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Influence of spontaneous vegetation in stormwater infiltration system clogging

Carolina Gonzalez-Merchan, Sylvie Barraud,
Jean-Philippe Bedell

Abstract The paper presents the role of spontaneous vegetation on the hydraulic performance of an infiltration basin. The objective of the research was more particularly to study this role of different types of spontaneous vegetation found in situ in an infiltration basin near Lyon. The saturated hydraulic conductivity of three areas covered by *Phalaris arundinacea*, *Polygonum mite*, *Rumex crispus* and similar non-vegetated zones was compared. Eight field campaigns were carried out from July 2010 to May 2011 in order to compare the performance of each type of vegetation and its evolution over time. The results suggest a positive impact of vegetation on hydraulic performance in particular in summer during the growth of the plants. The hydraulic conductivity in this period was twice to four times higher than in bare areas or in vegetated zones during the plant rest periods. Some species were also found more appropriate to limit clogging (*Phalaris arundinacea*) likely due to its specific structure and growth process.

Keywords Infiltration basin · Saturated hydraulic conductivity · Stormwater · Vegetation

Introduction

The hydrological and environmental balance of cities over time is affected by the fast urbanization rate, decreasing

pervious surfaces (Walsh et al., 2004; Wenger et al., 2009; Marsalek and Chocat, 2002). To counterbalance this urban evolution, alternative systems such as infiltration basins are often used to drain stormwater. These systems are thus implemented to restore a more natural hydrological regime, contribute to groundwater recharge (Lerner et al., 1990), maintain the soil humidity, limit peak flow and volumes in surface water bodies or sewer networks and reduce pollutant load to downstream water bodies (Geldof et al., 1994; Ellis, 2000; Li et al., 2009).

In Lyon (France), this practice has been implemented for decades in the form of infiltration basins. They are typically constructed in a very simple way (generally, soil excavations filled or not with specified filter media). They can also be designed as recreational areas and intentionally planted with vegetation.

However, the sediments due to solids contained in storm and runoff water tend to form a clogged layer (Baveye et al., 1998; Le Coustumer and Barraud, 2007; Emerson et al., 2010; Gilbert Jenkins et al., 2010), reducing their hydraulic performance. Because of their low frequency of maintenance and their frequent water supply, the infiltration systems can be spontaneously colonized by plants.

Some previous works regarding specific vegetation have already analyzed the influence of the type of vegetation on the permeability (Le Coustumer et al., 2009; Hatt et al., 2009; Virahsawmy et al., 2013). These works highlighted that (i) the vegetation could be very useful to maintain soil permeability and porosity if the type was well chosen and (ii) could control clogging evolution over time by creating macropores, whose efficiency depends on the vegetation type and soil. Another work (Gonzalez-Merchan et al., 2012), carried out on a large infiltration basin (Django Reinhardt, Lyon, France) continuously monitored during 6 years, has shown a clear limitation of clogging after the development of spontaneous vegetation. Considering the frequently wild vegetation growth on the

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infiltration systems, Saulais (2011) identified the main characteristics and species on six infiltration basins localized in Lyon region, France, and followed their evolution on the Django Reinhardt infiltration basin over 2 years. More recently, other infiltration basins have been studied and also showed spontaneous vegetation relating to sediment deposit and urban typology of land use (Bedell et al., 2013).

Even if the preliminary studies on the specific vegetation allowed improving knowledge of the vegetation influence on the hydraulic performance, the role of spontaneous vegetation has not been addressed in detail until now.

The aim of this paper is focused on (i) the comparison of the role of different types of spontaneous vegetation found in a basin regarding the saturated hydraulic conductivity, (ii) the study of the difference between the performance of vegetated and non-vegetated areas placed in the same conditions and (iii) the analysis of the evolution of vegetation performance considering its life cycle (i.e. rest and growth periods of plants).

The role of spontaneous vegetation on the clogging evolution was then conducted in situ and consisted to study the main characteristics of the media in which vegetation takes place in different points and at different periods together with the saturated hydraulic conductivity taken as a clogging indicator.

Methodology

Description of the experimental site

The infiltration basin monitored in this study is located at Chassieu, in the eastern suburbs of Lyon, France (Field Observatory on Urban Hydrology, www.othu.org). It is situated at the outlet of an urban and industrialized catchment of 185 ha, with a flat topography (mean slope 0.4 %) and an imperviousness coefficient of about 75 %. The total area of the basin is about 8,000 m² with a volume of 61,000 m³.

