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Selection Of A Granular Envelope For Problematic Calcareous Soils

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Abstract
Subsurface drainpipes installed in soils with limited cohesion (clay content is less than 30%) are typically enveloped with filter materials to prevent the entry of soil particles into the drains (filter function) and to reduce entrance resistance by creating a more permeable zone around drains (hydraulic function). Calcareous soils with calcium carbonate ($CaCO_3$) content of more than 15% are among the most problematic soils that cause envelope clogging and sedimentation in the subsurface drainage network. Globally, earlier testing of synthetic drain envelopes has revealed poor performance in combination with calcareous soils. Therefore, the main objective of this study is to demonstrate a sequence of criteria and approaches to determine the most appropriate granular envelope material(s) that can efficiently perform in calcareous soils. Possible theoretical investigations were clarified, hence nominating the optimal granular characteristics. Consequently, the proposed characteristics are evaluated on laboratory and field examinations to finalize the functional performance of granular materials.
Keywords: *subsurface drainage; filter materials; calcic soils; permeameter test; envelope performance.*

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I. Introduction

Agricultural subsurface drainage (ASD) is one of the main elements of land reclamation, enhancing salts and excess water removal from the root zone of plants, thus providing a healthy ecosystem in the area to improve plant growth conditions and increase productivity (H. Ritzema et al., 2023). One of the most crucial factors in implementing subsurface drainage systems is proper planning and design. This is achieved by ensuring proper drainage system spacing and depth compatible with the soil-plant hydrological requirements (Skaggs, 2017). However, other factors can lead to lessen the performance of ASD networks. These factors include the presence of these networks in "problematic soils" such as non-cohesive soils (clay content is less than 30%), which have the potential to migrate with water during its journey from the root zone to ASD network pipes (Vlotman et al., 2001), bringing about pipe clogging problems.

To overcome these problems, drain envelopes or drain filters are utilized. These porous materials are placed around buried drainage pipes to provide a good barrier for fine soil particles and prevent drainage pipes sedimentation. Generally, the drain envelopes are utilized to enhance the drain-line performance (Bahçeci et al., 2018). According to Ritzema (2006), the drain envelopes have three main functions: Hydraulic function, to improve the permeability of the drain-soil interface, hence, reduce entrance resistance; Filter function, to reduce or prevent soil particles from flowing into the drain pipes; Bedding function, to act as flexible support around the pipe.

Calcareous soils are among the most problematic soils, where clogging problems are more severe. These soils have a percentage of calcium carbonate of more than 15% which may be present in various forms like powdery, nodules, and crusts (FAO, 2005). It can also be found in all soil fractions: clay, silt, or even sand; however, the larger contents are usually found in fine fractions than coarse and medium fractions (Singare, 2022). Globally, Calcareous soil covers over 30% of the earth's surface, and its $CaCO_3$ fractions widely vary from a few contents to 95% (Marschner, 2012). The existence of calcareous soils is widespread in the Near East Region due to the arid and Semi-arid climate (FAO, 2005). Furthermore, the Mediterranean countries' soils contain high $CaCO_3$ content, particularly in coastal lands where the rock nature is frequently calcareous (FAO, 2005). In Egypt, there are about 650,000 feddans (1 feddan = 0.42 ha) considered as calcareous soils with various contents of ($CaCO_3$) (Taalab et al., 2019).

In Italy, more than 61% of the land is considered calcareous soils, with $CaCO_3$ contents varying from 17 (Regosols) to 43.5% (Calcic Kastanozems) (Costantini & Dazzi, 2013). Precipitation and siltation problems of calcium carbonate have been noticed in several subsurface drainage networks around the world (Ghobadi Nia et al., 2010). In France, calcreous deposits into and around drains installed in soils that contain rich groundwater in dissolved Ca^{2+} are reported (CEMAGREF, 1983). From the Egyptian and the Netherlands experience, soils with clay content higher than 30% would not need a drain envelope (Vlotman et al., 2001). Calcareous clayey soils with a clay content of 50–60%, average $CaCO_3$ content of 30% in south-eastern Turkey, however, were less stable, pipes siltations were noticed, and envelopes were highly prescribed for these soils (Bahçeci et al., 2018).

Envelope materials have been brought in three types: organic, like coconut fibers and rice straw, granular (mineral gravel or crushed stones), and Synthetic (geotextile) materials (Ghane et al., 2022). Synthetic materials are commonly utilized worldwide as a more durable alternative to organic materials and have replaced granular envelopes in many ASD instances because of their relatively low construction cost, where the transportation and installation costs of the granular envelopes are significantly higher (Byrne et al., 2023). Guo et al. (2020), however, reported that the permeability coefficients of synthetic envelopes haven't satisfied the minimal permeability coefficients necessary for nonvirgin envelopes. They justified that the physical and chemical clogging constituents were mainly calcium carbonate and silicon dioxide, and the contents of calcium carbonate of the soil and the within tested geotextile fabrics were consistent. Even if a multi-layer (single, double, and triple layer) synthetic envelope setup had been used in combination with calcareous loamy soil, different clogging regimes were noticed, comprising envelope self-clogging and impervious filter cake layer coating the drain envelope (Wang et al., 2024)

In Egypt, calcareous soils were encountered while the land reclamation was propagating towards the Nile delta fringes and the coastal strip of the Mediterranean. In the eastern Nile Delta fringes, five different types of synthetic materials (needle-punched PP290, PP310, PP360, knitted Big, O, Sock, and Typar) were tested under calcareous loamy and clayey soil conditions (Drainage Research Institute [DRI], 2012). The assessment concluded that all provided envelopes had been classified as poor to very poor in performance. This suggests that envelope material criteria for calcareous soils need revision, and further testing is required to identify the most suitable materials for use in Egypt (DRI, 2012).

Therefore, this research aims to establish a set of sequenced theoretical and experimental criteria for validating the most appropriate granular envelope characteristics, ensuring optimal hydraulic and filtration performance functions, often lacking in synthetic envelopes when used in combination with problematic calcareous soils.

II. Methodology

For problematic calcareous soils, theoretical approaches employing the standard methods utilized to determine the most proper granular envelope material are demonstrated. This should be accomplished by selecting the most proper granular envelope characteristics, in terms of the optimal gradation and the desired envelope thickness, compatible with the properties of the representative calcareous soils. The indicated granular envelope characteristics, consequently, are examined by applying experimental approaches, including field and laboratory performance assessments for the selected granular envelope materials in combination with calcareous soils.

