Int. Agrophysics 1993, 7, 197-201

A NEW APPROACH TO THE DESIGN OF A NOZZLE-TYPE RAINFALL SIMULATOR

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A b s t r a c t. The way to develop a classical nozzle-type rainfall simulator was noticed for further automatization of its work and for full control of all the parameters of rainfall formed. The module construction enables an easy development and extension of the simulator and makes possible the adjustment of the simulated rain to specific needs of experiments carried out both in the laboratory and field conditions.

K e y w o r d s: rainfall simulator, computer driving, soil erosion

INTRODUCTION AND DESIGN PRINCIPLES

The work of the most wide-sprayed, universal construction of rainfall simulators is based on the free outflow of water through capillary holes placed in the bottom of the supply tank. Drops formed in this way can be broken next on a wire grid in order to differentiate and to randomize their diameters. The Mariott's bottle is used both as a stabilizer and regulator of the rain intensity. An alternative construction uses the supplying tank in the shape of cylindrical bottle with some outflow holes in the vertical wall to regulate the intensity. The intensity regulation is realized by changing the water head in the tank [1,4,6]. Authors, using a rainfall simulator working on similar principles, have serious troubles to stabilize the intensity, which have been setting on the constant level in a few hours, decreasing exponentially to the value difficult to be predicted. To overcome this, as well as many other problems, a new construction was developed and somewhat different approach was proposed.

Desired characteristics included:

- quick adjustment to the constant work with required and absolutely replicable intensity;
- easy regulation of the intensity and drop size, and capability of applying the gradient of intensity;
- module construction, which allows an easy further development and modernization, and changeable raining area by connecting a few modules together.

DESIGN OF A NEW RAINING SYSTEM

Drop-forming unit

General layout of a new computer-controlled nozzle-type rainfall simulator is presented in Photo 1. Figure 1 presents a block-diagram of the designed rainfall simulated.

The basic drop-forming unit consist of a central supplying tube 40 cm long and 0.4 cm inner diameter, with 15 equally placed thin tubes ended with capillary nozzles. Hypodermic needles of 0.6 mm in diameter and 36 mm long were used as nozzles. The streams produced by needles are converted to drops by employed 20 cm long rubber tubes connected to the nozzles and a wire grid of a 2.5 mm quadrangular meshes placed below. Elastic

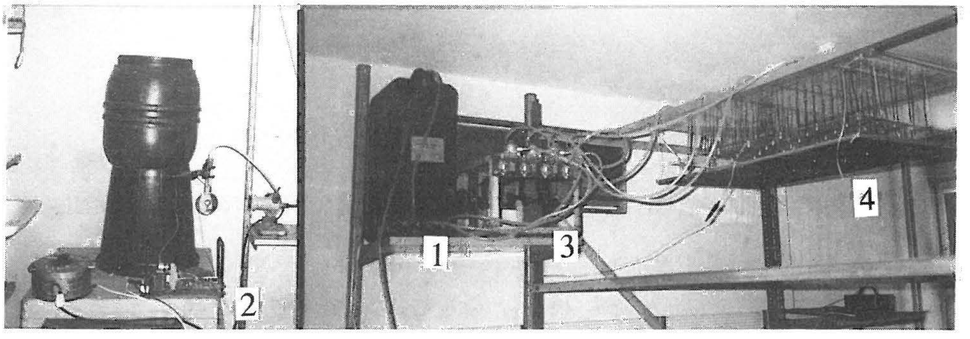

Photo 1. Layout of the rainfall simulated. 1 - water level control unit; 2 - main water rezervoir; 3 - injection pump unit; 4 - drop-froming units.

