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Evaluation of green roofs evolution impact on substrate soil water content by FDR sensors calibration

Roberta D'Ambrosio [1,*], Antonia Longobardi [1] and Mirka Mobilia [1]

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[1] University of Salerno, Department of Civil Engineering
* Correspondence: robdambrosio@unisa.it; Tel.: +39-089963409

Abstract: Green roofs (GRs) performance is strongly impacted by climatic conditions, design parameters and aging. In particular, the evolution in time of physical and chemical properties may lead to substantial changes in their hydrological behaviour. The growth of the roots, above all, seems to affect the interpretation of the soil water content, a key parameter for GRs retention performance. Generally, FDR (Frequency Domain Reflectometry) sensors are used in the assessment of the volumetric water content (VWC) of the soil but they require a calibration procedure in order to obtain reliable measurements. In this study, changes in FDR sensors calibration caused by the presence of root system were investigated. For this purpose, two substrate soil samples have been collected from an experimental GR located within the University of Salerno: the first, mainly consisting of peat, during the construction phase and the second, consisting of peat with a developed root system, two years later. FDR measurements were plotted against observed volumetric water content to obtain calibration curves. Results show that FDR sensors seem not to be able to predict the water adsorbed by the root system, confirming the hypothesis that GRs evolution can have an important impact on substrate VWC observation.

Keywords: Soil moisture content; FDR sensor calibration; GRs ageing

1. Introduction

In the last decades, strategies involving the use of green infrastructures became necessary to mitigate environmental problems and hydrogeological risks associated with invasive urbanization dynamics [1, 2]. Green roofs (GRs) are considered, in this context, a promising solution able to help traditional drainage systems to manage urban runoff in a sustainable and effective manner retaining stormwater and reducing the peak flow [3]. GRs retention capacity depends on numerous variables such as climatic conditions, design parameters and substrate ageing [4-9]. In particular, the evolution of physical and chemical properties of the substrate and vegetation layers of a green roofs may lead to substantial changes in their hydraulic parameters and in the overall hydrological behaviour. The growth of the roots in the substrate layer, above all, seems to affect the interpretation of the soil moisture content [10, 11]. The latter, especially in Mediterranean regions,characterized by long periods of drought and heavy rainfall, is considered one of the key parameters in the definition of GRs retention performance [12, 13]. Generally, FDR (Frequency Domain Reflectometry) sensors are widely used in the assessment of the volumetric water content (VWC) of the soil for their durability and reliability but a calibration procedure of these tools is essential to get accurate assessments.

This research investigated changes in FDR sensors calibration caused by the presence of root system in an experimental GR . In order to assess how the presence of root system affect FDR sensor calibration and therefore also soil moisture content observations, two substrate soil samples were collected from an experimental GR located within the campus of the University of Salerno, in

Southern Italy [14]. The samples differ in the presence of root system since the first one was collected during the construction phase in 2017 while a second one was collected two years later. FDR measurements from the two samples were plotted against actual volumetric water content to obtain calibration curves.

2. Materials and Methods

2.1. The University of Salerno experimental site

The experimental GR (Figure 1.a), set up in January 2017 at the Laboratory of Environmental and Maritime Hydraulic, Department of Civil Engineering of the University of Salerno UNISA (40.770425, 14.789427, altitude 282 m.a.s.l.), includes three layers: a vegetation layer made up of succulent plants called Mesembryanthemum, a 10 cm deep support substrate and a 5 cm deep drainage layer made up of expanded clay. The roof is placed on bench of stainless steel with a surface of 2.5 m^2 (1 x 2.5 m) and a double pitch slope of 1%.

The experimental site is continuously monitored (5 min time step) by a weather station, Watchdog 2000 Series (Model 2550), which includes: Tipping bucket rain gauge, hygrometer for air humidity measurement, pyranometer with silicon sensor (spectral field 300–1100 nm, range 1–1250 W/m2) for solar radiation measurements, and an anemometer for wind speed and direction measurements. Runoff from the experimental sites is collected in circular-shaped tanks located above digital calibrated scales for stormwater measurament at 5 min time steps).

Volumetric water content within the substrate layer is monitored with the use of the commercial moisture FDR sensor SM 100 (Figure 1.b). It is shaped as a thin plate with a sharp tip at the bottom. The sensor has a thickness of 3 mm, a height of 60 mm, and a width of 20 mm, and has been installed vertically. The sensor is made up of two electrodes that act as a capacitor, with the surrounding soil serving as the dielectric. An 80 MHz oscillator drives the capacitor and a signal proportional to the soil's dielectric properties.

(a) (b)

Figure 1. (a) Green Roof test bed within the University of Salerno Campus; (b) FDR sensor installed at the experimental site.

2.2. GR substrate soil sampling

A first substrate soil sample (S2017) was collected in 2017 (Fig. 2.a), at the moment of the GR instalation. It consists of a mix of blond peat, baltic brown peat, zeolites and simple non-composted vegetable primer (coconut fibers), completed with the addition of a mineral fertilizer (biostimulant algae). More information about physical and hydraulic properties are reported in [13].

