A NEW DRAIN PIPE-ENVELOPE CONCEPT FOR SUBSURFACE DRAINAGE SYSTEMS IN IRRIGATED AGRICULTURE

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Abstract

In irrigated lands, drain pipes are equipped with envelopes to safeguard the subsurface drainage system against the three main hazards of poor drain-line performance: high flow resistance in the vicinity of the drain, siltation, and root growth inside the pipe. A wide variety of materials are used as envelopes, ranging from mineral and synthetic materials to mineral fibres. The challenge is to match the envelope specifications with the soil type. As soils are rather variable, the design of envelopes is not straightforward as illustrated by the numerous norms and criteria that have been developed worldwide. These norms and criteria have been mainly developed in Western Europe and the USA and often lead to disappointing results when applied in other countries where their specifications and effectiveness have not been proven in field trials. In irrigated lands, problematical factors which are evident are that as compared to rainfed agriculture, the hydraulic function of an envelope is less important than the filter function moreover, the root growth inside the drain pipe is a major problem. To tackle these problems, an innovative envelope design concept, based on optimizing the geometry of the pipe and the envelope, has been tested in a 50 ha pilot area in Haran Province, Turkey. The new concept, Hydroluis®, consists of a corrugated inner pipe with two rows of perforations at the top and an unperforated outer pipe that covers about 2/3 of the inner pipe leaving the bottom part of the inner pipe in contact with the soil. The main advantage of the new concept is that it is less dependent on the soil type than the existing envelope materials. The new concept was tested and compared with a geotextile, a sand-gravel envelope and a control with no envelope material. All three envelope types had a lower sediment load as compared to the control and the sand-gravel and Hydroluis® envelopes had a considerable lower entrance resistance as compared to the geo-textile, which showed the best drain performance and showed no signs of root growth. It can be concluded that the Hydroluis® envelope is a good alternative for a sand/gravel or synthetic envelope in irrigated lands.

KEY WORDS: Subsurface drainage, Envelope materials, Entrance resistance, Drain performance.

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Introduction

Pipe drains are equipped with envelopes to safeguard the subsurface drainage system against the three main hazards of poor drain-line performance: siltation, high flow resistance in the vicinity of the drain pipe and root growth inside the pipe. A wide variety of materials are used as envelopes for drain pipes, ranging from organic and mineral material, to synthetic material and mineral fibres (Cavelaars et al., 2006). Organic material is mostly fibrous, and includes peat - the classical material used in Western Europe - coconut fibre, and various organic waste products like straw, chaff, heather, and sawdust. Mineral materials are mostly used in a granular form; they may be gravel, slag of various kinds (industrial waste products), or fired clay granules. Synthetic materials may be in a granular form (e.g. polystyrene) or in a fibrous form (e.g. nylon, acryl, and polypropylene). Glass fibre, glass wool, and rock wool, which all are mineral fibres, are also used. A drain envelope has three functions (Ritzema et al., 2006):

- Filter function: to prevent or restrict soil particles from entering the pipe where they may settle and eventually clog the pipe;
- Hydraulic function: to constitute a medium of good permeability around the pipe and thus reduce entrance resistance;
- Bedding function: to provide all-round support to the pipe in order to prevent damage due to the soil load. Note that large diameter plastic pipes are embedded in gravel especially for this purpose.

Apart from these conflicting filtering and hydraulic functions, the formulation of functional criteria for envelopes is complicated by a dependence on soil characteristics, mainly soil texture, and installation conditions (Stuyt and Dierickx, 2006; Stuyt and Willardson, 1999). Vlotman et al. (2001) reviewed the simultaneous development of theory and practical experience in Europe and North America. Traditionally, the required envelope around the drain pipe consisted of locally available materials like stones, gravel or straw. In arid areas, the technique of using gravel envelopes has been further developed to such a degree that effective gravel envelopes can be designed for most soils (United States Bureau of Reclamation, 1978). In practice, gravel envelopes are often expensive due to the high transport costs, while their installation is cumbersome and error prone, and requires almost perfect logistic management during installation (Ritzema et al., 2006). Moreover, gravel cannot be used when installation is done with trenchless equipment. Subsequently, pre-wrapped envelopes of synthetic material have been under development for some decades, but only limited research has been done on locally made synthetic envelopes for subsurface drainage in irrigated lands (El-Sadany Salem et al., 1995; Kumbhare and Ritzema, 2000). Specialized machines have been developed to pre-wrapped sheet and loose-fibre envelopes around the drain pipes, not in the field but in the factory, ensuring a better quality and easier quality control (Nijland et al., 2005). Pre-wrapped synthetic envelopes are presently used almost everywhere in Europe, in some areas of the United States, and in the countries in the Middle East.

