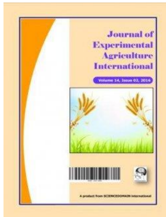

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Drain Envelopes for Problematic Calcareous Soils of Irrigated Agricultural Lands in Egypt

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

Envelope materials are used for surrounding subsurface drain pipes commonly installed to reclaim waterlogged and salt-affected lands to prevent entry of soil particles into drains and to constitute a medium of good permeability around the pipe and therefore reduce entrance resistance. In calcareous soils prone to the reduction of drainage capacity as a result of high clogging, determining adequate envelope materials is a crucial issue under Egyptian conditions. The study was conducted on a calcareous soil with a high risk of calcium carbonate precipitation. Four drain-envelope combinations of subsurface drainage systems were tested in an experimental field. It came out that granular and pre-wrapped drain envelopes, with a normal grade of 10cm/100m, were the best material regarding their hydraulic and mechanical performance for sub-surface drainage in calcareous soils.

Keywords: Subsurface drainage; envelope material; chemical precipitation; calcium carbonate; permeameter test; geotextile.

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1. INTRODUCTION

Problematic calcareous soils have often a percentage of calcium carbonate (CaCO3) of more than 15% in the soil that may occur in various forms like powdery, nodules, and crusts [1]. The high CaCO3 contents correspond to high silt content [2]. The potential productivity of calcareous soils is high where adequate water and nutrients can be supplied [1]. This should be followed by the establishment of an efficient drainage system [3].

Envelope materials are required to achieve better drain performance in irrigated lands. Drainage envelope materials have a dual function in the efficiency of subsurface drainage systems [4]. They are used to protect drain tubes against massive soil particle invasion, root growth inside the pipe, and to facilitate the flow of water into drainpipes by creating a more permeable zone around drains [5]. Generally, in the world, gravel and sand are known as traditional natural envelope materials [6]. But, due to their expensive cost, geo-synthetic envelope materials were developed to be used in subsurface drain pipes [7]. In the 1990's, gravel, pre-wrapped organic and synthetic fabrics (geotextiles) have become the most common drain envelope materials used to protect corrugated plastic drain pipes from the entry of sediments [8].

For an envelope selection process, a systematic comparison with experience gained elsewhere is generally very useful because soil behaviour is difficult to predict [9]. In Egypt, voluminous envelope materials being produced locally, namely PP and PA waste fibers, performed satisfactorily [10].

In view of drain-envelope functions, the drain envelope should be designed to prevent entry of soil particles into pipes [7]. The filtering effect, however, should not be such that the envelope, while keeping pipes free from sediments, itself becomes clogged [11]. Therefore, the main challenge for envelope material is to match the envelope specifications with soil type [12]. Since not only envelope specifications are dependent on soil characteristics but also soil types are rather variable, the envelopes to be designed have to be tested through field trials in local conditions [13].

In 1992, the Egyptian Public Authority for Drainage Projects (EPADP) has tested five different envelope materials in Haress Pilot Area of calcareous clay and loam soil, with 10 to over 50 cm thick layers of shells. The study involved five treatments where drains were provided with synthetic materials as follows: needle punched PP290, PP310, PP360, knitted Big, O, Sock and Typar which is a heat spun-bonded material [14]. The results showed that all values of entrance resistance of the laterals were greater than typical values mentioned in the literature. This would mean that all used envelopes would have been classified as poor to very poor performing. It would, therefore, appear that the criteria of envelope materials for calcareous soils need to be reviewed [14].

Precipitation of calcium carbonate has also been observed in many subsurface drainage systems around the world [15]. Abdel-Dayem, 2014 [16] mentioned that, using appropriate precipitation index help to assess the degree of potential risk of calcium carbonate precipitation which should be considered in the design and construction of a drainage system. Calcium carbonate (CaCO3) saturation indices are commonly used to evaluate the scale-forming and scale-dissolving tendencies of water [17]. The most common indices for the evaluation of the potential precipitation risk of calcium carbonate are Ryznar Saturation Index (RSI) and Langelier Saturation Index (LSI). These indices can be used to evaluate precipitation risks of calcium carbonate in agricultural drains and envelopes. Positive values of LSI and RSI less than 7 indicate the tendency of calcium carbonate to precipitate and its magnitude shows the severity of potential precipitation risk [15].

In 1936, Langelier developed an equation to predict the tendency of calcium carbonate either to precipitate or to dissolve under varying conditions [18]. It is a measure of a solution's ability to dissolve or deposit calcium carbonate, which is often used as an indicator of the corrosivity of water [15]. Langelier Saturation Index (LSI) involves an equilibrium model derived from the theoretical concept of saturation and provides an indicator of the degree of saturation of water with respect to calcium carbonate and can calculate as following [19]:

$$LSI = pHa - pHs \tag{1}$$

where:

pHa: the measured water pH.
pHs: the pH at which water with a given calcium content and alkalinity is in equilibrium with calcium carbonate.

