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LABORATORY STUDY OF THE SOIL CLAY PERCENT INFLUENCE ON THE NEED FOR SUBSURFACE DRAINAGE SYSTEM ENVELOPES

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ABSTRACT The necessity of the use of subsurface drainage envelopes (envelopes) is one of the major concerns which are brought up in the first stages of design and construction of a drainage project. Clay percentage of soil is the first index to predict this requirement. In this study, in order for the calculation of gradient ratio (GR) and the assessment of clogging potential and soil particles movement into the drainpipe, the permeameter test was carried out on three samples with clay and clay loam textures. Treatments in this experiment were drainage systems with and w/o envelopes. In system with envelope, two types of envelopes (granular and fiber) were used. Through conducting this experiment, discharge variation, system permeability, gradient ratio and exit gradient were investigated. The results showed that the values of gradient ratio in the systems without envelope in most cases were greater than one which indicates high particle movement potentials. Nevertheless, soil particles movement happened when the values of this index exceeded 3. The ratio of outflow from the systems with mineral and synthetic envelopes to the ones without envelope ranged 2.0-3.5 and 1.4-1.8, respectively. As hydraulic gradient was increased, system hydraulic conductivity decreased in a way that the greater decrease happened in the system without envelope. Furthermore, by the calculation of hydraulic failure gradient and its comparison to exit gradient at different hydraulic gradient values, the resistance of soil particles against flow pressure was analyzed. The results indicated that the system without envelope had the least and the most performance in samples No. 2 and 3, respectively.

Keywords: Permeameter test, envelope, clay percent, failure gradient, chemical properties.

INTRODUCTION

The envelope materials have important role in optimum performance of a subsurface drainage system. The stabilization of surrounding soil and preventing soil particles movement into drain pipe and facilitating inflow are the most important duties of drain envelopes. On the other hand, a great portion of expenses is related to envelope installation. Therefore, the necessity of the use of envelopes is brought up in the design phase. Providing that the criteria are reliable and there is no need for using envelopes in specific situations, the construction speed will increase and the costs will decrease. Nevertheless, non-use of drain envelopes in some situations will result in unfavourable consequences such as high sedimentation in drain pipes which, eventually, will result in drainage system failure. The need for envelopes depends on soil stability and hydraulic conditions around pipes (Vlotman *et al.,* 2000). Clay percentage of soil is the first index to predict this requirement (Vlotman *et al.,* 1997). The more clay percent, the more soil particle cohesion and therefore, the more soil shearing strength against flow pressure. The best method to determine this requirement is to install experimental drain pipes in a field. But this method is very expensive and time-consuming (Vlotman, 1998). The laboratory methods are accepted ways to determine the need for using drain envelopes. Among different methods to assess the performance of these envelopes, the method of gradient ratio (GR) determination is one of the well-known methods which has low complexity and long foretime (Yu Shana *et al.,* 2001; Dierickx and Vlotman, 1995). The results of the permeameter tests (gradient ratio determination) by Willardson and Walker (1979), Samani and Willardson (1981) and Vlotman and Omara (1996) in order to determine the need for envelopes are affirmed. In similar conditions in terms of soil texture, the soils of dry regions have less stability compared to wet regions (Willardson, 1992). Therefore, the soil percent index alone is not reliable to assess soil consistency and stability in these regions. Thus, hydraulic failure gradient is used to determine the shearing resistance against the flow pressure (Vlotman *et al.,* 2000). The failure gradient is the gradient at which the surrounding soil cannot resist the flow strength. By calculating exit gradient (the gradient at which water exits porous media and enters the drain) and comparing it with hydraulic failure gradient, it can conclude about the need for envelope installation. If the values of the exit gradient are more, the use of envelopes in order to reduce the exit gradient is necessary (Samani and Willardson, 1981). Furthermore, SAR (Sodium Adsorption Ratio) is effective in the dispersion of soil particles around drain pipes. Higher values of SAR cause the increase of fine soil particles movement into macro pores and eventually by decreasing soil permeability, the probability of soil particle movement into drain pipes increases (Dierickx and Yüncüoglu, 1982). Van Zeijts (1992) found a relationship between soil clay and silt percent and the need for envelopes such that in wet regions, soils with more than 30 percent of clay don't have any need for envelopes. The results of the studies in the Netherlands showed that drain pipes in soils with more than 35 percent of clay and SAR less than 13 can be installed without envelopes (Abdel Dayem, 1985). According to the results of Dierickx and Leyman (1991), the soils with D_{50} between 50 and 150µ are sensitive to erosion and need envelopes. Bonnell *et al.* (1986) assessed soil stability by calculating the hydraulic failure gradient in common plane between drain plate and soil and qualified this method as acceptable to predict drain pipes sedimentation. Moreover, the US Soil Conservation Service (SCS, 1991) and United State Bureau of Reclamation (USBR, 1995) presented some guidance about the need for envelope installation. Soil clay percent and SAR are the most important parameters in these standards. In current study, using hydraulic gradient ratio test, the performance of the system without envelope was compared with the systems with mineral and synthetic (PP-450) envelopes on soil samples with three different textures and clay percent.

