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Potentiel des arbres de pluie dans la gestion du ruissellement urbain : bilan global d’un dispositif expérimental au sein de la mini ville SenseCity

Hayath ZIME YERIMA[1*] Martin SEIDL[1], Abdelkader BENSAOUD[2], Emmanuel BERTHIER[3] et Marie-Christine GROMAIRE[1].

[1] Leesu, Ecole des Ponts, Université Paris Est Creteil, F 77455 Marne-la-Vallee, France.
*Auteur correspondant : hayath.zime-yerima@enpc.fr
[2]Bureau d’études Hydrasol, 39 avenue du Général Leclerc, 92350 Le Plessis Robinson
[3]Cerema, 12 Rue Léon Teisserenc de Bort, 78190 Trappes

ABSTRACT

The “stormwater tree” is presented as a solution to compensate for the strong waterproofing in urban areas, the effects of which will be exacerbated in the years to come by climate change. In order to optimize this technique and better understand how it works, a pilot device with maple balls was set up at the end of 2019 in the mini-city of Sense-City. On this device, the parameters measured concern the incoming and outgoing flows, the water content in the soil and the meteorological parameters. This communication deals with a 9-month period of data from March to November 2022. The results obtained indicate infiltration and transpiration rates on the device of 53% and 28% respectively. The exfiltration rate is more or less uniform over the different months compared to the incoming volume, which is not the case for transpiration, which varied according to the seasons. Our study is continuing in order to consolidate the first results obtained.

RÉSUMÉ

L’arbre de pluie se présente comme une solution pour compenser la forte imperméabilisation en milieu urbain dont les effets vont être exacerbés dans les années à venir par le changement climatique. Afin d’optimiser cette technique et de mieux comprendre son fonctionnement, un dispositif pilote avec des érables boule a été mis en place fin 2019 au sein de la mini ville de Sense-City. Sur ce dispositif les paramètres mesurés concernent les flux entrant et sortant, la teneur en eau dans le sol et les paramètres météorologiques. La présente communication traite une période de 9 mois de données allant de mars à novembre 2022. Les résultats obtenus indiquent des taux d’infiltration et de transpiration sur le dispositif de 53% et de 28% respectivement. La fraction du volume entrant qui est exfiltrée est relativement uniforme sur les différents mois, contrairement à la fraction transpirée qui varie fortement selon les saisons. Notre étude se poursuit afin de consolider les premiers résultats obtenus.

KEY WORDS

Urban runoff, tree, transpiration, infiltration, water balance, SUDS

INTRODUCTION

The increasing imperviousness of urban areas leads to an increase in runoff flow rates and a reduction in groundwater recharge. These effects are reinforced by climate change with rising temperatures, changing precipitation patterns and extreme weather events. In order to mitigate, nature-based solutions are increasingly being incorporated into new development plans such as compensatory stormwater management techniques (McClymont et al. 2020). In the case of a stormwater tree, this concept consist of a street tree, gravity fed by runoff from the adjacent roadway, where the rainwater infiltrates into the tree pit and then is returned to the subsoil, or to the sewer, or to the atmosphere through evapotranspiration (EPA 2012).The stormwater tree can thus be a tool for sustainable stormwater management by promoting retention, evapotranspiration and infiltration process while contributing to better tree growth, local runoff cleanup (Vaz Monteiro, Levanič, et Doick 2017). This paper focuses on the hydrological performance evaluation of the SenseCity experimental stormwater tree device designed for stormwater management of a roadway. The aim is to present the first results demonstrating its capacity to slow down and reduce the incoming flows as well the monthly evolution of its water balance.

1 MATERIALS ET METHODS

A pilot (Figure 1) consisting of 3 street trees (*Acer globosum*, 3.5 m canopy and 7 cm trunk diameter), collecting the runoff from a 88 m² portion of roadway was implemented within the experimental area of Sense-City (IFSTTAR 2019; Seidl et al. 2020) in Paris conurbation. The runoff is conveyed by gravity to the drain at the lowest point of the roadway before being redistributed to 1.6m diameter reservoirs at the foot of each tree. The tree pit consists of 2 layers, a 20 cm layer of Rainclean® substrate allowing both depollution and temporary runoff storage before infiltration into a 60 cm layer of topsoil. The incoming volume passes through the different layers before being exfiltrated into a subjacent underdrain at a depth of 80 cm and the underlying natural soil. An overflow placed on the opposite site of the inlet, at the surface of the Rainclean® layer, drains excess inflow into a stormwater collector.