The equation expresses the relationship of: pH, calcium, total alkalinity (Alkalinity as $CaCO_3$ is explained by bicarbonate (HCO^{3-}) and carbonate ions (CO_3^{2-}), dissolved solids (TDS) and temperature ($^{\circ}C$) as they are related to the solubility of calcium carbonate in waters with pH of 6.5 to 9.5. The pH*s* is defined as:

$$pHs = (9.3 + A + B) - (C + D) \quad (2)$$

where:

$$A = \frac{[\log_{10}(TDS) - 1]}{10} \quad (3)$$

$$B = -13.12 \times \log_{10}(^{o}C + 273) + 34.55 \quad (4)$$

$$C = \log_{10}(Ca^{+2} as CaCO_3) - 0.4 \quad (5)$$

$$D = \log_{10}[Alkalinity\, as CaCO_3] \quad (6)$$

Ryznar [20] developed an index, namely Ryznar Saturation Index (RSI), for determining the potential precipitation risk of calcium carbonate. This index is based on the saturation concept of calcium carbonate in water at a given pH. It is an empirical method for predicting scaling tendencies of water based on a study of operating results with water at various saturation indices. It uses the Langelier Index (LSI) as a component in a new formula to improve the accuracy in predicting the scaling or corrosion tendencies of water [19]. The Ryznar index is calculated as follows:

$$(RSI) = 2(pHs) - pH = pHs - LSI \quad (7)$$

The study objective was to determine the most appropriate envelope material to be used in problematic calcareous soils under Egyptian conditions regarding the reduction of drainage capacity resulting from clogging and potential risk of calcium carbonate precipitation.

2. MATERIALS AND METHODS

An experiment was conducted to study both granular and synthetic drain envelopes in more detail to determine which envelope material was more effective in problematic calcareous soils under Egyptian conditions.

The study was conducted in a field of problematic calcareous soils regarding to granulation in drain depth. The Egyptian Public Authority for Drainage Projects (EPADP) proposed different areas of problematic calcareous soils in Egypt including Fabes area, El-Bostan area, Abu-Masoud area which located in West Delta and El-Ameria area which located in Middle Egypt as shown in Fig. 1. The experimental area was selected according to the potential precipitation risk of calcium carbonate in the agricultural drainage system and results of a permeameter laboratory test. The laboratory test was carried out to investigate the performance of the current used synthetic drain envelope material and find out the degree of the risk of being clogged in these areas. Drain test lines were constructed in the experimental area with different criteria and envelope materials.

Tests carried out for each envelope material and soil combination involved three replications. To evaluate the hydraulic and mechanical functions of envelopes there is a need to assess drain lines performance and sediment occurrence [8]. The drain line performance was assessed by installing water table observation wells at appropriate locations and measuring drain discharge at the same time for a period of 6 months from the first of October 2014 to the end of March 2015. Sedimentation was observed by hand excavations along the tested lines of lateral drains in the area 6 months after construction.

To assess the best envelope material, entrance head loss (h_e) and entrance resistance (r_e) provide suitable parameters for determining drain line performance [14]. The entrance head loss (he) is the measuring of water table depth in an observation well immediately adjacent to the drain envelope and always at a fixed distance from the outside of drain pipe. For the entrance resistance which is a function of h_e and lateral discharge (ql), the same observations as before were needed. A discharge measurement at the end of lateral was also made. These two variables were used to decide which treatment was the best. Basically for the two values the lower the value the better the performance of the envelope.

The entrance resistance (r_e) describes the flow resistance as the head loss per unit rate of flow, it is calculated as: $r_e = h_eL/Q$ where: r_e = entrance resistance, in days per meter, h_e = entrance head loss in meters, L = length of drain in meters and Q = total drain discharge over length L. Table 1 shows the recommended criteria for consideration for the head loss fraction and the entrance resistance.

Table 1. The recommended criteria for drain line performance [21]

Entrance resistance r_e (days/m)	Entrance head loss h_e (m)	Drain line performance
smaller than 0.75	smaller than 0.15	Good
0.75 – 1.50	0.15 – 0.3	Moderate
1.50 – 2.25	0.3 – 0.45	Poor
larger than 2.25	larger than 0.45	very poor

Fig. 1. Location of proposed study areas

2.1 Laboratory Permeameter Test

Permeameter laboratory tests on the drain envelope material were carried out to investigate drainage performance in the proposed calcareous soils. One soil sample from the different proposed areas was collected during the pre-investigation phase and tested with the currently used envelope material using the permeameter set-up. The upward flow permeameters (Fig. 2) was used in which various soil-envelope combinations were tested. Drain envelope was tested against different soil samples collected from the drainage project areas of calcareous soils. The used Permeameter is made of good quality, clear plexiglass four cylinders (Cyl 1, Cyl 2, Cyl 3 and Cyl 4). Each soil envelope combination is replicated four times in these cylinders.