Before entering the infiltration basin, stormwater flows successively through a detention/retention basin whose area and volume are about 1 ha and 32,000 m³, respectively. The stormwater discharges into the infiltration basin via a pipe with a maximum flow rate of 350 L/s. Figure 1 shows the configuration of the retention and the infiltration basins.

The bottom of the basin was designed to be bare. The underground substratum of the infiltration basin is composed of quaternary fluvial and glacial deposits and the groundwater table is around 13 m below the bottom of the basin.

The basin has been functioning for more than 30 years. It has been rehabilitated in 2002 and totally scrapped in April 2004 (sediments and the topsoil completely removed). The detention compartment was also scrapped but in 2006.

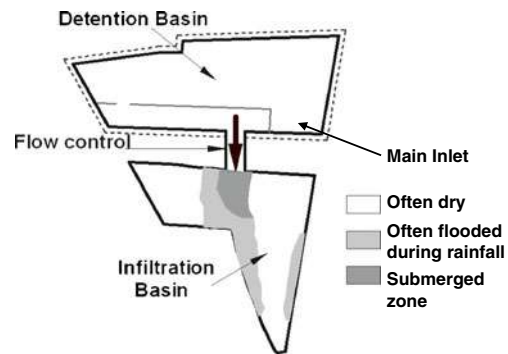


Fig. 1 Configuration of Django Reinhardt experimental site

From the end of 2006 to the beginning of 2007, the basin has been progressively overgrown with spontaneous native vegetation currently found in wet areas, in particular, in the submerged and often flooded zones, as shown in Fig. 1.

Material and method

Eight field campaigns were carried out from July 2010 to May 2011.

According to a previous study (Gonzalez-Merchan and Barraud, 2011a), three specific areas, considered to be more clogged, were more particularly monitored. These areas were also chosen because they presented different types of vegetation with similar soil (media) conditions. They were situated in areas frequently flooded and presented a sediment layer higher than 5 cm with an important vegetation density (more than 50 % according to Saulais et al. (2011)). The vegetation tested was then *Phalaris arundinacea*, *Polygonum mite* and *Rumex crispus*, which are typical invasive species. Figure 2 shows the localisation of these areas and Table 1 the main characteristics of the plants.

In order to evaluate the specific role of vegetation for each area, the saturated hydraulic conductivity K_s was systematically measured in two points situated in a very close vicinity (one on a bare part and one on a vegetated one).

To characterize the media (soil + sediment brought by stormwater), the measurement of other parameters was also necessary such as grain size, sediment depth, organic, biomass or water content.

Infiltration tests

In all the areas, infiltration tests were performed using single ring infiltrometers (three replicates per measurement). The tests consisted of (i) pouring 8 to 15 equal water volumes successively into a cylinder sealed with bentonite to avoid lateral loss of water during the experiment and (ii) measuring the infiltration times of water. The experiment stopped when a steady state was reached. Due to local heterogeneity of the media, different cylinder diameters were selected according to

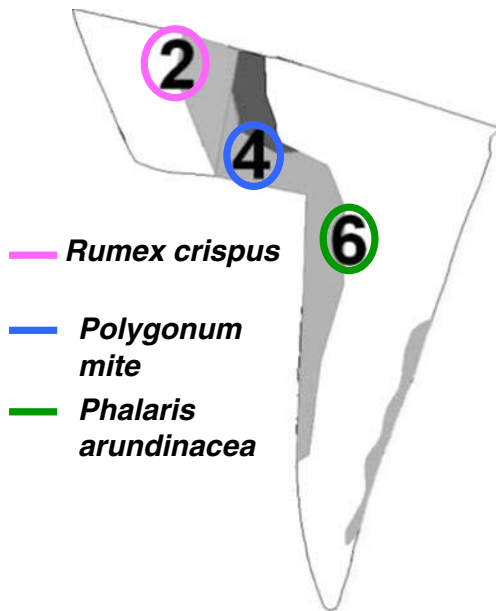


Fig. 2 Localisation of the three areas of measurement with their associated vegetation types (area 2: *Rumex crispus*; area 4: *Polygonum mite*; area 6: *Phalaris arundinacea*)

the grain size of each area. In our study, the cylinders used were 13.4 and 10.7 cm in diameter and 5 cm in height. The interpretation of the infiltration test was realized with the BEST method (Beerkan Estimation of Soil Transfer method) described in Braud et al. (2005) and Lassabatere et al. (2006). The results obtained for the saturated hydraulic conductivity K_s were corrected according to water temperature and normalized at 20 °C in order to compare all the results on a comparable basis (in particular to counterbalance the effect of water viscosity on the permeability of soil as shown in Jaynes (1990) and Emerson and Traver (2008)).

