	1.3835	0.99323	-3.131
Over	2.5262	-0.06771	0.074987	0.99973	1.3923	0.99665	-3.394

Table 2. Estimated parameters of Van Genuchten's model for heavy soil with and without drainage system and values of three best fit parameters.

Treatment	data points	Best fit parameters			a	b
	x, z	MSE	χ^2	SER		
No-drainage (Motopes)	4,6	1.74E-05	0.00030281	0.037978	0.0085359	1.5122
With drainage (Fuwa)	3,5	3.21E-05	0.00052853	0.063594	0.0094828	1.4133

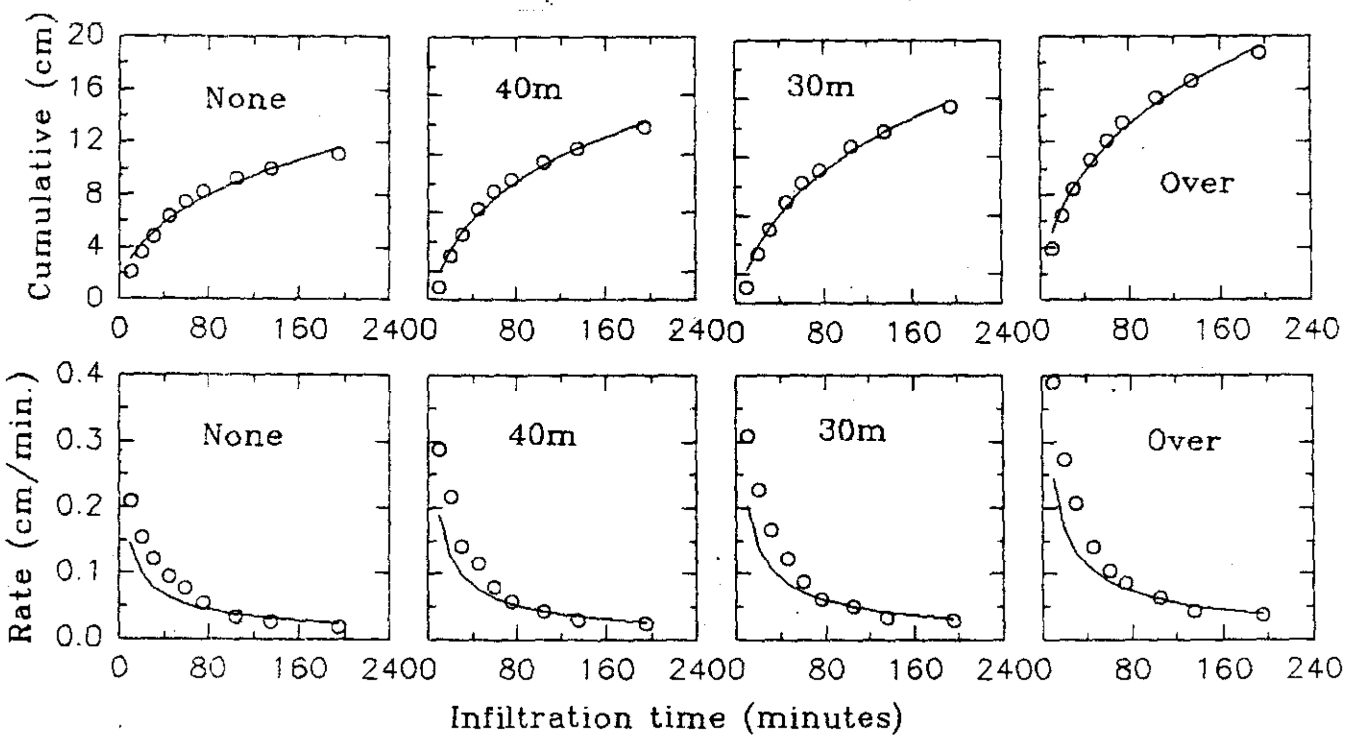

Fig.1. Measured and calculated cumulative and rate of infiltration under different drainage treatments using unmodified Philip's equations.

To improve the fit between measured and calculated values especially for infiltration rate, an additional constant (C) was added to compensate for the truncated terms in the Philip's equation for cumulative infiltration to be $I = S\ t^{1/2} + A\ t + C$. The additional constant did not change the form of the infiltration rate equation obtained by differentiating the cumulative infiltration equation and only affected the value of S and A. The calculated data of cumulative and rate of infiltration were estimated from the modified equation and was presented in Fig. (2).