MATERIALS AND METHODS

Permeameter Test (Gradient Ratio Determination)

A device according to standard ASTM D5101-90 was used to carry out the permeameter test. The main part of the device was a transparent cylinder made of Plexiglas with 100mm diameter and of 5mm thickness. The sequence of the components of this cylinder from down to top included drain plate, envelope and soil sample. In order to analyze the variations of the hydraulic gradient through the soil column, a few piezometers were installed at specific distances (Figure 1). In this study, a drain plate (Figure 2) with 4 rectangular openings was used (Asghar and Vlotman, 1995). In accordance with the soil bulk density of the study area, soil samples were placed in the cylinder in three layers with the height of 100mm in the whole. The tests were carried out when the systems were saturated. In order to saturate the systems, water flow entered the system from the bottommost part. Then, to create different hydraulic gradients, the height of the input tank was regulated. The gradient ratio tests were performed at five hydraulic gradients (1, 2.5, 5, 7.5 and 10). After creating each gradient, The flow rate from the system, the height of water in each manometer and water temperature were measured at 0, 0.5, 1, 2, 4, 6 and 24 hours after the beginning. Each test lasted about 168 hours (24 hours for each gradient). In the whole, nine tests (each test had 3 repetitions) were carried out. The tests included three different systems (without envelope, with mineral envelope and with synthetic envelope) each one included three soil samples.

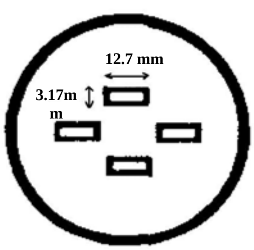


Figure 2. Type of drain plate used during the study.

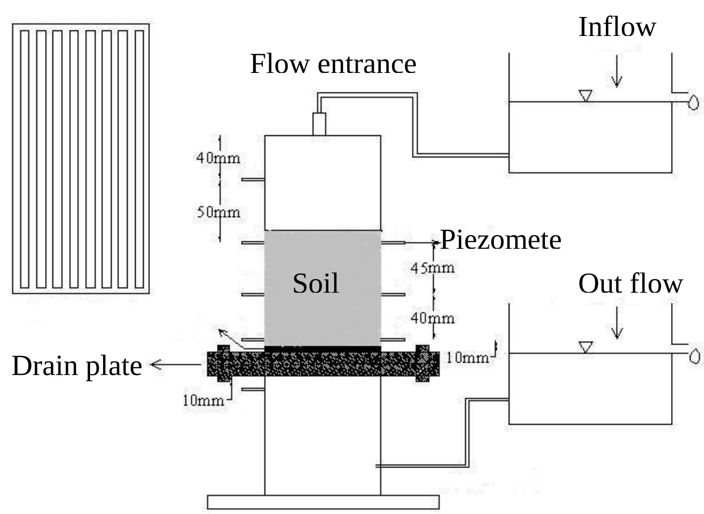


Figure 1. Schematic layout of one-dimensional downward flow permeameter in the laboratory

Calculations

System Hydraulic Gradient

System hydraulic gradient was calculated from the below equation:

$$i = \frac{\Delta h}{l} \qquad (1)$$

Where i is the hydraulic gradient (cm.cm^{-1}), Δh is the difference between the water height in manometers No. 7 and 8 (energy loss through the sample, cm), l is soil sample length (height, cm).

