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Performance assessment of a microsprinkler

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ABSTRACT. Surface hydrological processes are essential to the understanding and prediction of soil erosion. Several equipments are used to measure infiltration rate, runoff and soil loss. However, researchers build their own equipment due to the specific sites where the measurements are performed. This study evaluated the performance of a microsprinkler developed to measure the hydrological processes on unpaved rural roads. The microsprinkler is portable, lightweight, easy to operate, and also low cost. The measured parameters refer to different physical aspects of the rainfall produced as: intensity, drop size, kinetic energy and the simulation area. The microsprinkler was tested at different heights and pressures. The main results obtained: the intensity of simulated rainfall was 71.4 - 148.3 mm h^{-1}, the drop size ranged from 0.3 to 1.2 mm (mean 0.7 mm), the kinetic energy of rainfall varied between 51 and 77% compared with a natural rainfall of similar intensity, and the simulation area had 0.28 - 0.56 m^2 (mean 0.40 m^2). The parameters obtained in this study are within the limit of others simulators reported in the literature.

Keywords: geomorphology, experimental, prototype, simulated rainfall, soil erosion.

Avaliação de desempenho de um microaspersor

RESUMO. Os processos hidrológicos superficiais são fundamentais para o entendimento e predição da erosão do solo. Diversos equipamentos são utilizados para medir taxa de infiltração, escoamento e perda de solo. Todavia, as particularidades de sítios onde são realizadas as mensurações fazem com que pesquisadores construam seus equipamentos de pesquisa. O objetivo deste estudo é avaliar o desempenho de um microaspersor desenvolvido para mensurar processos hidrológicos superficiais em estradas rurais não pavimentadas. O simulador desenvolvido é portátil, leve de fácil operação e baixo custo. Os parâmetros avaliados referem-se a diferentes aspectos físicos da chuva produzida como: intensidade, tamanho de gota, energia cinética e área de molhamento. O microaspersor foi testado em diferentes alturas e pressões de trabalho. Os principais resultados obtidos com o microaspesor foram os seguintes: intensidade da chuva simulada entre 71,4 a 148,3 mm h^{-1}; o tamanho da gota produzida variou entre 0,3 a 1,2 mm (média 0,7 mm), a energia cinética da chuva variou entre 51 a 77% em comparação a uma chuva natural de mesma intensidade e o tamanho da área de molhamento ficou entre 0,28 a 0,56 m^2 (média de 0,40 m^2). Os parâmetros obtidos estão dentro do limite de simuladores reportados na literatura.

Palavras-chave: geomorfologia, experimentação, protótipo, chuva simulada, erosão do solo.

Introduction

Surface hydrological processes are fundamental to the understanding and prediction of soil erosion. Even at fine scale hydrological conditions of top soil need to be better understood, since are still sources of uncertainty both in measurements and in modeling of this process (AUZET et al., 2002).

Given the relevance of infiltration, various measurement techniques are used to estimate this process. Among the techniques are the single ring infiltrometer, double ring infiltrometer (REICHARDT, 1990), closed plot (MORGAN, 2005) and rainfall simulator (MEYER, 1994).

The techniques to measure infiltration usually include advantages and disadvantages. Infiltrometers are relatively inexpensive and easy to operate, however, may overestimate the infiltration rate (BRANDÃO et al., 2006).

Sidiras and Roth (1984) verified that the infiltration rate measured with ring infiltrometer was on average 9 fold higher than rates obtained with rainfall simulator. Closed plots (eg 1 m^2) provide a good and realistic estimate of infiltration to monitor rainfall with different physical characteristics over a period of time. Nevertheless, its handling is laborious, since the collection of runoff must occur after each event or at least within a 24-hour period (CASTRO et al., 1999; THOMAZ, 2007). In addition, it requires a reasonable number of repetitions to represent the pattern of infiltration of an area and can also be damaged by vandalism.

In turn, rainfall simulators are diverse in relation to the size, physical characteristics of simulated rainfall and simulation area, as well as the costs involved in the construction. The rainfall simulator began to be used in the study of infiltration in 1938 in the U.S., and the construction and application of this equipment grew significantly from the 1970s (CERDÀ, 1999). For this reason, many simulators are constructed to meet specific needs of simulation (AGASSI; BRADFORD, 1999; ALVES SOBRINHO et al., 2002; CERDÀ, 1999; MEYER, 1994).