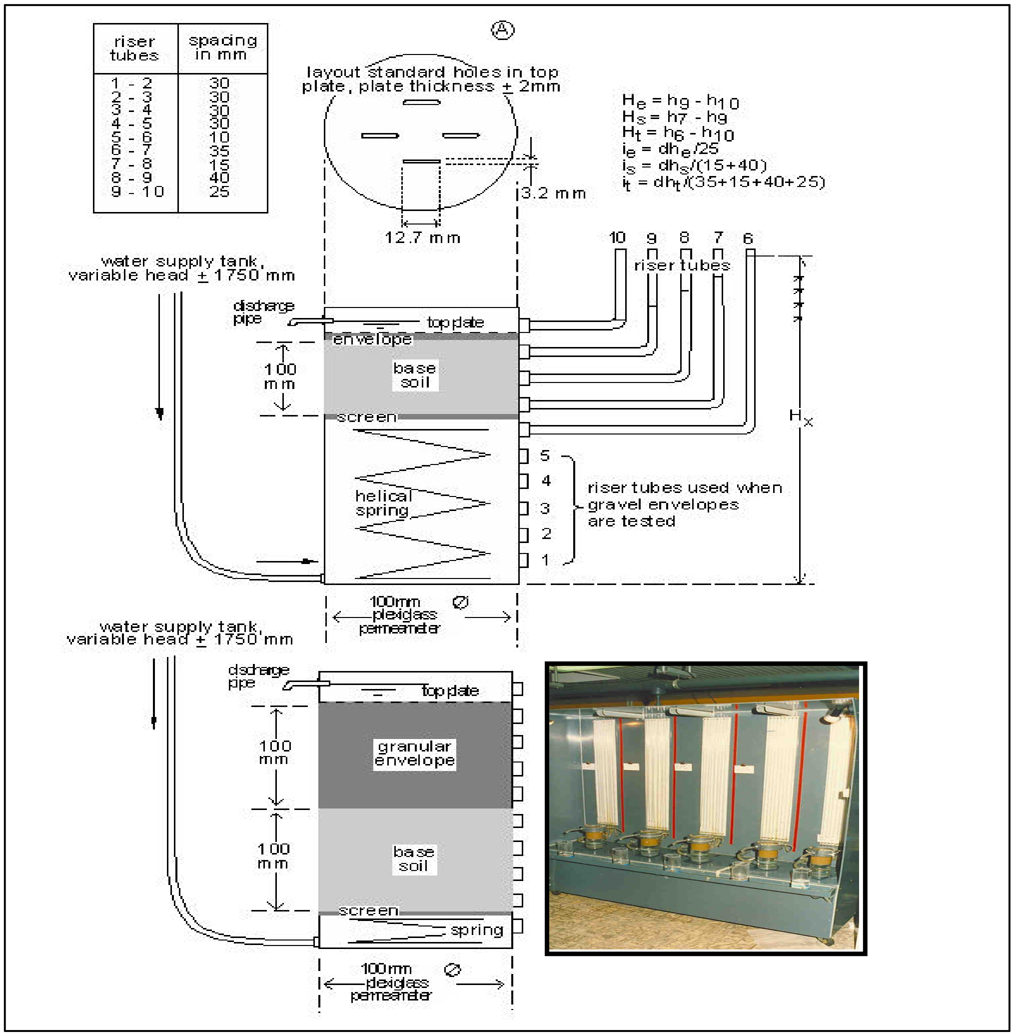

Fig. 2. Upward flow permeameter [11]

2.2 Calcium Carbonate Precipitation Indices

In this study, Ryznar and Langelier indices were used to assess the risk of calcium carbonate precipitation in drainage water. Potential precipitation risks of calcium carbonate following LSI and RSI indices are shown in Table 2.

2.3 Field Measurements

Soil samples for laboratory analysis were taken from the different proposed area of EPADP. About 60 soil samples were collected from each area at different drainage depths (0-50 cm, 50-100 cm, 100-150 cm and 150-200 cm). Chemical and physical soil properties regarding the investigated areas are given in Table 3. Results shown in Table 3 indicate that soil texture varied between loamy sand and sandy clay loam with high percentage of Calcium carbonate (CaCO3) in fine form. Based on that, the experimental area was selected according to the degree of the risk of calcium carbonate precipitation in the agricultural drainage system and the results of the permeameter laboratory test. It was carried out to determine the degree of the risk synthetic envelope materials used were prone to clogging under calcareous soil conditions.