A second sample (S2019) was then collected two years later, in 2019 (Fig. 2.b), and in this case a well developed root system was detected within the previously mentioned soil mix . The sample was took making sure to preserve vegetation and GR functionality.

(a) (b)

Figure 2. (a) GRs soil sampling in 2019; (b) Sample with roots

2.3. FDR calibration curves

The FDR calibration curve was obtained by plotting each value of the soil moisture content provided by the FDR sensor against the corresponding volumetric water content (VWC) of the sample. In total, 18 FDR measurements were collected for S2017 and 20 for S2019. For each reading the VWC has been derived as:

$$VWC\ \% = GWC\ (\%) \cdot BD \qquad (1)$$

Where BD is the the bulk density of the soil (g cm^{-3}) calculated as the ratio between Dry Weight and Volume of the Sample, and GWC is the gravimetric water content given by:

$$GWC\ (\%) = (Wet\ Weight - Dry\ Weight)/\ (Dry\ Weight) \cdot 100 \qquad (2)$$

In the previous equation, "Dry Weight" is the weight of the dried sample while "Wet Weight" is the actual weight of the sample during the single measurement.
The calibration of FDR sensors was made within the range of 0-40% VWC, above the substrate soil water holding capacity of about 30%.

3. Results and Discussion

Figure 3 shows calibration curves obtained by soil moisture content measuramente of sample S2017, green dots, and sample S2019, blue dots.

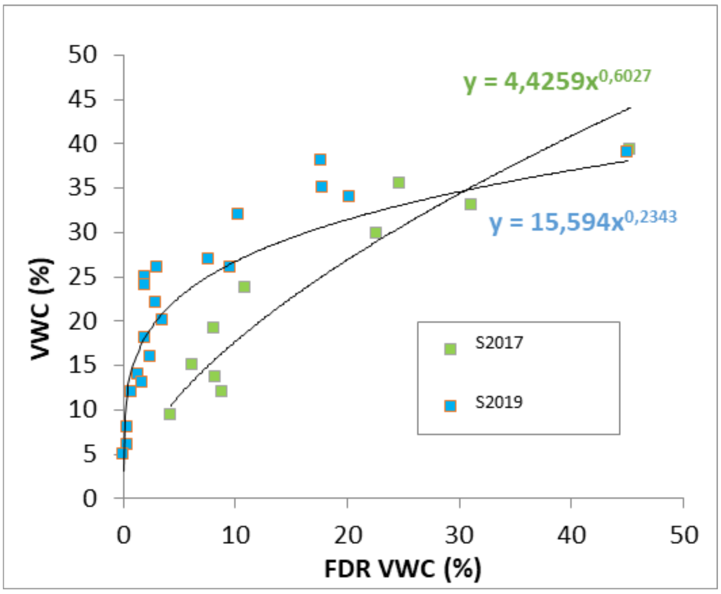

Figure 3. FDR calibration curves

From the observation of Figure 3, it results that the same reading provided by the FDR sensor could return, for the sample with root system, a VWC at most 90% larger than for the sample without the root system. The closer the VWC is to the water holding capacity of the soil, the lower is the difference between actual VWC of S2017 and S2019. On the other side, the same value of actual VWC returns a lower FDR reading for the sample with root system. This finding would suggest that, likely, a part of the water inside S2019 is adsorbed by the root system but FDR sensor is not able to measure this amount of water. The overall findings are:

- from the analysis of the two samples (with and without root system), the GR hydraulic and physical characteristics could change in a small time period (within 2 years);
- the use of an unique relationship between FDR measurements and actual VWC, calibrated during the GR installation phase would have led to an underestimation in time of the observed values of VWC with associated consequences;
- The monitoring of the VWC should be carried out by considering the GR ageing effects.

4. Conclusion

Green roofs are effective tools able to mitigate the negative hydrological impact of the rapid urbanization. The performances of these infrastructures strongly depend on a number of factors including the ageing. Indeed, in time, the GR substrate is interested by the growth of a root system which could affect the interpretation of the soil moisture content. In light of this, the FDR sensors, widely used in the assessment of VWC of the soil, require a calibration procedure in order to return accurate measurements. The aim of the present work was to investigate changes in FDR sensor calibration curves caused by the presence of root system. Two samples were collected in different years, from an experimental GR located in the campus of university of Salerno. The two samples differ in the presence of the root system. For each sample, a calibration curve was built by plotting the FDR measurements against the corresponding VWC values. The result showed that the growth of the roots within the GR substrate impacts the VWC observation indeed, the calibration curves significantly differ for the two samples. The use of the wrong calibration curve could imply incorrect estimates of the GR performances, especially for low VWC. In conclusion, a careful interpretation is needed when monitoring substrate moisture content in presence of a growing root system through FDR soil moisture sensors.

Author Contributions: A.L. conceived and designed the experiments; R.D. and M.M. performed the experiments; A.L. analyzed the data; A.L. contributed reagents/materials/analysis tools; R.D. wrote the paper."

Conflicts of Interest: The authors declare no conflict of interest

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