Since the specifications of envelopes are very soil specific and soils are rather variable, the specifications and effectiveness of envelopes have to be proven in field trials in the areas where they are to be applied (Vlotman et al., 2001).

The life of subsurface drainage systems can be hundred years if no blockage, deformation nor siltation occurs (Jahn et al., 2006; Stuyt et al., 2005). Blockage of the pipes generally occurs due to sanding, siltation, chemical and biological settlement, penetration of plant root into the pipe, accumulation of compressed filling soil in drainage trenches (in very wet environments) or improper installation of individual pipes (Eggelsmann, 1987). A common practice to prevent penetration of plant roots into the pipes is to increase installation depth. To prevent entry of sediments into drain pipes, pipes are wrapped with envelopes selected according to the characteristics of the soil in which they will be installed. In soils that are problematic in terms of siltation, it is important to prevent penetration of soil grains into the drain pipe (Zaslavsky, 1978). The envelope material wrapped around the pipes to prevent sediment penetration into pipes must have characteristics that does not increase entrance resistance (Wesseling and Homma, 1967). Head losses that occur due to the compression during the entering of water into the drains reduce efficiency of the systems. Increasing the size of the perforations and consequently the total area of holes in plastic drain pipes decrease entrance resistance (Cavelaars, 1965). In an experiment conducted in a horizontal sand tank with a fine sand loamy soil, Chiara and Ronnel (1987), who tested different envelope options, achieved the greatest flow rate and lowest siltation in the pipes wrapped with geotextiles.

Although there are many studies and publications that suggest that there is no need for envelopes in matured, structurally developed, stable soils that contain certain amount of clay (Vlotman, 1998), in Turkey drain pipes in these type of soils are generally equipped with envelopes (Bahçeci et al., 2001). The envelope material that has the best performance under these conditions is gravel obtained from natural sand gravel pits. These envelopes, however, are very expensive and often the particle-size distribution of these natural sand gravels doesn't match the design specifications. More recently geotextiles are used but they have the twin problem of clogging and root penetration.

A new concept, the **Hydroluis®** pipe-envelope system has been developed to overcome these shortcomings. It is designed in such a way that penetration of plant roots and soil particles into the pipe is prevented. The new concept consists of a corrugated inner corrugated pipe with two rows of perforations at the top and an unperforated outer pipe that covers about 2/3 of the inner pipe leaving the unperforated bottom part of the inner pipe in contact with the soil (Figure 1). The outer pipe has an egg-box profile to ensure that there is an open space between the two pipes through which the water can flow upward to the perforations in the inner pipe. The distance between the two pipes determines the flow velocity. The new concept has recently been certificated by the Turkish Bureau of Standardization (Türk Standardlari Enstitüsü, 2016). The two pipes are transported in roles to the field and put in place during installation using a specially developed extension on the trench box of the trencher. Another special punching device has been developed that is also mounted on the trench box to perforate the inner pipes during installation to ensure that the holes are in the correct position.