In recent decades, the hydrological and erosion studies have been extended beyond the fields of crops and pastures. There is an increase in studies on rural roads and forested areas, due to their importance in runoff and sediment yield (LUCE; WEPLE, 2001; JORDÁN; MARTÍNEZ-ZAVALA, 2008; SHERIDAN; NOSKE, 2007). Therefore, equipment for the simulation on road must meet the specificities of this site (e.g. road width ≈ 4.0 m, vehicle movement during the simulation, compaction of the rodbed, impossibility to maintain tool for monitoring, among others).

In this way, the goal of the present study was to evaluate the performance of a microsprinkler developed to measure surface hydrological processes on unpaved rural roads. The evaluated parameters refer to different physical aspects of the rainfall produced as intensity, drop size, kinetic energy, and rainfall simulation area.

Material and methods

Structure of the equipment

The structure of the microsprinkler consists of a 20 mm diameter metal tube, and a minimum height of spray of 0.90 m, which can be extended up to 1.50 m. The microsprinkler arm is supported by a metal tube with 15 mm in diameter and 1 m in length supported at one of its ends for fixing the sprinkler nozzle (Figure 1). The structure facilitates adjustments before and during the procedure, since the joint is formed by extenders adjustable and firmly attached by thumbscrews.

In this prototype we used a nozzle (S.S.co. 1/8 GG *full jet*) manufactured by Spraying System. The water supply is done through an automotive fuel pump with maximum working pressure of 3.0 bars. After using, the pump should work with appropriate fuel (kerosene, gasoline or alcohol) to remove water from inside and prolong service life. The power supply to the pump is conducted through an automotive battery, connected directly to an automobile. The control of the pressure exerted by the pump is made by a manometer. The water supply of the simulator is made by a reservoir with a capacity 100 liters of water. Costs of components are described in Table 1.

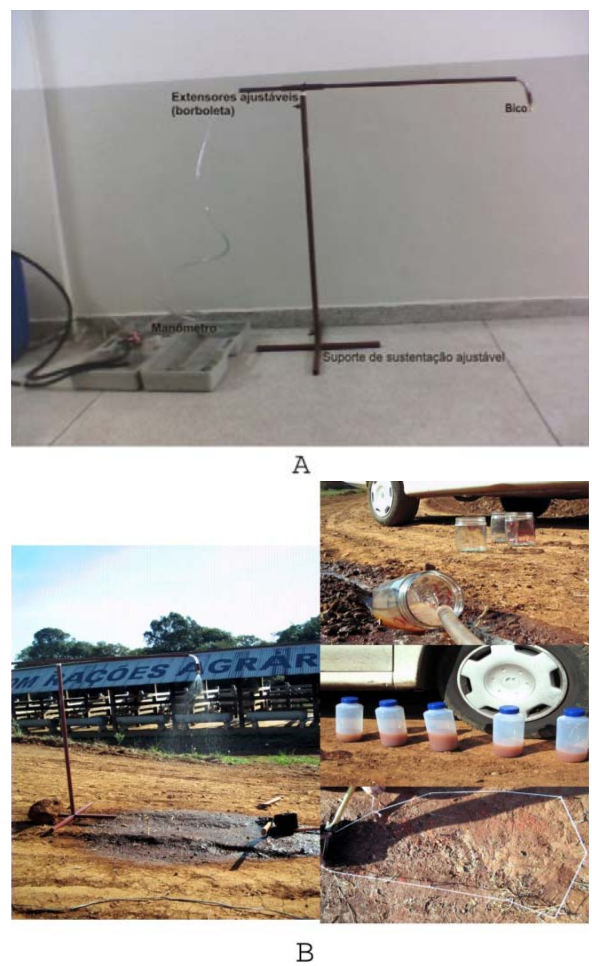

Figure 1. a) Characteristics of the microsprinkler; b) Microsprinkler in service.

Table 1. Estimated cost of components of the equipment[1].

Components	Estimated value (R$)
Nozzle (1/8 GG *full jet*)	180.00
Tripod for support (material and manpower)	145.00
Reconditioned fuel pump[2]	150.00
Manometer, raingauge and manpower	150.00
Barrel (100 L)	25.00
Total	650.00

Note: [1]The material for the development of the equipment was purchased in 2003, adjusted to current values by variation of the IGP-M. [2]The fuel pump can be achieved by much lower value in repair shops.