At a selected drain depth of each drainage project area investigated, parameters required for determining saturation indices namely pH, calcium, total alkalinity, dissolved solids and the drainage water temperature were measured. A selected soil sample was used in the Permeameter tests as no significant variation in soil texture was observed during the pre-investigation at each drain depth.

Table 2. Potential risk of calcium carbonate precipitation following Langelier and Ryznar Indices [22]

LSI*	RSI*	Precipitation risk
< 0	> 7	No
0-0.5	6-7	Low
0.5-1	5-6	Moderate
1-2	4-5	High
> 2	< 4	Very high

3. RESULTS AND DISCUSSION

3.1 Risk Assessment of Calcium Carbonate Precipitation

Ghobadi et al. [15] indicated that based on the Ryznar index, the drainage water has a higher potential precipitation risk of calcium carbonate if pH, bicarbonate and calcium quantities are higher, while the Langelier index mostly depends on the pH and at high pH, even if bicarbonate and calcium amounts are low, it shows a higher estimation of precipitation risk. In this context, the Ryznar index presents a more logical estimation compared with the Langelier index [15]. The required measured parameters to calculate the Ryznar and Langelier indices are shown in Table 4. Subsequently, the indices were calculated using Equations (1), (2) and (7).

Results showed that all agricultural drainage systems in the study areas were submitted a potential risk of calcium carbonate precipitation, although the severity of the problem differs from one system to another. The results also showed that the Ryznar index provides a better estimation of potential precipitation risk of calcium carbonate than the Langelier index. From LSI and RSI data, potential precipitation risks of calcium carbonate for the proposed studied areas vary from low to high. Nonetheless, Abu-Masoud area shows the higher precipitation risk.

3.2 Permeameter Tests

One soil sample from the different proposed areas was collected and tested with the current used envelope material using the permeameter set-up to investigate the performance and find out the degree of the risk of being clogged with these soils.

Dierickx and Sluys, 1990 [23] mentioned that there would be no blocking or clogging of the tested envelope material if the following conditions over the time in the laboratory tests is met: $I_{es}/I_s < 1.0$ and $Kes/Ks > 10$, where: I_{es}/I_s is the hydraulic gradient ratio, I_{es} is the hydraulic gradient over the envelope material, I_s is the hydraulic gradient over the soil column, Kes/Ks is the hydraulic conductivity ratio, Ks is the soil hydraulic conductivity, and Kes is the envelope hydraulic conductivity.

Table 3. Chemical and physical properties of calcareous soils investigated

Soil sample	Soil particles %			Soil texture	$CaCO_3$ %
	Clay	Silt	Sand		
Fabes	11.5	0	88.5	Calcareous loamy sand	14.6
El-Bostan	20.9	6.4	72.7	Calcareous sandy clay loam	12.6
Abu-Masoud	20	20	60	Calcareous sandy clay loam	27
El-Ameria	14.5	0	86	Calcareous loamy sand	12.3

Table 4. Chemical parameters and calculated precipitation indices for studied areas

Sample location	EC (dS/m)	pH	T (°C)	Ca^{+2} (mg/l)	Alkalinity (mg/l)	TDS (mg/l)	LSI	RSI
Fabes	2.60	7.96	25.2	155.90	429	1669	0.78 M	6.35 L
El-Bostan	2.20	8.00	24.3	184.46	375	1422	0.82 M	6.40 L
Abu-Masoud	5.76	8.35	25.6	707.36	433	4032	1.79 H	4.75 H
El-Ameria	6.13	7.58	26	583.45	390	4294	0.90 M	5.77 M

L: Low precipitation risk M: Medium precipitation risk, H: High precipitation risk

It is important to check the above points to make sure that the trend of the ratio indeed indicates the expected. Fig. 3, Fig. 4, Fig. 5 and Fig. 6 show the permeameter test results for Fabes, El-Bostan, Abu-Masoud and El-America areas respectively. From these figures it can be seen that I_{es}/I_s ratio is always below one for the different areas except for Abu-Masoud area, it has an upward trend (Fig. 5a) and for some rare cases like Cyl 4 for Fabes area (Fig. 3a). For Kes/Ks ratio, the results show that this ratio is always less than ten for the different areas except also for some cases (Fig. 4b and Fig. 6b). These results are compatible with the results of potential precipitation risk assessment of calcium carbonate which show that Abu-Masoud area has the higher precipitation risk and consequently has more problem of envelope clogging.