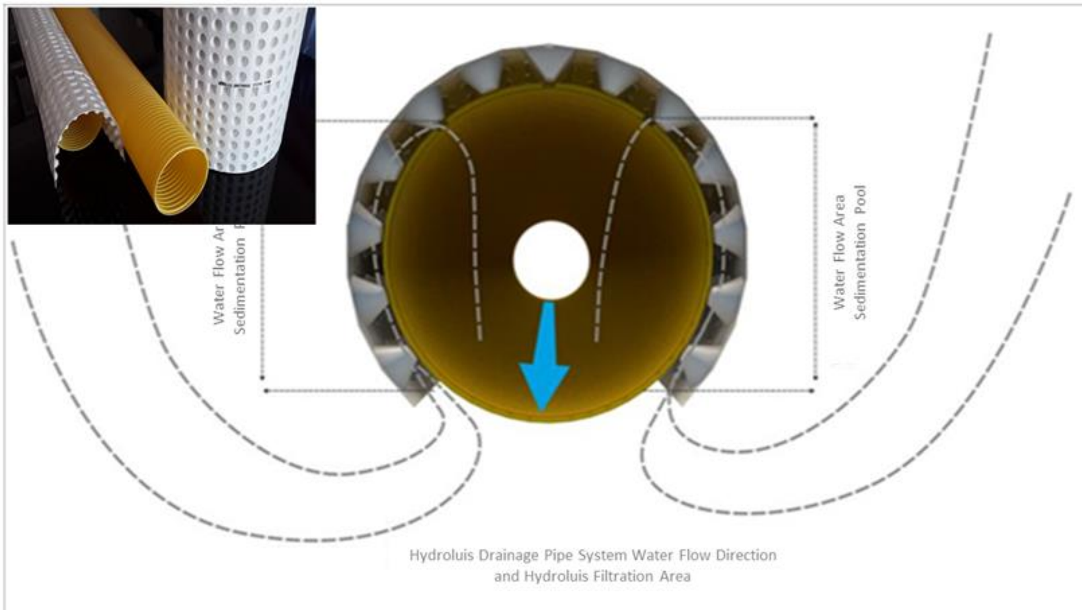

Figure 1. Hydroluis® pipe-envelope combination and working principle

The concept is based on the assumption that about 70% of water entering the drain pipes takes place with radial flow from underneath the pipes (Cavelaars et al., 2006). In a 'traditional' drain envelope system, water velocity increases when the water flows toward the perforations, increasing the risk of soil particle movement that results in either clogging of the envelope or sediment entering the pipe. In irrigated agriculture, this is particularly risky after irrigation when the water table rises well above drain level and consequently increases the hydraulic head. In the new concept, the velocity of the water decreases when it flows upward between the two pipes, significantly reducing the movement of the soil particles and thus the risk that these particles enter the inner drain pipe. The lighter and smaller particles that will stay in suspension during this upward movement, will stay in suspension when they enter the inner pipe eliminating or minimizing clogging and sedimentation.

A second problem for subsurface drains in irrigated agricultural lands is that root penetration is a major risk when the water table falls below drain level, because of the favourable humid conditions in the drain pipe (air & water). In the new concept, root penetration will be eliminated as the space between the inner and outer pipe is either saturated (when the water table is above drain level) or filled with air (when the water table is below drain level). Both conditions prevent root penetration. The objective of this study was to test the new concept under field conditions.

Materials and methods

The field study was conducted at the GAPTAEM research station (50 ha) near Harran (36º 56’44 N, 38º 54’44 E), located in south eastern Turkey 30 km south of city of Şanliurfa, at an altitude of about 400 m (Figure 2). The area is representative for the Şanliurfa Harran Plain, an area of about 150 000 ha that is already under irrigation. Water is mainly supplied from the Atatürk Dam with two tunnels (General Directorate of State Hydraulic Works, 2003).