Physical characteristics of the sprinkling

Intensity

The estimate of the rain intensity was obtained by means of the arrangement of five pluviometers with average area of 0.007764 m² below the sprinkler nozzle on the rainfall simulation area. The pluviometers were distributed at a spacing of 15 cm from each other. The water was collected for one minute, and then to obtain the intensity rate in mm h^{-1} we used the Equation 1 described by Ribeiro et al. (2007). Five replicates were performed to obtain the average intensity at pressures of 0.5 bar, 0.75 bar and 1.0 bar. The intensity was estimated in the heights of 0.9 m and 1.2 m.

$$I = \frac{V/S}{t} \times 60 \quad (1)$$

where:

I = rainfall intensity (mm h^{-1})
V= volume of water collected (L)
S= section area of the collecting container (m²)
t = time of collection (minutes)

Size and quantity of drops

The size and number of droplets produced by the simulator were evaluated using the flour method described by Eigel and Moore (1983). Thus, Petri dishes containing flour were prepared and positioned below the sprinkler nozzle. The dishes were kept in the same positions of the pluviometers previously used to obtain the intensity rates.

After arranging the plates, the simulator was turned on with a beaker below the sprinkler nozzle in first instants until stabilization of sprinkling. Subsequently, the beaker was quickly removed and placed again to collect the drop samples in the plates.

After sampling, dishes were taken to the laboratory for evaluation of droplet size. The drops were evaluated using a microscope connected to a computer, in which the samples could be amplified and measured using the software *ImageJ*®. The drops were magnified seven times from their original size, for better observation and measurement. To estimate the average size of the droplets were measured at random about 15 drops into each Petri dish to obtain the average size of the droplets.

The estimated number of drops was performed using the same samples collected for measurement of droplet size. For counting the drops, five random points restricted to 0.5 cm² were considered in each Petri dish. All drops contained in this area were counted to obtain a mean value. From this mean value of drops in each area of 0.5 cm² per plate we estimated number of drops per square meter.

Kinetic energy

The kinetic energy of the drops produced by the microsprinkler was estimated using the equation 2, as described by Hudson (1993). The drop mass was estimated by equations 3 and 4. To obtain the volume of droplets we used the equation 5, described by Pessoa and Chain (1999). The final speed of the drop was estimated by the equation 6, as described by Halliday et al. (2006).

The initial speed of fall of the drop was estimated using the equation 7, described by Amorim et al. (2001). The discharge coefficient is the ratio between the actual flow, and theoretical flow, in this case was adopted the value of 0.61, once according to Azevedo Netto and Alvarez (1973) this is the average value adopted for solving practical problems.

$$E.c = \frac{1}{2} \times mv^2 \quad (2)$$

where:

E.c = Kinetic energy (J m^{-2})
m = Specific mass of water (kg m^{-3})
v = Speed of the drop (m s^{-2})

$$d = \frac{m}{v} \quad (3)$$

where:

d = density (kg m^{-3})
m = Specific mass of water (kg m^{-3})
v = volume (m³)

$$m = dV \quad (4)$$

where:

m = Specific mass of water (kg m^{-3})
d = density (kg m^{-3})
V = volume (m³)

$$V = \frac{4}{3} r^3 \quad (5)$$

where:

V = volume (m³)
r = radius of the drop (mm)

$$v = v_0^2 2gS \quad (6)$$

where:

v = final speed (m s^{-1})
v_0 = initial speed (m s^{-1})
g = gravity (m s^{-2})
ΔS = drop height (m)

$$v_0 = Cd \frac{2gP}{\gamma} v_o \quad (7)$$

where:

v_0 = initial speed (m s^{-1})
Cd = Discharge coefficient (dimensionless)
g = gravity (m s^{-2})
P = working pressure (kPa)
γ =specific weight of water (N m^{-3})

Rainfall simulation area

The simulation area of the sprinkler was estimated at two heights: 0.9 m and 1.2 m, considering the area a perfect circle because there is only one sprinkler nozzle. After the simulation, the area was marked on the ground surface, and the perimeter easily delimited. Thus, we measured the diameter of the circle with a measuring tape, and then we applied the equation 1. In total 15 replications were performed to obtain the average area produced by the sprinkler at two heights, 0.90 and 1.20 m.

Results and discussion

Intensity of simulated rainfall

In tests of sprinkling intensity, we used the following levels of pressure: 0.5 bar, 0.75 bar and 1.0 bar (Table 2). The pressure of 0.25 bar was ruled out by spraying water only to the central area below the nozzle, showing no satisfactory distribution of simulated rainfall.

Table 2. Intensity of simulated rainfall (mm) at different heights and pressures.

