Impact of soil saturation on the storm water trees health

Impact de saturation du sol sur la santé des arbres de pluie

Martin Seidl*, Hayath Zime Yerime* and Didier Técher**

**ENPC IPP LEESU - martin.seidl@enpc.fr et hayath.zime-yerima@enpc.fr
* Cerema, Equipe TEAM - didier.techer@cerema.fr

RÉSUMÉ

L'urbanisation, de par l'imperméabilisation des sols, perturbe profondément le cycle de l'eau. Dans ce contexte, les Solutions Fondées sur la Nature portant sur la mise en oeuvre d'ouvrages tels que les toitures végétalisées, les jardins de pluie ou les arbres de pluie sont de plus en plus plébiscitées, contribuant à restaurer les processus de naturels de rétention, d'infiltration et d'évapotranspiration des eaux pluviales. Cette étude examine les effets d'une saturation prolongée du sol dans les dispositifs de type "arbres de pluie" en se focalisant sur le fonctionnement écophysiologique et hydrologique de l'érable, couramment rencontré en milieu urbain en Europe. Les données des arbres de pluie du dispositif expérimental de Sense-City (agglomération parisienne), ont d'abord été analysé, indiquant qu'une période de saturation est en moyenne une demie journée, mais que des périodes d'une dizaine de jours se produisaient jusqu'à une fois par an. A la base de ces données des expériences en pot ont ensuite été menées en automne 2023, consistant en la saturation artificielle des substrats pendant trois semaines. Après sept jours d'exposition, une diminution significative de la conductance stomatique et du flux de sève, ainsi que des modifications des paramètres biochimiques des feuilles ont été observées, illustrant des effets dommageables de l'engorgement. De plus certaines altérations des traits foliaires chez les arbres exposés étaient du nouveau observables l'année suivante, suggérant une sorte d'« effet mémoire » ou de processus d'adaptation au stress préalablement subi. Ces données devront contribuer pour améliorer les lignes guide pour la gestion des eaux pluviales à l'aide des arbres.

ABSTRACT

Urbanization profoundly disrupts the water cycle through soil sealing. To mitigate these impacts, Nature-Based Solutions such as green roofs, permeable pavements, rain gardens and stormwater trees are increasingly being proposed to restore water retention, infiltration and evapotranspiration processes. This study investigates the effects of prolonged soil saturation in stormwater trees focusing on the ecophysiological and hydrological functioning of maple tree, frequently found in urban environments in Europe. Therefore the stormwater trees data of the Sense-City experimental facility (Paris metropolitan area) were analysed, indicating that a saturation period lasts on average half a day, but that periods of around ten days occurred up to once a year. Based on these data, pot experiments were then conducted in the fall of 2023, consisting of artificially saturating the substrates for three weeks. After seven days of exposure, a significant decrease in stomatal conductance and sap flow, as well as changes in the biochemical parameters of the leaves, were observed, illustrating the damaging effects of waterlogging. In addition, certain alterations in leaf traits in exposed trees were still observable the following year, suggesting a kind of "memory effect" or adaptation process to the stress previously experienced. These data should contribute to improving guidelines for stormwater management using trees.

Keywords

Storm water trees, soil saturation, water logging, stomatal conductance, chlorophyll,

1 BACKGROUND

Urbanization is a major phenomenon involving the transformation of natural spaces into built-up areas, as a result of populational growth. Even if it is accompanied by economic development, it modifies natural spaces and affects its natural hydrological cycle, mainly through soil impermeability (Fini et al. 2022). In response to this problem, various forms of compensation have been implemented, such as green roofs, permeable pavements, rain gardens, and stormwater trees. These Nature-Based Solutions (NBS) are increasingly being incorporated into new urban developments (Jouin, Mlocek 2020; McClymont et al. 2020). Included vegetation provides multiple ecosystem services, like sustainable runoff management, particularly by optimizing retention, evapotranspiration and (in)filtration processes (Berland et al. 2017; Seidl, Saifane 2021). In the case of stormwater trees (EPA 2016; Zime-Yerima et al. 2025; Seidl, Zime-Yerima, Chebbo 2025) this adaptation could lead to modified hydrological conditions in the soil, exposing the roots to prolonged saturation and temporally water logging. This paper proposes therefore to focus on the consequences of these conditions on the eco-physiological and hydrological functioning of maple tree (*Acer platanoides* 'Globosum') widely used in European cities.

