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Use of Software for Image Analysis and Calibration of Automated Rain Simulator

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Authors' contributions

This work was carried out in collaboration among all authors. Authors TJAS and EMBS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors RDSA and JVJ managed the analyses of the study. Author RDSA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To calibrate and evaluate a rain simulator, with automatic operation, as well as determine the average size, the effect of the height of the equipment (2.12; 2.42 and 2.72 m) and of the oscillations of the spray nozzle of the rain simulator (21, 29 and 40 oscillations min^{-1}). Finally, to test and to compare the results of the count of drops by the software of analysis and processing of images Able Image Analyser, ImageJ and Safira.
Study Design: The experimental design was completely randomized, with 3 x 3 x 3 factorial scheme, with three repetitions (81 units).
Place and Duration of Study: The research was conducted in a greenhouse, in the municipality of Rondonópolis, Mato Grosso, located geographically at latitude 16°27'49 "S, longitude 550°34'47" W.
Methodology: For the calibration tests, the rainfall simulator was adjusted according to the heights (2.12; 2.42 and 2.72 m) and oscillations (21, 29 and 40 oscillations min^{-1}), followed by trays with a uniform layer of wheat flour, 2 cm thick, where the simulated raindrops were sprayed for a period of

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4 seconds. From this procedure, the drops were dried, sifted, weighed and counted. Droplet analysis was performed using three image analysis software Able Image Analyser, ImageJ and Safira.

Results: The softwares Able Image Analyzer, ImageJ and Safira did not show any significant difference in counting of the number of drops. It was observed that in the oscillation factor in setting that if gets drops of larger size (21 oscillations min^{-1}) the terminal velocity is also greater. In the height factor of the equipment, the drops presented larger sizes at the lower height (2.12 m). There are larger drops, higher terminal velocity as the height of the spray nozzle decreases, and higher kinetic energy value per unit area as the height of the spray nozzle increases. The range of drop sizes observed was 1.2 mm to 3.1 mm.

Conclusion: Although the software does not present significant differences, the ImageJ software proved to be more suitable as a research tool, since it has the license of free use and greater ease of use. Satisfactory results were obtained compared to natural rains in more than one combination of height and swings.

Keywords: Artificial rain; calibration; scaling of drops; water erosion.

1. INTRODUCTION

The study on the effects of water erosion on the ground is difficult to accomplish with the pluvial precipitation, because despite the weather forecasts, you have no control over the duration, intensity, distribution and type of precipitation [1–4].

The field monitoring under conditions of rain precipitation is the conventional method for studying the characteristics of runoff and sediment production. However, precise measurements of the process of soil loss during natural rainfall are almost impossible [5–8]. An alternative that has been shown to be very effective is the use of rainfall simulators [9–11].

The rain simulators are equipments into which the water is applied to experimental plots by sprinkling reproducing the pluvial precipitation and controlling the intensity and duration with precision [1,10,12].

Works with artificial rainfall simulators provide a relatively quick and economical way to obtain necessary information about erosion in a controlled environment and replicable [13–15], providing valuable information about the runoff [16], water infiltration in the soil and erodibilidade [17,18]. In addition to the impact of the physical properties of the soil [19], some studies also investigate the impact of vegetation cover [20].

The use of the equipment requires calibrations with the objective of identifying the combination of height and oscillations of the rainfall simulator that provide the adequate result in obtaining rainfall characteristics similar to natural ones.

It is essential the development of devices with latest technologies, built with of low cost materials and reduced weight, but also meet the requirements of the characteristics that send to natural rainfall. Existing rain simulation models, although they have evolved considerably, are still structurally difficult to handle and transport, and still rely on their mechanical operations.

The objective of the study is to calibrate the portable rainfall simulator with automatic operation, determine the effect of falling height, and estimate the terminal velocity of the drops. To Test and to compare drop count results with ImageJ, Safira and Able Image Analyzer image analysis and processing software.

2. MATERIALS AND METHODS

The research was conducted in a greenhouse, in the municipality of Rondonópolis, Mato Grosso, located geographically at latitude 16°27'49 "S, longitude 550°34'47" W, and altitude of 284 m. The region, according to the classification of Köppen, is of type Aw of the climate, hot and humid, characterized by the rainy season in the summer and dry in the winter [21].

