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An investigation on geotextiles as envelopes of subsurface drainage pipe in Ningxia of China

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ABSTRACT: This paper presents the results of both laboratory and field tests on the permeability of geotextiles as the envelopes. In laboratory, 12 geotextiles with two soils were tested and analyzed. The results from the lab tests showed that there was a tendency that geotextiles with larger opening sizes likely gave a higher drain discharge and no significant relationship was found between drain discharge and thickness of the geotextiles. On the other hand, the mass of soil particles retained within the envelope was increased with the thickness increase of geotextiles. In the field, three geotextiles selected based on the lab tests and gravel filters were installed and evaluated. Finally, the synthetic envelopes for this area were proposed.

1 INTRODUCTION

A large area of lands suffers from soil salinity in Ningxia of northwest China due to dry climate and high groundwater table induced by irrigation that is diverted from the Yellow River. Subsurface pipe drainage has been used for controlling groundwater table and soil salinity of the irrigated lands in this region during the last decade. Envelopes for drainage pipe are extremely necessary in the weak-structured silt loam soils. The experiences and practices there showed that to apply subsurface drainage in a large area must adopt machinery installation methods to guarantee the quality and reduce the cost of construction. The progress of subsurface drainage technology is not only expressed in the development of installation methods with machines but also in the development of materials, such as, plastic pipes and synthetic envelopes. Trenchers were then imported from the Netherlands by Ningxia Agricultural Comprehensive Development Office in 1999, and a production line of perforated corrugated plastic pipes was also introduced in 2000. Gravel filters are no long accepted in this area since it is costly and heavy. It is then becoming important and essential to find out the proper synthetic envelopes as the substitution for this area.

Compare with traditional gravel envelopes, synthetic envelopes have advantages of more variety of products, light-weight, convenience in transportation and installation, long-life, less labor cost and, fast speed of construction with pre-wrapped plastic pipes and trencher machines. Since 1960's, geotextiles have been applied to dams, bank protection, water wells, and during the last two decades have been successfully applied to land drainage as well in Europe, Canada and USA (Ritzema 1994, Stuyt et al. 2000). With the development of installing machines and plastic drain pipes, studies now focus more on synthetic envelopes. These studies have been undertaken in approaches including theoretical investigation from 1950 to 1980, laboratory tests with analogue models and sand tanks and flow perpeameters worldwide since 1960's, field experiments from 1960-1990, and use of internal TV and 3D x-ray analysis (Stuyt et al. 2000). In 1987, laboratory tests on several woven and non-woven geotextiles as subdrain pipe envelopes was carried out at China Institute of Water Resources and Hydropower Research to compare their permeability and soil retention capacity (Ding et al. 1994). Socks-like nylon woven envelope wrapped on perforated corrugated plastic pipes used as horizontal collectors of radial wells in a silt loam soil showed a satisfied result in permeability after two years field run (Ding et al. 1994). However, studies and applications of synthetic envelopes for land drainage in China are far from enough. Although many criteria on synthetic envelopes have been developed worldwide (Ritzema 1994, Stuyt et al. 2000), they are not regarded as traditional, effective and universal as those on granular materials, and the appropriateness of envelope is uncertain (Stuyt 2001). Therefore, to select synthetic envelopes should be relied on testing and final test should be the field installation (MWR 1999, Stuyt 2001).

This paper presents the results of both laboratory and field tests on the permeability of synthetic envelopes. Together with other factors, recommendations for this area were proposed.

2 MATERIALS AND METHODS

2.1 *Soils and envelopes*

Two soil samples from the project area in Helan and Huinong of Ningxia and 12 geotextiles were used for laboratory tests. Soil bulk density and hydraulic conductivity were measured with 100 cm^3 undisturbed soil samples in lab. Pipes with 5 different envelopes including gravel filters were installed in Helan in 2000 for field evaluation. Soil properties are given in Table 1 and Figure 1. Geotextile properties are listed in Tables 2 and 3.

Table 1. Soil properties.