Study area planning and investigations

Soil properties are the primary guide to indicate the optimal drain envelope characteristics as a filter material, or even the need for a drain envelope (Ağar, 2011). Firstly, soil physical properties have to be carefully specified, including the soil calcification, undisturbed soil density, particle size distribution (PSD), and $CaCO_3$ content. Secondly, the hydrological characteristics such as saturated hydraulic conductivity (K) and the depth to the impervious layer should be precisely determined. The aforementioned soil hydrological characteristics, besides two other parameters related to served growing plants: the drainage depth (function of plant root depth) and the drainage coefficient (fraction of crop water duty), are utilized to determine the drainpipe (lateral) spacing. The steady-state equation presented by Hooghoudt (1940) is commonly utilized to indicate the drain spacing in irrigated lands (Ayars & Evans, 2015). Eventually, ASD is produced: A buried gravity network consisted of perforated drain pipes (lateral) set at the desired drainage depth, regularly replicated by the designed spacing, and connected to larger pipes provided with inspection manholes (collectors), which deliver the agricultural drainage into the open drainage system as shown in

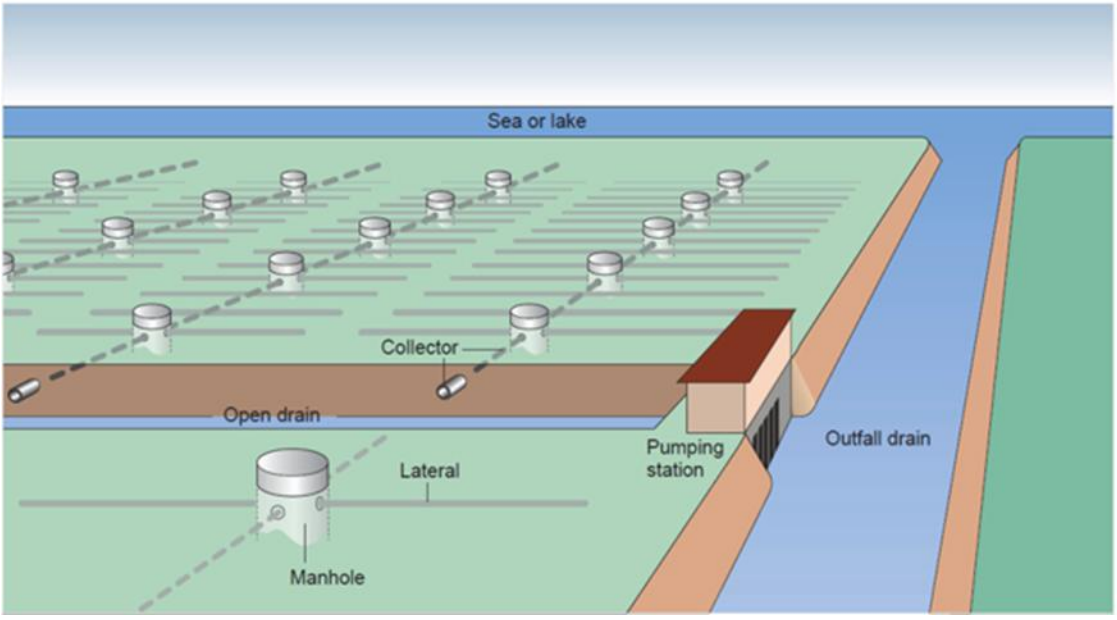


Figure 1. Collectors are divided into sub-collectors if the served area by one collector becomes too large (Ritzema et al., 2023).

For field experimental purposes, the ASD system has to be planned so that the connection between the lateral and the collator is a manhole of 80 cm diameter or more, and the clearance between the drain pipe and the manhole water level should be about 50 cm, to facilitate the instrument setup for later outflows. Generally, the drainage depth varies between 1 and 1.8 m depending on the plant's root depth (Tanji and Kielen, 2002). For instance, if the desired drainage depth is 1.3m, the required level difference between the mean ground level (G.L) and water level (W.L) at the terminal open drain has to be more than 1.8m (

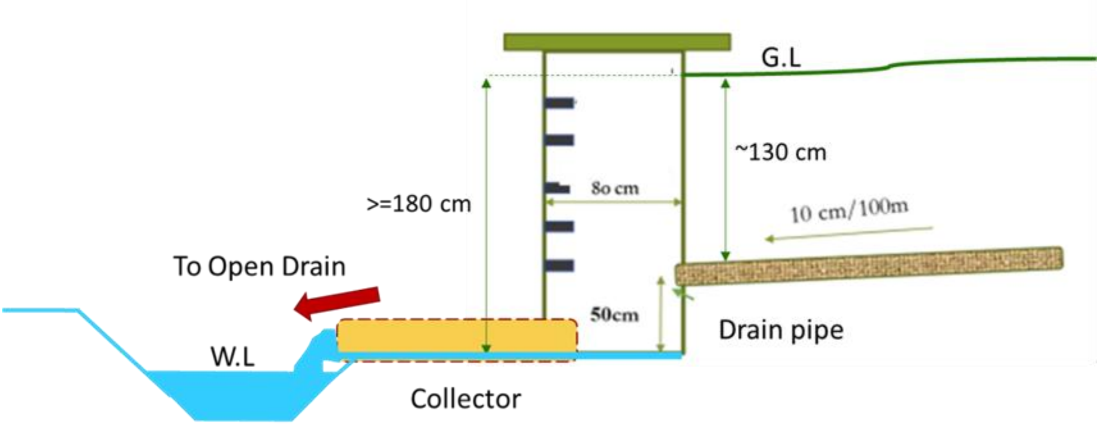


Figure 2). The tested drain lines should neither be installed nearby open channels nor intersected with, hence their monitored outflow wouldn't be impacted by potential seepage from these channels. Additionally, for lab test purposes, soil samples should be collected at the drainage depth during the study area investigation, hence guaranteeing a more accurate representation of the field condition, when the collected soil samples are tested in combination with the proposed drain envelope.

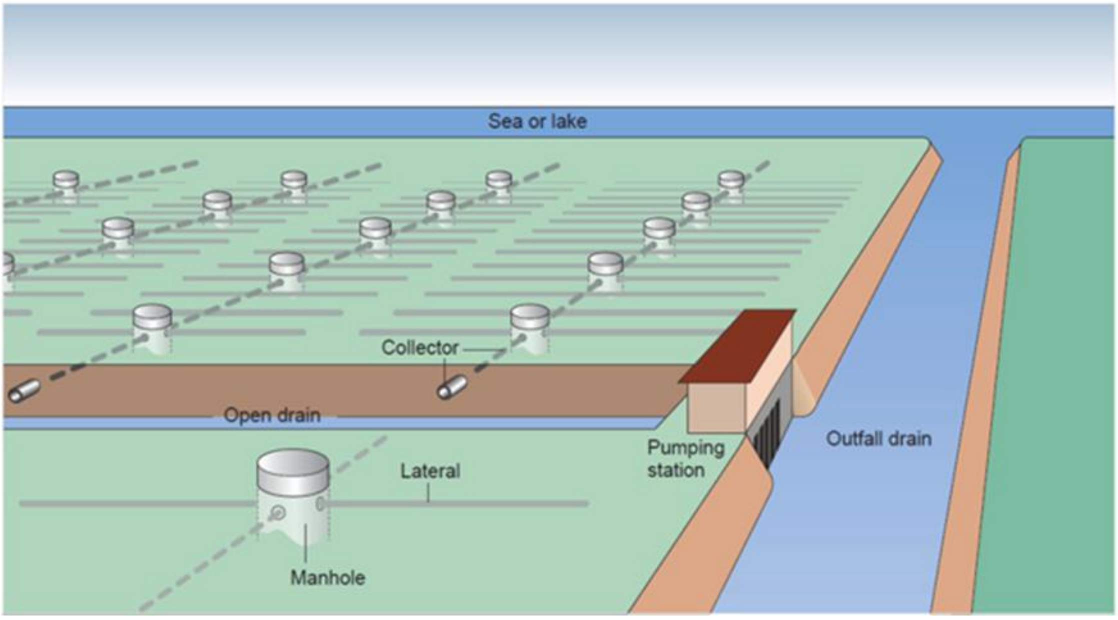


Figure 1. Typical representation of the agricultural subsurface drainage used in Egypt (Ritzema et al., 2023)