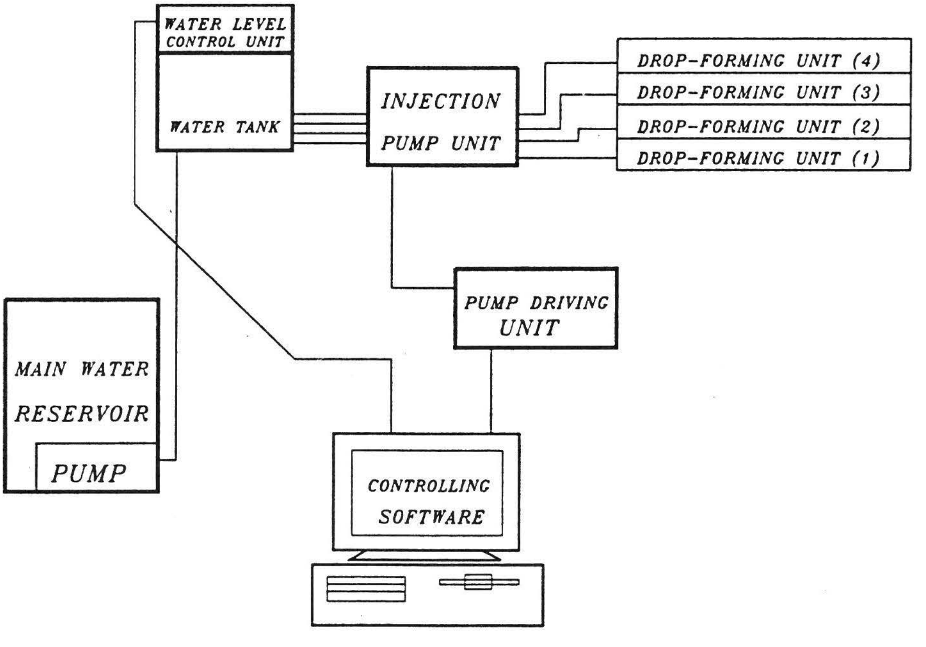

Fig. 1. Block-diagram of a designed rainfall simulated.

tubes and the nozzles are changeable and they consist an important element of regulation. In the prototype construction discussed here, one pump drives one base raining module. It gives 15 nozzles over the area of 20 x 40 cm. The whole raining unit consists of 4 base raining modules (raining area 80 x 40 cm). To differentiate the drop diameter, an automatically moving wire grid (2.5 mm meshes) is placed at a changeable distance below the tube ends. The output of the pump is enough to produce 3 drops on every nozzle in each pumping movement. The regulation of the rain intensity can be performed by increasing or decreasing the time of break between the consecutive cycles of drop formation and it does not depend on the pump or nozzle outputs.

Supplying pump system

Raining unit is supplied by four miniature membrane pumps moved by a common electric motor (DC 12V, 15W). By selecting such a motor, the authors paid attention to the field application of the construction. Pumps are driven through crank-shaft in the way that the cycles of following pumps are displaced in a fase of 45°. This allows to obtain a uniform rain distribution over the raining surface. Additionally, this parameter is improved by peculiarity of applied pumps, in which pumping is realized by an energy saved in a spring during the sucking cycle. Such a mode of pump work allows on an automatic matching of pumping efficiency to the need of raining system as well as it prolongs the time of drop emission by about 1/3 of a full cycle. Moreover, it does not disturbed the maintained rain intensity because it only depends on the number of pumping acts in time unit, and not on the output of nozzles. Of course, by changing the nozzle types we can also regulate the intensity, however, a set of nozzles mounted on the raining system is treated as a constant part of the construction and may be used for the global adjustment of device but not to the current regulation (Fig. 2).

Intensity regulation and control unit

As it can be easily recognized, the simulator uses all the water received from the tank to produce the rain. Hence, there is possibility to measure the rain intensity on the basis of water output from that supplying tank. In order to measure physically the decreasing water level in the tank, some converters working on the float base and respective electric joint were used here. It produced some technical problems, but finally after their solution the conviction of accurateness of this idea has been proved. A very simple way to solve the trouble is employing a digital balance with an automatic signal transmission to the computer.

Software

A computer uses the digital to analog converter to input an electrical information of current intensity and a printer port and pump

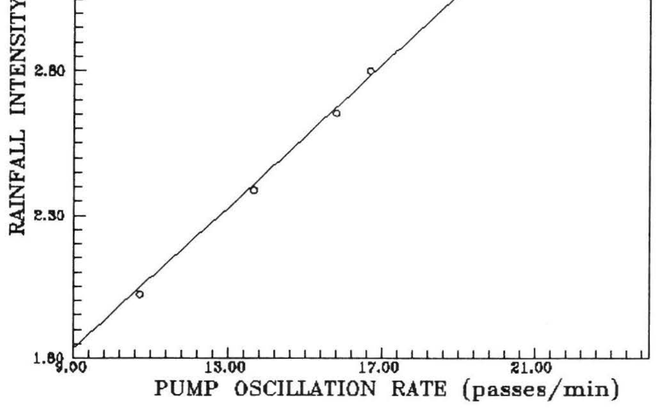

Fig. 2. Dependence of rainfall intensity on the number of pump rotation.

driver to control pump velocity.

An algorithm of the system consists of the following steps.