3.3 Field Data

Abu-Masoud area was selected to conduct the experiment at the field as it shows the higher precipitation risk and high expectations of envelope clogging according to permeameter test results. In the area, soil salinity, water-logging and yield reduction were observed. The soil salinity in the area was varied from 1.5dS/m to 7dS/m with an average value of about 3dS/m. The water table depth was equal to about 60cm below soil surface which prevent aeration of the soil and causes reduction in the crop yield of about 20% compared to the national gross productivity in Egypt. There were also significant amounts of sediment in the lateral drains in the area which provided with subsurface drainage system of 60m spacing, 1.4m depth and synthetic envelope material. The drain test lines were constructed in September 2014 in an area of about 20 feddans (1 feddan = 0.42 ha) which has no subsurface drainage system yet. The area provided with different treatments of envelope materials as follows:

- Drain with currently used criteria of pre-wrapped synthetic envelope material and applying a slope of 10 cm/100 m for the lateral (Treatment 1),
- Pre-wrapped drain with the current used synthetic envelope material and increasing the slope of the lateral to 30 cm/100 m (Treatment 2),
- Granular drain envelope and applying slope of 10cm/100m for the lateral (Treatment 3), and
- Granular and pre-wrapped drain envelopes with a normal slope of 10cm/100m for lateral (Treatment 4).

The slope of the lateral was increased to increase the velocity of water in drain pipes to avoid CaCO3 precipitation and soil sedimentation. The synthetic envelope material that used in the study is sheets of voluminous polypropylene fibers wrapped around field drains in the factory with an average thickness of 5 mm and average pore size index PP of 400 microns. To design the granular drain envelope for Abu-Masoud soil, the following procedures are applying:

1. Make a particle-size analysis of the soil and define the lower and upper limits of the proposed gravel envelope according to Winger and Ryan, 1970 [24] that depend on the value of d60 of the soil (the diameter of the sieve at which 60% of the soil is passing);
2. Compare the particle-size distribution curves; and
3. Decide the proposed gravel envelope material to be used as shown in Fig. 7.

According to the proposed gravel envelope material curve (Fig. 7), soil particles percentages were defined as shown in Table 5.

Table 5. Soil particle percentages of the applied granular drain envelope

Particle size of the granular envelope material (mm)	Soil particles %
38 - 20	16
< 20 - 10	11
< 10 - 5	24
< 5 - 1	29
< 1 - 0.5	15
< 0.5	5

In the experimental field water table depth and laterals drain discharge were measured continuously for six months (66 measurements). The overall measurement results are summarized in Table 6. The averages of the test results were used for evaluation the entrance head loss (h_e) and the entrance resistance (r_e) for the different treatments of drain test lines.