Table 1 Main characteristics of the spontaneous vegetation tested (Meyer et al., 2008)

Plants	Characteristics
<i>Phalaris arundinacea</i> (Area 6)	Reproduction by seed, by stem fragments, and by underground horizontal stems (rhizomes). The fine roots emerge from the stem. <i>Phalaris arundinacea</i> can grow on dry soils in upland habitats and in the partial shade of oak woodlands but does best on fertile, moist organic soils in full sun.
<i>Polygonum mite</i> (Area 4)	Reproduction by way of seeds. This plant presents a main taproot, with well-branched and complex root system. <i>Polygonum mite</i> grows under wet conditions. Its life cycle is short and the plant is not visible during winter
<i>Rumex crispus</i> (Area 2)	Reproduction by seed. The root is tubercular type and the stem is robust. Between the root and branch the sediments are accumulated in crown buds. <i>Rumex crispus</i> grows under wet and dry conditions. With bi-annual life cycle.

The infiltration test used for the vegetated areas was about the same. The cylinder was just put around the plant as indicated in Fig. 3.

Uncertainty of K_s measurements was assessed by a Monte Carlo procedure (ISO/IEC, 2008) applied to BEST method whose details can be found in Gonzalez-Merchan (2012).

Two stages of the life cycle of the plants were considered: (i) the growth and/or reproduction period basically occurring from March to October (i.e. spring, summer and the beginning autumn) and (ii) the “rest” period between November and February (i.e. the late autumn and winter).

Grain size distribution

Grain size distribution analysis was performed by laser diffraction particle size according to ISO 13320 (2009) (Malvern Mastersizer 2000G) on samples taken in each area. Due to the matter aggregation, the samples were submitted to ultrasounds during 10 min before the analysis (Badin et al., 2011). Previous experiences showed significant differences when this rule was not respected, with low stability due to aggregation (i.e. hydrophobia phenomena).

Organic matter content

Organic matter content was estimated by weighing soil samples before and after heating them at 450 °C, according to standards (AFNOR, 1998).

Biomass content

Biomass content (soil microbial biomass) was quantified on the basis of Ninhydrin-reactive-N determined by the fumigation extraction method (Amato and Ladd, 1988). Sediment samples were fumigated with ethanol-free chloroform during 10 days. Extraction with 2 M KCl was executed before and after fumigation. The dead organisms react with Ninhydrin (proteolysis process) and were thus determined by colorimetry. For the estimation of the biomass-C, Ninhydrin-N results were multiplied by a conversion factor of 21 as obtained in the calibration experiment of Joergensen and Mueller (1996).

Statistical analysis

The statistical comparison between different situations (e.g. difference between the hydraulic conductivity of vegetated and non-vegetated areas and evolution of the hydraulic conductivity over time) was carried out with the Wilcoxon test. In the framework of this study, we considered that the difference was significant when p -value < 0.05.



Fig. 3 Saturated hydraulic conductivity measurements for vegetated areas (here in area 4 with *Polygomon mite*)

Results

Topsoil (media) main characteristics

For the different areas studied here, the fluvio-glacial underlying soil was covered by a layer of sediments mainly due to solids brought by stormwater and to a lesser extent to vegetation degradation and external matters (Gonzalez-Merchan, 2012). For all the areas, a peaty aspect linked to low dry bulk densities ranging from 630 to 765 kg/m³ was observed (Gonzalez-Merchan and Barraud, 2011b).

The grain size characterization of the top layer prone to clogging showed a very fine aspect, D50 being less than 11 µm for all the campaigns and areas (see Tables 2, 3 and 4). The top layer was then mainly composed of silt, according to the USDA (1975) texture triangle with an organic content ranging from 17 to 36 %.