2 METHODOLOGY

The Sense-City research facility situated within the Paris conurbation possess a storm water tree pilot system collecting a portion (88 m²) of runoff from a small roadway of about 50 m. The runoff is drained by gravity to the lowest point of the roadway, and is then distributed to three 1.6 m diameter reservoirs at the foot of each maple tree. The tree pit consists of a 20 cm layer of absorbing substrate, before infiltrating into a 60 cm of topsoil before exfiltrating into underlying natural clayey soil or being collected by underdrain at the bottom at the depth of 80 cm. in a 30 cm x 30 cm trench filled with gravels or surrounded by a geotextile. Multiple sensors are deployed to assess water flows and storage levels in the various parts of the system. Inlet runoff volumes are assessed using electromagnetic flowmeters (Optiflux Krohne), the outlet of the underdrain is followed by tipping bucket flowmeter (Précis Mécanique), while soil water content is monitored every 15 minutes using TDR probes (Soilvue Campbell) positioned at the foot of the trees, at depths of 5, 10, 20, 30, 40 and 50 cm. The sap flow of each tree is quantified by a heat dissipation sensor (Implex Edaphic). In addition, meteorological parameters are monitored at a height of 8 meters (Vaisala), and precipitation is also recorded in the middle of the road at a height of 1 meter. The site is described in detail by (Zime Yerima et al. 2023; 2024). For this paper were used more specifically the soil humidity data.

To study the effect of water logging or water saturated soil profile on the efficiency and the physiology of the storm water trees a complementary experiment was set up as the in-situ soil humidity cannot be managed. A set of 6 maple trees (3 m) were followed in huge planting pots (150 L). Each pot was equipped with tensiometer, same TDR probe as above, dendrometer and inspection hole for pore water analysis (oxygen and redox potential) and the same sapflow sensor as above. The trees were planted in the spring of 2023 and monitored. At the end of the summer half of them was saturated with tap water and all trees were also monitored each day for leaf parameters: chlorophyl, anthocyanin, flavonoid (Dualex), stomatal conductance and photosynthetic efficiency (Licor LI-600) on a set of 30 leaves per tree. After 3 weeks of logging the pot were emptied and followed for till the next summer with a new campaign of crown parameter measurements.

The main objective was to first, identify the distribution of soil saturation frequencies in situ and then to use these values to evaluate the effect on tree physiology and functions in a complementary but controlled experimental set-up. In both cases the natural climatic conditions were present and only in the case of the planting pots water was added if the soil tension reached the irrigation limit of 100 cbar.

3 RESULTS AND DISCUSSION

3.1 Soil saturation

The soil can be defined as saturated if the majority of its pore volume is filed up with water and it will be somewhere between the field capacity and porosity. According to the soil characteristics it will be somewhere between 0.4 and 0.6. In the case of the Sensecity, planting substrate it can be defined as sandy loam, where this limit is somewhere between 0.4 and 0.45. The figure below gives for the soil humidities between 0.4 and 0.45 the frequencies of their occurrence at 50 cm depth during 2022 and 2023. Only about 10 % of the periods is longer than 1 day and only 3% longer than 5 days corresponding to 4 events.