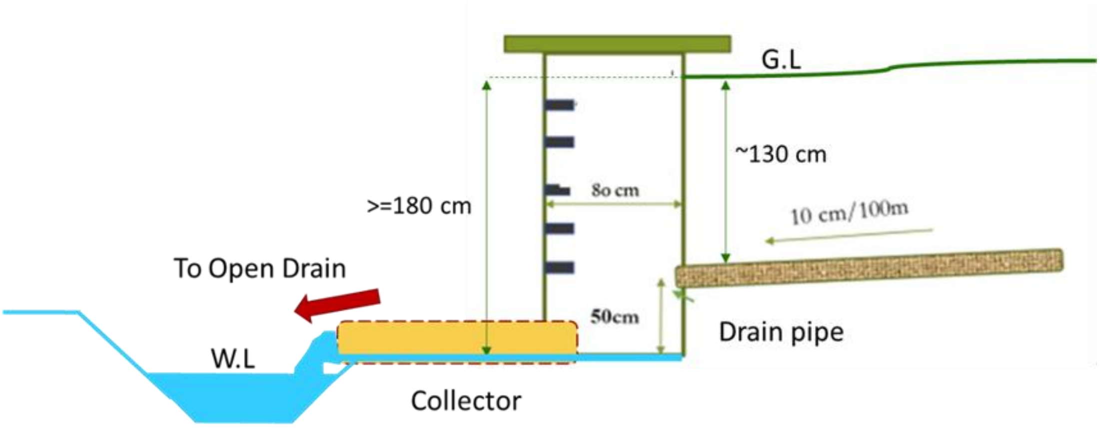


Figure 2. Schematic of the required geometry for drain pipe monitoring

Theoretical approaches

Granular envelope selection

For the design of the granular envelope (filter), Winger and Ryan (1971), adopted by the United States Bureau of Reclamation (USBR) (1993), proposed criteria which are so restrictive for agricultural drainage purposes. Seeking these criteria to match the rule that says the filter hydraulic conductivity has to be at least ten times the base problematic soils (FAO, 2005). Therefore, Winger and Ryan proposed the coarser filter among all criteria mentioned in the literature; hence, it may be easier and cheaper to obtain (Dieleman and Trafford, 1976). Depending on the d_{60} of the base soil, criteria suggest upper and lower (PSD) limits for the proper granular envelopes. The filter maximum size should not be more than 38 mm, i.e. all filter grains would pass the sieve of 38 mm opening size; The minimum filter size has to be more than 0.3 mm (FAO, 1976).

Table 1 summarises Winger and Ryan's recommendations.

Table 1. Granular envelope gradation ranges according to base soil gradation (Winger and Ryan, 1971)

Base soil,	Gradation limitations for granular envelope (diameter of particles, mm)											
d60 range	Lower limits gradation ,percentage passing						Upper limits gradation ,percentage passing					
(mm)	100	60	30	10	5	0	100	60	30	10	5	0
0.02-0.05	9.52	2	0.81	0.33	0.3	0.074	38.1	10	8.7	2.5	-	0.59
0.05-0.10	9.52	3	1.07	0.38	0.3	0.074	38.1	12	10.4	3	-	0.59
0.10-0.25	9.52	4	1.3	0.4	0.3	0.074	38.1	15	13.1	3.8	-	0.59
0.25-1.00	9.52	5	1.45	0.42	0.3	0.074	38.1	20	17.3	5	-	0.59

Accordingly, to design the granular drain envelope for the tackled soil, the following procedures can be applied:
1. Conduct a particle-size analysis of the base soil, hence the d60 of the soil (the diameter of the sieve at which 60% of the soil is passing) is obtained;
2. Define the lower and upper gradation limits of the proposed granular envelope following Winger and Ryan (
3. **Table** 1), based on the value of soil d60;
4. Compare the particle-size distribution curves; and
5. Decide the proper granular envelope PSD to be applied, so that it lies in between the selected lower and upper gradation limits, thus the particle-size fractions of the granular envelope are determined.

Granular envelope thickness

The philosophy of choosing the envelope thickness is to reduce the exit hydraulic gradient (I_{ex}) at the soil-envelope interface, especially to be lower than the hydraulic failure gradient (HFG) at which soil movement will occur. Therefore, a desired thickness should be provided so that the drainpipe's effective Radius, hence the exposure envelope surface area, are increased until water exit velocity is reduced; thereby, the I_{ex} at the soil-envelope interface is sustained below the erosive HFG. Generally, the determination of the envelope thickness is a multi-aspect task function in three factors: the properties of the envelope material type itself, tackled soil characteristics, and the characteristics of the provided subsurface drainage system. Vlotman et al. (2001) produced an approach to determine the minimum required envelope thickness, and to decide on the optimal envelope material, i.e. synthetic or granular materials, which can fulfil the desired thickness. Nevertheless, if the required envelope thickness is equal to 5 mm or more, utilizing a granular envelope would practically be the optimal alternative (Vlotman et al., 2001). The envelope property included in the proposed approach is the porosity, which can be evaluated for the granular envelope after obtaining the granular material based on the criteria stated in Sec 2.2.1. The minimum envelope thickness (t_e) is the difference between the actual drainpipe radius (r_o) and the minimum radius of the enveloped drainpipe ($r_{e\ min}$) (

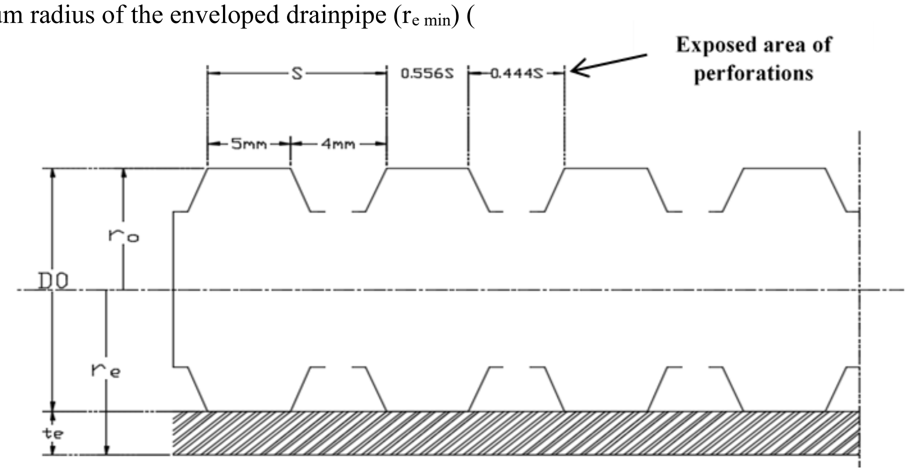


Figure 3), which can be obtained by the following equation:

$$r_{e\,min} = (ql_{max}) \,/\, (2\pi * R_u * a_e * \varepsilon * K_s * HFG) \qquad \textbf{Eqn 1}$$

Where:
HFG= $e^{(0.332-0.132ks+1.07\ln(PI))}$, PI= the soil plasticity index (Samani & Willardson, 1981)
K_S= soil saturated hydraulic conductivity,
ε= porosity of selected granular envelope,
a_e= the ratio of the perforated pipe surface area exposed to water flow (0.444 under Egyptian condition),
R_u= the ratio wetted perimeter (0.5), assuming that the drainage flow is received over the lower half of the drain-pipe.
ql_{max} = the maximum possible discharge per unit length, based on a drainage coefficient (ex: 2 mm d^{-1}), lateral spacing (ex: 60 m), is 0.12 m^3 day^{-1}.