Comparison of bare and vegetated areas

The results of the comparison of all the bare and all the vegetated areas irrespective of the vegetation types are presented in Fig. 4a. The Wilcoxon test showed a significant difference between bare and vegetated surfaces at the 5 % level (p -value=0.016). The saturated hydraulic conductivity was then found higher for vegetated parts compared to bare ones.

Comparison of vegetation types

If vegetation is supposed to control clogging evolution over time by creating macropores, its efficiency depends on the vegetation type and soil (Hatt et al., 2009; Le Coustumer et al., 2009). The conditions of soil between the test areas being approximately equivalent in terms of organic matter, density bulk and grain size distribution (Tables 2, 3 and 4), the bare and vegetated surfaces were compared for the three plant types (*Phalaris arundinacea*, *Polygomon mite*, and *Rumex crispus*).

The results are given in Table 2 for *Phalaris arundinacea*, Table 3 for *Polygomon mite* and Table 4 for *Rumex crispus*.

Figure 4b compares the distribution of all K_s values obtained for each area with its vegetation type. The statistical difference between bare and vegetated soils was significant for *Phalaris arundinacea* (p -value=0.0236) but not for *Rumex crispus* (p -value=0.377) nor for *Polygomon mite* (p -value=0.426). With *Phalaris arundinacea*, the median saturated hydraulic conductivity increased by a factor of about 2.

The structure of the plant seems to be an important factor. Species such as *Phalaris arundinacea* turns out to be appropriate to limit clogging. Even if the roots are fine and finer than those of *Rumex crispus*, its growth mode by horizontal

Table 2 Bio-physico-chemical characteristics for area number 6 (partly covered by *Phalaris arundinacea*)

Date	$K_s \times 10^{-5}$ m/s 20 °C surface		Organic matter (%)	Biomass (µg C/g DW)	D50	Season [(CV-bare)-(CV-veg)]
	Bare	Vegetated				
July 10	4.54±0.44	9.92±0.59	24±0.94	3,321±112	8.7±1.3	Summer
Sept 10	3.26±1.67	12.0±2.84	33±2.76	4,490±1,501	7.9±1.1	[(23 %)-(14 %)]
Oct 10	0.96±0.17	6.13±0.58	36±0.91	1,902±636	5.7±0.8	Autumn
Nov 10	0.95±0.59	3.52±0.54	30±0.7	2,365±790	9.4±1.4	[(27 %)-(38 %)]
Jan 11	0.98±0.29	3.34±0.16	33±0.82	1,169±390	7.7±1.1	Winter
Feb 11	2.05±0.53	2.93±0.56	28±1.50	2,133±713	8.7±1.3	[(50 %)-(9 %)]
Apr 11	1.79±0.17	1.94±0.61	35±1.48	2,658±889	9.9±1.5	Spring
May 11	1.63±0.32	3.59±0.92	18±0.58	6,410±2,143	6.9±1.0	[(7 %)-(49 %)]
CVT	63 %	79 %				

CV-bare: coefficient of variation of K_s in the bare zones for a given season; CV-veg: coefficient of variation of K_s on the vegetated zones for a given season; CVT: global temporal coefficient of variation

Table 3 Bio-physico-chemical characteristics for area number 4 (partly covered by *Polygonum mite*)

Date	$K \times 10^{-5}$ (m/s)20 °C surface		Organic matter (%)	Biomass ($\mu\text{g/g}$ DW)	D50	Season [(CV-bare)-(CV-veg)]
	Bare	Vegetated				
July 10	1.61±0.71	2.5±0.62	36 ±3.9	1,642±507	9.22±1.67	Summer
Sept 10	2.71±0.83	11.6±3.20	29±0.50	1,703±526	8±1.19	[(35 %)-(91 %)]
Oct 10	3.35±0.42	4.96±1.50	33±5.91	872±269	9±1.57	Autumn
						–
Apr 11	2.62±0.80	0.85±0.23	32±6.93	2,386±737	8±1.80	Spring
May 11	0.71±0.31	1.37±0.37	26±1.74	4,704±1,452	7±1.17	[(77 %)-(33 %)]
CVT	62 %	95 %				

CV-bare: coefficient of variation of K_s in the bare zones for a given season; CV-veg: coefficient of variation of K_s on the vegetated zones for a given season; CVT: global temporal coefficient of variation

and underground stems could keep the soil more porous and permeable.