Introducing the constant (C) dramatically changed the values of S and A, since the change was from 0.99 to 1.71 for S and from 0.012 to 0.051 for A, and significantly improved the fit for both cumulative and rate of infiltration. The SER for unmodified equation ranged between 0.57 to 0.88 for I, and from 1.89 to 2.45 for i., decreased to be 0.075 to 0.146 for I, and from 1.33 to 1.46 for i. with average percentage of 15 % and 64.3 % of the unmodified for I and i, respectively.

Generally sorptivity was increased with installation of drainage system and the increase was 34-42 % between drains increased to 70 % directly above drains for unmodified equation. As for the modified equation, the calculated sorptivity increased by 20-28 % between drains and 48 % above drains. There was a noticeable difference in the value of A between the control (no-drainage) and drainage treatments, while the differences among drainage treatments above and between drains were very slight.

To reduce the need for using time consuming instruments for determining soil pressure head (or soil suction) at different moisture contents, the model of Van Genuchten (1978) was used. The model mathematically expresses the moisture characteristic curves of most soils through fitting number of parameters to actual data, obtained for each soil, under different conditions. An attempt was carried out to estimate the model parameters for the soil under study with and without drainage system. The parameters values are listed in Table (2) with an estimate of the best fit parameter SER (summation of error ratios). Measured and model estimated values of pressure head for different treatments were plotted in Fig. (3). Data indicated that the model succeeded, near

Table 3. Mean values of soil penetrability (kg/cm^2) under different drainage conditions.

Soil depth (cm)	Un-drained soil	Drained soil		
		30/40 m over	30m between	40m between
0-15	21.17	11.85	14.50	15.00
15-30	23.50	13.38	15.40	16.33
Average	22.34	12.23	14.95	15.67

Table 4. Average crop yields and increasing percentage over the control for different drainage treatments and five crops (mean values of two years).

Crop	Yield			Increase %		
	no-drainage	40m.	30m.	40m.	30m.	Avg.
Cotton (kentar/fed.)	5.31	8.33	8.25	56.63	55.12	55.87
Rice (ton/fed.)	2.01	3.02	3.07	50.03	52.34	51.18
Maize (ton/fed.)	1.94	3.28	3.13	68.51	60.80	64.65
Wheat (ton/fed.)	1.25	2.00	1.98	60.57	58.97	59.77
Sugar Beet (ton/fed.)	18.25	21.68	22.00	18.70	20.50	19.60

