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InfiAsper: a rainfall simulator with varying precipitation intensity to assess soil erosion

InfiAsper: um simulador de chuva com intensidade de precipitação variável para avaliar a erosão do solo

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A B S T R A C T

Research involving the use of rain simulators dates to 1930. Since then, the evolution of this equipment has made it increasingly accessible, practical, and accurate. Its applications include the assessment of the impacts of water erosion on soil degradation as a function of land use and occupation and the rate of water infiltration into the soil. The reproduction of the rainfall pattern by varying the intensity of precipitation is one of the main limitations of the use of simulators. However, the recent modification in *InfiAsper* (Macedo *et al*., 2021) allows instantaneous varying the intensity of rainfall application and provides high uniformity in rainfall of different patterns.

Keywords: Rainfall simulator, Soil erosion process, Soil water infiltration.

R E S U M O

As pesquisas envolvendo o uso de simuladores de chuva datam de 1930. Desde então, a evolução desse equipamento o tornou cada vez mais acessível, prático e preciso. Suas aplicações incluem a avaliação dos impactos da erosão hídrica na degradação do solo em função do uso e ocupação do solo e da taxa de infiltração da água no solo. A reprodução do padrão pluviométrico variando a intensidade da precipitação é uma das principais limitações do uso de simuladores. No entanto, a modificação recente no *InfiAsper* (Macedo *et al*., 2021) permite variar instantaneamente a intensidade de aplicação das chuvas e proporciona alta uniformidade nas chuvas de diferentes padrões.

Palavras-chave: Simulador de chuvas, Processo de erosão do solo, Infiltração de água no solo.

INTRODUCTION

The use of rainfall simulators (RS) in the investigation of soil erosion dates to 1930. Since then, the evolution of this equipment has made it increasingly accessible, practical, and precise (Alves Sobrinho *et al*., 2008; Carvalho *et al*., 2022). Its applications include assessing the impacts of soil erosion as a function of land use and land cover (Almeida *et al*., 2016) and soil water infiltration rate (Almeida *et al*., 2018; Moraes *et al*., 2020), as well as assisting in the calibration of hydrological models for erosion estimation.

Studies with RS have numerous advantages, such as the reduction of time and costs required to obtain the results and the repeatability of precipitation, the elimination of the erratic and unpredictable variability of natural precipitation, which allows a better evaluation of the factors influencing the process (Alves Sobrinho *et al*., 2008; Iserloh *et al*., 2013).

The *InfiAsper* simulator, developed by Alves Sobrinho *et al*. (2008) is composed of five independent modules, which facilitate transport and operation in the field. It has two fixed spray nozzles (Veejet 80.150 model), which must be positioned 2.30 m above the ground during operation. The nozzles are located above the overlapping shutter disks, whose rotation is set by the input frequency of the shutter motor, using the frequency inverter installed on the panel of the precipitation simulator.

Most RS works with constant rainfall intensity (RI), which does not represent the characteristics of natural precipitation and can lead to differences in soil and water loss studies. However, Macedo *et al*. (2021) developed an automatic RI control system for *InfiAsper* by adjusting the rotation of the shutter disk to allow for RI variation. The authors created an electronic control system that changes the frequency of the motor power inverter, allowing the user to enter the desired precipitation pattern via a text file, stored on a micro-SD memory card.

Here, we present the innovations of *InfiAsper* in the last 14 years and some results obtained from using it to assess soil erosion and soil water infiltration under different conditions of land use, land management, and land cover, in the field, in Brazil.

MATERIAL AND METHODS

The *InfiAsper* simulator (Figure 1) operates with two Veejet 80.150 nozzles parallel to each other, installed at a height of 2.3 m above the ground and with a service pressure of 35.6 kPa. The micro-plots have an area of 0.7m^2 and are delimited by galvanized steel plates, with a funnel at the end, which allows collecting the volume of surface runoff (Alves Sobrinho *et al*., 2008; Almeida *et al*., 2018; Macedo *et al*., 2021).