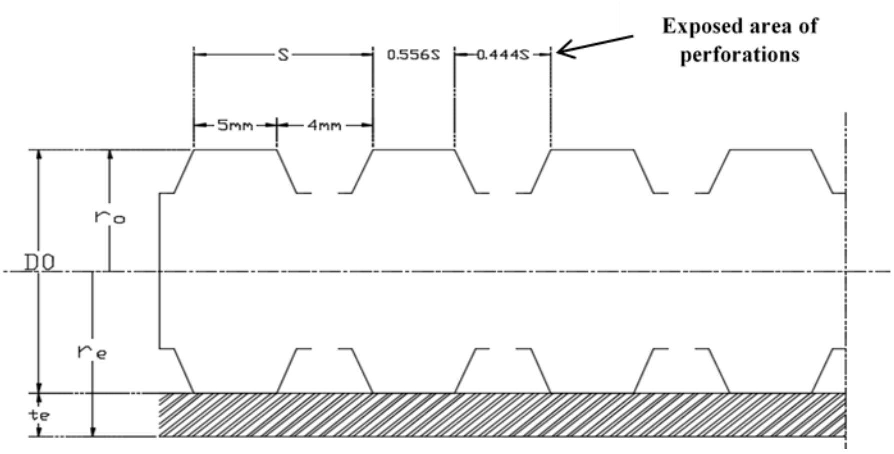


Figure 3. A schematic of an enveloped drainpipe

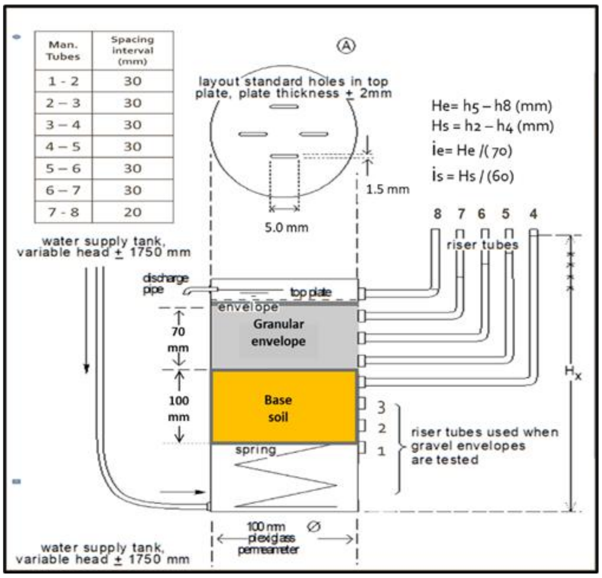
Practically, if the required minimum envelope thickness (t_e) is equal to or more than 5 mm, a granular envelope would be the optimal alternative (Vlotman et al., 2001)

Experimental approaches

Once the type and gradation of the granular envelope (G.E.) is obtained following the desired gradation criteria, and the corresponding required thickness is indicated, the experimental approaches are applied to examine these theoretically obtained characteristics. Investigating a proposed drain envelope in an area has to be conducted in two consecutive steps to save time and money. Firstly, examining the performance of the drain envelope in the laboratory with the soil of the experimental field in the short term and consequently, if the laboratory results prove promising performance, investigating the long-term performance soil-envelope combination on a field basis (Alavi et al., 2021). Accordingly, the objective of the lab experiments is to evaluate the hydraulic functional performance, investigate clogging of the envelope and explore potential substantial passage of soil particles (filter function), shortly after drainpipe installation (FAO, 2005).

Laboratory assessment

Permeameters are the most common lab facilities that can be used to simulate field conditions to verify hydraulic and filtration functions of different envelope materials in combination with various types of soils. Permeameters can simulate the flow towards a bare or enveloped drainpipe in the field, via one-dimensional confined flow towards a flattened piece of drainpipe, or a combination of an envelope-flatten pipe (FAO, 2005). Considering a granular envelope with a desired thickness of 7 cm (Sec. 3.2), the Permeameter set-up can be established as shown in (**Error! Reference source not found.**). Consisting of a vertically plexiglass cylinder (1), which is partially filled with the tested soil-envelope combination. The cylinder is connected to an adjustable head water supply tank, from which an upward flow is developed. A supporting metal screen (4) covered by a highly permeable geotextile disk (5) carries the soil column, the granular envelope, and the open-folded flattened drainpipe (6) rested on the envelope material column, respectively. Both the permeable geotextile and metal screen are resting on the inner plaxiglaas ring (2), hence preventing soil particles from flowing back to the bottom of the permeameter. The flattened drain pipe and envelope material are fixed between flanges. A spring (3) underneath the supporting screen ensures the soil is slightly in contact with the envelope and the flattened drainpipe. A movable reservoir with overflow enables applying the desired hydraulic gradient. Looking at the top part of the cylinder, a piezometric tube is installed (top cap (7)) above the flattened drainpipe and another one is fitted just below it, through the envelope material. Other piezometric tubes are installed every 30 mm along the envelope and soil columns.



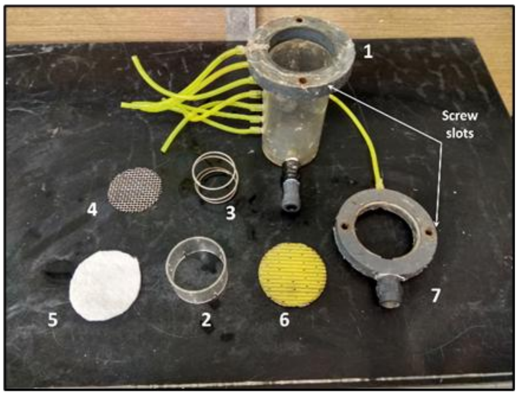


Figure 4. The Permeameter set-up for granular Envelope test

For accurate field simulation, three permeameter-cylinder replicates have to be simultaneously tested; the tested soil samples have to be collected from the drainage levels (1-1.8 m) below the soil surface. The tested samples, however, have to be moistened to a moisture content that varies between 8 and 15%, less or near the field capacity, to be sieved at the most desirable condition (Vlotman, et al., 2001). Therefore, the collected samples should be dried in the oven after retrieval from the field for two reasons. The first one is to turn the samples from the wetted dough case to the solid case, hence they can be crushed till reaching to loose soil case, easy to mix and have the needed workability for the filling process. The second reason is to bring the tested soils to the desired moisture content, exactly before the cylinders filling so that the soil does not lose its moisture due the air drying.

The cylinders have to be packed at a density within a range of 1.3- 1.4 gm cm^{-3} based on dry soil, i.e. within the estimated bulk density of the study area (DRI, 2012). Therefore, the loose dry soil is mixed well to form a homogenous soil quantity, enough to fill the permeameter cylinders, then it is moistened to a moisture content of 15% or less. The art is to moisten the tested soil to increase compaction susceptibility without losing its workability, which is fulfilled by experience and trial and error, depending on the soil response during the hydration process (Vlotman et al., 2001). Accordingly, there is a wide range of optimal moisture contents to which the cylinder soil column weight can be estimated, as follows:

*The cylinder soil weight = the dry density * filled volume + moisture content * the dry soil weight.* **Eqn 2**

The permeameter apparatus has a water supply system, which is designed to develop the hydraulic gradients in any dynamic sequence. The recommended sequence, however, is to run the test at progressive hydraulic gradients, thus the critical or failure hydraulic gradients can be detected (L. Stuyt et al., 2005).

