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DEVELOPMENT OF A PORTABLE RAINFALL SIMULATOR

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ABSTRACT: Water erosion in agricultural production systems in Brazil is the main factor capable of making these systems unsustainable, as its environmental impacts are reflected in increase in production costs. The aim of this work was to build and evaluate a portable rainfall simulator, easy to handle and low cost for erosion evaluation. The rainfall simulator was built using the operating principles of simulator described by Souza (2004); however, a new angular movement transmission model for the linear movement of the sprinkler nozzle was developed. VeeJet 80.150 sprinkler nozzle was used, which oscillated 60 cycles per minute over the plot. Evaluation was carried out through the uniformity of the equipment's precipitation inside the plot, collecting the simulated rainfall in rain gauges distributed in the plot for a period of 2 minutes. Statistical Uniformity Coefficients obtained in rainfall simulator tests were considered adequate and indicate that there is good uniformity of droplet distribution. Data obtained from the evaluation allowed concluding that the simulator meets the basic requirements to serve as a tool for scientific research related to water erosion. Thus, the developed rainfall simulator meets the technical requirements established in literature and can be used in various works in agricultural and environmental sciences.

KEYWORDS: low cost, soil erosion, water erosion, simulated rainfall

DESENVOLVIMENTO DE UM SIMULADOR DE CHUVA PENDULAR PORTÁTIL

RESUMO: A erosão hídrica em sistemas de produção agrícola no Brasil é o principal fator capaz de tornar insustentáveis esses sistemas, já que seus impactos ambientais têm reflexos no aumento dos custos da produção. O trabalho teve como objetivo construir e avaliar um simulador de chuva pendular portátil de fácil manuseio e baixo custo para avaliação da erosão. O simulador de chuvas pendular foi construído utilizando os princípios de funcionamento do simulador descrito por Souza (2004), contudo foi desenvolvido um novo modelo de transmissão de movimento angular para movimento linear do bico aspersor. Utilizou-se um bico aspersor VeeJet 80.150, que oscilava 60 ciclos por minuto sobre a parcela. A avaliação se deu por meio da uniformidade da chuva precipitada do equipamento no interior da parcela, coletando-se a chuva simulada em pluviômetros distribuídos na parcela por um período de 2 minutos. Os Coeficientes de Uniformidade Estatístico obtidos nos testes do simulador de chuvas foram considerados adequados e indicam haver uma boa uniformidade de distribuição das gotas. Os dados obtidos a partir da avaliação possibilitaram concluir que o simulador construído atende aos quesitos básicos para servir de ferramenta para pesquisas científicas relacionadas à erosão hídrica. Dessa forma, o simulador de chuvas desenvolvido atende os requisitos técnicos estabelecido na literatura podendo ser utilizado em diversos trabalhos nas ciências agrárias e ambientais.

PALAVRAS CHAVE: baixo custo, erosão do solo, erosão hídrica, chuva simulada

INTRODUCTION

External agents, such as rainfall, have great influence on the physical behavior of the soil, having direct influence on soil losses through erosion processes. The correct soil management is essential for the improvement of agricultural production, as its inadequate use can result in the negative alteration of its properties, promoting its degradation (Neves Neto et al., 2013). Erosion is one of the main environmental problems with regard to soil degradation and the quality of water resources. In tropical countries, rainfall is the most important type of precipitation, due to its ability to produce erosion resulting from the impact of droplets on the soil and surface runoff (Alves Sobrinho et al., 2002). Water erosion in Brazil is the main factor capable of making agricultural production systems unsustainable, as its environmental impacts are reflected in increase in production costs (Faria Júnior et al., 2013).

The soil response to rainfall is essential for choosing the appropriate soil and water management system (Alves Sobrinho et al., 2002). Soil cultivation with mechanical mobilization and burning of plant residues increases the amount of sediments that are disaggregated and available for runoff transport (Bertol et al., 2010). Soils with traditional preparation and with little vegetation cover are more susceptible to water erosion, as this condition contributes to the formation of superficial sealing (Panachuki et al., 2011). However, in systems such as no-tillage and pasture under proper management, the formation of larger and more stable aggregates is favored, which increases soil resistance to erosion (Engel et al., 2009). The use of perennial grasses in integrated crop-livestock systems, intercropped, in succession or rotation with annual crops, can minimize soil degradation due to the beneficial effect of these grasses on the soil physical attributes (Beutler et al., 2016).