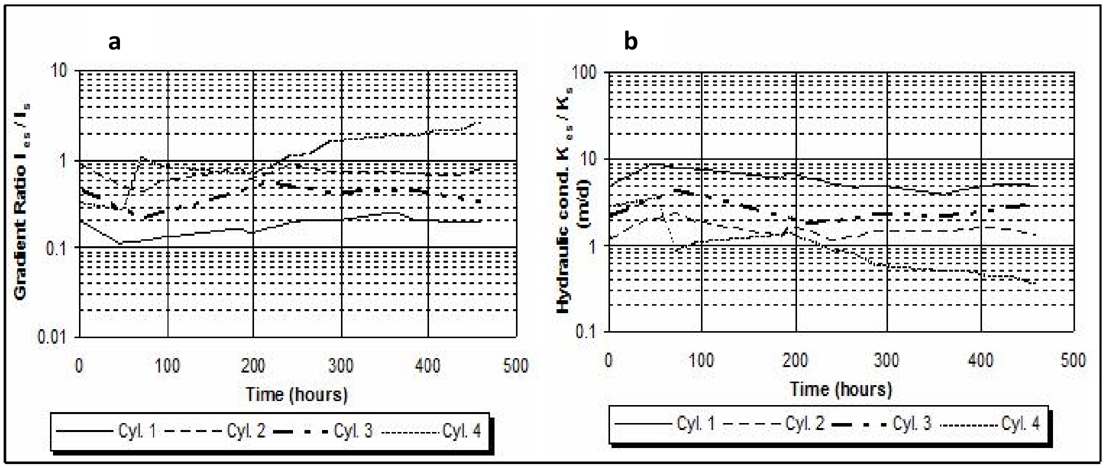

Fig. 3. Permeameter test results for Fabes area

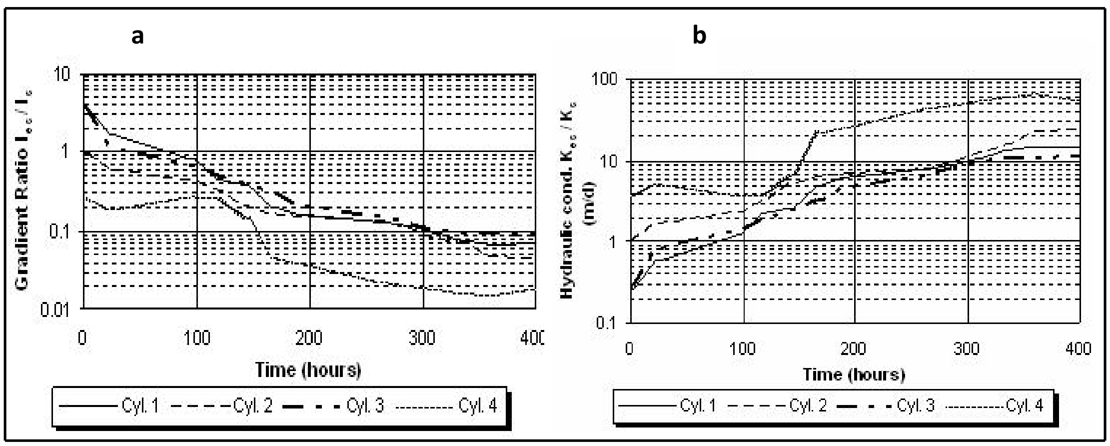

Fig. 4. Permeameter test results for El-Bostan area

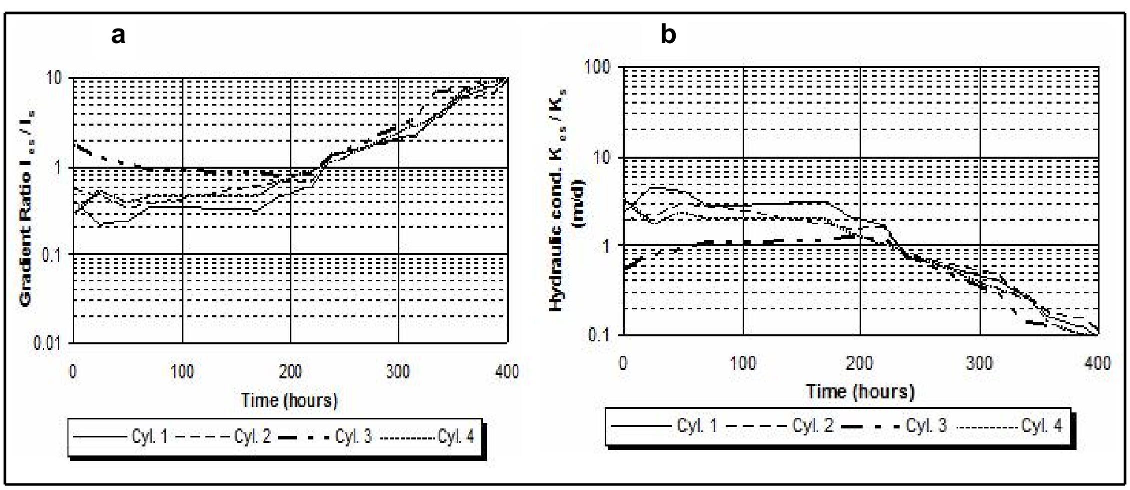

Fig. 5. Permeameter test results for Abu-Masoud area

Table 6. The performance criteria for the tested drain lines

Lateral	entrance head loss h_e (m)	Q total drain discharge over length L (m^3/day)	L length of drain (m)	Entrance resistance r_e (days/m)	Results of excavation sedimentation	Drain line performance
Treatment 1	0.23	38.88	177	1.02	Moderate	Moderate
Treatment 2	0.15	47.09	177	0.62	NO	Good
Treatment 3	0.04	50.98	177	0.15	Slight	Good
Treatment 4	0.04	57.02	177	0.11	NO	Very good