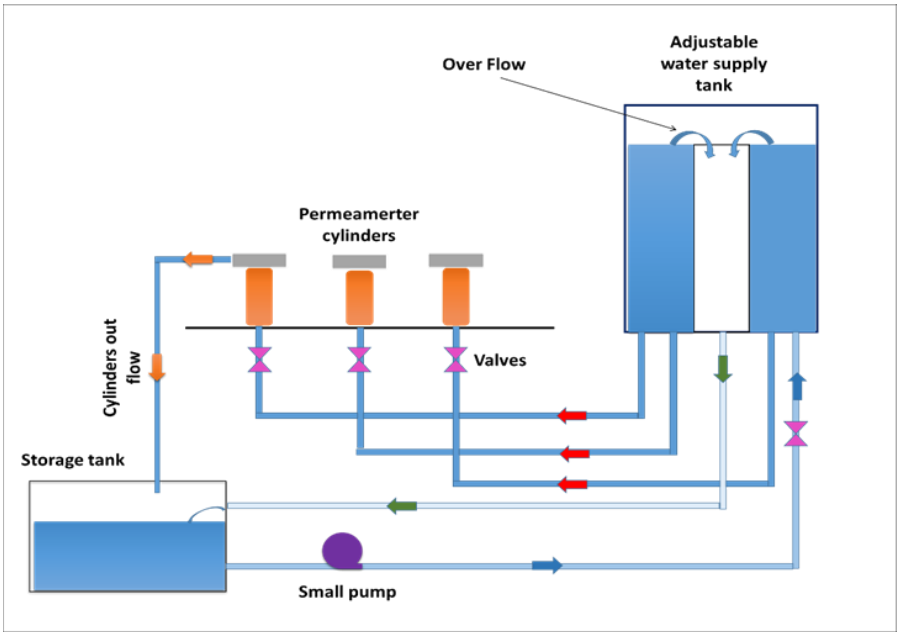


Figure 5 clarifies the water cycle components and mechanism. The water cycle starts from a pre-filled storage tank, feeding an adjustable water supply tank via a small pump. The adjustable water supply tank is freely moved in the vertical direction and connected by three pipes of the same diameter, controlled by valves. Therefore, the adjustable water supply tank sets the desired hydraulic heads equally on each cylinder of the replicates. The overflow of the adjustable water supply tank goes back by gravity to the storage tank, and so does the outflow from each tested cylinder, unless it was collected during measurements. The hydraulic head of the piezometers and the cylinders out-discharge are observed over time with increasing the total applied hydraulic gradients. Consequently, hydraulic gradients over both soil and envelope are calculated, and so are the corresponding hydraulic conductivities using Darcy's equation, as follows:

$$\boldsymbol{K} = \frac{\boldsymbol{Q}}{\boldsymbol{i} * \boldsymbol{A}} \qquad \textbf{Eqn 3}$$

Where:
K: is the hydraulic conductivity of tested mediums in (L T^{-1}),
Q: is the discharge across the Plexiglas cylinder in (L^3 T^{-1}),
i: is the hydraulic gradient across the tested mediums (dimensionless),
A: is the cross-sectional area of the Plexiglas cylinder (L^2).

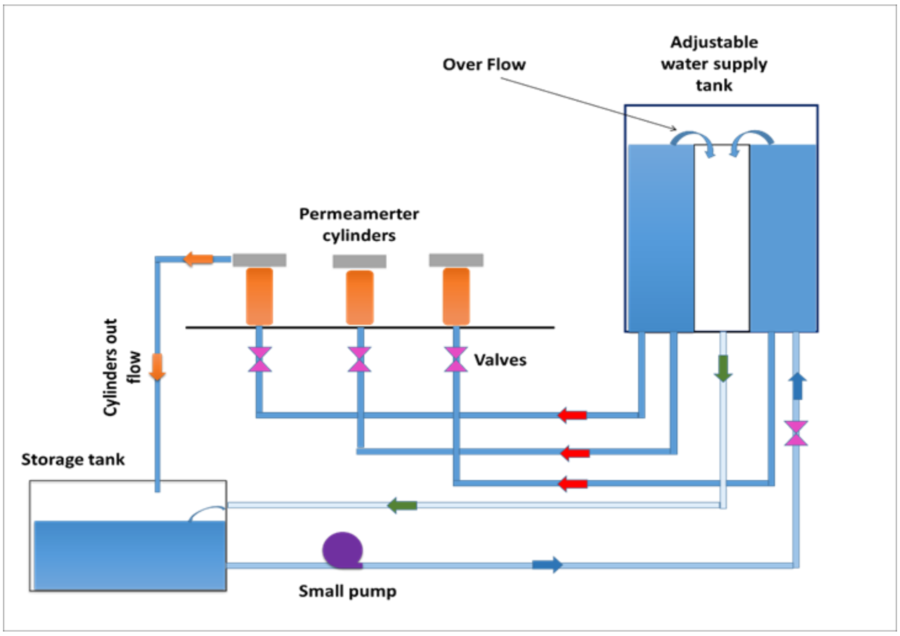


Figure 5. Permeameter water supply system (Loop system)

Eventually, the Permeameter enables evaluating the soil and envelope hydraulic gradients (i_s, i_e), hence the hydraulic conductivities over the tested soil and envelope (K_s, K_e). Dierickx and Sluys (1990), cited by Sallam (2018), stated that there would be no blocking or clogging in the tested envelope material if the following conditions last throughout the time of the test: Ie/Is < 1.0 and Ke/Ks > 10. The U.S. Army Corps of Engineers (1977), however, recommended Ie/Is < 3.0 to express no clogging condition. For granular envelopes examination, the majority of design criteria have recommended a hydraulic conductivity ratio (Ke/Ks) of 10: 100 to ascertain effective drainage and prevent clogging (Lakruwan et al., 2025), (Rüegger and Hufenus, 2003).

Field assessment

Examine the drain envelope under field conditions of problematic soils is the most effective approach to conclude the envelope performance, but the most expensive. Therefore, the envelope material has to be carefully selected and explored under a consecutive series of criteria, i.e. the aforementioned theoretical and experimental-lab criteria, before reaching to field assessment.

Evaluate the drain line performance on a field basis, comprising both hydraulic and mechanical (filtration) assessments. Dieleman and Trafford (1976), cited by (FAO, 2005), proposed a field approach to assess a drain line hydraulic performance, depending on evaluating entrance head loss (h_e) and entrance resistance (r_e) of the flow towards the drain (Error! Reference source not found.). The core of these criteria is to test the degree of the envelope transmissivity or the hydraulic conductivity, or in other words, to evaluate the degree of envelope clogging. Basically, the higher entrance resistance values would correspond to the lower hydraulic performance. The entrance resistance (r_e) can be described as the head loss per unit rate of flow of the drain lateral per meter length; the entrance resistance component can be expressed as:

$$r_e = h_e * \frac{L}{Q} \qquad \textbf{Eqn 4}$$

Where:

r_e	=	entrance resistance, in days per meter;
h_e	=	entrance head loss, in meters;
L	=	length of drain, in meters;
Q	=	total drain discharge over drain length L, in m^3 per day.