The experimental design was completely randomized, with 3 x 3 x 3 factorial scheme, with three repetitions (81 units). The treatments were of three heights of the rain simulator equipment (2.72; 2.42 and 2.12 m), three water spray nozzle oscillations (21; 29 and 40 oscillations min^{-1}) and three-image analysis software (ImageJ, Sapphire and Able Image Analyser).

The rain Simulator equipment built consisted of aluminum bars with mobile rods of three meters in height and three meters in length. The equipment has a windshield wiper motor voltage 12 V, with electronic system capable of oscillating movements. Mated to the engine, with the aim of fragmenting the drops on the plots, simulating a rain near natural condition, have a spray nozzle the Spraying Company 80-100 VEEJET® made in stainless steel, with opening angle range of 80°, operating a 34.47 the service pressure 3447.38 kPa and flow rate of 2.2 x 0.3 x 103 to 103 m3 s^{-1}, Fig. 1.

The water is pumped into the spray nozzle by a centrifugal pump with 367.749 power W, 220 V voltage, 147.1 kPa pressure and suction of 5 m. Hydraulic load is suctioned from the tank and taken by 0.025 m polyethylene hoses. The working pressure used for promotion of the drops of rain is equal to 137.29 kPa, monitored by a pressure gauge and controlled by a valve. The simplified scheme of the rain simulator system is presented in Fig. 1.

The system has a voltage regulator, device that has the function to keep the output voltage of the electrical circuit in order to balance it within the limits required by the electronic system of the rain Simulator. The device has voltage regulator, coupled in your structure, a frequency meter, electronic device capable of measuring the frequency promoted by periodic movement of the wiper motor windshield.

Two simulation times were programmed: 4s (calibration) and 15 min (water slide test and water and soil loss evaluations), as well as the monitoring of the electromagnetic pulses emitted by the water flow sensor through of the programming language C. For coupling were used: Hardware Arduino Uno R3, software ARDUINO version 1.0.5 - R2, relay module, momentary switch, protoboard and jumpers.

In determining the average diameter of drops was used the method of wheat flour [22]. For this, three trays with dimensions of 0.54 for 0.95 m were filled with a uniform layer of 2 cm thick wheat flour, then the sprinkling water test on trays during 4 seconds with the rain simulator [23,24].

Drying of wheat flour was held in forced air circulation oven at 60°C for 24 hours and mesh sieves separated granules formed 2.000; 1.180; 0.425 and 0.300 mm. For determination of average size (D50), weighed 2 grams of drops retained in each sieve [25], as shown in Equation 1 [24,26]. Then the number of drops was determined by counting the granules deposited in each sieve with help of the softwares of image processing and analysis.

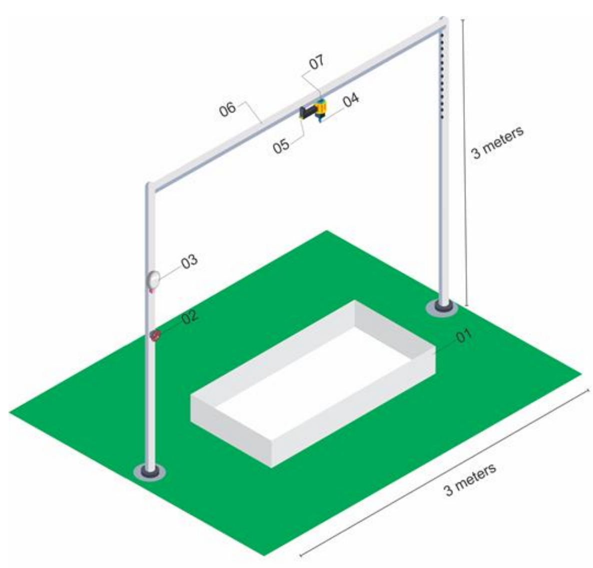

Fig. 1. Illustrative view of the rain simulator equipment; (01) tray; (02) retention valve; (03) gauge; (04) spray nozzle; (05) rain sensor; (06) aluminum movable rod; (07) windshield wiper motor

$$D_{50} = \sqrt[3]{\frac{6m}{\pi\rho}} \quad \text{(Eq.1)}$$

Where:

D_{50} - drop diameter (mm);
m - drop average mass (mg);
ρ - density of water (mg mm^{-3}).