Some works related to soil and water losses have used devices that simulate rainfall in order to quantify the real potential of agricultural conservation practices in view of the most diverse scenarios of rainfall intensity and surface slope (Eltz, 2001). Rain simulators are equipment that apply water via sprinkler, thus being able to control the rainfall intensity on soil plots under study, which are smaller than 1.0 m² (Abudi et al., 2012; Iserloh et al., 2012). Simulators with pressurized spray nozzles generate droplets that impact the soil at high speeds and thus with higher rainfall intensities, which are more common in natural rainfall (Corona et al., 2013; Lora et al., 2016). This type of equipment has been used in soil management studies since 1930 (Hudson, 1993; Souza, 2004) and is widely accepted in soil erosion studies (Sachs and Sarah, 2018). However, the results of rainfall simulators cannot be easily compared due to significant differences in the structure of simulators, size of precipitation areas, types of nozzles, and size and height of droplets (Mayerhofera et al., 2017).

One of the most important aspects that need to be evaluated in a rainfall simulator, among other factors, is the uniformity of precipitation distribution and the repeatability of tests (Vergni et al., 2018). According to Spohr et al. (2015) in infiltration and runoff studies, it is not necessary that simulated rainfalls have exactly the same characteristics as natural rainfalls. Regarding the necessary plot size for tests with erodibility studies, when different types of soil cover are compared, small plots may be more adequate (Hudson, 1993). Among variables commonly measured in rainfall simulators, infiltration, runoff and sediment production stand out, both in the field and in the laboratory (Corona et al., 2013). Therefore, the consolidation of clear constructive rainfall simulator methodologies helps quantifying the real impacts associated with water erosion. Furthermore, they contribute to determine the real benefit of conservation practices, widely disseminated in literature, but which have been poorly evaluated in several rainfall intensity scenarios.

The aim of this work was to build and evaluate a portable rainfall simulator, easy to handle and low cost for application in sedimentology research.

MATERIAL AND METHODS

The portable rainfall simulator was developed at the “Instituto Federal Goiano” Campus Iporá, according to the operating principles of simulators described by Souza (2004). This equipment was designed to meet the following requirements: (a) portability, easy assembly and operation; (b) ability to reproduce rainfalls with varying intensities and; (c) ability to produce uniformly distributed rainfall in the experimental area. The simulator was built using metallic support structure and anchorage to the ground; low-speed electric motor (used in sliding gates) welded to a crown and a rod to transfer angular movement into linear movement; flexible hoses; Veejet 80.150 adjustable sprinkler nozzle (Montebeller et al., 2001; Alves Sobrinho et al., 2002; Faria Júnior et al., 2013); and a motor-pump set to pressurize the system.

The equipment support consists of a rectangular-shaped frame of 1.00 m in width by 2.00 m in length (Figure 1), supported by four legs at height of 3.00 meters above the soil surface (Figure 2). At the center of the frame, adjustable Veejet 80.150 spray nozzle from the Spraying System Company was placed, which was positioned at height of 2.00 m in relation to the soil surface in order to provide proper droplet velocity (Figure 3). The Veejet 80.150 nozzle is more suitable for rainfall intensity above 40 mm h^{-1}, while the Veejet 80.100 nozzle can be used to simulate rainfall with intensity up to 40 mm h^{-1} (Alves Sobrinho et al., 2002).

Figure 1. Top view of the rectangular-shaped support structure, with low-speed motor positioned at the center of the structure, as well as the angular to linear movement transfer mechanism.