- Loading of input information on the required rain intensity and duration.
- Filling the water supplying tank.
- Setting the system into motion:
  - initiating and steering the pump unit to maximum intensity;
  - measuring the water level decrease in the tank (3 x 30 s);
  - setting and measuring the pump unit work at minimum intensity;
  - calculation a code and setting the simulator at the required intensity (display on a PC monitor);
  - measurement of a current intensity (water level decrease control in the tank 1 x 30 s, break 1 x 30 s, second water level decrease in the tank 1 x 30 s);
  - current intensity display and eventual correction and new control till the desired intensity is maintained by the system (display).
- Display ending of start calibration and ability to produce desired rain.
- Full control of the investigation cycle: display and sound signal for sampling time and/or other laboratory work specific for a given test. Simultaneously, the system continuously records and stabilizes current intensity, saves and stores all information on a disc. The rain stabilization is made by changing the code which, in turn, by pump driver corrects and changes the number of pumping cycles in unit time.

In the same way the simulator and the system may be used in the field conditions, supplied by a car battery and battery-supplied computer with analog to digital card. If the computer is not available, there is a possibility to work in the field by using a manual control unit consisted of a block of switches.

RAINFALL-SIMULATOR CHARACTERISTICS

Intensity regulation

The simulator maintains settings very well, even without computer and provides an easy regulation. It was noticed that when passing from higher to lower intensities the rain amount is different as compared to that obtained in opposite direction. The deviation is about 1 % and it does not add any trouble. It rather even soothes the jumping step regulation.

The kinetic rainfall energy (K.E.), calculated by using the drop height fall-velocity data published in paper [3], reached 19.3 J m^{-2} mm^{-1} for the laboratory conditions (drop-falling height - 3 m). It means that this value is about 10-15 % lower than the mean kinetic energy value of natural rainfall published by various scientists [7,8].

Drop-size distribution

Drop-size distribution has been determined by using oil method and photographs as described in the papers [2,5]. Three positions of a wire grid in relation to the end of drop-forming nozzles have been chosen in order to show the possibility of easy regulation of drop size distribution (Fig. 3).

The grid position change requires less then 2 min to stabilize the work of a device. In that time a number of drops hang on the grid and after a while they are hurled down by new drops, but again new drops are kept. Therefore, a smooth automatic shaking of a wire-grid has been introduced in order to protect from producing over-sized drops as well as to enlarge the rained area and to randomize the rain-drop distribution.

CONCLUSIONS

The presented simulator is a useful tool in various studies on soil water erosion, structural stability as well as hydrologic processes both in the field and in the laboratory conditions. All structure elements are easily mounted and transported. The new computer-controlled rainfall simulator offers the following:

- High stabilized and continuously monitored and controlled rain intensity.
- Easy regulation of intensity (by software) and drop-size distribution.
- Easy further development that enables module-type construction.

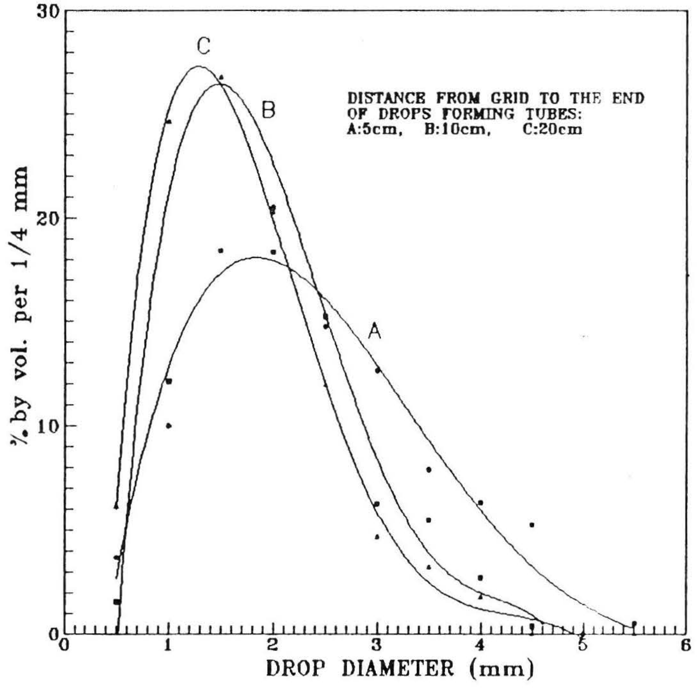

Fig. 3. Drop size distribution as a function of wire-grid distance from the drop-forming tubes (nozzles). The average drop size for particular distance is as follows: 2 cm - 1.6 mm; 7 cm - 1.3 mm; 9 cm - 2.1 mm.

- Adjustment to work both in the laboratory and field conditions.

ACKNOWLEDGEMENTS

The authors wish to thank to Prof. Dr. Jerzy Lipiec and MSc. Andrzej Guc for their help in making characteristics of the raindrop-size distribution.

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