Items	Helan	Huinong
Bulk density (g/cm^3)	1.4	1.5
Hydraulic conductivity (cm/s)	$7x10^{-5}$	$1x10^{-5}$
Texture	Silt loam	Silt loam

Table 2. Geotextiles used in laboratory tests

No.	Type	Mass	Thickness	Kg	O_{90}
		g/m^2	mm	cm/s	mm
A	NW	50	0.24	$3.3x10^{-2}$	0.33
B	NW	68	0.35	$4.3x10^{-2}$	0.23
C	NW	70	0.26	$7.8x10^{-2}$	0.27
D	NW	75	0.3	$5.0x10^{-2}$	0.47
E	NW	90	0.38	$3.4x10^{-2}$	0.18
F	NW	100	0.5	$5.0x10^{-2}$	0.16
G	NW	100	0.47	$3.0x10^{-2}$	0.25
H	NW	100	0.45	$3.2x10^{-1}$	0.20
I	W	100	0.75	$2.5x10^{-1}$	0.32
J	NW	150	0.42	$2.7x10^{-2}$	0.12
K	W	160	0.9	$1.2x10^{-1}$	0.16
L	NW	200	2.55	$2.7x10^{-2}$	0.12

Table 3. Envelopes used in field tests

No.	Type	O_{90}	Thickness	Mass
		mm	mm	g/m^2
A	NW	0.33	0.24	50
B	NW	0.23	0.35	68
L	NW	0.12	2.25	200
B+Gravel	NW+Gra	0.23+	0.35+	68+
Gravel	Gra	(Sieving crushed stones 3-5 mm)		

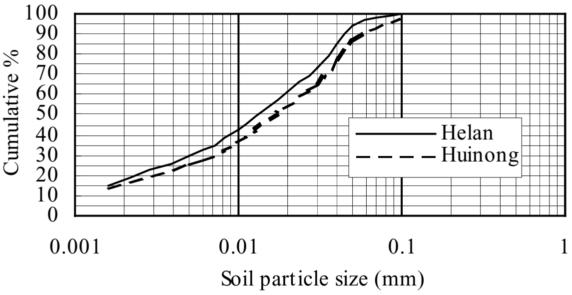

Figure 1. Distribution of soil particle size

2.2 *Laboratory test*

Laboratory tests included one-dimension and two-dimension permeameters as shown in Figures 2-3. The one-dimension permeameter with 20cm in diameter and 10 cm of soil depth above the synthetic envelopes were used to test the permeability under different hydraulic gradients applied. Discharge under each steady hydraulic gradient from 1 to 10 was measured after two-hour run and the corresponding piezometers at different height in the soil were recorded. Then, keep a constant gradient of 7 within 24 hours to measure the changes of discharge and piezometers. The hydraulic gradient was changed from low to high by increasing the upstream water level with fixed outlet water level. Soil masses retained within and passing through the envelopes were measured after tests.

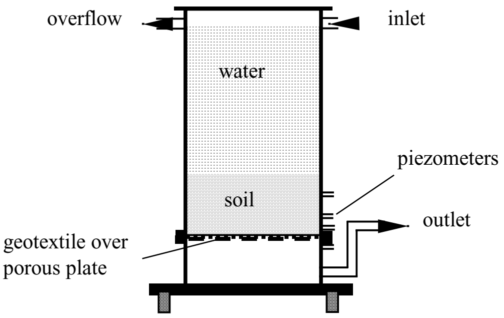

Figure 2. Sketch of one-dimensional test model

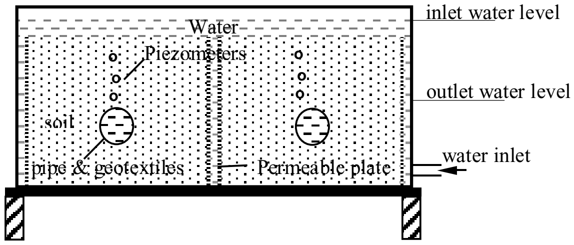

Figure 3. Sketch of two-dimension tests model

The two-dimension permeameter has two separated parts with 70 cm x 50 cm x 40 cm of soil volume on each side. A 50 cm long and 75 mm in diameter drain pipe pre-wrapped with envelope was horizontally placed in the soil and sealed at the junctions with the walls making them water tight. This enables to run two combinations simultaneously. Water infiltrated from the two sides and the soil surface into the soil body and drained out through the outlet. Water levels of upstream and downstream were kept constant. Flow discharge and piezometers at different locations were measured. This tested the long term performance of the envelopes selected based on the results of one-dimension tests.

