A rainfall simulator using porous pipes as drop former

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Highlights

- Design of a drop-former rainfall simulator using porous pipes
- Easier to build and maintain than rainfall simulators using capillaries
- Performances in the range of previous designs

Abstract

A drop-former rainfall simulator was designed and tested. Its novelty is the use of porous pipes instead of capillaries. Compared to rainfall simulators using capillaries, this feature makes easier its building and maintenance. Rainfall intensity can be selected by simply setting the water supply pressure. The rainfall simulator was able to deliver rainfall intensities between 24 and 75 mm/h for a pressure range of 0.25-1.40 bar. As other drop-former rainfall simulators, the

rainfall kinetic energy (expressed in $J.m^{-2}.mm^{-1}$) and drop size do not depend on the rainfall intensity. Tested on a 0.25 m² area, larger format could be build.

Keywords:

Rainfall simulator, drop former instrument, raindrop, kinetic energy

1. Introduction

Rainfall simulators are widely used in surface hydrology and in soil science (Iserloh et al., 2013; Kesgin et al., 2018; Nielsen et al., 2019). While they come in many variations, there are two basic types of rainfall simulators: nozzle-based and drop-former (Iserloh et al., 2013).

The present paper describes a drop-former simulator. While drop-former simulators typically make use of capillaries (needles, holes or small tubes), the present design uses porous-pipes to generate the drops.

While our laboratory have used for years an oscillating-nozzle simulator (Foster et al., 1979), an experiment required (1) a continuous rainfall over a surface of 0.25 m², and (2) that rainfall intensity could be changed without altering the other rainfall properties (kinetic energy, drop size). Aware of the complexity of (1) building a regular drop-former rainfall simulator (with its hundreds to thousands of capillaries per square meter) and (2) maintaining it (especially the clogging of the capillaries) over long periods, we came with a new design that replace the capillaries with porous pipes.

After detailing the design of the porous-pipe rainfall simulator, its performances are evaluated and its use is discussed.

2. Materials and methods

2.1 Design

The design of the present porous-pipe rainfall simulator is part of the drop-former rainfall simulator category. Basically, the capillaries and their specifically-designed water supply are replaced by porous pipes connected to a manifold pipe.

Porous pipes are cheap and commonly used in gardens and horticulture for irrigation. They are similar to water hoses, and can be bought in any garden shop. They may come in different brands and specifications. The one used here is made of a rubber-like material, with an outside diameter of 16 mm and an inside diameter of 13 mm.

For our simulator, 25 sections of porous pipe of 0.9 meter long are used (Fig. 1). They are lined up parallel to each other, with an inter-pipe spacing of 24 mm. One end of the porous pipe section is blocked with a stopper, while the other end is connected to a manifold pipe.

The porous pipes are placed under a one meter square sheet of expanded metal, and attached to the sheet with plastic tie straps every 20 mm. The sheet of expanded metal provides both a rigid frame and attachment holes for the tie straps. The tie straps are key in achieving a homogeneous spatial distribution of the drops: they collect the water coming out of the pipes and are the location where falling drops are formed.

The manifold is connected to a water pump. A digital manometer is installed on the manifold to allow for pressure monitoring and adjustment of the rainfall intensity.

Like in Ulrich et al. (2013) and Mayerhofer et al. (2017), a fine mesh (square 3 mm openings, wire diameter of 0.5 mm) is placed 65 cm below the drop former device. This mesh has two purposes: breaking the big drops into smaller drops, and

avoiding the drops to constantly fall onto the exact same location of the experimental surface.

The porous pipes of the rainfall simulator are set 6.60 m above the experimental area.

2.2 Rainfall properties assessment

36 pluviometers (cylindrical beakers of 64.5 mm in diameter and 110 mm in height) are used to assess the intensity and spatial variability of the rain inside a central area of 50 cm by 50 cm, which is the size of the test bench to be used in subsequent experiments. The collected amount of water is measured by weighting the pluviometers. The uniformity coefficient of Christiansen is calculated (Iserloh et al., 2013).