System Hydraulic Conductivity

System hydraulic conductivity was calculated according to the following equation:

$$K_T = \frac{Q}{iAt \times 100} \qquad (2)$$

Where: K_T is the system permeability at the test temperature (m. sec^{-1}), Q is the water volume from the system (cm^3), A is sample section area (cm^2) and t is time (sec). The temperature dependency of the hydraulic conductivity was calculated from the following equation:

$$K_{20} = \frac{K_T \times \mu_T}{\mu_{20}} \qquad (3)$$

In which K_{20} is the system permeability at 20 ^{o}C (m.sec^{-1}), μ_T is the water viscosity at the test temperature and μ_{20} is the water viscosity at 20 ^{o}C.

Gradient Ratio

In order to analyze the clogging potential of the systems, the gradient ratio (GR) was used according to the following equation equations:

$$GR = \frac{i_{es}}{i_s} \qquad (4)$$

$$i_{es} = \frac{\Delta h_{sf}}{L_{sf}} = \frac{(M_3 - M_8) + (M_4 - M_8)}{2L_{sf}} \qquad (5)$$

$$i_s = \frac{\Delta h_s}{L_s} = \frac{(M_5 - M_3) + (M_6 - M_4)}{2L_s} \qquad (6)$$

Where: GR is the gradient ratio, i_{es} is the hydraulic gradient of the soil-envelope system, i is the soil hydraulic gradient, L_{sf} is the length (height) of the soil-envelope system (55mm) and L_s is the length (height) of the soil column (45mm). In case of the gradient ratio of more than 1, the envelope is prone to mineral clogging.

Hydraulic Failure Gradient

Hydraulic failure gradient (HFG, equation 7) can be a complementary index to diagnose the need for envelope installation for subsurface drain pipes. This index depends on the fixed physical and mechanical soil properties (saturated hydraulic conductivity, plasticity index). If the exit gradient is less than the hydraulic failure gradient, there is no need for envelope installation.

$$HFG = e^{0.322 - 0.132K_s + 1.07Ln(PI)} \quad (7)$$

$$i_x = \frac{(M_1 + M_2) - 2M_8}{2l_s} \quad (8)$$

Where i_x is the exit gradient, K_s is the saturated hydraulic conductivity of the soil sample ($m.day^{-1}$), *PI* is the plasticity index and *e* is the base of natural logarithm.

RESULTS AND DISCUSSION

Soil Samples Properties

Physical and chemical properties of three soil samples used in the tests are presented in Table 1. Sample No. 1 was from *Eshtehard*, Sample No. 2 was from *Khorram Shahr* and Sample No.3 was from *Karaj*. The samples were chosen in a way that the effect of clay percent on the requirement of envelope installation could be analyzed.

Table 1. Chemical and physical properties of the soil samples.

Sample No.	Clay (percent)	Silt (percent)	Sand (percent)	PI	Cu	ρ_b	EC(*dS/m*)	SAR	PH
1	27	61	12	15.4	19.7	1.36	33.2	17	7.42
2	35	62.2	2.8	9	14	1.34	100.8	83	7.51
3	36	49	15	20	16	1.31	10.6	26	7.82

Water Chemical Properties

The water used in the tests was municipal water from Karaj city. Chemical properties of water affect the soil chemical processes. Soil particle dispersion and the hydraulic conductivity are affected by the amount of water solutes and SAR. Table 2 shows water chemical properties.

Table 2. Water chemical properties (municipal water).

EC (*dS/m*)	PH	No_3 (mg/l)	HCo_3 (mq/l)	Mg (mq/l)	Ca (mq/l)	Na (mg/l)	K (mg/l)
0.65	7.21	46.72	3.8	5.8	3.8	73.4	0.8

Envelopes

Mineral Envelopes

In order to design mineral envelope, the design standards of USBR were used. Using the information obtained from the soil particle size distribution (PSD) curve, according to the samples D_{60} value, the particle distribution of the envelope was chosen. Figure 3 shows the PSD curve related to the 2nd soil sample.

Synthetic Envelope As the synthetic envelopes (geotextiles) are getting more and more popular worldwide, in this study, a synthetic envelope model PP-450 (made of propylene) was also assessed.