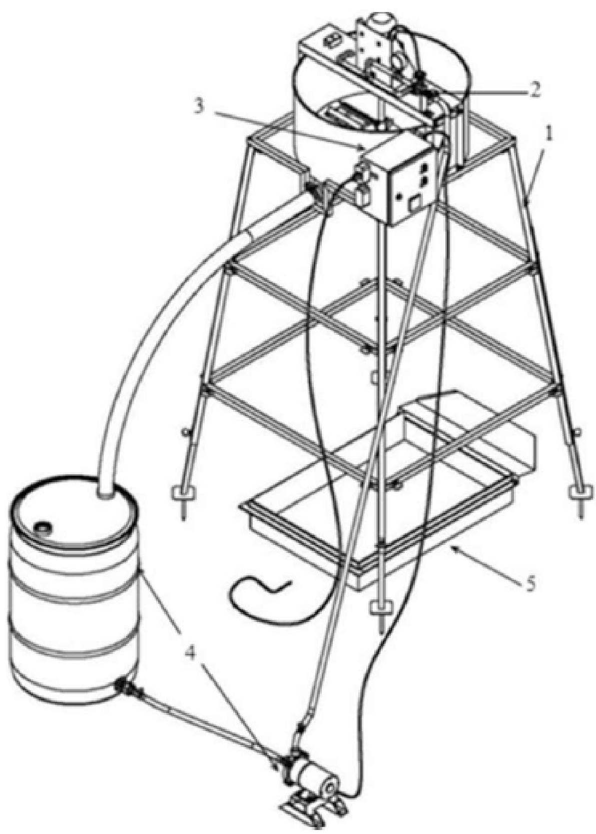

Figura 1 - Scheme of the components of the *InfiAsper* rainfall simulator (Legend: metallic structure (1); water application unit (2); control panel (3); reservoir and water pump (4); and runoff collector (5). Source: Macedo *et al*. (2021).

To demonstrate the use of *InfiAsper* in soil erosion assessment, we will present results from two studies done with the equipment in the field. In the first, Almeida *et al*. (2018) evaluated the effect of soil tillage and soil cover on soil water infiltration by measuring this parameter in areas under bare soil, soybean (conventional tillage and no-till), and pasture. The experimental design was completely randomized, arranged in subdivided plots (in time – 6 evaluation periods), with four repetitions for treatment. The predominant soil in the area is an *Argissolo Vermelho Distrófico típico* (Santos *et al*., 2018) (Dystric Acrisol with a sand loam texture, 0.0-0.24 m) (IUSS Working Group WRB, 2015). The depth of water infiltration (DWI) was estimated by the difference between the artificial rain and the surface runoff (SR). The SR was calculated each minute through the relation between the volume of water and the experimental plot area. The infiltration rate was calculated by the relation between the DWI and the considered sampling time. The stable infiltration rate (SIR) of water in the soil was obtained when the SR remained constant (Almeida *et al*., 2018).

In the study by Carvalho *et al*. (2022), the authors evaluated the *InfiAsper* operating with a new control panel to program rainfalls with different RI. Infiltration rates and soil and water losses were evaluated in a *Argissolo Vermelho-Amarelo Distrófico típico* (Santos *et al*., 2018) (Dystric Acrisol with a clay loam texture) (IUSS Working Group WRB, 2015) with simulated rainfalls of 30 mm and duration of 40 min, considering advanced (AD), intermediate (IN), delayed (DE), and inverted intermediate (II) patterns, all with PI peaks of 110 mm h^{-1}, and a constant (CT) pattern. The experimental design was in randomized blocks with five treatments and five repetition each.

In both studies, we verified the normality and homogeneity of the residuals using the Shapiro-Wilk (Shapiro & Wilk, 1965) and Bartlett's (Bartlett, 1937) tests, respectively. When a significant difference was confirmed in the analysis of variance, we compared the means of the treatments using the Scott-Knott (Scott & Knott, 1974) grouping test, considering a significance level of $p < 0.05$. We use R language (R Core Team, 2021) to do all the analysis and data plotting.