The terminal velocity of the droplet, equation 2 [27], and the kinetic energy of the drop by Equation 3 [24] estimated the impact of drops with the soil surface.

$$VT = \sqrt{\frac{9{,}81}{0{,}4671 \times D50^{-0{,}9859}}} \quad \text{(Eq.2)}$$

Where:

VT - terminal velocity of drop (m s^{-1}).

$$E\,c/a = \frac{10^{-3}}{2}\rho\omega \; x \; L \; x \; V^2 \quad \text{(Eq.3)}$$

Where:

$E\,c/a$ - droplet kinetic energy (J m^{-2});
$\rho\omega$ - water density (kg m^{-3});
L - water average applied by nozzles (mm).

2.1 Analysis of the Data

Data were submitted to the Shapiro-Wilk (P > 0,01) and Levene (P > 0,01) tests, respectively, to verify the homoscedasticity normality. When the hypothesis of the residual homoscedasticity of the data was not true, the Kruskal-Wallis non-parametric statistical method (P > 0,05) was used as a complement for multiple comparisons of Fisher-Bonferroni test means (P > 0,05).

In the data analysis, the free software R Statistical 3.4.2® [28] was used. The parametric and non-parametric statistical analysis were implemented, using functions available in the ExpDes.pt [29] and agricolae packages [30]. To find the most appropriate transformation to reach the approximately Gaussian behavior the Box-Cox transformation family was used through the MASS package [31]. The construction of the graphs was performed by the ggplot2 package [32].

3. RESULTS AND DISCUSSION

Able Image Analyser, ImageJ and Safira did not show a significant difference in counting of the number of drops (Fig. 2). Each software was able to read different image formats, converting file formats, processing and analyzing the images The Able Image Analyser software was able to perform the particle sizing [33], although it is not efficient, neither practicality of use, at the same time that can be used to use it. ImageJ and Safira software are free software. However, in terms of ease of implementation, ImageJ has a more accessible interface. According to [34], ImageJ provides a powerful macro language to automate repetitive tasks. As ImageJ's source code opens, you can also optimize existing functions and plugins for your own needs [35].

This image processing plugin can be applied to rapid dimension measurements and particle size distribution analysis of various particulate systems from a digital image of disjoint particles [35].

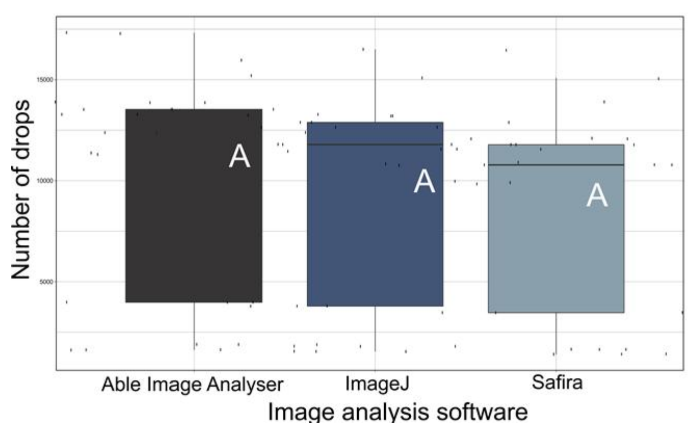

Fig. 2. Number of drops counted by image analysis software. Mean followed by the same letter does not differ by Fisher - the 5% probability of Bonferroni

The image processing technique can be successfully implemented for accurate drop size measurement [36]. The method of image processing can analyze a wide diameter range [35] and despite the elimination of some data that were recorded in the image, the number of drops counted digitally is considered sufficient for the analysis [36,37].

In the simulators, the wind is represented by the oscillations of the spout. Analyzing the variables that refer to droplet size, such as average mass, diameter and volume, in the oscillation of the spray nozzle of 21 min^{-1} oscillations, the droplets presented larger sizes (Fig. 3).

It was observed that in the oscillation factor, in the configuration obtaining larger droplets (21 oscillations min^{-1}) the terminal velocity is also higher, where the rate of drop increases as the droplet size increases [38].

The terminal speed is directly related to the kinetic energy of the drop (Eq. 3). For your time, the kinetic energy with which the drop reaches the soil is crucial to infer the erosive potential of that ground, since it is responsible for promoting the detachment of soil aggregates, thus causing the disposal of sediments, generating erosion.