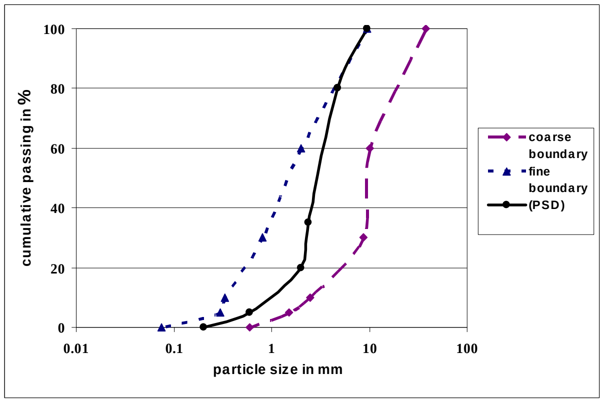


Figure 3. The mineral particle size distribution according to USBR standard.

These fibers are from the waste materials of carpet factories. According to international standards, this kind of envelopes can fulfill the criteria of soil particles stability and mineral clogging prevention. The main reason for choosing this type of synthetic envelopes was the fact that this model had a long study history showed that the performance of this type was better than the others.

Outflow Rate

After measuring the outflow rate for each test, these results were obtained: the outflow rate at a constant hydraulic gradient had a decreasing trend in time (Figure 4). The reason was probably the movement of the fine soil particles into micro pores and also envelopes (if existed) because of water flow pressure which eventually resulted in the hydraulic conductivity reduction. Table 3 shows the variations of the soil hydraulic conductivity (in system without envelope) and the hydraulic conductivity of the soil-envelope systems (in systems with envelope). It can be seen that any increase in the hydraulic gradient resulted in a reduction in the values of the hydraulic conductivity. But, since the pressure of the water flow increased, the outflow rate showed an increasing trend. The outflow rates of the system with mineral envelope were always greater than the rates of the other systems. The main reason was high hydraulic radius (because of envelope hydraulic functions) and therefore, the hydraulic ease of the inflow into the drains.

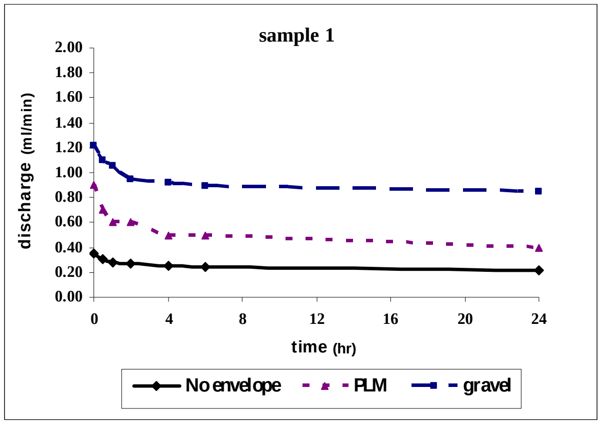


Figure 4. The outflow rates variations at the hydraulic gradient of soil sample No.1.

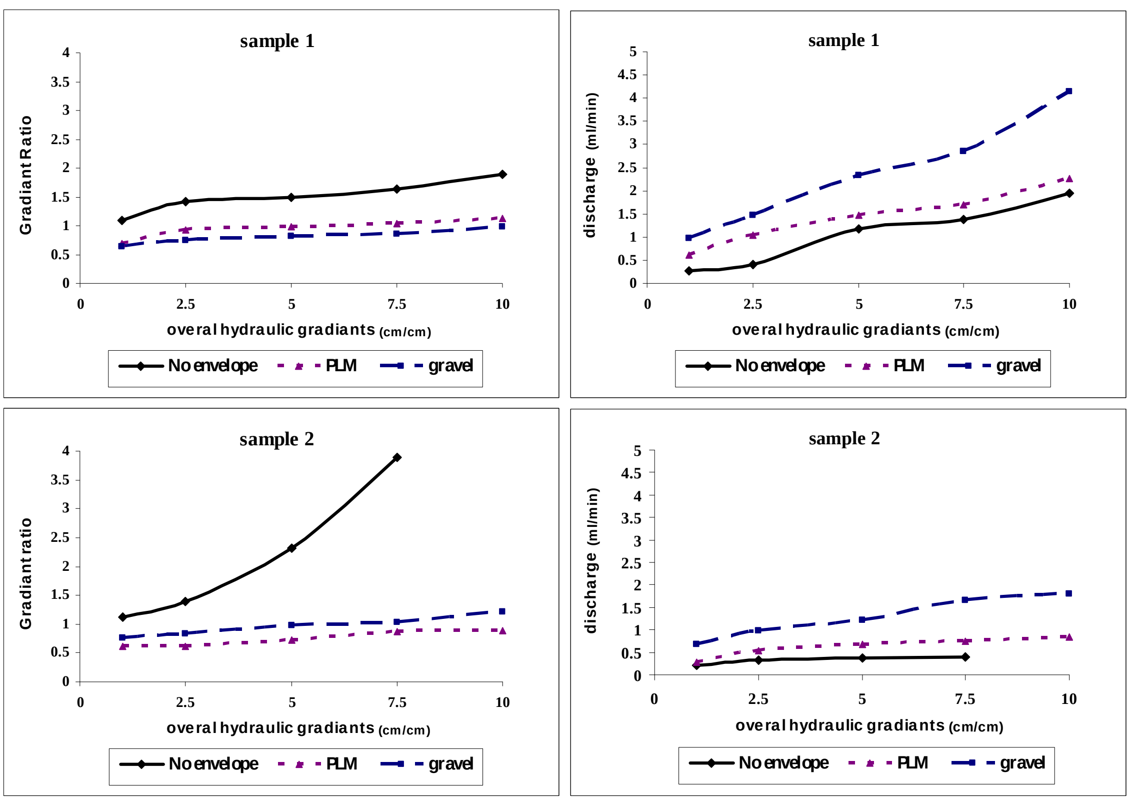
Table 3. The average values of the system hydraulic conductivity (m.day^{-1}) and its variation.