Life cycle analysis of plants

In a second step, the variation of infiltration capacity linked to seasonal and annual cycle of the plants was studied.

Evolution of the infiltration capacity in the area planted with Phalaris arundinacea

The K_s values measured for each campaign on the bare and vegetated surfaces regarding *Phalaris arundinacea* are shown in Fig. 5 and Table 2.

The evolution of bare surface was rather constant over the time (Wilcoxon test, p -value>0.05) whereas the results showed more important variations of vegetated surface regarding K_s values. The vegetated surface was systematically higher compared to the bare surface for every field campaign and every season (see Fig. 5).

The rest periods of the plant (January and February 2011) showed significant lower values of K_s according to Wilcoxon test (p -value=0.0409) compared to the period of growth (autumn and summer). In this period of growth, K_s value was from twice to four times higher than in winter.

During the rest period of the plant, the infiltration capacity of vegetated surface remained very close to values obtained on bare surfaces. During summer, the stems and root present a development and an extension through the sediments, probably allowing the creation of the preferential flows that could explain the improvement of the infiltration capacity.

Evolution of the infiltration capacity in the area covered with Polygonum mite

The K_s values measured for each campaign on the bare and vegetated surfaces regarding *Polygonum mite* are shown in Fig. 5, with Table 3 presenting the bio-physico-chemical characteristics in the area 4. In winter, no measurements were done for this area. During this period, *Polygonum mite* did not

Table 4 Bio-physico-chemical characteristics for area number 2 (partly covered by *Rumex crispus*)

Date	$K_s \times 10^{-5}$ (m/s)20 °C surface		Organic matter (%)	Biomass ($\mu\text{g C/g}$ DW)	D50	Season [(CV-bare)-(CV-veg)]
	Bare	Vegetated				
July 10	2.43±0.25	3.78±0.66	17±0.65	334±123	8.4±1.27	Summer
Sept 10	6.10±2.09	12.8±0.66	25±0.80	1,052±387	7.9 ±1.19	[(61 %)-(77 %)]
Oct 10	4.68±1.15	6.01±1.55	30±2.64	1,534±563	7.8±1.17	Autumn
Nov 10	0.95±0.33	2.43±0.15	33±0.60	358±132	7.1±1.07	[(94 %)-(60 %)]
Jan 11	3.18±0.48	0.62±0.27	30±1.04	1,421±522	8.8±1.33	Winter
Feb 11	1.44±0.39	2.66±1.25	22±0.90	805±296	10.6±1.59	[(53 %)-(88 %)]
Apr 11	4.16±1.71	5.11±0.90	33±0.93	2,459±903	10.6±1.60	Spring
May 11	3.57±1.09	10.5±2.00	24±0.74	3,600±1,322	7.8±1.17	[(11 %)-(49 %)]
CVT	51 %	76 %				

CV-bare: coefficient of variation of K_s in the bare zones for a given season; CV-veg: coefficient of variation of K_s on the vegetated zones for a given season; CVT: global temporal coefficient of variation

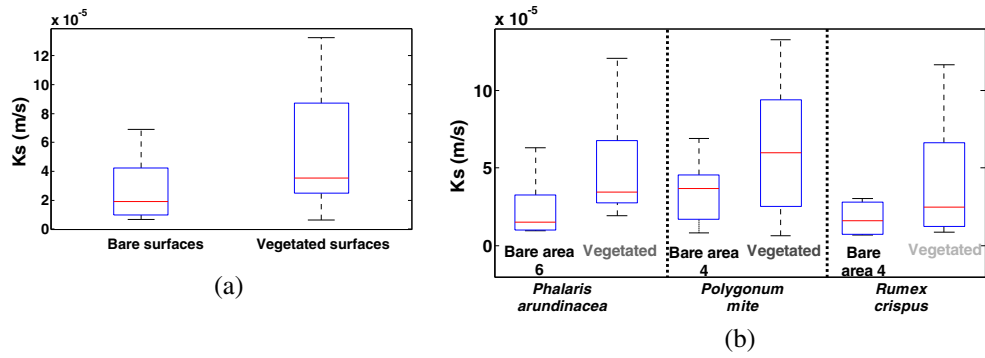


Fig. 4 (a) Boxplots of the distribution of saturated hydraulic conductivity on bare and vegetated surface irrespective of the vegetation types. (b) Boxplots of the distribution of saturated hydraulic conductivity for the

three different plants and comparison with bare surfaces. For the boxplot, the *central box* represents the values from the lower to upper quartile (25 to 75 percentile). The *middle line* represents the median