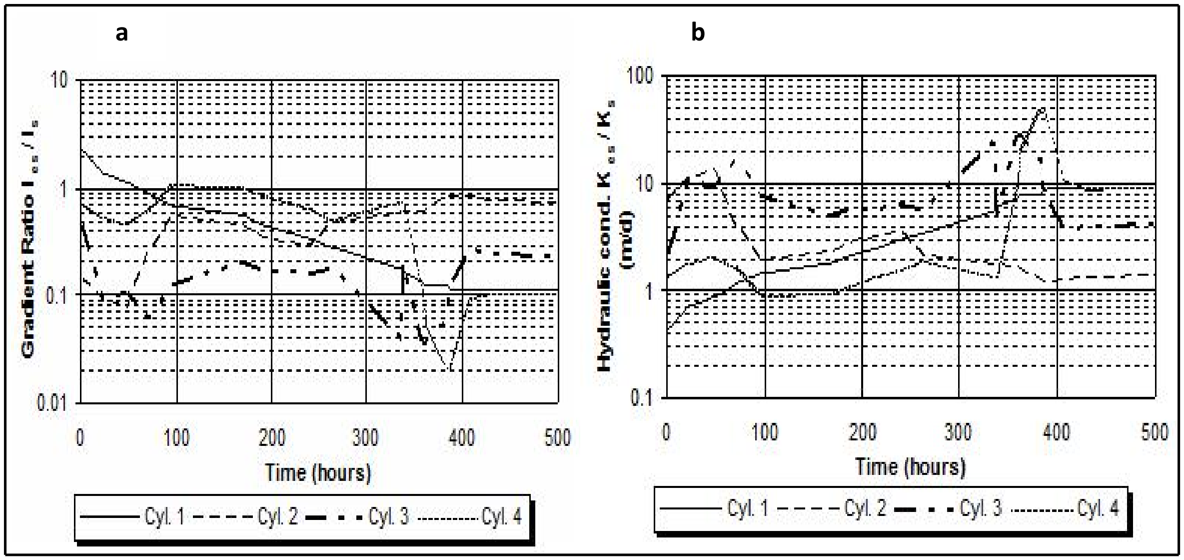

Fig. 6. Permeameter test results for El-Ameria area

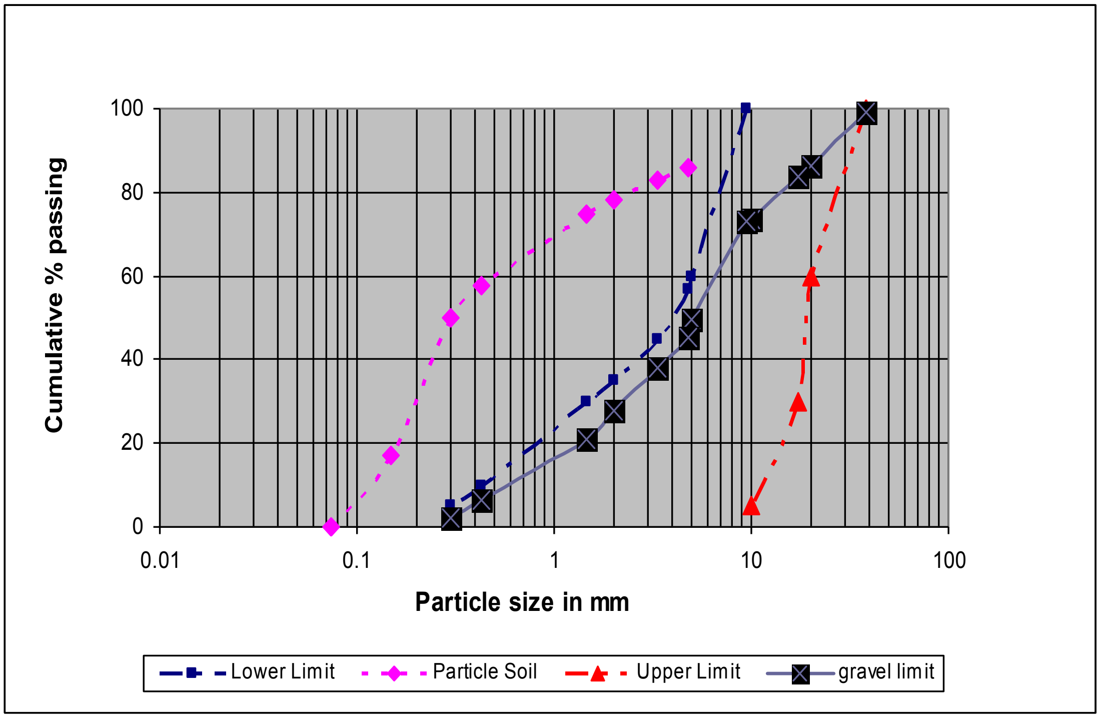

Fig. 7. Representative curve of granular drain envelope material

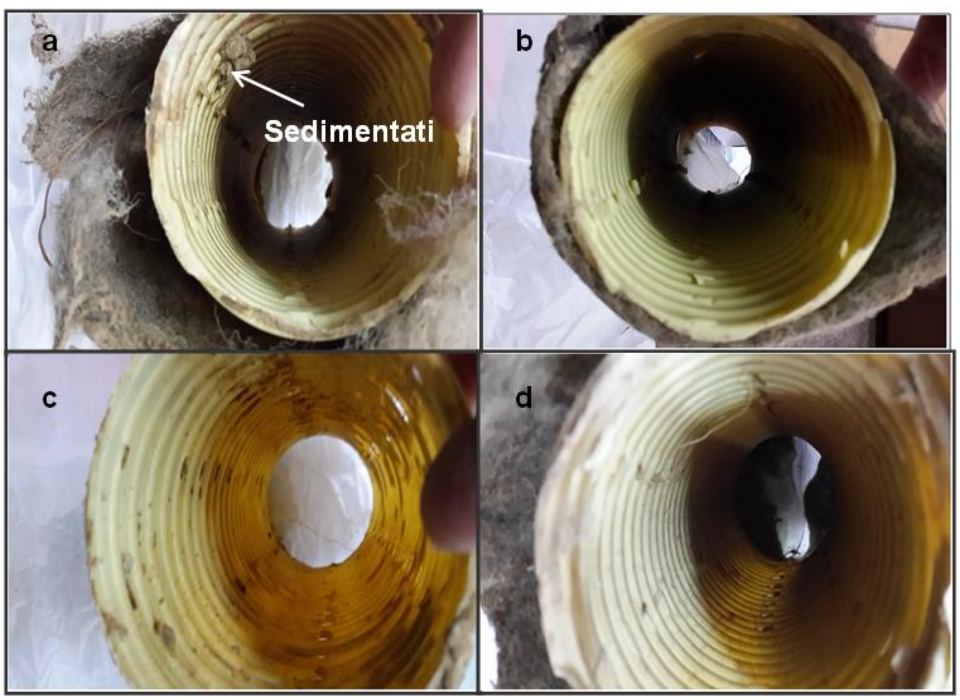

Fig. 8. Example of the excavation results of the tested drain lines

After six months of construction, two excavations were made by hand along tested lateral drains in the area (at 1/4 and 1/2 of the lateral length) to examine and recognise sedimentation and clogging of drain tubes along its length and measure the mechanical function of envelopes. Fig. 8 gives an example of these excavations. The results show that the first tested line with currently used criteria has a moderate hydraulic performance and sedimentation as shown in Fig. 8-a. Meanwhile, the second and third tested lines have a good hydraulic performance with no sedimentation for the second tested line as shown in Fig. 8-b and slight sedimentation for the third one as shown in Fig. 8-c. Finally, the last tested line with synthetic and gravel envelopes has the most perfect hydraulic and mechanical performance as shown in Fig. 8-d.

In comparing Treatment 2 of using pre-wrapped drain with the current used synthetic envelope material and increasing grade to 30cm/100m with Treatment 4 of using granular and pre-wrapped drain envelopes with normal grade of 10cm/100m as they have the most appropriate performance in the case of problematic calcareous soils, Treatment 4 would be preferred. This is attributed to the problem of the entrance of flood water in the case of second scenario because of the submergence of the outlet pipe for several hours due to the increasing grade and the deep depth of the outlet in the open drain. Therefore, it is recommended to apply Treatment 4 to achieve the most appropriate hydraulic and mechanical performance for sub-surface drainage with problematic calcareous soils.

4. CONCLUSION