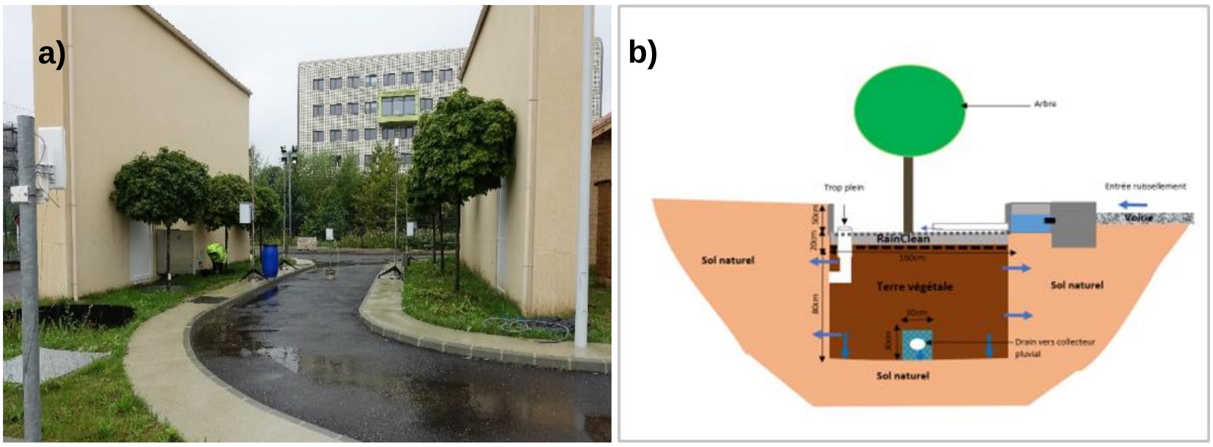

Figure 1 : a) North-south view of canyon street, with rain trees on the left and reference trees on the right; b) SenseCity rain tree configuration

Numerous sensors are used to measure the water flows and stocks in the different compartments of the system. Inflow runoff volumes are measured by 25mm and 50mm diameter electromagnetic flowmeters (Optiflux Krohne), mounted in parallel in order to measure a wide range of flow rates. The underdrain outflow is measured by a 2x1litre tipping bucket (Précis Mécanique) and soil water content is measured by TDR probes (Soilvue Campbell) placed at the tree foot, at depths of 5,10, 20, 30, 40 and 50 cm. The tree sap flow of each tree is measured by a heat dissipation sensor (Implex Edaphic) at 1m above the ground. Water content and sap flow are recorded at 15-minute time steps, while inflows are measured every minute. In addition, meteorological parameters are monitored at 8 meters height (Vaisala), while the precipitation is also recorded in the middle of the road at 1m height.

To evaluate the hydrological and hydraulic performance of the stormwater tree , we use indicators from the Methodological guide for the evaluation of the performance of stormwater source control structures (Flanagan et al. 2022) such as the event volume reduction (Vev is the difference between rain high and the ratio of outflow by watershed surface) , the reaction time (Tr time between start of inflow and start of outflow) or the emptying time (Tv is time between the end of rain and the end of outflow.The data used concerns the period from March to November 2022.

To establish a water balance on the system presented in Figure 1(b) a planting pit of 1.6m diameter was considered, limited by natural clay soil. The water balance was established by the following relationship:

$$\text{Initial stock} + \text{Incoming volume} = \text{End stock} + \text{Sap flow} + \text{Exit volume drain} + \text{Exfiltration}$$

The soil stock is determined as the sum of the products of the depth and water content of the 5 layers mentioned before, based on homogeneity of the tree pit substrates. The lateral and vertical exfiltration flux to the natural surrounding soil is calculated as residual term.

2 PRELIMINARY RESULTS

2.1 Hydrological and hydraulic functioning

The town of Champs-sur-Marne where the experimental facility is located is characterized by interannual (1993 – 2020) average rainfall of 716 mm (Méteo France 2022). The total rainfall observed over the study period from March to November 2022 is 346 mm. The table below presents the hydrological performance indicators Vev, Tr and Tv at event scale for two rain events. Among the hundred events recorded, only about ten produced a flow at the outlet. We have taken the example of two events, the smallest (4.8mm, preceded by 5 days of rain) and the biggest (27.8mm, preceded by 6 days of dry period), in order to illustrate the impact of the rainfall on the performance of the device.