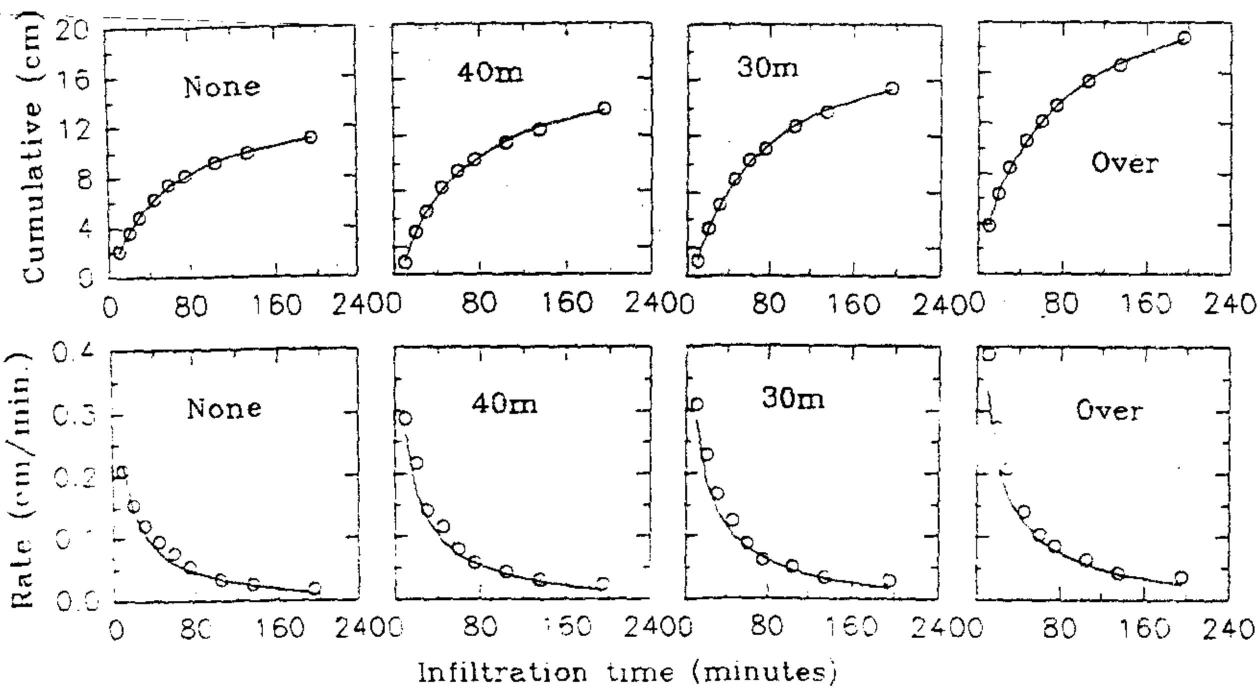

Fig. 2. Measured and calculated cumulative and rate of infiltration under different drainage treatments using modified Philip's equations.

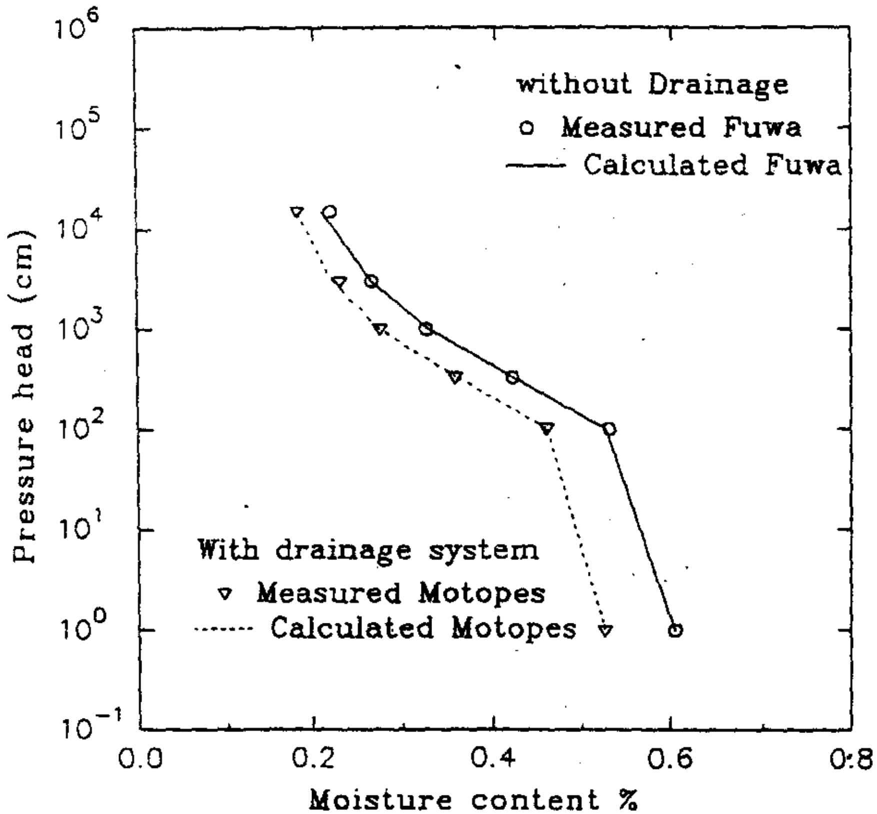

Fig. 3. Measured and calculated soil moisture retention data for soils with (Fuwa) and without drainage system (Motopes).

perfectly, to predict the actual values, that made using the model time and effort saving. Tables can also be prepared relating moisture content to pressure head for a given soil under different conditions.