Table 2. The Recommended Criteria to obtain drain performance (FAO, 2005)

entrance resistance re (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

To guarantee symmetric homogeneous behavior of the groundwater in the field of the tested drain line, three replicate drain lines (laterals) have to be installed with the same envelope alternative (

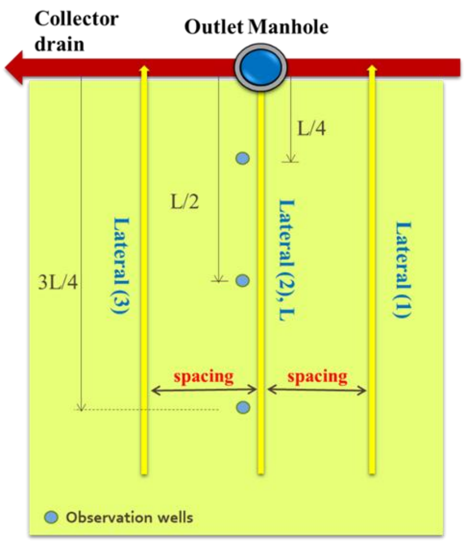


Figure 6). Hence, the entrance resistance (r_e) of the drain line is obtained relying on the outflow (Q) at the end and the corresponding entrance head loss (h_e) measured for the middle drain line. The entrance head loss (h_e) is the water table depth, over the drainpipe, in an observation well immediately adjacent to the drain line (

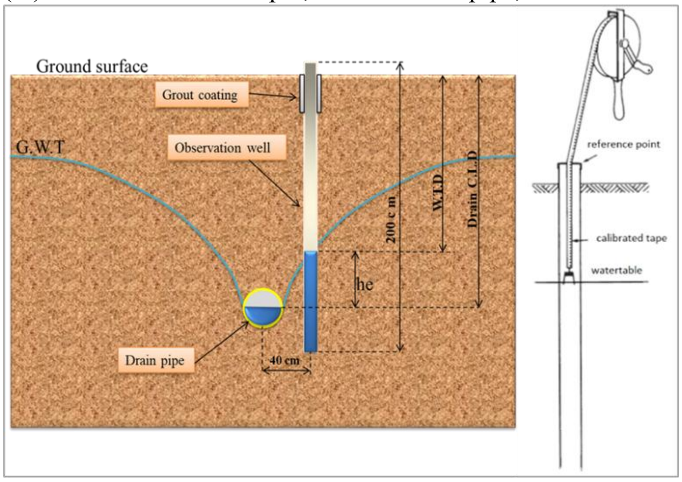


Figure 7). Usually, the observation well is at a fixed distance from the outside of the drainpipe trench, 40cm from the drainpipe centerline is advised. The observation wells are installed at the 1/4, 1/2, and 3/4 of the tested lateral length to evaluate the average h_e along (

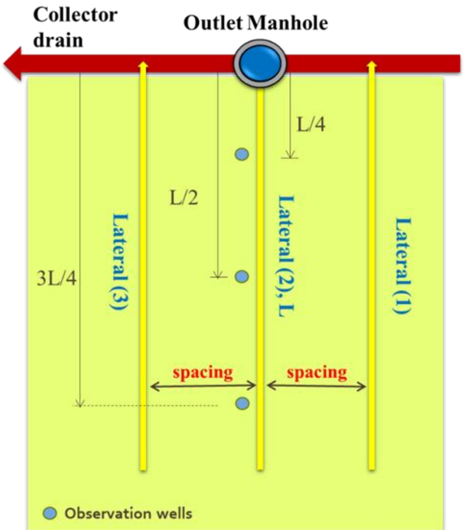


Figure 6). Generally, the drain line with the lowest values of entrance head loss (h_e) and entrance resistance (r_e), further, a “Good” performance, is considered the best envelope treatment. Consequently, this drain envelope can be prescribed for the tested case of problematic soil, hence generalized for the other fields of similar soil conditions.

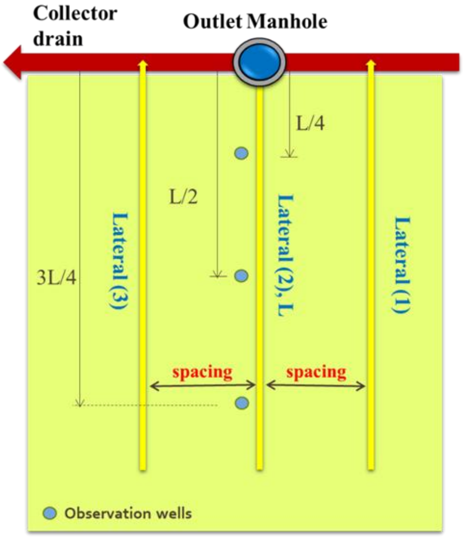


Figure 6. Layout of each tested treatment and observation wells distribution

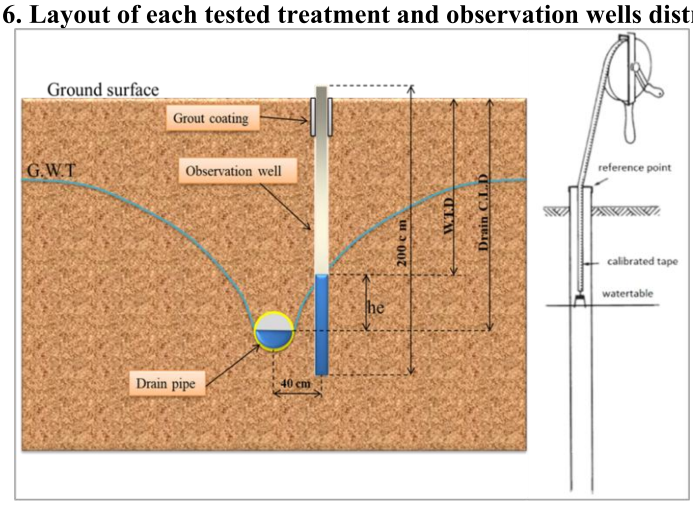


Figure 7. Measuring water table depth, and entrance head loss (he)

Investigating the sediments inside the drainpipe is an essential part of field evaluation criteria. It is used to test the filtration performance of the drain envelopes. In the Netherlands, a layer of sediment exceeding 15 mm inside a 60 mm drainpipe is considered unacceptable because the transport capacity of the drain is reduced too much (Stuyt, 1992). In other words, the ratio of the sediment height to pipe diameter (h/D) has to be less than 0.25 to accept the filtration efficiency of the envelope. The height of sediment deposition (h) in a drainpipe of radius (r) (as shown in

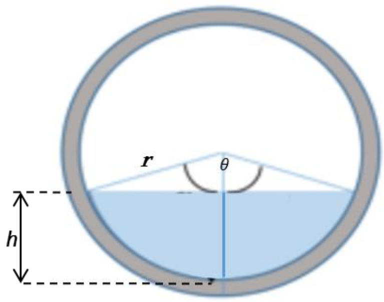


Figure 8) can be calculated from the following equation:

$$h = r - r\cos\alpha \qquad \textbf{Eqn 5}$$

Where α= Θ/2, Θ is the radial angle of the sediment deposition.

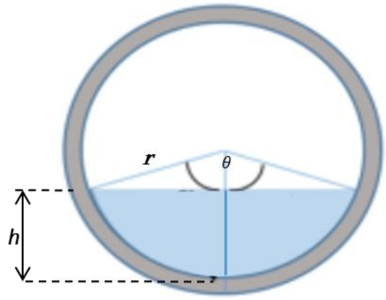


Figure 8. Cross-section of a drainpipe with a layer of sediment of height (h)

To study the influence of the drain sediments on the drain discharge capacity, the discharge ratio of a clogged pipe to the same pipe free of sediment (Q/Q^*), can be deduced using the Manning equation. The discharge of a clean pipe of a radius (r) can be expressed as follows:

$$Q^* = (A^*)\left(\frac{S^{0.5}}{n}\right)\left(\frac{r}{2}\right)^{0.667} \quad \textbf{Eqn 6}$$

Where, $A^* = \boldsymbol{\pi r^2}$, is the full area of the clean pipe

While the discharge through a clogged pipe (Q), assuming the Manning coefficient (n) is the same for the sediment and pipe materials, can be formulated as follows:

$$Q = (A)\left(\frac{S^{0.5}}{n}\right)\left[\left(\frac{r}{2}\right)\left(\frac{2\pi - \theta + \sin\theta}{2\pi - \theta + 2\sin\alpha}\right)\right]^{0.667} \quad \textbf{Eqn 7}$$

Where, $A = \pi r^2\left(1 - \frac{\theta - \sin\theta}{2\pi}\right)$, is the full flow area of a clogged pipe.