Table 1: Hydrological indicators: event volume reduction (Vev), reaction time (Tr) or emptying time (Tv) for 2 extreme events

Date of event	Rain High (mm)	Vev (mm)	Retention	*Tr* (h)	*Tv* (h)
08/04/2022	27.8	27.1	97.3%	0.28	89.6
30/09/2022	4.8	4.5	93.5%	2.53	2.92

The event volume reduction characterizes the capacity of the stormwater tree to limit the volume of runoff. It can be seen that this retention for the two selected events is higher than 90%, which illustrates the high capacity of the technique to reduce the volumes. Comparing these results with those of vegetated roofs, for example, the abatement of storm trees is much higher. Studies by (Ramier et al. 2018) on 35m^2 vegetated roofs showed an abatement ranging from 50 to 70%. The characteristics of the rainfall or the input surface can have an impact on the volume reduction. The higher rate for stormwater tree could be explained by the more important thickness of the storage layer, which is higher than for green roofs.

2.2 Water balance

In Figure 2 we observe that for the period studied, the exfiltration is predominant. The highest transpiration is observed in the summer, especially in June, decreasing from October onwards. The overall exfiltration is 53%, followed by transpiration of 29% and drainage of 18%. The variation of the stock is almost zero over the period. Transpiration rates are lowest in October and November, at the beginning of the winter period, characterized by the necrosis and loss of leaves. Studies by Prévosto (et al. 2018) and INRA (2010) showing transpiration between 15% and 30%, confirm our results. These values should however be used with precaution. Comparing the sap flow between a same tree, we obtain a standard error of 28 %, similar to the uncertainties evaluated by the sap flow sensor designers of 30% (Forster 2015). The negative exfiltration value in July might be explained by the uncertainty in sap flow estimations or by capillary recharge from the groundwater.

In summer the transpiration rate is higher which on one side favors the cooling of the local environment, but on other side the tree may deplete the soil water stock, needing even additional watering. In winter, however, the transpiration is zero, which does not reduce the inflows. In the context of stormwater management in the Paris region, it would be interesting to have also high transpiration rates in the (rainy) winter months rather than in the summer because of the summer hydric stress and the flood risk in the winter period. Possible solution could be evergreen species, able to reduce flows even in the winter and an increase of the water stock through a dedicated storage.

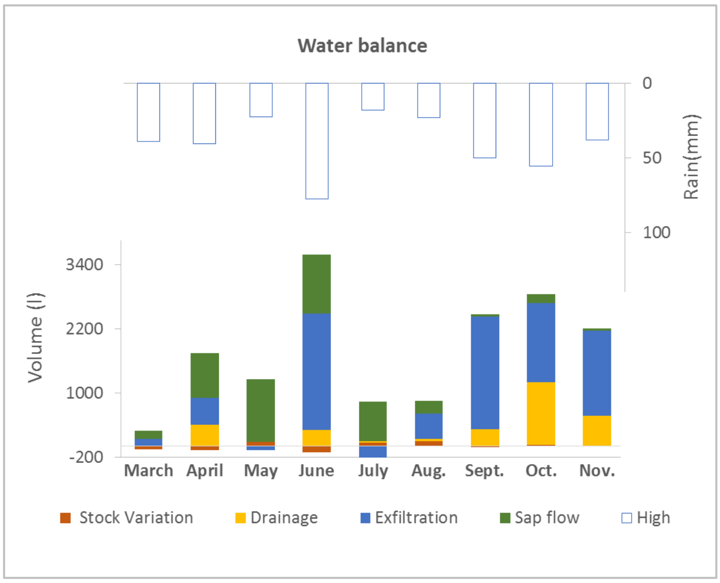

Figure 2: Evolution of the water balance from March to November 2022

Actually, some uncertainties persist linked to on one hand the contributing surface, influenced by the variable slope of the sidewalks and possible losses through cracks between the kerbs and the road, and on other hand to the detection limit of the electromagnetic flowmeter making that a part of flow for low rain intensities might not be well counted. Efforts are made to estimate and eliminate these uncertainties.

3 CONCLUSION

The first results of the SenseCity stormwater tree system have shown an almost total abatement of the runoff volumes, which is an essential for sustainable drainage systems. Most of the incoming volumes are exfiltrated, contributing to groundwater recharge and an important part is eliminated by transpiration. However, the evaporative is the highest in summer accompanied by low rain intensities and risk of depleting of soil water stock.

The presentation will further develop the hydrological functioning with complete rainfall set.

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