Test	Height					
	0.9 m			1.2 m		
	Pressure			Pressure		
	0,5 bar	0,75 bar	1 bar	0,5 bar	0,75 bar	1 bar
1	128.8	140.5	132.7	83.8	77.6	110.2
2	102.5	125.7	148.3	88.5	108.7	93.2
3	107.9	132.0	132.0	72.9	116.4	96.2
4	114.9	124.2	125.0	80.7	100.9	90.0
5	124.2	123.4	128.8	71.4	99.3	99.3
Mean	115.7A	129.2B	133.4B	79.5A	100.6B	97.8B
Standard deviation	10.9	7.2	8.9	7.2	14.5	7.8

Note: Same letters are not significantly different at 5% by F-test (least significant difference 5.84 mm).

The results of average intensity ranged between 115.6 and 133.4 mm h^{-1} at the height of 0.9 m and between 79.5 and 100.6 mm h^{-1} at the height of 1.20 m. The simulation at 0.9 m had intensity rates higher than the simulations at 1.20 m, this is due to greater distribution of rainfall at this last height. That is, with increasing height of sprinkling there is an increase in rainfall simulation area and reduction of intensity due to rainfall dispersion. Furthermore, with increasing simulation height also increases the influence of wind. In all tests (Table 2) the intensity of rain sprinkled at 0.5 bar showed a significant difference in relation to others (0.75 and 1.0 bar) to both height of 0.9 and 1.2 m. For the pressures 0.75 and 1.0 bar was not registered significant differences in the two heights simulated.

It was found that the sprinkler pump has sufficient strength to sprinkle a large amount of water for several minutes without suffering significant variation. It was found that at 0.90 m height and at higher pressures as 0.75 and 1.0 bar, the dispersion occurred with greater uniformity among the pluviometers. Moreover, at 1.20 m height, the best results were obtained at pressures of 0.5 and 1.0 bar. At a pressure of 0.75 bar there was a greater variation in the sprinkler.

Physical characteristics of the droplets produced by the microsprinkler

It was evaluated 220 drops in the three working pressures above. Drops below 0.5 mm accounted for 16.8% of total (n = 37), in the frequency in which are found the mean and median (0.5 to 0.8mm) we recorded 61.4% of total (n = 135), and in the spectrum greater than the mean (0.8 to 1.2mm) we observed 21.8% (n = 48). The spectrum of drops distribution concentrates around the mean and median, and very large or small drops had a low frequency (< 5.0%). The smallest droplet had 0.3 mm, and the largest, 1.25 mm, and the average droplet size produced by the sprinkler nozzle was 0.7 ± 0.19 (n = 220).

As for the size of the droplets produced by the microsprinkler, larger droplets were found with the simulator at 0.5 bar pressure, with an average size of 0.73 mm, only the dish # 5 showed droplets smaller than the average, both at 0.5 and 0.75 bar pressure (Table 3).

At 1.0 bar pressure there was a reduction in the size of the droplets produced by the simulator and also a smaller standard deviation in the samples of each dish, only the dish # 5 showed an increase in average droplet size.

The dish # 5 exhibited the lowest amount of drops as well, which may indicate that at pressures below 1.0 bar, the simulator applies a greater amount of water toward the sides in relation to its center, causing only smaller drops reach this dish.

By evaluating the size of droplets produced at various pressures, the variation between the pressures was small. The equipment produces droplets of uniform size in spite of pressure variations. In this sense, there was no significant difference between the droplet sizes produced at different pressures (p = 0.53)

Table 3. Mean size of droplets produced by the microsprinkler under different working pressures (mean ± standard deviation).

Pressure (Bar)	Mean
0.5	0.73 ± 0.10 ns
0.75	0.69 ± 0.10 ns
1.0	0.68 ± 0.06 ns

Note: Mean of 5 repetitions; ns = non-significant at 0.5% by F-test.

The equipment produced a large quantity of droplets, mean of 7.0 ± 2.4 in an area of 0.5 cm^2 (n = 64). The simulator had uniform distribution in the number of drops between the dishes, once all dishes showed close averages, only the dish # 5 had fewer drops, and in the repetition 4 the dish showed no drop in the evaluated area. Dishes # 3 and 4 had the highest number of drops and also the larger droplets produced by the simulator. This may be the result of a slight deviation of the nozzle sprinkler, which applied water at a higher intensity in the direction of these dishes. The amount of drops produced at each pressure was: 0.5 bar (6.7 ± 2.7 drops 0.5 cm^{-2}), 0.75 bar (7.3 ± 2.3 drops 0.5 cm^{-2}) and 1.0 bar (7.9 ± 3.8 drops 0.5 cm^{-2}). There was no statistically significant difference in the number of droplets produced in the three applied pressures (p = 0.44).

When examined the images of droplets under 25x magnification, it was noted that the sprinkler nozzle produces droplets in an almost perfect circular shape. From the average size of the drops at 0.5 bar pressure, 0.73 mm, it is achieved drops with a volume of 0.20 mm^3.