Soil sample No.	System w/o envelope			System with Gravel envelope			System with PLM envelope		
	Start of test	End of test	variation percent	Start of test	End of test	variation percent	Start of test	End of test	variation percent
1	0.039	0.019	51	0.155	0.095	38	0.067	0.041	38
2	0.017	o.oo4	76	0.091	0.034	62	0.025	0.008	68
3	0.0145	0.0054	62	0.041	0.018	54	0.033	0.011	66

The ratio between the outflow rates from system with mineral envelope to the system without envelope in samples No. 1, 2 and 3 were 2.7, 3.4 and 2.6, respectively. Also, this ratio for the system with synthetic envelope and the system without envelope were 1.7, 1.4 and 1.8, respectively. Figure 5 shows the variations of the outflow rate vs. the system hydraulic gradient values. The results showed that the differences between the outflow rates of the systems with synthetic envelope and without envelope was negligible in sample No.2. The higher values of SAR in this sample caused the dispersion of soil particles and reduction of the hydraulic conductivity. On the other hand, the amount of the envelope clogging was more in this situation. Moreover, when the hydraulic gradient of the system exceeded 5, the permeability decreased substantially in this sample in a way that the outflow rate hardly changed and then after the hydraulic gradient exceeded 7.5, soil particles movement from the drain plate openings happened. The reduction of the outflow rate in the system with mineral envelope was less than the system with synthetic envelope and the outflow rates were 2-3 times more at all the gradient values. This indicates the higher hydraulic conductivity of the mineral envelope as compared to the synthetic envelope. The differences between the outflow rates of the system without envelope and the systems with envelope were lower at the hydraulic gradients less than 5 and were higher at the hydraulic gradients of 10 and more. In the other words, the hydraulic role of the envelope is more remarkable at higher gradients.

Gradient Ratio Index

The index of gradient ratio was used to assess the clogging potential of the soil-envelope system. Furthermore, this index was used to analyze the clogging potential of the system without envelope because the change of the flow lines shape into drain pipe and the increase of the head loss near the drain plate, increases the clogging potential in the lower part of the system and also increases the potential of the soil particle movement into the drain pipes. The gradient ratio values less than one shows a higher soil-envelope system hydraulic conductivity near the drain plate as compared to the soil hydraulic conductivity. On the contrary, the values greater than one shows the clogging potential. Almost in all tests, as the system hydraulic gradient increased, the values of the gradient ratio increased (Figure 6). The highest values of this index in all the samples occurred in the system without envelope. Moreover, more variations happened in this system. The reason was the movement of the fine soil particles towards the drain plate and also into the macro pores. These particles could not pass the openings and eventually caused the openings to be clogged and increased the entrance resistance. While in the systems with envelope, these particles could find a path outward, and then, less head loss was measured in this part. The values of the gradient ratio index in the system with mineral envelope were less in samples No. 1 and 3 as compared to sample No. 2. In sample No. 2, when the hydraulic gradients exceeded 5, the values of this index were calculated more than 1 which indicates more danger of clogging in this sample. Nonetheless, the mineral envelope had a better performance in all samples. Also, in the system with synthetic envelope, nearly in all soil samples, the values of the gradient ratio were less than one. According to the test results of this study, the serious danger of clogging happens when the gradient ratio exceeds 3. Only in sample No.2, the values of the gradient ratio were more than 3 and the potential of the soil particle movement into the drain pipe existed.