To keep the calcareous soils in well form and good condition, it should be provided with an efficient drainage system. Subsurface drainage system in problematic calcareous soils in Egypt usually suffers from problems. The main problems in these soils are clogging of envelope materials and reduction of drainage efficiency. The experimental area was selected according to the potential precipitation risk of calcium carbonate in the agricultural drainage system and results of a permeameter laboratory test. From the outcome of the investigation it is possible to conclude that using granular and pre-wrapped drain envelopes with a normal slope of 10cm/100m has been very successful to achieve the most appropriate hydraulic and mechanical performance for sub-surface drainage in case of problematic calcareous soils. It performed very well with a normal entrance resistance and a very good drain performance. The second and third scenarios of using pre-wrapped drain with current used synthetic envelope material and increasing slope to 30 cm/100 m and using granular drain envelope with a normal slope of 10 cm/100 m, both scored second with a normal entrance resistance and moderate to good drain performance. Both performed better than the drain with a pre-wrapped synthetic envelope material and applying slope of 10 cm/100 m.

Finally, it is recommended to apply Ryznar and Langelier precipitation indices in the pre-investigation phase of a subsurface drainage project in problematic calcareous soils to assess the Calcium carbonate ($CaCO_3$) precipitation tendency which should be considered in the decision-making on the construction of a drainage system. It is also recommended to apply soil-water management in calcareous soils to determine the most effective time of irrigation to keep soils wetting and in good condition for tillage.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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