2.3 *Field test*

Field drainage measurements were made during the irrigation in May 2001. 75 mm in diameter perforated corrugated plastic drainpipes wrapped with 5 different envelopes forming 5 testing treatments were installed at 1.3 m depth using the trencher. These envelopes include A and B selected from the laboratory tests and L that was ever used in that area, gravel filter (Gra), and the combination of B and gravel (B+Gra), as given in Table 3. Treatments replicated with three pipes of 300 m long each in average and randomly installed in one field. A slope of 1/1000 and spacing of 68 m for all treatments were adopted. Water without pressure from the pipes flows into an open ditch from both sides and then into a main drain. Groundwater table observation wells were installed midway between drains and at points 50 cm away from both sides of the pipe. Flow discharges and groundwater levels for all pipes were measured after irrigation application. The relationships of the discharge and water height above the pipe were used to compare the effectiveness of the envelopes.

3 RESULTS AND ANALYSIS

3.1 *Soil and envelope properties*

Table 1 and Figure 1 shows that both soils are silt loam with high silt and low clay contents that imply low soil cohesion and unstable structures. These soils have clogging problems with the subsurface pipe drainage as demonstrated in that area. Thus, envelopes are needed to prevent or minimize clogging. Table 2 shows 2 woven (W) and 10 non-woven (NW) geotextiles with O_{90} of 0.12-0.47mm, 0.24-2.55 mm in thickness, and 50-200 g/m^2 of mass. These covered a possible wide range of opening size and available products in China.

3.2 *Laboratory tests*

3.2.1 *One-dimension test*

Figure 4 shows the relationships between the drain discharge and hydraulic gradient under various soil and envelope combinations. The discharge increased with the increase of gradient for all combinations in non-linear resulted from many effects including soil and envelope compression, fine soil particle movement and clogging at the interface and inside envelope. However, discharge differences between envelopes became greater at higher gradients. Figure5 indicates that there was a tendency that more soil particles were retained and clogged inside envelopes with thicker ones. From the viewpoints of permeability and soil retention, it can be seen in Figure4. that envelopes A, and B provided higher discharge for both soils. L was the poorest one possibly because of its highly compressibility resulting in decrease in the actual opening size and of its bigger thickness implying more soil particle clogged inside as shown in Figure5, these two factors caused reduction of permeability. This can also be analyzed by comparing the hydraulic conductivity of the soil body itself (Ks) and of the combination of soil and envelope system (Kc) as shown in Figure 6. If Ks and Kc can keep close and stable with time, it indicates the stable structure and less clogging developed with time, and vice versa. Figure6 shows the stable Kc and close to Ks with A and B, but much lower Kc than Ks with L implying high water head loss and thus clogging within the envelope. The other envelopes were the cases in between of these above. Although not significant, there was a tendency that the envelope with a larger O_{90} likely gave a higher drain discharge without regard to the thickness. This indicated that the opening sizes of the geotextiles had an important influence on the permeability under the combination conditions of soil and geotextiles infiltration system, but not significantly related to each other.

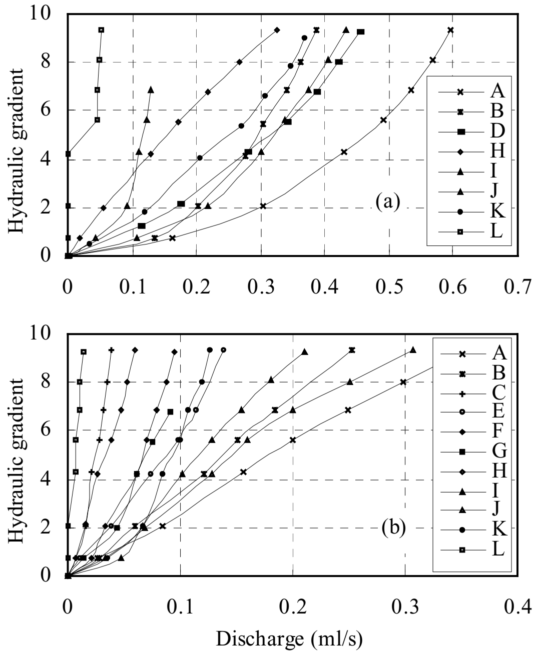

Figure 4. Discharge and hydraulic gradient of one dimension test with (a) Helan and (b) Huinong soil