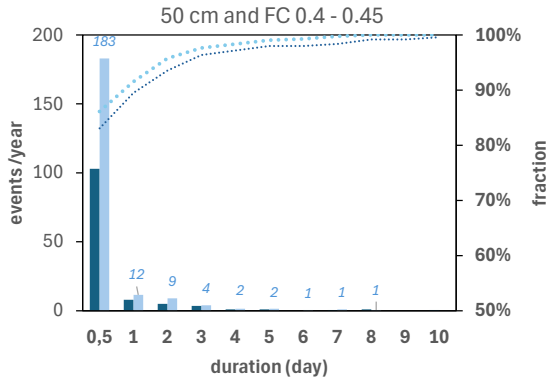

Figure 2 : Duration of soil saturation as observed in the SenseCity demonstrator for tree 1 during 2022 and 2023 with respectively 550 and 740 mm annual precipitation

The risk of soil anoxy in a logged soil depends on its organic matter content, its degradability and the temperature. In the case of the SenseCity planting soil with about 8% of OM a relatively fast depletion within 3 days was observed leading to negative redox within 1 week, conditions strongly impacting the principal vegetative functions as will be showed in the next paragraph

3.2 Tree physiology effects

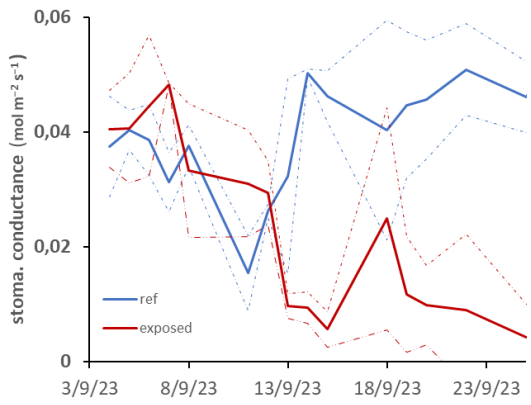

Figure 2 : Average (straight line) stomatal conductance for the references and for the water-logged trees (n=3), with the standard deviation (dashed line)

The figure 2 shows the general tendency, no initial difference between the reference trees and the water-logged trees. After 7 days of exposition to saturated condition the parameters diverge, significant decrease of stomatal conductance and sap flow and increase of anthocyanin and daily trunk diameter variation in the exposed group. The period of 7 days corresponds to the minimum of interstitial redox potential and 3 days of interstitial oxygen depletion. Similar impact of waterlogging was observed by others (Rao, Li, Cui 2021) , mainly explained by direct and indirect inhibition of root metabolism.
Besides the effects in 2023 we could observe a delayed effect on leaves one year after. In the spring of 2024, the chlorophyl and anthocyanin content were 70% respectively 40% higher in the water logged trees than in the reference one. The quotient Chl/Anth was thus 25% higher in the formally exposed trees than in the reference, most probably as reaction to the prior stress.

4 CONCLUSION

In the first part of the work was established that the waterlogging might be present in some storm water tree dispositive like that of SenseCity, characterised by collecting / infiltrating surface ratio of 15, young trees and slightly permeable underground in average temperate climatic conditions. Though the median duration is less than one day longer duration like 1 week might be present once a year. These sporadic conditions can though limit strongly the tree transpiration and in extreme cases like 3 weeks they can led to partial population death. The presentation will propose more complete view of the impact and propose some measures for better storm water tree design.

BIBLIOGRAPHIE *(obligatoire uniquement pour les communications à caractère scientifique)*

BERLAND, Adam, SHIFLETT, Sheri A., SHUSTER, William D., GARMESTANI, Ahjond S., GODDARD, Haynes C., HERRMANN, Dustin L. et HOPTON, Matthew E., 2017. The role of trees in urban stormwater management. *Landscape and Urban Planning*. juin 2017. Vol. 162, pp. 167-177. DOI 10.1016/j.landurbplan.2017.02.017.

EPA, 2016. *Stormwater Trees: Technical Memorandum* [en ligne]. 2016. Disponible à l'adresse : https://www.epa.gov/green-infrastructure/stormwater-trees

FINI, Alessio, FRANGI, Piero, COMIN, Sebastien, VIGEVANI, Irene, RETTORI, Andrea Alberto, BRUNETTI, Cecilia, MOURA, Bárbara Baesso et FERRINI, Francesco, 2022. Effects of pavements on established urban trees: Growth, physiology, ecosystem services and disservices. *Landscape and Urban Planning*. 1 octobre 2022. Vol. 226, pp. 104501. DOI 10.1016/j.landurbplan.2022.104501.