Draw down curves Fig. (4), as a measure of how fast water level moves underneath the soil surface with time, indicated that the fastest draw down was observed directly above drains followed by between drains 30m, 40m and the control. The fastest draw down was also observed at the first day after irrigation (22.8, 18.9, 16.5 and 14.5 cm for over, 30m, 40, and control, respectively). The smallest draw down was noticed the last day before the next irrigation (after 14 days), ranging between 1.37 and 0.72 cm following the same order of treatments. For all treatments, draw down was much higher at the first five days than the rest of the period between irrigations, where it was marked with high rates of decrease, after which the rates were significantly lower and were comparable for all treatments. These results are confirmed by Yang *et al.* (1977), Brink and Lesaffre (1990) and Ibrahim *et al.* (1999) who reported that the rate of water table draw down increases as the distance between tile drains decreases. Moreover, El-Hamchary *et al.* (1989) showed that the draw down was affected by the drain spacing. The calculated rate of draw down between two irrigations was found to be 6.2, 3.7 and 3.1 cm / day for tile drain spacing treatments of 15, 30 and 40 m. respectively. Whereas, El-Gohary *et al.* (1989) pointed out that drop in water table level above drains was faster than between drains and the drop was greater in 15 m. than in both 30 or 40 m. spacing treatments. Mohamedin (1995) declared that the rate of water table draw-down increased in tile drained soils by 1.2 and 1.7 times compared with open and non-drained soils respectively.

Hydraulic conductivity measurements using the auger hole method produced wide range of values depending on the location of the measurement sight relative to the installed drains. The over all hydraulic conductivity average was 0.5778 m/d and 0.6682 m/d for the control and drained soils, respectively. Differences between hydraulic conductivity values of drainage treatments were very small, as the values were 0.648, 0.6755 and 0.6808 for 30m, 40m and over drains treatments.

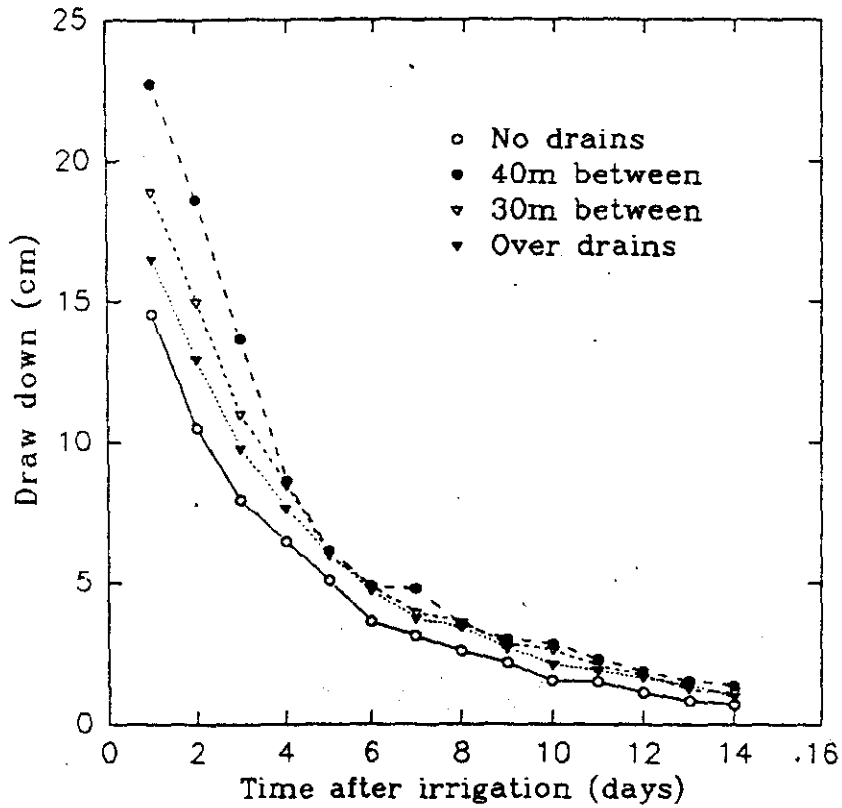

Fig. 4. Draw down curves with time for different drainage treatments.