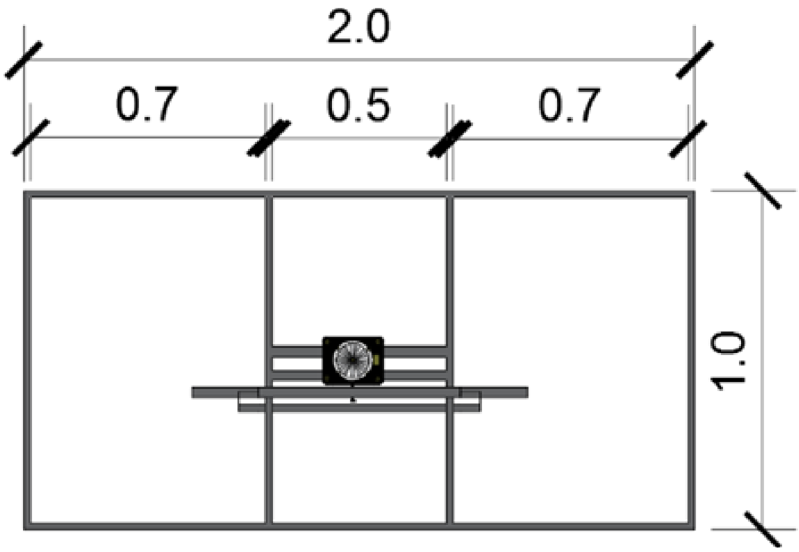
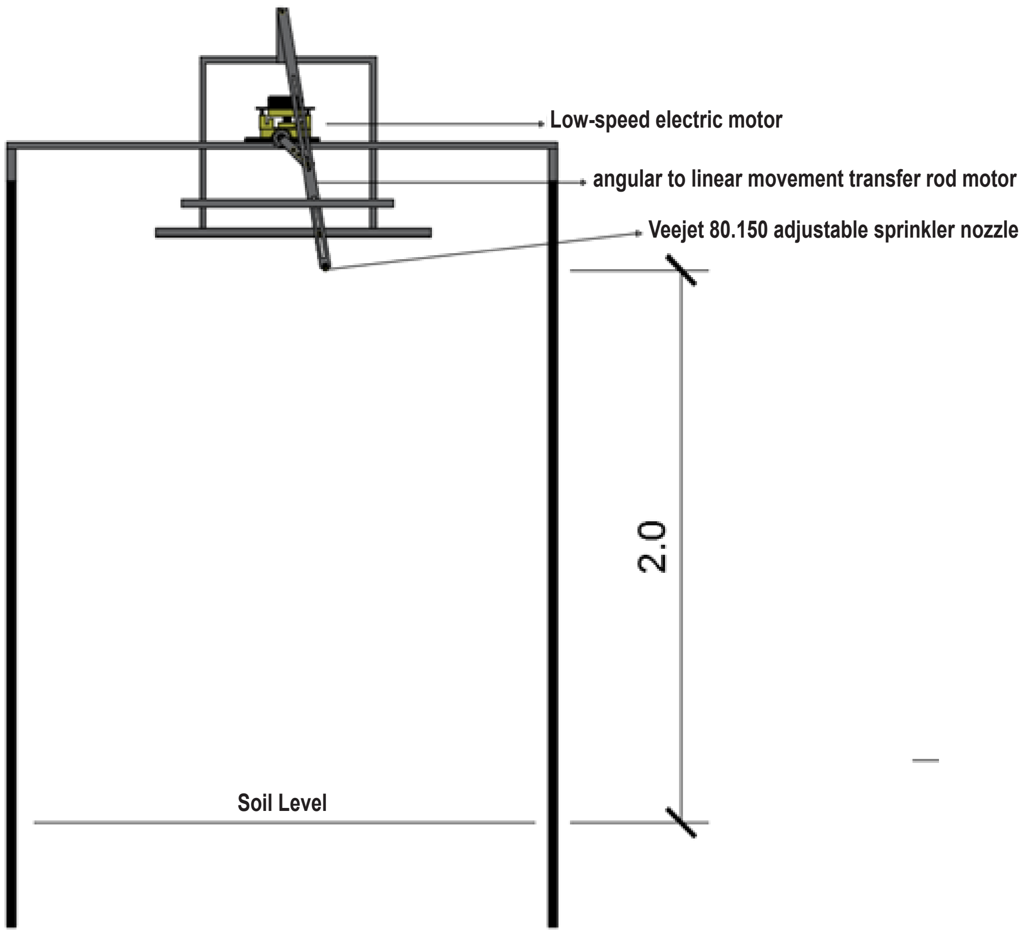


Figure 2. Front view of the rainfall simulator with the position of the sprinkler nozzle at the center of the structure at distance of 2.0 from the soil, which performs a pendulum movement under the experimental plot.



Ciência Agrícola, Rio Largo, v. 19, n. 1, p. 17-24, 2021

Figure 3. Front view of gears and cranks for converting angular movement into linear movement of the system for nozzle oscillation.