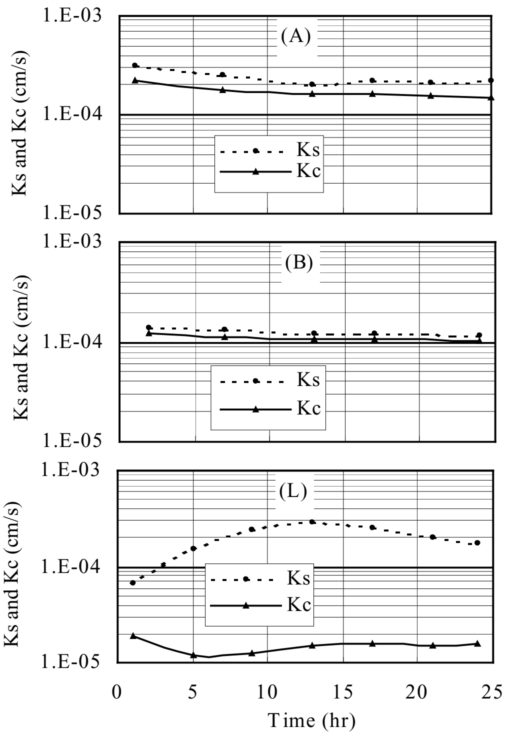

Figure 5. Hydraulic conductivity of soil (Ks) and of combination of soil and the envelope (Kc), with (a) A, (b) B and (c) L in one dimension tests

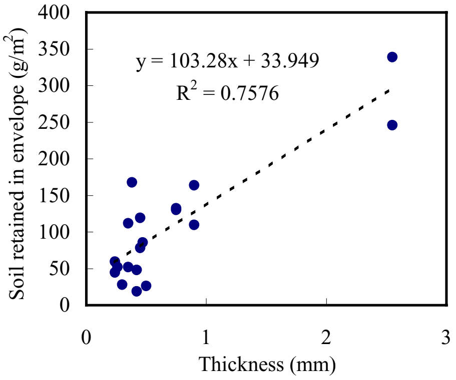

Figure 6. Relationship of soil mass retained in envelope and its thickness in one-dimension tests

3.2.2 *Two-dimension test*

Figure7 shows the relationship between drain discharge and time in two-dimension tests under a constant gradient, at which the upstream water level was 5cm above the soil surface and the downstream level was just above the drain pipe that ensured full of water in the pipe. During the initial days the discharge decreased quickly, and peizometers showed great increases in water head losses across the envelopes that indicated soil particles movement and clogged in the envelopes. After 20 days, however, the discharge with both envelopes became practically steady and finally stabilized at 11 ml/min and 9 ml/min for A and B respectively. The result of higher discharge with A than that with B was in agreement with that of one-dimension tests. At 60 days water supply was stopped and soil body became unsaturated for one week to simulate groundwater changes in field, as in Figure7. It showed that the discharges after supplying water again kept the same stable values as above until the test finished at 110 days. Few soil particle and sediment was visibly observed in the discharge flow and in the pipes during the whole test period. In summary, these showed that, with envelopes A and B, stable discharge and soil retention criteria could be maintained although some clogging was unavoidable. Therefore, it is possible to use these envelopes in the field if the stable discharge can meet the designed drainage rate of this area.

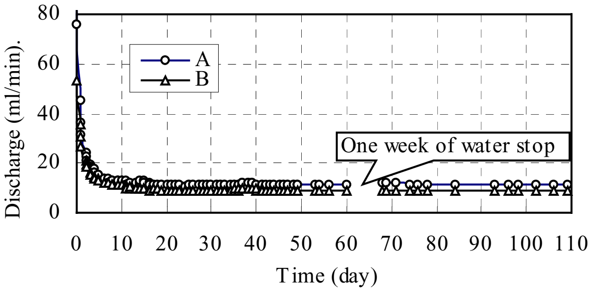

Figure 7. Changes of drain discharge with time in two-dimension test with Helan soil