RESULTS AND DISCUSSION

The stable infiltration rate (SIR) in the soybean no-tillage system is higher than in the other systems at 40 days after planting. In addition, SIR values in bare soil and soybean under conventional tillage systems were iqual (Table 1).

Table 1 - Stable infiltration rate (mm h^{-1}) in the systems (BS, SCT, SNT and PA) at six evaluation stages

Management systems	Stable infiltration rate (mm h^{-1}) in the systems (BS, SNC, SNT and PA) at six evaluation stages					
	0 DAS	20 DAS	40 DAS	60 DAS	80 DAS	100 DAS
BS	26.71 b	16.14 b	14.29 b	22.93 b	14.29 c	5.71 c
SCT	23.43 b	15.29 b	20.14 b	19.07 b	24.00 b	13.42 c
SNT	46.39 a	33.36 a	39.36 a	52.79 a	54.21 a	47.82 a
PA	53.71 a	34.79 a	33.79 a	30.33 b	31.86 b	29.52 b

Stable infiltration rate (mm h^{-1}) in the systems BS = bare soil; SCT = soybeans cultivated in conventional tillage; SNT = soybeans cultivated in no-tillage; and PA = pasture, during the six evaluation stages (0, 20, 40, 60, 80 and 100 days after soybean sowing. (Scott Knott, $p < 0.05$).

According to Almeida *et al*. (2018), the SIR in the SNT and PA systems did not differ among the stages 0, 20 and 40 days after sowing (DAS). In these two treatments, the SIR is greater than in the other treatments. From 60 DAS on, the no-tillage SIR is significantly greater than in the other treatments. On the other hand, between the two conventional tillage systems, with disturbed soil, (BS and SCT), the SIR differed at 80 DAS when the soybean proportionated greater vegetal cover in the SCT, therefore, favoring water infiltration in the soil. At this stage, the highest percentage of soybean cover in the SCT tend to promote a high soil water infiltration in this system, such as reported by Almeida *et al*. (2016).

Carvalho *et al*. (2022) did not verify surface runoff associated with the simulated rainfall under the CT and II patterns. For the other patterns, the time to start runoff (TSR), the runoff ending time (RET), and the maximum runoff rate (MRR) varied with the PI peak, and their values were significantly different from each other (Table 2).

Table 2 - Mean values and respective standard deviations of the time to start runoff (TSR), the runoff ending time (RET), and the maximum runoff rate (MRR

Treatment	TSR (min)	RET (min)	MRR (mm h^{-1})
Advanced	7.40 ± 1.52 c	22.60 ± 5.18 c	24.62 ± 10.83 b
Intermediate	16.40 ± 1.67 b	38.60 ± 4.22 b	46.48 ± 19.97 a
Delayed	23.00 ± 4.69 a	43.40 ± 1.82 a	56.23 ± 13.13 a

Mean values followed by different letters, in the column, represent significant statistical differences between them ($p < 0.05$).

Differences regarding TSR and RET are associated with the PI peaks that characterize the precipitation patterns. On the other hand, MRR values vary according to surface conditions and soil moisture in the superficial layers. The MRR in DE pattern was 2.28 times higher than in the AD pattern.

For Macedo *et al*. (2021) and Carvalho *et al*. (2022), the new modified simulator panel, built with a friendly interface, allows the selection of the desired rainfall pattern and operating mode (manual or automatic). After modification of *InfiAsper*, the simulated precipitation had an application uniformity higher than 75%, used as a prerequisite in field-generated soil erosion, infiltration, and runoff studies.

CONCLUSIONS

Regardless of the soil tillage, soil ground cover, or rainfall intensity used (considering the efficiency range that the equipment works properly), *InfiAsper* performs very well in assessing soil water infiltration and soil erosion.

With the modification made by Macedo *et al*. (2021), *InfiAsper* can be used in various applications to fill many old gaps in the comparison of simulated rainfall with natural rainfall through the instantaneous variation of rainfall intensity and the reproduction of natural rainfall.

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