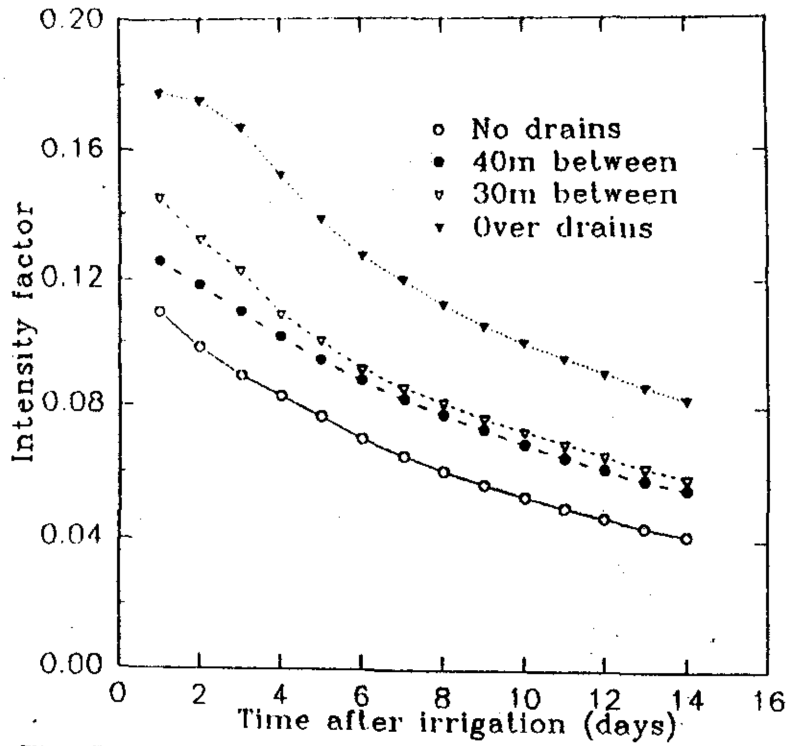

Fig. 5. Drainage intensity factors with time for soil under different drainage treatments.

Drainage intensity factor, DIF (defined as $\ln(h_0-h_t)/t$, where h is the pressure head at different times (t)) can be considered as a measure of drainage efficiency with elapsing time after irrigation (with the process of drying) which is related to the amount of drained water per unit time. Drainage intensity factor Fig. (5) increased with installation of drainage system, and was significantly higher over drains than between drains. DIF ranged between 0.06 to 0.18 for soil with drainage system compared to 0.04 to 0.11 for soil without drainage. DIF decreased consistently with time after irrigation up to 14 days (the period between irrigations) and the differences between 30m and 40m spacing treatments were slight being evident only at the first few days after irrigation. Daily intensity factors increase over the control were (62-98%), (32-42%), and (14-33%), for Over, 30m and 40m treatments, respectively. The overall average increases over the control for the same treatments are ~ 83, 35 and 25 %. The high improvement of DIF of the over drains treatment, could be attributed to the high speed water movement towards the drains due to the short path way and to the improved hydraulic properties brought about by digging and back filling during drains installation. These results are in good agreement with that of Wesseling (1964), Van beers (1965), and Mohamedin (1995).

Soil penetrability defined as the force (kg cm^{-2}) required to thrust a penetrometer probe into the soil is presented in Table (3) for two depths (0-15cm and 15-30 cm). Generally penetrability increased with soil depth and was significantly decreased for drained soils than the control (without drainage). Penetrability were less above drains than between drains as the drainage system generally lowered .soil penetrability by 30 to 45 %, where the decrease was ~45% above drains and 30 – 33 % between drains. Although soil moisture content was slightly higher midway between drains, the penetration resistance was also slightly higher than above drains. This result was attributed to the better drainage environment by Ward (1967) and also may be due to the presence of higher content of certain ions such as sodium or magnesium between drains than above drains.

Concentrations of cations (Ca^{++}, Mg^{++}, Na^{+} and K^{+}) and anions (Cl^{-}, HCO^{-}_3 and $SO4^{-2}$) were graphically presented with soil