JOUIN, C. et MLOCEK, Z., 2020. Évolutions des techniques alternatives de gestion des eaux pluviales : l'exemple de trois projets à Villeneuve-la-Garenne. *Techniques Sciences Méthodes*. 20 mars 2020. N° 3, pp. 61-70. DOI 10.36904/tsm/202003061.

MCCLYMONT, Kent, FERNANDES CUNHA, Davi Gasparini, MAIDMENT, Chris, ASHAGRE, Biniam, VASCONCELOS, Anaí Floriano, BATALINI DE MACEDO, Marina, NÓBREGA DOS SANTOS, Maria Fernanda, GOMES JÚNIOR, Marcus Nóbrega, MENDIONDO, Eduardo Mario, BARBASSA, Ademir Paceli, RAJENDRAN, Lakshmi et IMANI, Maryam, 2020. Towards urban resilience through Sustainable Drainage Systems: A multi-objective optimisation problem. *Journal of Environmental Management*. décembre 2020. Vol. 275, pp. 111173. DOI 10.1016/j.jenvman.2020.111173.

RAO, Liangyi, LI, Siyuan et CUI, Xue, 2021. Leaf morphology and chlorophyll fluorescence characteristics of mulberry seedlings under waterlogging stress. *Scientific Reports*. 28 juin 2021. Vol. 11, n° 1, pp. 13379. DOI 10.1038/s41598-021-92782-z.

SEIDL, Martin et SAIFANE, Manal, 2021. A green intensity index to better assess the multiple functions of urban vegetation with an application to Paris metropolitan area. *Environment, Development and Sustainability* [en ligne]. 22 février 2021. [Consulté le 22 février 2021]. DOI 10.1007/s10668-021-01293-4. Disponible à l'adresse : https://doi.org/10.1007/s10668-021-01293-4

SEIDL, Martin, ZIME-YERIMA, Hayath et CHEBBO, Samih, 2025. L'arbre de pluie, le dernier venu des aménagements pour la gestion du ruissellement urbain. In : *Eau dans tous ses états* [en ligne]. Presses des Ponts et Chaussées. Transitions, les nouvelles annales des Ponts et Chaussées, 5. ISBN 978-2-85978-587-1. Disponible à l'adresse : https://www.presses-des-ponts.fr/ouvrage/sciences-humaines-sociales/transitions-les-nouvelles-annales-des-ponts-et-chaussees-n5-leau-sous-contraintes-un-objet-detude-a-lintersection-de-multiples-recherches/

ZIME YERIMA, Hayath, SEIDL, Martin, BENSAOUD, Abdelkader et BERTHIER, Emmanuel, 2024. Stormwater management by urban trees: case of the SenseCity experimental device. In : *16th International Conference on Urban Drainage, Delft, June, 2024*. Delft. 2024. pp. 969-973.

ZIME YERIMA, Hayath, SEIDL, Martin, GROMAIRE, Marie-Christine, BENSAOUD, Abdelkader et BERTHIER, Emmanuel, 2023. Potential of "stormwater trees" for sustainable urban runoff management: overall assessment of an experimental device within SenseCity. In : *Proceedings 11th International Conference Novatech, 3-7 July 2023 Lyon France* [en ligne]. Lyon, France : Novatech. juillet 2023. [Consulté le 17 janvier 2024]. Disponible à l'adresse : https://enpc.hal.science/hal-04083207

ZIME-YERIMA, Hayath, SEIDL, Martin, BENSAOUD, Abdelkader, BERTHIER, Emmanuel et GROMAIRE, Marie-Christine, 2025. L'arbre de pluie : analyse d'un concept émergeant dont les contours restent à préciser. [en ligne]. 2025. Vol. 10. DOI 10.36904/tsm/20251065. Disponible à l'adresse : https://astee-tsm.fr/articles/tsm-10-2025-larbre-de-pluie-analyse-dun-concept-emergeant-dont-les-contours-restent-a-preciser/