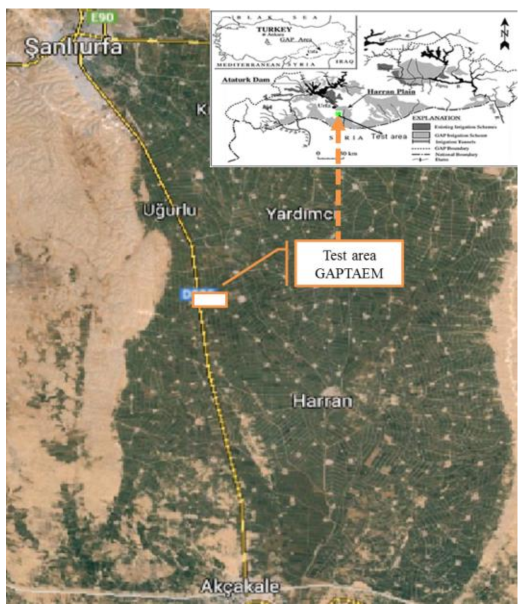

Figure 2. Location of Harran pilot area

The climate in the Harran Plain is arid, hot in summer and cold and rainy in winter (Table 1). The average annual precipitation is 365 mm, the average temperature 17°C and open water surface evaporation 1849 mm. The distribution of the precipitation over the seasons is 56% in winter, 30% in spring, 1% in summer and 13% in autumn. The average number of rainy days is 70 and number of days covered with snow is 3.

Table 1. Meteorological data in the Harran plan (monthly averages).

	Precipitation (mm)	Temperature (°C)	Relative Humidity (%)	Evaporation (Class A - pan) (mm)	Wind speed (m/s)
Jan	66	5	69	-	1.6
Feb	63	6	64	-	1.7
Mar	60	10	58	52	1.6
Apr	27	15	58	117	1.6
May	23	22	42	199	1.9
Jun	4	28	33	315	2.4
Jul	0	31	34	376	2.3
Aug	0	30	40	338	1.9
Sep	1	25	38	250	1.5
Oct	20	18	45	152	1.0
Nov	42	10	60	51	0.9
Dec	61	6	72	-	1.2
Year	365	17	51	1849	1.6

The pilot area has a flat topography and deep alluvial soil profile with A and C horizons (Table 2). Soil texture is clayey with a clay content of more than 50–60%, the lime content is about 30% and the soil pH between 7.1–8.0. Soil samples were collected from different soil layers and their respective total porosity and effective porosity were determined in the laboratory by standard procedures (Braun and Kruijne, 2006).

Table 2. Soil properties in Harran Pilot Area

Treatment	Depth (cm)	Sat. Cap. (%)	Texture (%) Sand	Clay	Silt	Class	pH	EC_e dS/m	Lime (%)
Control (no envelope)	0-30	78	24	56	20	Clay	7.6	0.7	30
	30-60	74	24	58	18	Clay	7.7	0.9	30
	60-90	70	22	58	20	Clay	7.8	1.2	30
	90-120	74	22	58	20	Clay	7.7	1.2	30
	120-150	68	32	44	24	Clay	7.8	0.9	30
	150-180	74	26	48	26	Clay	7.8	0.8	30
	180-210	77	24	54	22	Clay	7.8	0.7	30
Geotextile	0-30	71	24	66	20	Clay	7.6	0.8	31
	30-60	70	24	56	20	Clay	7.7	1.1	29
	60-90	71	20	58	22	Clay	7.7	1.4	30
	90-120	73	20	60	20	Clay	7.6	1.7	30
	120-150	74	22	58	20	Clay	7.6	1.6	32
	150-180	83	22	56	22	Clay	7.8	1.0	32
	180-210	79	22	58	20	Clay	7.9	0.8	29
Gravel	0-30	70	22	56	22	Clay	7.6	0.8	30
	30-60	71	24	56	20	Clay	7.7	0.9	29
	60-90	69	24	56	20	Clay	7.7	1.0	29
	90-120	70	22	58	20	Clay	7.7	1.0	35
	120-150	69	26	54	20	Clay	7.6	1.1	42
	150-180	74	24	56	20	Clay	7.7	0.9	43
	180-210	75	20	60	20	Clay	7.5	0.9	43
Hydroluis	0-30	72	22	60	18	Clay	7.7	0.9	30
	30-60	70	20	58	22	Clay	7.6	0.9	31
	60-90	70	20	60	20	Clay	7.6	0.9	32
	90-120	71	22	60	18	Clay	7.7	0.9	33
	120-150	72	18	60	22	Clay	7.6	1.0	35
	150-180	73	20	62	18	Clay	7.6	1.0	33
	180-210	78	22	56	22	Clay	7.6	0.8	44