For the drop size and the rainfall kinetic energy, an optical disdrometer is used (Laser Precipitation Monitor, Thies clima, part number 5.4110.00.XXX). This disdrometer senses the drops crossing a laser beam and reports their number, sizes and falling speeds every minute. It is located in the center of the test area. During preliminary tests, an underestimation of the rainfall intensity by the disdrometer was found, as previously reported (Prata de Moraes Frasson *et al.*, 2011; Angulo-Martinez *et al.*, 2018). Hence, kinetic energies are linearly compensated based on the differences between disdrometer intensity and pluviometer intensity.

Rainfall properties are assessed at four water pressures (0.25, 0.50, 0.86, and 1.40 bar). Three replicates were carried out for the 0.86-bar pressure to assess the reproductibility of the rainfall intensity.

3. Results and discussion

For the range of pressure 0.25–1.40 bar, rainfall intensity varied between 24 and 75 mm/h (Table 1). The dependency of the intensity to the water pressure was mostly linear, making it easy to reach a prescribed intensity. The variability of the rainfall intensity was about 10% between replicates, which is in the usual range for rainfall simulators (Iserloh et al., 2013). The uniformity coefficient of Christiansen is always above 90%, which is in the higher range compared with other rainfall simulators (Iserloh et al., 2013). The spatial variability of rainfall intensity showed a gradient along the direction of the porous pipes (Fig. 2): compared to the mean value, the intensity was lower by 7% on the half of the test surface located to the manifold side, and higher by 7% on the half of the test surface located on the stopper side. This gradient was mostly independent of the rainfall intensity.

The simulator produced droplets with a mean weighted diameter of 3.0 mm. This value did not change with the rainfall intensity. This is typical of drop-former rainfall simulators which, by design, cannot alter their drop size (except by changing the wire mesh).

The drop velocities were independent of the rainfall intensity (data not shown). Drop-former rainfall simulators generates drops with an initial zero velocity. During their fall, drops interact with the wire mesh and accelerate due to gravity. Hence their final velocity depends simply of their size and falling height.

Rainfall kinetic energies were in the range of 18-23 $J.m^{-2}.mm^{-1}$ (Table 1). These values are quite close, meaning that the kinetic energy of the rain did not depend on the rainfall intensity. This was expected because (1) drop sizes and velocities were constant whatever the water pressure, and (2) the kinetic energy is expressed by millimeter of rainfall. The obtained kinetic energies are higher that in

the previously-reported range (Iserloh et al., 2013), owing to the larger drop fall height.

Overall, the results are in accordance with the expected behavior of a drop-former rainfall simulator, validating the present design for further use. The present design allows changing the rainfall characteristics independently: rainfall intensity depends on the water supply pressure, while the drop size and kinetic energy depends on mesh size and falling height. This feature could be advantageous to study the sensitivity of processes (such as particle splash or herbicide transfer) to the different rainfall properties.

Upon designing and using this simulator, we encountered several issues that should draw attention:

- The porosity of the hose roll may not be constant along its length. It may depends on the batch and on the brand. Hence, after testing, some 0.9 m sections have been discarded.
- On start-up, the rainfall intensity may be lower than expected: the porous pipes need to be moistened before they provide a constant water flow. Hence, the simulator needs to be run for a few minutes before being fully functional. By contrast, the rainfall stops instantaneously when the water supply pipe is disconnected from the pump.
- As underlined earlier, the intensity is lower on the manifold side than on the stopper side. If this rainfall intensity gradient is too high compared to the requirements, two manifolds could be used, supplying water from both sides of the porous pipes.
- For a given pressure, rainfall intensity decreases over the course of several weeks. This could be due to aging and clogging of the porous pipes (Teeluck and Sutton, 1998). With a few exceptions, such as Battany and

Grismer (2000), clogging is rarely mentioned in publications about drop-former rainfall simulators. However, this issue is well-known to users. Clogging results in a decrease of the rainfall intensity and an increase of its spatial variability. For the present design, such inconvenience could be slow down by adding a water filter (Teeluk et al., 1998). Such an effect should be monitored, and, if significant, porous pipes can be easily replaced with new ones. While clogging occurs with porous pipes as with needles, it is much easier and faster to change the 25 porous pipes of the present design that the hundreds of capillaries of previous designs.