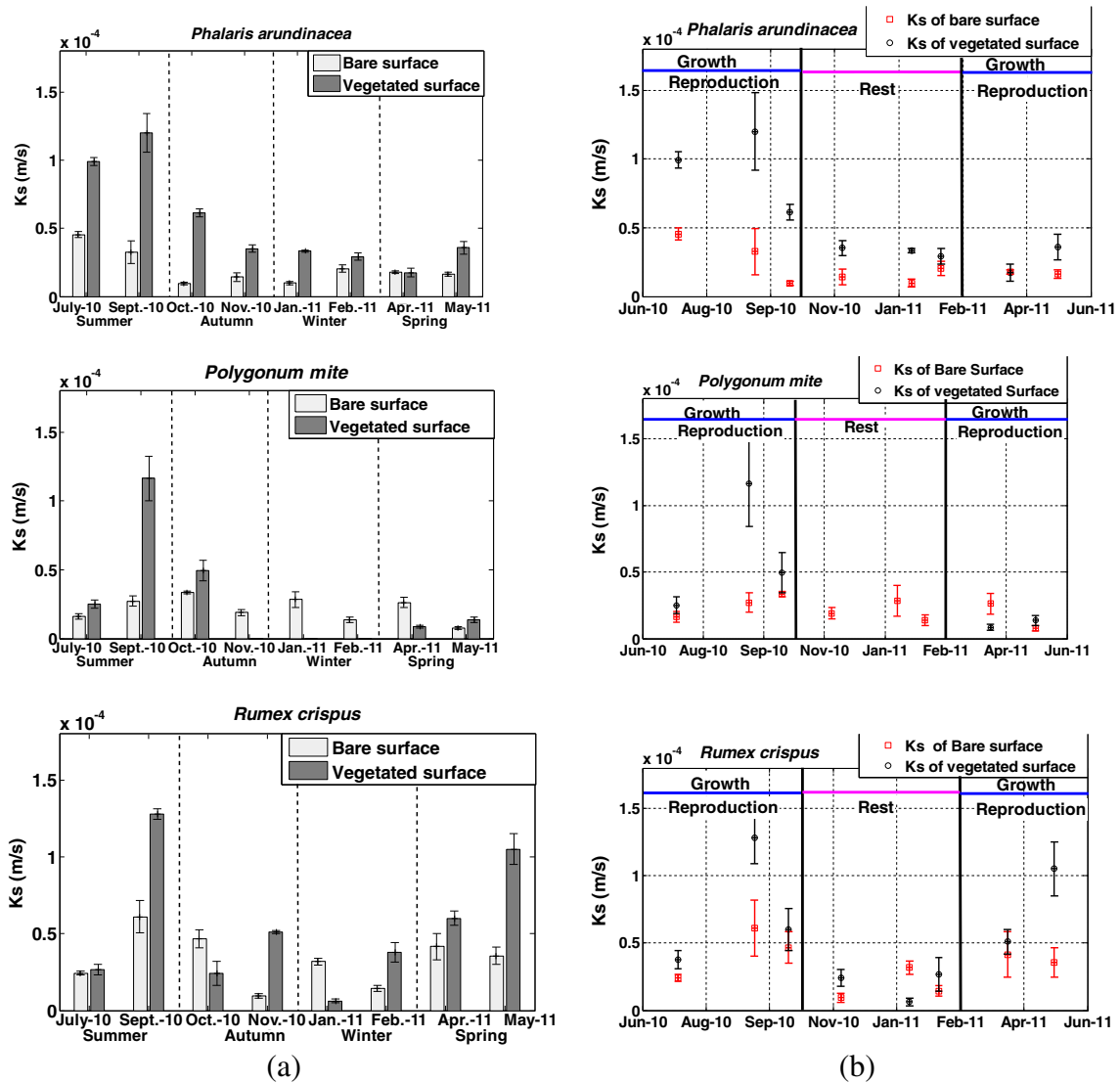


Fig. 5 K_s values of the bare and vegetated surfaces with their uncertainties: (a) according to seasons and (b) according to growth and rest periods of the plant life cycle

present any aerial parts. As the plant was not visible, it was impossible to perform infiltration tests.