Experimental site layout

In the test plot, plastic drain pipes were installed at an average depth of 1.50 m, with a 0.1% slope, with a length of 200-250 m and 25-60 m spacing. Four combinations were tested:

1) Sand-gravel filter envelope around the drain pipe
2) Pre-wrapped geotextile
3) Hydroluis® pipe-envelope combination
4) No envelope material (control)

For each combination, three field drains were connected to a collector drain through a manhole (Figure 3). Hydraulic heads were measured in three rows of observations wells: midway between the drains, adjacent to the drain pipe just outside the drain trench and inside the drain pipe (Figure 3 & 4). The head differences were used to assess the entrance resistances for the four drain/envelope combinations based on the classification proposed by (Cavelaars et al., 2006) (Table 3). Measurements were repeated 3-4 times a day to obtain data for different hydraulic heads. Water samples of the drain outflow were collected for pH, EC and silt-load analyses. The monitoring programme started in 2015, but only a limited number of data could be collected, thus the monitoring programme was repeated in 2016. At the end of each season, root growth was manually checked using a video system.

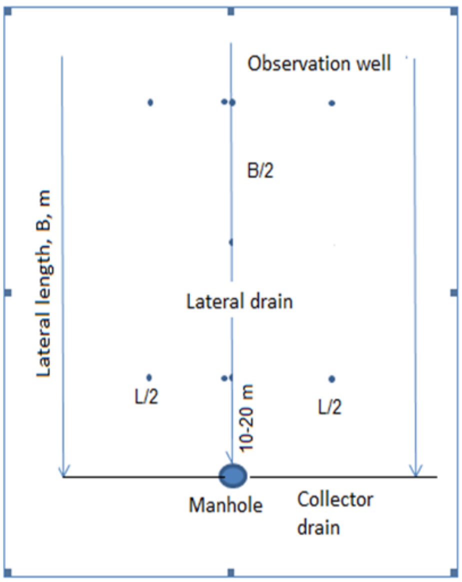

Figure 3. Measurement and observation network: each combination consists of three field drains connected to a collector drain through a manhole.

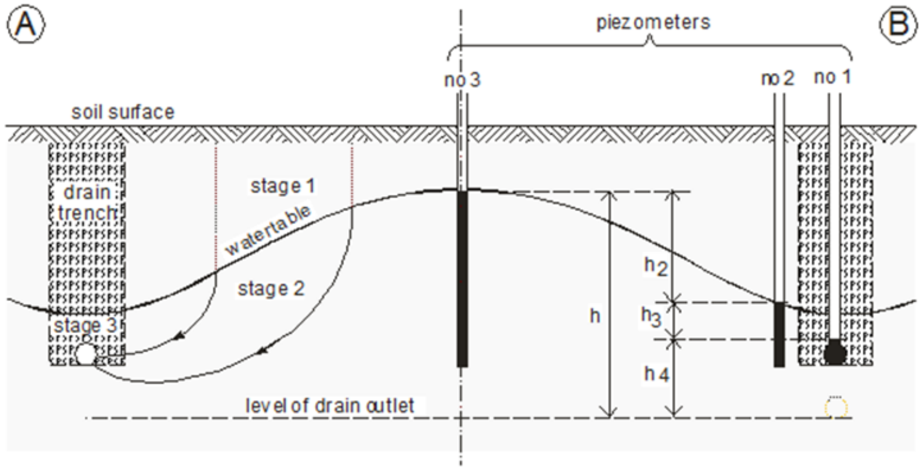

Figure 4. Principle of drainage testing: (A) Four stages of water flow towards and inside the drains; (B) Head losses in the four stages (Cavelaars et al., 2006).

Table 3. Drain performance criteria for different drain envelope combinations (Cavelaars et al., 2006)

$h_3/(h_2+h_3)$	Entre resistance	Drain performance
< 0.2-0.3	normal	good
0.3 – 0.6	high	moderate to poor
> 0.6	excessive	very poor

Results and discussion

The results of the monitoring programme in 2015 are presented in Table 4. The drain performance of the Hydroluis® pipe-envelope combination and the gravel envelope was good, but the performance of the geotextile was moderate to poor. The entrance resistance in the control plot was not measured, thus the drain performance could not be established. The sediment load was measure in all four combinations. The control plot had the highest sediment load (46 g m^{-3}), the sediment load in the drains with geotextile was 24% lower (35 g m^{-3}), the Hydroluis® combination had about the same reduction 26% (34 g m^{-3}), but the sediment load of the gravel envelope (26 g m^{-3}) was with 43% significant lower.