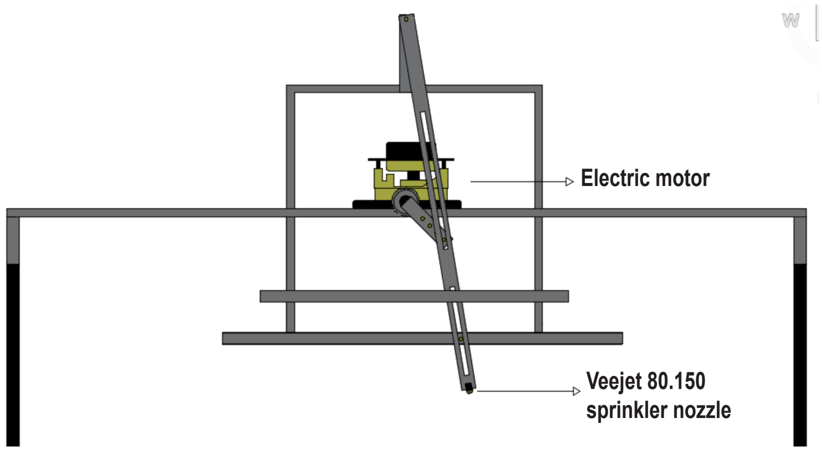


Figure 4. Rainfall simulator assembled for the sprinkler nozzle uniformity test.

The simulator is portable to facilitate transport and assembly in the field. The water supply was an independent reservoir pressurized by a motor pump (Schneider MBI^{-1}) with constant flow and pressure adjusted by means of a pressure gauge. The connection between the motor pump and the injection nozzle was made by means of a flexible hose with diameter of 25 mm. In operation, the nozzle oscillated over an area of 1.00 (one) square meter, isolated from the rest of the plot by a delimiter, and the number of oscillations was controlled by a mechanical system, with approximately 60 oscillations per minute. A set of gears and sliding cranks transformed the angular movement, carried out by a low-speed motor, into linear movement, causing the nozzle attached to the rod to move like a pendulum.

Two preliminary calibrations were carried out to adjust the rainfall simulator parts, such as positioning and fixing the sprinkler nozzle and adjusting the nozzle stroke to improve the performance of the oscillator. After adjustments to the nozzle oscillator, the precipitation test of the rainfall simulator was performed. To estimate the uniformity of the precipitation distribution, the square of 1.00 x 1.00 m in area below the nozzle was divided into three sections of 0.33 x 1.00 m each. In each section, two plastic collectors of 13.50 cm in diameter were placed on the soil surface (Figure 4). The nozzle was positioned at height of 2.00 m and submitted to three different pressures of 50; 100; 150 kPa. Three repetitions were performed for each pressure, each repetition lasting 2 minutes (Alves Sobrinho et al., 2002). In each test, the average water precipitation intensity was determined by the relationship between the average water depth obtained in collectors and the application time. The Wilcox-Swailes Statistical Uniformity Coefficient - CUE (1947) was used to assess the precipitation uniformity provided by the simulator, as presented in equation 1:

$$CUE = 100\left(1-\frac{S_q}{\bar{q}}\right) = 100\,(1 - CV_Q)$$

where, $\bar{q}$ the average applied flow, S_q is the standard deviation of flows in relation to the mean and CVq is the coefficient of variation of the flow.

RESULTS AND DISCUSSIONS

The equipment and the methodology used proved to be sensitive for evaluating intensity and uniformity of precipitation distribution. Initially, after assembling the rainfall simulator, distribution uniformity tests were carried out using different service pressures (50, 100 and 150 kPa).

The average volumes obtained during tests performed are shown in Table 1; the sampling indicated that the water collectors located more on the edge of the simulator had higher precipitation values. This was due to a stoppage of the sprinkler nozzle at the end of the stroke, which may have reduced precipitation uniformity. Spohr et al. (2015) evaluated a portable rainfall simulator and observed greater water volume deposited at the central region of the area occupied by collectors, a situation in which they found uniformity coefficient below recommendation. After reducing the nozzle contribution area, the same authors found CUE of 80.7% for precipitation of 116 mm h^{-1}. Faria Junior et al. (2013) also found different volumes in collectors in all evaluated rainfalls, but this effect was reduced with the increase of rainfall time. The authors attribute this behavior to the fact that the nozzle used is of flat fan type, which tends to sprinkle greater amount of water into two centers of greater droplet distribution that are located over them.