Once again, the evolution of the infiltration capacity of bare surface remained approximately constant over the time compared to the vegetated surface that showed an important temporal variation with a more significant variation in summer (temporal coefficient of variation reaching 91 %).

K_s values decreased significantly during spring period, (Wilcoxon test, p -value=0.044). The K_s values on the vegetated surface in the summer season were about three times higher than those on the bare surface. So, like for *Phalaris arundinacea*, *Polygonum mite* showed a significant difference compared to bare surface in summer.

Evolution of the infiltration capacity in the area covered with *Rumex crispus*

The K_s values measured for each campaign on the bare and vegetated surfaces regarding *Rumex crispus* are shown in Fig. 5 and Table 4.

Infiltration capacity of the bare part was a little more fluctuant than in the other areas. The fluctuation on the vegetated surface were significant over the time (Wilcoxon test, p -value=0.0409). A clear decrease in hydraulic conductivity in winter was observed. It reached values in the range of K_s values of bare surfaces. During summer and spring seasons (i.e. growth and reproduction period), the K_s values were significantly different and about twice to four times higher than those of bare surface or vegetated area in winter condition.

Discussion

Hydraulic performance of infiltration systems appears to be influenced by the growth of spontaneous vegetation. These results suggest a positive effect of vegetation on infiltration capacity of the topsoil composed of sediments accumulated on the surface of the infiltration system generally forming a clogged layer.

Whatever the zone of the basin, K_s values of bare parts showed very low fluctuations compared to vegetated parts. All over the measurement periods, the clogging of bare surfaces was not so notable. However, the higher values were found in summer. This could be explained by the creation of cracks linked to temperature conditions as observed on site during this period.

K_s values of vegetated areas were significantly higher than those of the bare surfaces but not for all the campaigns. All the plants studied showed high values during their growth and/or reproduction periods (from twice to four times higher than in the rest period or than values obtained on bare surfaces).

The metabolism of plant and sessional rhythm due to variation of temperature, luminosity or resources available in the soil are closely linked. During reproduction and growth

period of the vegetation, the plant roots present an elongation of stem and roots. This phenomenon can create preferential flows through the top and underlying soil of the infiltration systems, improving its infiltration capacity. The temperature also contributes to produce macropores of the media as observed on bare surface.

In the same way, biomass content showed important values in this period (see Tables 2, 3 and 4) that could favor bioturbation of the media (Nogaro and Mermillod-Blondin, 2009). Microbiological activity is also known to develop with high temperature in natural ecosystems (Pichan and Okelly, 2012).

This study confirms the influence of summer condition on infiltration capacity already exhibited in different situations (e.g. Cerda 1996, 1997).

During the rest period of the plants, the root growth stops and leaves fall down. The plant transformation contributes to increase the content of organic matter (see Tables 2, 3 and 4) that could also explain the low hydraulic performance.

Lastly, the vegetation type seems to play a role in clogging limitation. *Phalaris arundinacea* was found to be the most efficient and *Rumex crispus* the less one. As already discussed, the stems and roots of *Phalaris arundinacea* presented a development and an extension through the sediments favoring the creation of the preferential flows. On the contrary, *Rumex crispus* seemed to accumulate sediments in crown buds between its roots and branches forming a sort of impervious buffer favoring clogging.

Conclusions

The results suggest a positive impact of vegetation regarding hydraulic performance of infiltration basin. Even if these observations were done in previous works, considering plants of specific types, the present study assessed the efficiency of spontaneous vegetation.

The role of wild vegetation was examined by comparing the saturated hydraulic conductivity of bare and vegetated parts situated in the close vicinity and its evolution over time.

The study showed the following:

- (i) The vegetated areas were globally less clogged than bare surfaces in particular in summer.
- (ii) Some species were more appropriate to limit clogging. It is the case of *Phalaris arundinacea* that presents a particular root system development (by stem fragments and underground horizontal stems). The monitoring of vegetated surface allowed suggestion that during summer periods the roots growth and soil conditions improve infiltration capacity of the media composed of sediments accumulated in the system. The hydraulic conductivity was thus twice to four times higher than in bare or in vegetated parts during rest periods of plants.

The results also allowed suggestion that the infiltration system management should strive for the right balance between the benefits that vegetation can bring and the efforts needed to maintain the system in particular during “rest” periods of plants in winter.

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