Table 4. Drain performance values for different drain envelope combinations (2015)

Envelope pipe combination	$h_3/(h_2+h_3)$ (-)	Drain performance	pH	EC (dS m^{-1})	Silt (g m^{-3})
Gravel	0.25	Good	7.2	0.96	26
Geotextile	0.38	Moderate to poor	7.5	0.99	35
Hydroluis®)	0.28	Good	7.0	0.97	34
Control	-	-	7.2	1.03	46

There is no significant difference between pH and EC values of drainage discharges and the siltation values are not high when they are evaluated in terms of irrigation water.

The results of the monitoring programme conducted in 2016 are presented in Table 5 to 8 for respectively the Hydroluis® pipe-envelop system, the gravel envelope, the geotextile and the control plot.

Table 5. Groundwater levels, hydraulic heads and entrance resistance for the Hydroluis® pipe-envelope system in 2016

No.	h (cm)	h_2 (cm)	h_3 (cm)	h_{pipe} ($h-h_2-h_3$) (cm)	h_{trench} ($h-h_2$) (cm)	Entrance Resistance $h_3/(h_2+h_3)$ (-)
1	16.0	12.7	1.7	1.6	3.3	0.12
2	15.7	12.6	1.6	1.5	3.1	0.11
3	15.2	12.6	1.2	1.4	2.6	0.09
4	16.0	12.7	1.7	1.6	3.3	0.12
5	15.7	12.6	1.6	1.5	3.1	0.11
6	15.5	12.7	1.2	1.6	2.8	0.09
7	15.2	12.6	1.2	1.4	2.6	0.09
8	15.2	12.8	1.1	1.4	2.5	0.08
9	14.9	12.9	0.6	1.4	2.0	0.05
10	14.7	12.7	0.6	1.3	1.9	0.04
11	14.7	12.7	0.6	1.3	1.9	0.04
12	14.3	12.2	0.7	1.4	2.1	0.06
13	14.2	12.3	0.5	1.4	1.9	0.04
14	14.2	12.3	0.5	1.4	1.9	0.04
15	14.2	12.3	0.5	1.4	1.9	0.04
16	14.3	12.2	0.7	1.4	2.1	0.05
17	14.3	12.2	0.7	1.4	2.1	0.05
18	14.1	11.9	0.7	1.4	2.1	0.06
Average	14.9	12.5	1.0	1.4	2.4	0.07
St. Dev.						0.03

In the plot equipped with the Hydroluis® pipe-envelope system the average drain discharge was 0.062 l/s or 2 mm/day. This value is lower than the design drainage coefficient used in the project. The average hydraulic head midway between the drains was 14.9 cm, the head just outside the drain trench (h_{trench}) was 2.4 cm and the head just outside the pipe 1.4 cm (Figure 5). Based on the criteria presented in Table 3, the entrance resistance, with an average of 0.07 and a standard deviation of 0.03, can be classified as "normal" and the drain performance as "good".