In experiments to evaluate rainfall simulators, it is important to know the kinetic energy values of the drops produced because one of the main applications of the equipment is in the study of water erosion, so we must know the kinetic energy value of the simulated rain in the studies of erosive process under laboratory conditions, since each kinetic energy value provides different values of soil particles detachment, regardless of whether the rainfall is simulated or natural.

However, when working only with precipitation intensity, such an assertion could not be made, since there would be quite different impact energies between simulated and natural rainfall for the same intensity [39].

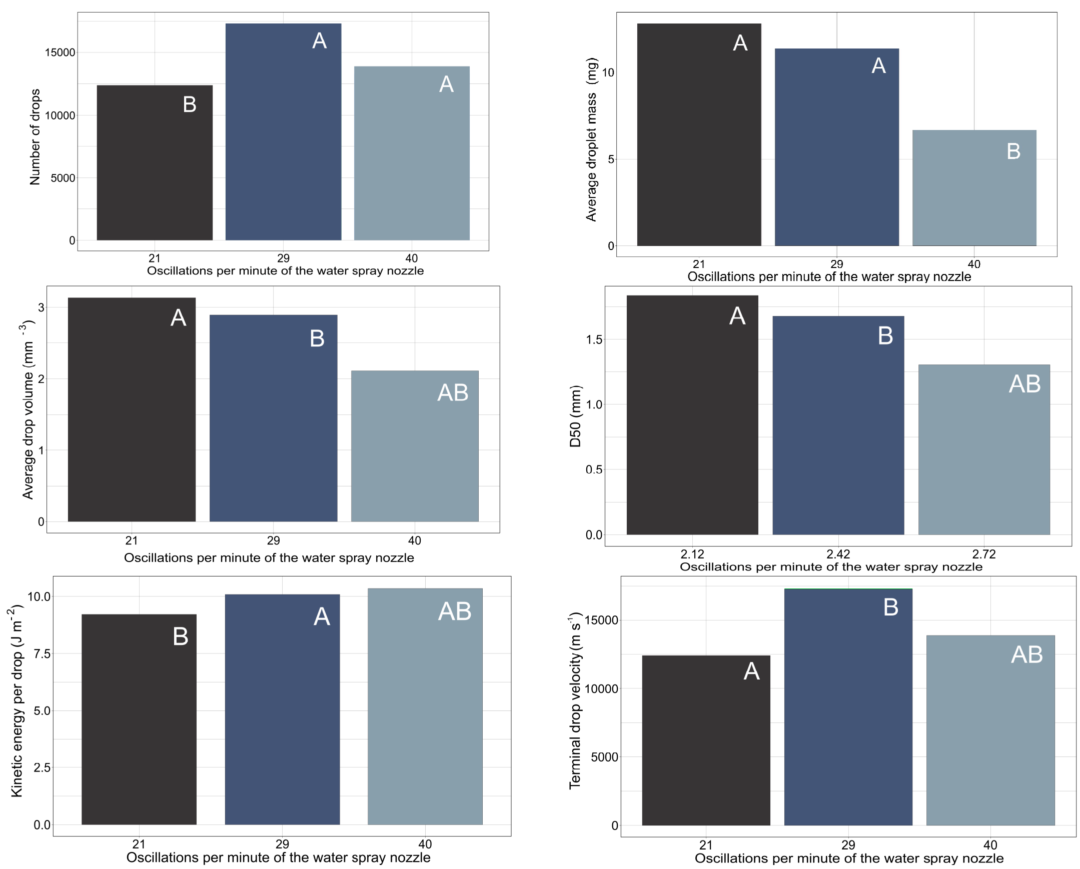

Fig. 3. Oscillations per minute of the water spray nozzle. Mean followed by the same letter does not differ by Fisher - the 5% probability of Bonferroni