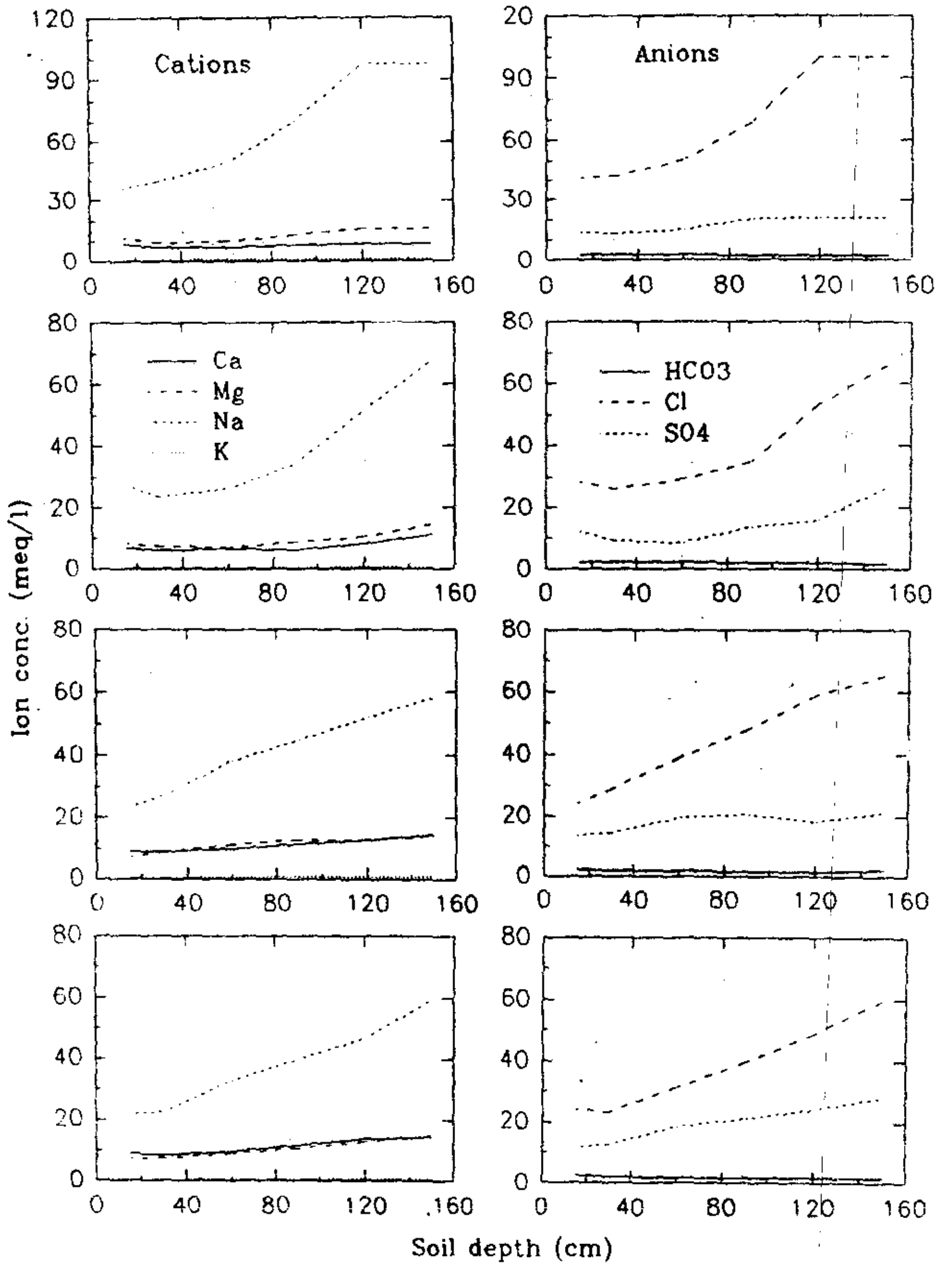

Fig. 6. Concentrations of cations and anions in soil at increasingdepths under different drainage treatments.

depth, for all treatments, in Fig. (6). Generally ion concentrations increased with soil depth at different rates. The concentration magnitude and rate of change with depth was highest with Na^+ and Cl^-, intermediate with Ca^{++}, Mg^{++} and $SO4^{-2}$ while the lowest change rate was observed with k^+ and HCO^-_3. It was noticed that ions having similar rate of increase with depths also have similar magnitudes. Installation of drainage system resulted in average increase of 40% and 1.7 % of Ca^{++} and $SO4^{-2}$ and average decrease of 15.3, 40.9, 53.0, 40.0 and 15.5 % for Mg^{++}, Na^+, k^+, Cl^-, and HCO^-_3, relative to the control values of 7.9, 17.8, 12.9, 70.4, 1.0, 72.0 and 2.3 meq l^{-1} of the same order of cations and anions. Drainage system also after two years from installation, reduced EC of the soil solution (9.13 ds m-1) by 31% and the SAR (21.15) by 41%. These results are in agreement with Abu Sinna (1991), Rao and Leeds Harrison (1991), and Sharma *et al.* (1992).