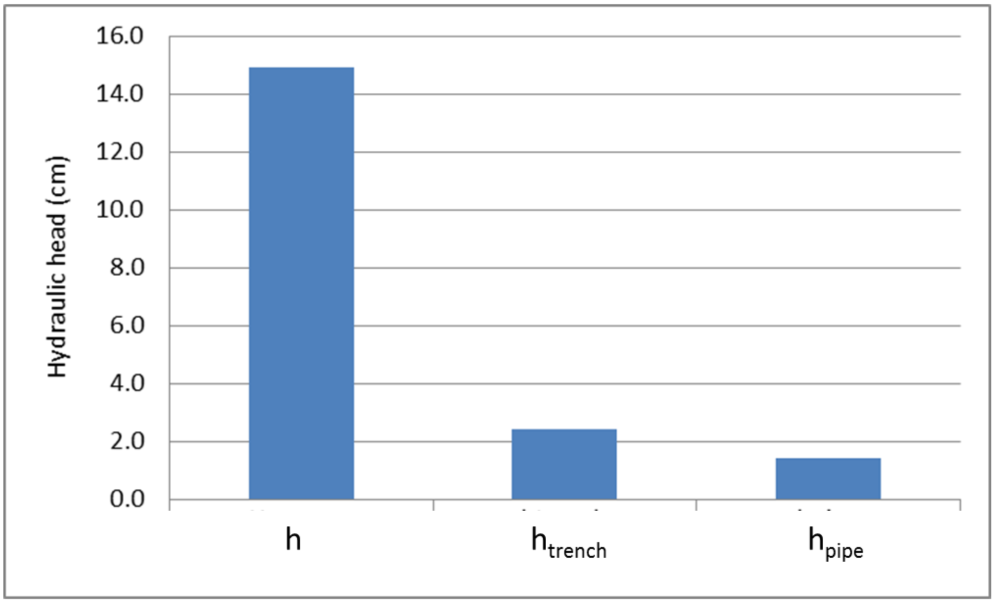

Figure 5. Average hydraulic head in the Hydroluis® pipe-envelope system

Table 6. Groundwater levels, hydraulic heads and entrance resistance for the sand gravel envelope in 2016

No.	h (cm)	h_2 (cm)	h_3 (cm)	Entrance resistance $h_3/(h_2+h_3)$ (-)
1	17.7	8.4	4.4	0.34
2	13.7	9.4	6.4	0.41
3	11.7	8.4	4.4	0.34
4	12.2	7.4	5.9	0.44
Average	13.8	8.4	5.3	0.38
St. Dev.				0.04

The entrance resistance of the gravel envelope, with an average of 0.38 and a standard deviation of 0.04, can be classified as "high" and the drain performance as "moderate".

Table 7. Groundwater levels, hydraulic heads and entrance resistance for the geotextile envelopes in 2016

No.	h (cm)	h_2 (cm)	h_3 (cm)	Entrance Resistance $h_3/(h_2+h_3)$ (-)
1	19.8	9.3	5.9	0.39
1	8.6	3.6	7.0	0.66
2	8.0	4.0	6.0	0.60
3	7.1	7.1	4.0	0.36
6	17.3	4.4	13.0	0.75
7	8.1	3.8	6.5	0.63
8	13.8	3.4	11.0	0.76
9	9.6	2.6	6.5	0.71
10	8.6	3.1	5.0	0.61
11	8.6	3.6	7.0	0.66
Average				0.61
St. Dev.				0.14

The entrance resistance of the geotextile was significantly higher and with an average of 0.61 and a standard deviation of 0.14 can be classified as "excessive", subsequently the drain performance is "very poor".

Table 8. Groundwater levels, hydraulic heads and entrance resistance for pipes without envelopes (control plot) in 2016

No.	h (cm)	h_2 (cm)	h_3 (cm)	Entrance resistance $h_3/(h_2+h_3)$ (-)
1	8.5	2.0	2.0	0.49
2	12.2	-0.2	9.0	1.03
3	25.0	26.5	19.5	0.42
4	8.0	25.0	14.0	0.36
5	5.2	23.8	12.5	0.34
6	4.0	23.5	11.5	0.33
Average				0.49
St. Dev				0.27

In the control plot, the average entrance resistance was 0.49 and can thus be classified as "high" and the drain performance as "moderate to poor".

When we compare the four drain-envelope combination for both years, we can concluded the Hydroluis® drain-envelope combination had a normal entrance resistance and a good drain performance (Table 9). The gravel envelope scored second with a normal entrance resistance and moderate to good drain performance. Both performed much better than the geotextile and the drain without envelope in the control plot. The performance of the geotextile envelopes in 2016 was significantly poorer compared to 2015, suggesting a clogging problem of the envelope.