Consequently, the (Q/Q^*) ratio and (A/A^*) are expressed respectively as follows:

$$\frac{Q}{Q^*} = \frac{(2\pi - \theta + \sin\theta)^{1.667}}{2\pi(2\pi - \theta + 2\sin\alpha)^{0.667}} \quad \textbf{Eqn 8}$$

$$\frac{A}{A^*} = \left(1 - \frac{\theta - \sin\theta}{2\pi}\right) \quad \textbf{Eqn 9}$$

Based on Eqn 5, Eqn. 8, and Eqn 9, a relationship between the (Q/Q^*) ratio, (A/A^*), and (h/D) ratio can be figured out as shown in

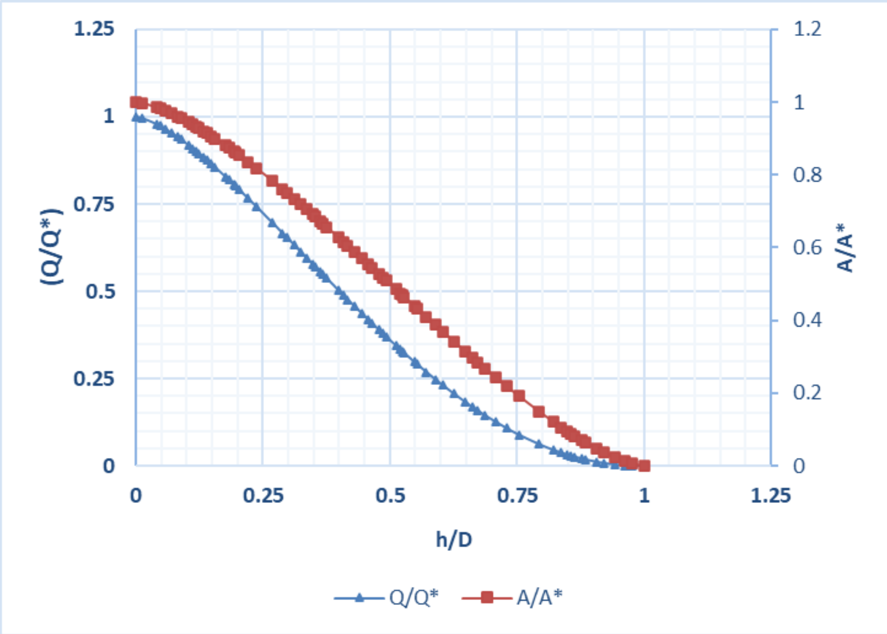


Figure 9. By returning to the rule, (h/D) has to be less than 0.25; therefore, the (Q/Q^*) ratio has to be greater than 0.75 and/ or (A/A^*) ratio has to be greater than 0.80 to accept the capacity performance of the drainpipe.

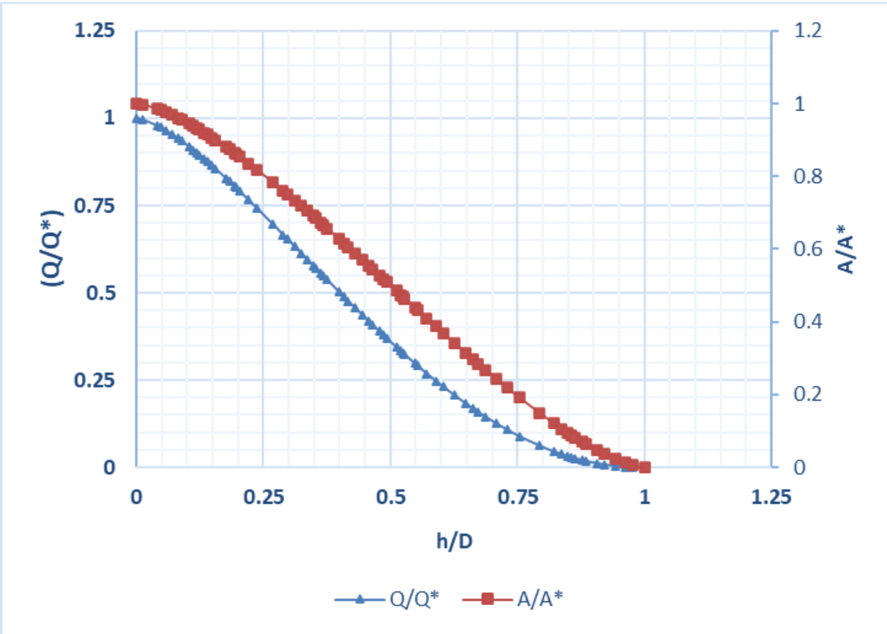


Figure 9. Pipe discharge capacity as a function of the height of the sediment layer

Practically, two excavations should be made at the tested drain line, not before six months from construction, at L/4 and L/2 of the drain line length (L) from the outlet side (Sallam, 2018). Pipe samples of 30 cm are taken for mechanical assessment; hence, they should be replaced by another blind (unperforated) pipe (unperforated) with the same diameter. The blind pipe is attached with couplers from two sides to guarantee a good connection between the cut drain line and the new section.

Figure 10 clarifies the processes of excavation, sampling, and replacing the cut section with the new one.

Figure 10. Excavation, sampling, replacing processes, and the two-side coupler pipe

III. Conclusion

This research seeks to develop an integrated approach to select the optimal granular envelope for problematic soils, where synthetic envelopes have performed poorly, such as calcareous soils. The approach combines theoretical design criteria with experimental investigations in both the laboratory and the field to evaluate envelope performance.

Firstly, the theoretical criteria are basically applied depending on the soil properties to select the granular envelope gradation and then the envelope thickness based on the indicated envelope gradation, ASD design, drainpipe geometry, and again the soil properties. ASD design and drainpipe geometry are determined earlier from the field soil physical and hydrological characteristics. Therefore, investigating the problematic soil properties is a crucial factor in the envelope selection scheme.

Secondly, the nominated envelope material is examined in combination with representative problematic soil samples in the laboratory using a permeameter apparatus to evaluate the filtration and the hydraulic functions in the short term. If the drain envelope revealed a good performance during the lab tests, the envelope is then reassessed under field conditions. Field evaluations ultimately provide evidence of the envelope's long-term performance.

References

[1]. Ağar, A. I. (2011). Selection Of Geo-Synthetic Filter Materials As Drain Envelopes In Clay And Silty Loam Soils To Prevent Siltation: A Case Study From Turkey. African Journal Of Agricultural Research, 6(16), 3930–3935. Https://Doi.Org/10.5897/AJAR11.716

[2]. Alavi, S. A., Naseri, A. A., Bazaz, A., Ritzema, H., & Hellegers, P. (2021). Performance Evaluation Of The Hydroluis Drainpipe-Envelope System In A Saline-Sodic Soil. Agricultural Water Management, 243(May 2020), 106486. Https://Doi.Org/10.1016/J.Agwat.2020.106486

[3]. Ayars, J. E., & Evans, R. G. (2015). SUBSURFACE DRAINAGE — WHAT ' S NEXT ? †. 392(March), 378–392.