Overall, the porous-pipe rainfall simulator allows to generate a continuous rain, with drops of significant size, velocity and kinetic energy, having a random distribution of the impact points, for a significant range of rainfall intensities, and a limited spatial heterogeneity over a square surface of 0.25 m².

Potentially, the current design may be extended to provide rainfall over larger surfaces. This may be achieved by using longer or more numerous sections of porous pipes. As a reference, drop-former rainfall simulators exist for areas of 0.06 m², using 49 capillaries (Kamphorst, 1987) to areas of 6 m², using 4800 capillaries (Huang et al., 2016). We believe large drop-former rainfall simulators could advantageously use porous pipes instead of capillaries.

4. Conclusions

A rainfall simulator based on porous pipes was designed and tested. It can generate rainfall intensities between 24 and 75 mm/h. Rainfall intensity can easily be preset by choosing the water supply pressure. Rainfall kinetic energy (expressed in $J.m^{-2}.mm^{-1}$) and drop size do not depend on the rainfall intensity. The given advises will make easier its building and use. Compared to rainfall

simulators using capillaries, design and maintenance are easier. Tested on a 0.25-m² area, it could be expanded to larger surfaces.

Competing interests: authors declare no competing interests.

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References

Angulo-Martinez, M., Begueria, S., Latorre, B., Fernández-Raga, M. (2018). Comparison of precipitation measurements by OTT Parsivel² and Thies LPM optical disdrometers. Hydrology and Earth System Sciences. 22, 2811–2837. https://doi.org/10.5194/hess-22-2811-2018.

Battany, M. C., Grismer, M. E. (2000). Development of a portable field rainfall simulator for use in hillside vineyard runoff and erosion studies. Hydrological Processes. 14, 1119–1129. https://doi.org/10.1002/(SICI)1099-1085(20000430)14:6%3C1119::AID-HYP8%3E3.0.CO;2-O.

Foster, G. R., Eppert, F. P., Meyer, L. D. (1979). A programmable rainfall simulator for field plots. Proceedings of the Rainfall Simulator Workshop. Tucson, Arizona. March 7–9, Agricultural Reviews and Manuals, ARM-W-10. United States Department of Agriculture – Science and Education Administration, Oakland, CA, 45–59.

Huang, J., Wang, J., Zhao, X., Li, H., Jing, Z., Gao, X., Chen, X., Wu, P. (2016). Simulation study of the impact of permanent groundcover on soil and water

changes in jujube orchards on sloping ground. Land Degradation & Development, 27, 946-954. https://doi.org/10.1002/ldr.2281.

Iserloh, T.; Ries, J. B.; Arnáez, J.; Boix-Fayos, C.; Butzen, V.; Cerdà, A.; Echeverría, M. T.; Fernández-Gálvez, J.; Fister, W.; Geißler, C.; Gómez, J. A.; Gómez-Macpherson, H.; Kuhn, N. J.; Lázaro, R.; León, F. J.; Martínez-Mena, M.; Martínez-Murillo, J. F.; Marzen, M.; Mingorance, M. D.; Ortigosa, L.; Peters, P.; Regüés, D.; Ruiz-Sinoga, J. D.; Scholten, T.; Seeger, M.; Solé-Benet, A.; Wengel, R. & Wirtz, S. (2013). European small portable rainfall simulators: A comparison of rainfall characteristics. Catena, 110, 100–112. https://doi.org/10.1016/j.catena.2013.05.013.

Kesgin, E., Dogan, A., Agaccioglu, H. (2018). Rainfall simulator for investigating sports field drainage processes. Measurement, 125, 360–370. https://doi.org/10.1016/j.measurement.2018.05.001.

Kamphorst, A. (1987). A small rainfall simulator for the determination of soil erodibility. Netherlands Journal of Agricultural Sciences, 35, 407–415.

Nielsen, K. T., Moldrup, P., Thorndahl, S., Nielsen, J. E., Duus, L. B., Rasmussen, S. H., Uggerby, M., Rasmussen, M. R. (2019). Automated rainfall simulator for variable rainfall on urban green areas. Hydrological Processes, 33, 3364–3377. https://doi.org/10.1002/hyp.13563.