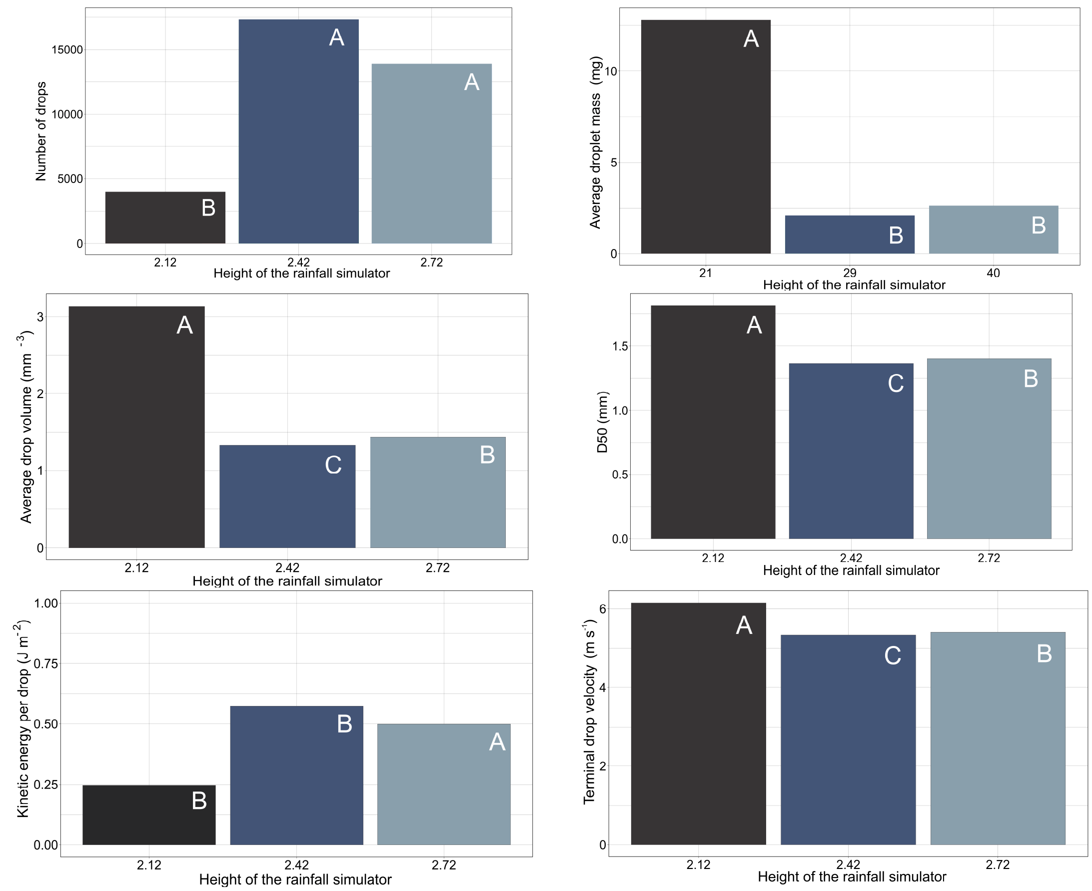

Fig. 4. Height of the rainfall simulator. Means followed by the same letter do not differ by the Fisher-Bonferroni test at 5% of error probability

In the height factor of the equipment, the droplets presented larger sizes at the lower height (2.12 m) (Fig. 4). However, the kinetic energy per unit area had an inverse behavior, showing higher values for higher equipment heights. There are larger drops, higher terminal velocity as the height of the spray nozzle decreases, and higher kinetic energy value per unit area as the height of the spray nozzle increases.

The range of drop sizes that can be observed was 1.2 mm to 3.1 mm, similar values were obtained in the experiment [40], using a rain simulator.

The terminal speed is directly related to the size of the drop (Eq. 2). The small drops are usually similar to natural speeds, to calm conditions vertical showers. Because the smallest heights of fall, the larger falls have smaller terminal velocity compared to drops of rain that fall naturally and reach your maximum speed between 5.1 m s^{-1} and 6 m s^{-1}. The terminal velocity is directly related to the droplet size (Eq. 2). Small droplet speeds are generally similar to natural speeds, for vertical rains in calm conditions. Due to the smaller fall heights, larger falls have lower terminal velocities compared to naturally occurring raindrops reaching their maximum velocity between 5.1 m s^{-1} and 6 m s^{-1}.

4. CONCLUSION

Able Image Analyser, ImageJ and Safira did not show any significant difference in counting of the number of drops. However, ImageJ software proved to be more suitable as a research tool, since it has the license of free use and greater ease of use.

With the calibration of the rainfall simulator, the produced drops presented the necessary standards so that the use of this equipment in water and soil loss practices may be valid.

Satisfactory results compared to natural rains are obtained in more than one combination of height and oscillation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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