[4]. Bahçeci, I., Nacar, A. S., Topalhasan, L., Tari, A. F., & Ritzema, H. P. (2018). A New Drainpipe-Envelope Concept For Subsurface Drainage Systems In Irrigated Agriculture. Irrigation And Drainage, 67(S2), 40–50. Https://Doi.Org/Https://Doi.Org/10.1002/Ird.2247

[5]. Byrne, I., Gerard, M., Fenton, O., & Tuohy, P. (2023). Geoderma Regional Investigating The Suitability Of Synthetic Envelopes As An Alternative Or Complement To Stone Aggregate In Clay-Textured Soils In Ireland. Geoderma Regional, 32(November 2022), E00598. Https://Doi.Org/10.1016/J.Geodrs.2022.E00598

[6]. CEMAGREF. (1983). Le Colmatage Des Drains Agricoles: Etat Des Connaissances En France En 1983 [Clogging Of Agricultural Drains: Current Knowledge In France In 1983]. Information Techniques 51-5, CEMAGREF.

[7]. Costantini, E. A. C., & Dazzi, C. (2013). The Soils Of Italy. Https://Doi.Org/10.1007/978-94-007-5642-7

[8]. Dieleman, P.J. And Trafford, B. D. (1976). Drainage Testing. FAO Irrigation And Drainage Paper 28.

[9]. \Dierickx, W., & Sluys, V. (1990). Research Into The Functional Hydraulic Properties Of Geotextile. Proceedings Of The 4th International Conference On Geotextiles, Geomembranes And Related Products, 1, 285–288.

[10]. Drainage Research Institute (DRI). (2012). Subsurface Drainage Research On Design, Technology And Management: Final Report Of Evaluation Study Of Envelope Materials For Loosing Soils In East And West Delta And Middle Of Egypt. Delta Barrages, POB 13621/5, Cairo, Egypt.

[11]. F A O. (2005). Materials For Subsurface Land Drainage Systems (L.C.P.M.Stuy, W. Dierickx., & J. M. Beltrán. (Eds.); 60th Ed.). FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, Rome.

[12]. Ghane, E., Dialameh, B., Abdalaal, Y., & Ghane, M. (2022). Knitted-Sock Geotextile Envelopes Increase Drain Inflow In Subsurface Drainage Systems. Agricultural Water Management, 274(May), 107939. Https://Doi.Org/10.1016/J.Agwat.2022.107939

[13]. Ghobadi Nia, M., Rahimi, H., Sohrabi, T., Naseri, A., & Tofighi, H. (2010). Potential Risk Of Calcium Carbonate Precipitation In Agricultural Drain Envelopes In Arid And Semi-Arid Areas. Agricultural Water Management, 97(10), 1602–1608. Https://Doi.Org/Https://Doi.Org/10.1016/J.Agwat.2010.05.014

[14]. Guo, C., Wu, J., Zhu, Y., Lin, Z., He, S., & Qian, Y. (2020). Geotextiles And Geomembranes In Fl Uence Of Clogging Substances On Pore Characteristics And Permeability Of Geotextile Envelopes Of Subsurface Drainage Pipes In Arid Areas. Geotextiles And Geomembranes, 48(5), 735–746. Https://Doi.Org/10.1016/J.Geotexmem.2020.05.006

[15]. Hooghoudt, S. B. (1940). Bijdrage Tot De Kennis Van Eenige Natuurkundige Grootheden Van Den Grond. Versl. Landbouwkd. Onderz. B, 40, 215–345.

[16]. J. Winger, R., & And William F. Ryan, J. (1971). Gravel Envelopes For Pipe Drains-Design. Transactions Of The ASAE, 14(3), 471–474. Https://Doi.Org/Https://Doi.Org/10.13031/2013.38317

[17]. Lakruwan, M., Ph, D., Oikawa, H., Kamura, A., Ph, D., Kazama, M., & Ph, D. (2025). Effect Of Perforation Arrangement On Entrance Head Loss Of Horizontal Drains And Selection Criterion For Permeability Of Geotextile Envelope. 151(M), 1–13. Https://Doi.Org/10.1061/JIDEDH.IRENG-10362

[18]. Marschner, H. (2012). Preface To Second Edition (P. B. T.-M. M. N. Of H. P. (Third E. Marschner (Ed.); P. Ix). Academic Press. Https://Doi.Org/Https://Doi.Org/10.1016/B978-0-12-384905-2.00026-1

[19]. Ritzema, H., Abdel-Dayem, S., El-Atfy, H., Nasralla, M. R., & Shaheen, H. S. (2023). Challenges In Modernizing The Subsurface Drainage Systems In Egypt. Agricultural Water Management, 288(October 2022), 108484. Https://Doi.Org/10.1016/J.Agwat.2023.108484

[20]. Ritzema, H. P. (2006). Drainage Principles And Applications; 3rd Ed. (Issue 16). ILRI.

[21]. Rüegger, R., & Hufenus, R. (2003). Bauen Mit Geokunststoffen - Ein Handbuch Für Den Geokunststoff-Anwender.

[22]. Samani, Z. A., & Willardson, L. S. (1981). Soil Hydraulic Stability In A Subsurface Drainage System. Transactions Of The ASABE, 24, 666–669. Https://Api.Semanticscholar.Org/Corpusid:129766137

[23]. Singare, P. B. . P. D. R. . B. R. S. (2022). 13. Calcareous Soil And Their Management – A Review. Just Agriculture, 3(4), 1–6. Https://Www.Justagriculture.In/Files/Newsletter/2022/December/021. Calcareous Soil And Their Management.Pdf

[24]. Skaggs, R. W. (2017). Coefficients For Quantifying Subsurface Drainage Rates. Applied Engineering In Agriculture, 33, 793–799. Https://Doi.Org/10.13031/Aea.12302

[25]. Stuyt, L. C. P. M. (1992). The Water Acceptance Of Wrapped Subsurface Drains. [External Phd, WU]. Https://Doi.Org/Https://Doi.Org/10.18174/201279

[26]. Stuyt, L., Dierickx, W., & Beltrán, J. M. (2005). Materials For Subsurface Land Drainage Systems (Vol. 60). Food \& Agriculture Org.

[27]. Taalab, A. S., Ageeb, G. W., Siam, H. S., & Mahmoud, S. A. (2019). Some Characteristics Of Calcareous Soils. A Review. Middle East Journal Of Agriculture Research, 96–105.

[28]. Tanji, K. K., & Kielen, N. C. (2002). Agricultural Drainage Water Management In Arid And Semi-Arid Areas. (Issue 61).

[29]. U.S. Army Corps Of Engineers. (1977). Civil Works Construction Guide Specification For Plastic Filter Fabric (Issue CW-02215).

[30]. United States Bureau Of Reclamation. (1993). Drainage Manual (3rd Ed.). U.S. Department Of The Interior, Bureau Of Reclamation. Https://Www.Usbr.Gov/Tsc/Techreferences/Mands/Drainman.Html

[31]. Vlotman, W. F., Willardson, L. S., & Dierickx., W. (2001). Envelope Design For Subsurface Drains (S. A. ILRI). International Institute For Land Reclamation And Improvement, P.O. Box 45,6700AA Wageningen, The Netherlands,.

[32]. Wang, X., Zhang, Y., Fan, L., & Shen, J. (2024). Salt Drainage Efficiency And Anti-Clogging Effects Of Subsurface Pipes Wrapped With Geotextiles. Water (Switzerland), 16(10). Https://Doi.Org/10.3390/W16101392