Mayerhofer, C., Meißl, G., Klebinder, K., Kohl, B., Markart, G. (2017). Comparison of the results of a small-plot and a large-plot rainfall simulator – Effects of land use and land cover on surface runoff in Alpine catchments. Catena, 156, 184–196. https://doi.org/10.1016/j.catena.2017.04.009.

Prata de Moraes Frasson, R., Kindl da Cunha, L., Krajewski, W. F. (2011). Assessment of the Thies optical disdrometer performance. Atmospheric Research, 101, 237–255. https://doi.org/10.1016/j.atmosres.2011.02.014.

223 Teeluck, M., Sutton, B. G. (1998). Discharge characteristics of a porous pipe
224 microirrigation lateral. Agricultural Water Management, 38, 123–134.
225 https://doi.org/10.1016/s0378-3774(98)00060-2.
226 Ulrich, U., Zeiger, M., Fohrer, N. (2013). Soil structure and herbicide transport on
227 soil surfaces during intermittent artificial rainfall, Zeitschrift für Geomorphologie,
228 57, 135–155. https://doi.org/10.1127/0372-8854/2012/s-00097.

229 **List of tables**

231

232 **List of figures**

235

237

238

Pressure (bar)	Intensity (mm/h)	Kinetic energy ($J.m^{-2}.mm^{-1}$)	Coefficient of uniformity (%)
0.25	23.9 ± 2.5	18	92
0.50	36.0 ± 3.5	Not measured	93
0.86	49.0 ± 5.2	23	92
1.40	74.5 ± 6.9	23	92

239

240 Table 1: Rainfall properties at different water pressures.

241

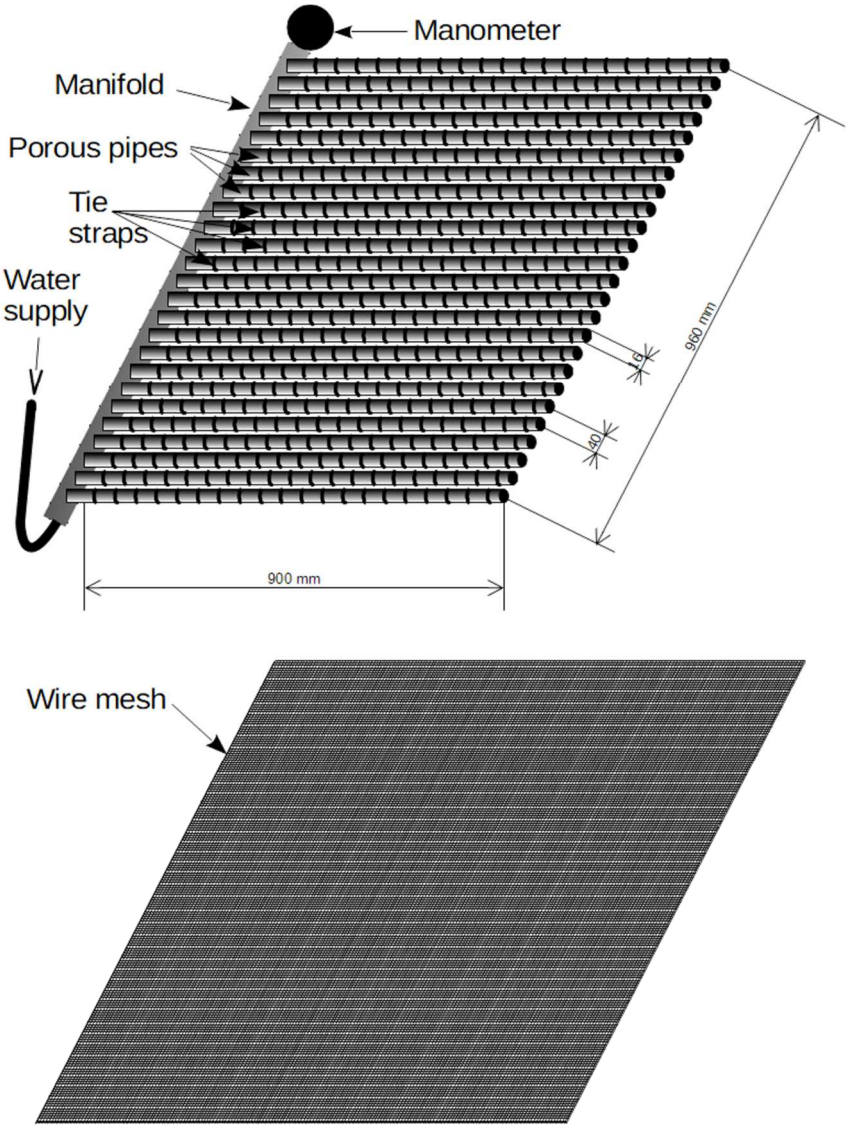

Fig. 1. Scheme of the rainfall simulator.