3.3 *Field test*

Figure7 shows the relationship between the drain discharge, Q (calculated as per 100 m long), and the average water height of water table midway between drains, H. H was regarded as the highest between drains and as the corresponding water head to the discharge measured at the same time. A linear relationship through the origin between Q and H can be expected (Ritzema 1994). In Figure7, the correlation coefficients, r, obtained by pooling Q-H data points of each envelope, are 0.9, 0.8, 0.9, 0.8 and 0.8 for envelopes A, B, B+Gra, Gra and L respectively. The permeability order is A > B > B + Gra> Gra + B > L. To assess the suitability, we need to calculate if the drain discharge can meet the designed drainage rate after irrigation. As water table in unsteady flow changes with time in an exponential function (Ritzema 1994) and the average water height, H_0, between H_1 and H_2 can be calculated with $H_0=(H_1 - H_2) / ln\ (H_1 - H_2)$, where, H_1 and H_2 are the maximum and the minimum water table respectively. Considering the water height changes from 1 m to 0.2 m after one irrigation, then the average water height is 0.5 m and the average drain discharge, from Figure7, is 0.20 to 0.33 l/s/100m, or, 2.5 to 4.1 mm/day. These actual drain discharges are higher than the designed drainage rate of 1.5 mm/day for this area (NACDO 1998) and, thus, can meet the requirement.

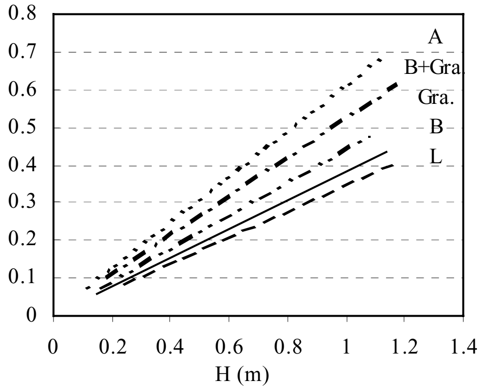

Figure 8. Drainage discharge and water head for different envelopes under the field test

4 DISCUSSIONS AND RECOMMENDATIONS

4.1 *Discussions*

The results from the lab tests showed that the opening sizes of the geotextiles have a very important influence on the permeability under the combination conditions of soil and envelope infiltration system. The amount of soil particles passing through envelope was not large for all of the geotextiles even under as high as 10 gradients. Normally, the geotextiles with a bigger opening size of O_{90} gave a higher drainage flow and no significant relationship was found between drain discharge and thickness of the geotextiles. On the other hand, the mass of soil particles retained in the envelope was increased with its thickness increase. This implied that geotextiles with bigger opening sizes and less thickness may be expected as envelopes for these silt soils.

However, this does not guarantee reliable relationship between pore size and the permeability. Comparing the results of the tests with the design criteria, it was difficult to apply them to selecting synthetic envelopes, like O_{95}/d_{85} values or gradient ratio (GR) criteria. This indicated that, for such silt soils, there are considerable uncertainties that are difficult to attempt sound criteria due to the wide variety in envelope materials and in their characteristics and, the complexity in soil/envelope interactions. Because field tests are very costly and time consuming, laboratory tests, therefore, are still useful to make a preliminary selection of envelopes.

For the field tests, some influence may not be easily prevented, such as, non-uniformity of irrigation water application although the drain discharges were presented by per 100m long pipe. To check the design drainage rate of 1.5 mm/day with the observed discharge were safer in practice. It should noted that installation under wet condition will adversely affect on envelope permeability and can not be compensated by good materials (Stuyt 2001).

It should also be pointed out that four other synthetic envelopes with larger diameter pipes (80mm) were also installed in the field. Discharges with them were very unstable resulting in a poor relationship with the water heads although they showed higher discharges than that of those presented in this paper. These materials were imported as very limited amount for field test samples only and not available in the local market. Therefore, It was difficult to evaluate and thus not presented here. But evaluation will be done with more observation data available.

4.2 *Recommendations*

Gravel envelopes are practically difficult to be accepted as it is of limited in availability and inconvenience in construction, and its advantage was under expectation in this test. L was demonstrated in this study and in previous field use as being liable to clogging and unstable permeability. Therefore, it was concluded that envelopes A and B can meet both drainage rate and practical requirement, thus they can be used in this project area with caution of further field evaluation.

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