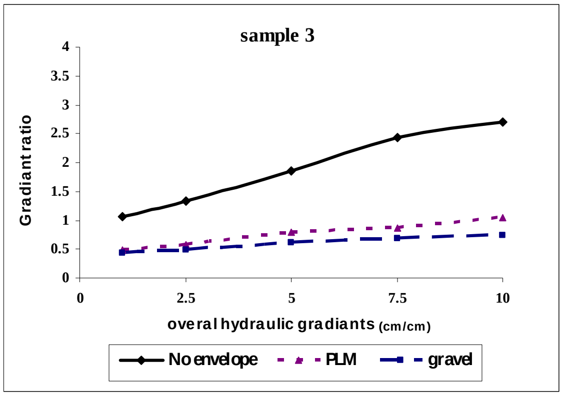


Figure 6. The variations of the gradient ratio index vs. the system hydraulic gradient.

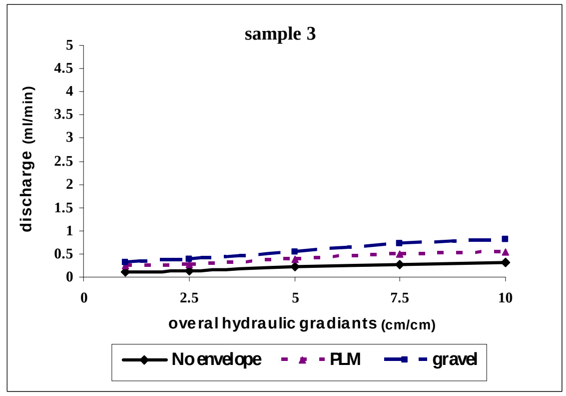


Figure 5. The variations of the outflow rate vs. the system hydraulic gradient.

Exit Gradient

Table 4 shows the values of the exit gradient for the system without envelope and at all the gradient values. In all three soil samples, the exit gradient increased by the increase of the system hydraulic gradient. The lower value of SAR besides high salinity of sample No.1 decreased the soil dispersion and the exit gradient. Although because of the lower clay percent, the failure gradient was also low and this increased the potential of soil particle movement into drain pipe at the gradients of 7.5 to 10. In sample No.2, substantial increase of the exit gradient and also the lower value of the failure gradient occurred. These were because of the lower clay percent which caused a critical condition in a way that the system without envelope had an acceptable performance just at the gradients of 1 and 2.5. The high amount of plasticity in sample No.3 was the main reasons for the acceptable performance of the system without envelope in this sample since the danger of soil particle movement into drain pipe existed only at the gradient of 10. The systems with mineral and synthetic envelopes showed lower values of the exit gradient which were lower than the failure gradient in all the tests.

Table 4. The values of the exit gradient in the system without envelope.

Soil sample No.	**Overall Hydraulic Gradient**					**Hydraulic Failure Gradient**
	1	**2.5**	**5**	**7.5**	**10**	
1	3.9	16.8	25.6	29.5	32	24.5
2	4.8	19.5	51	84	-	14.5
3	3.1	11.5	19.5	33.2	48.5	34.2

CONCLUSION

The system without envelope had a better performance in sample No.3 and the danger of soil particle movement into drain pipe existed only at the gradient of 10. In this sample, despite of the high values of SAR (more than 12), the performance of the system without envelope was acceptable and it seems that the suggested criteria in the method of clay percent and the value of SAR is more cautious. In sample No. 1, in spite of the positive effect of salinity, the lower amount of plasticity caused the more transfer of the soil particles towards the drain plate and therefore, the head loss in the exit part increased. In sample No. 2, the high values of SAR was the main reason of the lower performance of the system without envelope and the critical condition existed at the gradients of more than 5. By the increase of the clay percent, the difference between the performance of the systems with and without envelope decreased. With a constant amount of clay, the less silt percent caused the less potential of drain pipe clogging. The performance of the systems without envelope in the soils with the clay percent of more than 35 and the PI values of more than 12 may be acceptable providing the proper chemical properties of water exists (SAR less than 25).

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