To measure the effect of drainage system installation on soil productivity, in such heavy soil, average yield of two years was recorded for five crops in Table (4). However yields obtained from soils provided with tile drainage at 30 and 40 m. spacings were higher than that obtained from the undrained soil. The increase during the years of 1996 and 1997 was 51 – 60 % for rice, cotton, wheat and mayze, respectively and was 20% for sugar beet. Only slight yield differences were observed between 30 and 40 m. spacing treatments. These results are confirmed by Abd El-Dayem and Ritzema (1990); Abu-Sinna (1991); Faltas *et al.* (1991), Abd El-Dayem and EL-Safty (1992), and Sharma *et al.* (1992).

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تأثير نظام الصرف المغطي علي بعض خواص التربة شمال دلتا نهر النيل

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تم تنفيذ نظام صرف مغطي في منطقة كفر الشيخ شمال دلتا نهر النيل بمسافات ٣٠, ٤٠ متر بين المصارف وقد تم تقييم النظام في عامين متتاليين وذلك بدراسة مستوي الماء الأرضي ومعامل التوصيل الهيدروليكي ومعدل الرشح وكذلك صلابة التربة وتركيز الأملاح مع العمق. وقد تم تقدير الرشح التجميعي ومعدل الرشح من البيانات الحقلية وكذلك حسابها من معادلة Philip حيث كانت القيم المقاسة فوق المصرف مباشرة أو بين المصارف للمعاملات ٣٠ , ٤٠ متر أعلي من تلك المقاسة في الأرض بدون مصارف بنسب ٧٠, ٣٩ , ٢٧% علي التوالي. وقد تم الحصول علي تطابق جيد بين القيم المقاسة والمحسوبة للرشح التجميعي بينما كان التنبؤ بمعدل الرشح غير دقيق وخاصة في المراحل الأولي من الرشح. ولتحسين التنبؤ وخاصة لمعدل الرشح فقد تم إضافة معامل جديد C للتعويض عن الحدود المحذوفة من معادلة Philip للرشح التجميعي حيث لم يؤثر ذلك علي صورة معادلة معدل الرشح ولكنه أثر بصورة واضحة علي قيم الأمتصاصية sorptivity وكذلك الرشح النهائي المحسوبين للأرض. كما أدي إلي تحسين معامل التطابق بنسب ١٥ , ٦٤,٥% لكل من الرشح التجميعي ومعدل الرشح علي التوالي. عموما ذادت الأمتصاصية بين المصارف وبدرجة أكبر فوق المصرف مباشرة مقارنة بتلك الخاصة بالأرض بدون مصارف. معدل هبوط الماء الأرضي كان سريعا نسبيا في الخمسة أيام الأولي عن بقية الفترة بين الريات التي ظل بعدها منخفضا وكانت القيم متقاربة لكل المعاملات. اعتمدت قيم معامل التوصيل الهيدروليكي المقاسة بطريقة حفرة الأوجر علي مكان القياس بالنسبة للمصرف حيث ذادت بالقرب من المصرف بينما تراوح معامل شدة الصرف Drainage intensity factor بين ٠,٠٦- ٠,١٨ للأراضي تحت نظام الصرف مقارنة ب ٠,٠٤- ٠,١١ للأراضي بدون صرف. كان معامل اختراق التربة منخفضا فوق المصرف عنه بين المصارف وعموما خفض نظام الصرف معامل الاختراق بنسب تتراوح بين ٣٠-٤٥% بينما أدي إلي زيادة تركيز كل من الكالسيوم والكبريتات وخفض كل من الماغنسيوم والصوديوم والبوتاسيوم والكلور والبيكربونات في التربة. كما أدي إلي زيادة إنتاجية الأرض بنسب تتراوح بين ٥١-٦٠% لكل من الأرز والقطن والذرة بينما زادت إنتاجية بنجر السكر بنسبة ٢٠%.