Table 1. Volumes obtained for each pressure during the three repetitions (R1, R2, R3) for a period of 2 minutes, mean of volumes and standard deviation in relation to the mean.

	Pressure 50 kPa	Pressure 100 kPa	Pressure 150 kPa
Mean volume R1 (ml)	375.0	462.67	468.33
Mean volume R2 (ml)	372.5	429.17	511.67
Mean volume R4 (ml)	392.5	438.33	510.00
Mean	**380.0**	**431.39**	**496.67**
Standard deviation	**60.42**	**68.51**	**73.88**

Figure 5 shows increase in the dispersion of collected water depths values (ratio between the collected volume and the area of contribution of the collector) as the test pressure increased. Alves Sobrinho et al. (2002) evaluated the same nozzle in a rainfall simulator with overlap and observed that with higher rainfall intensities (around 1500 mm h^{-1}), lower uniformities were obtained. After reducing the rainfall intensity (around 300 mm h^{-1}), the authors found uniformities close to 87%. What could have occurred was the choice of very high pressures for carrying out the tests, a fact that was caused by the high power of the motor pump used. According to Alves Sobrinho et al. (2002) for the Veejet 80.150 nozzle, the ideal pressure, the one that presented the greatest uniformity, was 35.60 kPa. For higher pressures, the 80.150 nozzle will present higher uniformity coefficients (Montebeller et al., 2001); however, the authors studied pressure range from 13 to 34 kPa, corroborating the idea that very high pressures were used and that lower-power pump should be used.

The increase in pressure caused increase in rainfall intensity in the order of 796.43; 904.13 and 1040.95 mm h^{-1}, respectively (Table 2). The variation in service pressure generated maximum variation of approximately 18.84% in rainfall intensity, which value is a little higher when compared to that found by Spohr et al. (2015), which was 17.3%. The same authors reported that this amplitude in intensity is small to be used in field tests with rainfall simulator. The mean CUE value observed at the three pressures was equal to 84.45% (Table 2).

Figure 5. Box-plot with median, maximum, minimum, values at 25% and 75% of water depths observed in each of the 3 experimental sections, for 3 pressures.