Table 9. Classification of the entrance resistance and drain performance for the four drain-envelope combinations

Pipe - Envelope combination	2015			2016		
	$h_3/(h_2+h_3)$	Entrance resistance	Drain performance	$h_3/(h_2+h_3)$	Entrance resistance	Drain performance
Gravel	0.25	normal	good	0.38	normal	moderate
Geotextile	0.38	normal	moderate	0.64	high	very poor
Hydroluis®	0.28	normal	good	0.07	normal	good
Control	-		-	0.49	high	moderate to poor

The silt content was only measured in the plots with the Hydroluis® pipe-envelope system and the gravel envelopes (Table 10). In both plots the silt load of the drainage water is low and it will not create a risk of clogging the pipelines.

Table 10. Electric Conductivity (EC), pH and sediment load of the drainage effluents for the drains with Hydroluis® and geotextile in 2016

No.	Solid matter (%)	EC (dS/m)
Hydroluis:		
1	0.07	0.78
2	0.07	0.78
3	0.07	0.78
4	0.06	0.79
Average	0.07	0.79
Geotextile:		
1	0.07	1.01
2	0.07	1.00
3	0.08	0.95
4	0.07	1.03
Average	0.07	1.00

On 14 June, 2016 a visual inspection of the four drain-envelope combinations was done using a video camera (Figure 6). The drain pipes were also excavated for a visual inspection of root growth (Figure 7). Although root growth was limited, probable because the crops were still in their initial stage of development, it is clearly visible that the Hydroluis® combination didn't have any sedimentation inside the pipe nor any signs of root growth.

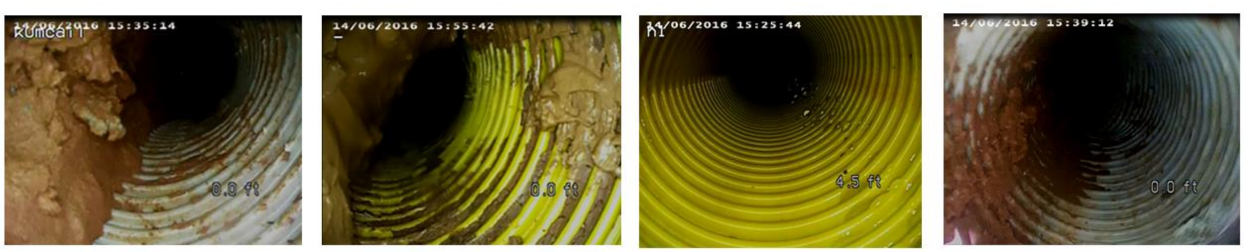

Figure 6. Visual inspection of the four drain-envelope combinations: from left to right: gravel – geotextile - Hydroluis® combination - control. (Note: vertical orientation of the photos is not correct because of the moving camera).

Figure 7. Visual inspection for root growth after excavation of the drain pipes with a geotextile (left), no envelope (middle) and Hydroluis® combination (right).

Conclusion

Three drain-envelope combinations of subsurface drainage systems were tested in a field plot and compared to a control plot with no envelope. Based on the two-year monitoring programme, it can be concluded that the Hydroluis® drain-envelope combination performed good with a normal entrance resistance and a good drain performance. The gravel envelope scored second with a normal entrance resistance and moderate to good drain performance. Both performed much better than the drains with a geotextile envelope and the drain without envelope in the control plot. The performance of the geotextile envelopes was significantly poorer in 2016 compared to 2015, suggesting a clogging problem of the envelope as the sediment load in the drainage water was comparable to the sediment load of the drainage water from the Hydroluis® plot. Another advantage of the Hydroluis® pipe envelope combination is that no sign of penetration of plant roots into the pipe were visible. Furthermore, the Hydroluis® pipe envelope combination has features that prevent or reduce deformation of the pipes by providing mechanical support through the egg-box profile of the outer pipe. The production costs are comparable to the cost of a pre-wrapped synthetic envelope (personal communication, PipeLife Nederland, 24-08-2016) and transportation and installation costs are lower than for a gravel envelope. Although the new concept looks promising, it is recommended to do more research to verify the long-term resistance to root growth and the performance under other soil, hydrological and agricultural conditions.

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