For clarity, the sheet of expanded metal is not drawn. Not to scale.

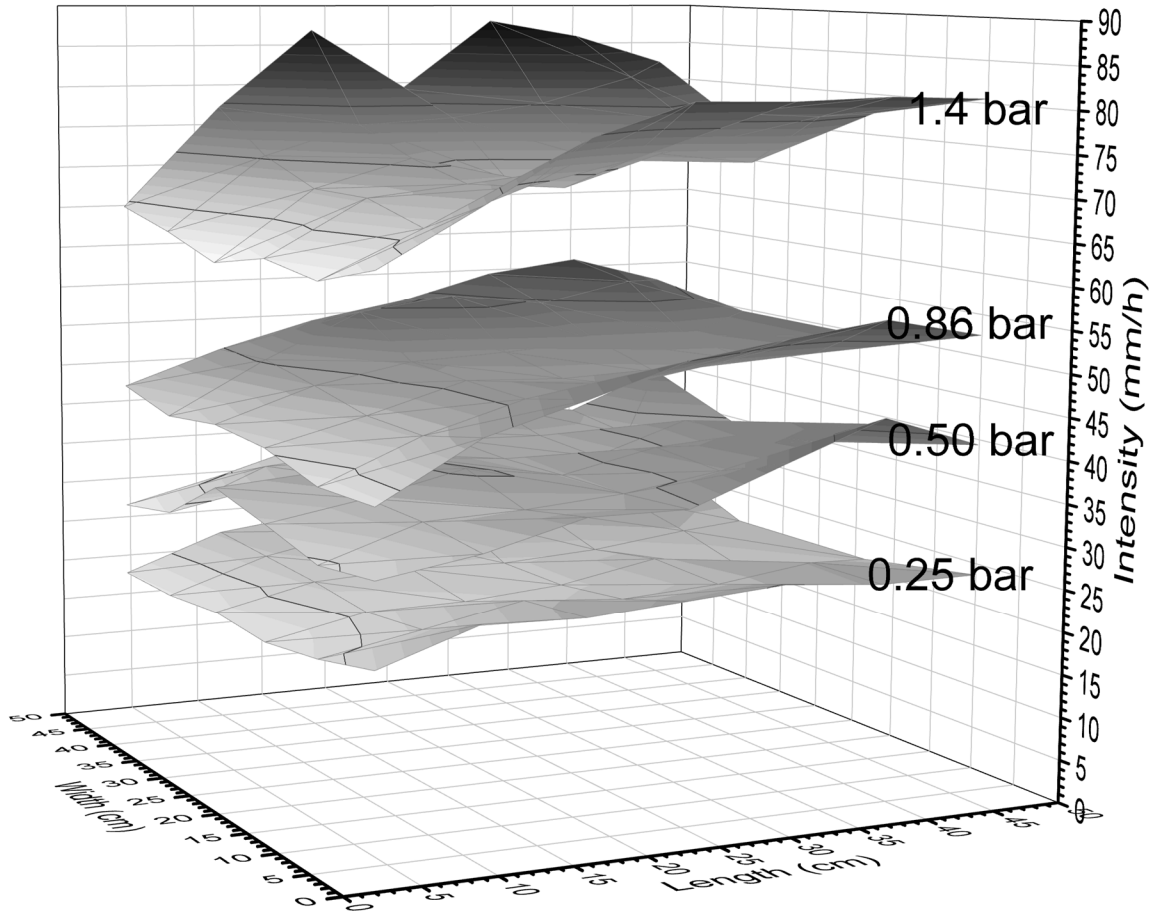

Fig. 2. Spatial variability of rainfall intensity at different water pressures.

The manifold is located to the left.