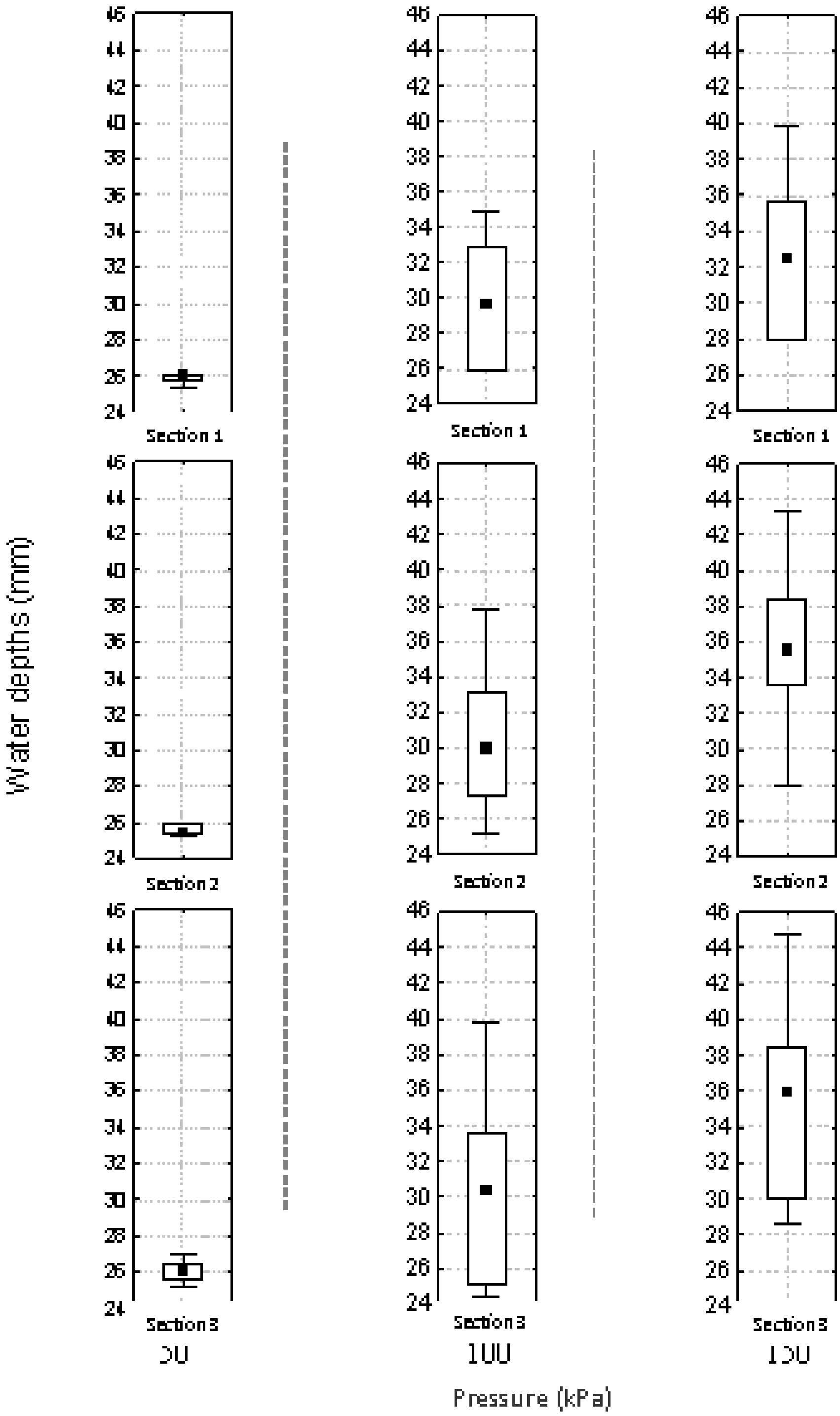


Table 2. Average rainfall calculated from values obtained for each pressure, CUE values and criteria regarding the performance of the sprinkler nozzle.

Pressure	Mean rainfall intensity	CUE	CUE Acceptance Criteria [a]
kPa	mm/h	%	
50	79.43	84.10	Very good
100	904.13	84.12	Very good
150	1040.95	85.12	Very good
Mean	**913.84**	**84.45**	
Standard deviation	**172.19**		

[a] Frizzone et al. (2012)

Faria Junior et al. (2013) evaluated the same nozzle in a rainfall simulator, but with different oscillation mechanism, and found uniformity coefficients above 95%. Alves Sobrinho et al. (2002) evaluated the Veejet 80.150 nozzle with overlapping nozzles and found Uniformity Coefficient values between 81 to 83% for rainfall above 1500 mm h^{-1}. Several researchers consider uniformity coefficient values above 80% acceptable for water distribution in simulators (Montebeller et al., 2001). For a rainfall simulator, the 80.150 nozzle must work with service pressures above 27.2 kPa and rainfall intensity below 160 mm h^{-1} (Montebeller et al., 2001).

The equipment was built so that its assembly and disassembly in the field are carried out by three people. The use of rain simulators in field works often comes up against the difficulty of transporting them to distant locations. (Spohr et al., 2015). In the case of the developed simulator, a lightweight and portable equipment was built, so that it can be easily transported in a passenger vehicle. The front view of the rainfall simulator, showing the drive system, transmission mechanism, water application system and equipment structure, is shown in Figure 2.

The rainfall simulator developed enables determining the runoff in an experimental plot of 1.00 m^2. The lower and upper parts of the structure must be assembled separately. In the sequence, the lower part must be assembled by burying the feet of the structure in the ground and then, the drive system and water application must be attached to the upper part of the structure. When assembling the rainfall simulator in the field, the nozzle must be positioned at height of 2.00 m from the soil and centered in relation to the useful rainfall area of 1.00 m^2. The area of the experimental plot is surrounded by a rectangular-shaped device constructed of galvanized steel plates, to allow the determination of the water volume drained on the surface. It is important to emphasize that in places where the rainfall simulator will be used, there must be an easily accessible water source. Thus, it is possible to use the rainfall simulator in the most diverse conditions and places.

Based on the results of this study, it was observed that the equipment developed meets the basic technical requirements to serve as a tool for scientific research in the area of water erosion. The rainfall simulator presented satisfactory performance and meets the validation criteria established in literature, that is, statistical uniformity coefficient greater than 80% for useful plot of 1.00 m². The rainfall simulator developed is easy to build, maintain and operate. In addition, it is lightweight, portable and easy to transport, allowing its use in different places.

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