Kinetic energy

The results demonstrated that the kinetic energy generated by each raindrop produced by the microsprinkler is reduced about 12 x 10^{-5}. In Table 4 is presented the estimated mean value of kinetic energy for the average size of droplets in the three pressures used during the tests on the simulator.

Table 4. Kinetic energy per drop produced by the microsprinkler at various pressures at 0.9 m high.

Physical parameters				
Pressure (bar)	Drop diameter (mm)	Drop volume (mm^3)	Final speed (m s^{-1})	Kinetic energy (Joule)
0.5	0.73	0.20	7.40	1.11 x 10^{-5}
0.75	0.69	0.17	8.57	1.26 x 10^{-5}
1.0	0.68	0.16	9.58	1.51 x 10^{-5}

Despite a reduction in droplet size with increasing pressure, the kinetic energy increased due to the increase in impact velocity of the droplet to the ground. About 60% of the droplets had sizes between 0.5 mm and 0.8 mm, and droplets with such size generate kinetic energy between 5 x 10^{-6} and 19.4 x 10^{-6}.

The total kinetic energy of the rainfall simulation area showed reasonable results, around 1596.2 J m^{-2}, at 0.5 bar pressure, 0.9 m height and intensity of 115.7 mm h^{-1}, and 1618.7 J m^{-2} at 0.5 bar pressure, 1.2 m height and intensity of 79.5 mm h^{-1}, this results in about 51.3 and 77.2%, respectively, of the kinetic energy generated by a natural rainfall of the same intensity. According to Amorim et al. (2001), rainfall with these intensities have kinetic energy between 3110 J m^{-1} and 2095.3 J m^{-2}.

Rainfall simulation area

The average rainfall simulation area of the microsprinkler, at 0.5 bar pressure and 1.2 m height, based on 19 repetitions, was 0.40 ± 0.08 m^2, reaching in some tests 0.56 m^2. These results of sprinkling at 1.20 m are satisfying, since the equipment has been developed to work with small plots, that is, at fine range.

Bryan (2000) argues that the first studies in the 1940s overestimated the size of raindrops and its erosive power. Agassi and Bradford (1999) examined 10 rainfall events recorded at different points in the Aleutian Islands (tropical environment), and reported that the size of raindrops ranged from 0.8 to 1.6 mm.

In Figure 2 is possible to compare the physical characteristics of rainfall produced by the microsprinkler evaluated in this study and rainfall produced by some simulators described in the literature.

Source	Intensity (mm h^{-1})	Droplet size (mm)	[1]Kinetic energy (%)	Simulation height (m)	Simulation area (Plot m^2)
Emmett (1970)	198.1 – 215.9	0.5	-	-	-
Cerdà et al. (1997)	54.6	<0.82 (56%)	-	2.0	0.24
Battany and Grismer (2000).	-	-	70	3.5	0.64
Idowu et al. (2002)	128.0	1.45	-	1.75	-
Alves Sobrinho et al. (2002)	100.0 (19 – 308)	1.5 – 3.0	90	2.0	0.70
Ziegler and Sutherland (2006)	90 - 120	0.99	-	2.7	-
Martínez-Zavala et al. (2008)	90.0	-	-	3.5	0.23
Jordán and Martínez-Zavala (2008)	33.0 – 54.0	5.9	-	-	0.0625
Present study	71.4 – 148.3	0.7 (0.3 - 1.2) (n=220)	51 - 77	0.90 -1.5	0.40 (0.28 – 0.55) (n=19)

Figure 2. Physical characteristics of rainfall produced by different simulators.

Note: [1]Kinetic energy compared with a natural rainfall of the same intensity. (-) Parameter not evaluated.

Droplet size lies within the lower limit presented by the various simulators, on the other hand, the kinetic energy and the rainfall simulation area are compatible with existing simulators. Cerdà (1999) inventoried 229 rainfall simulators in operation between 1930 and 1999, and 9% of the total showed drops of size similar to the sprinkler under examination, and in 20%, the rainfall simulation area (plot) was less than 0.5 m^2, also consistent with the results obtained herein.

According to the results, it was verified that the microsprinkler performed stable application of water in the heights of 0.90 and 1.20 m, despite the small size of the droplets produced. It was found that the product generated droplets of similar size, with a low variation between samples examined. Another breakthrough was the constant size of the drops independent of pressure rise. In contrast, the main drawbacks of the microsprinkler were: smaller drops are influenced by wind (dispersion) and the simulator tends to have higher intensity of rainfall from the edges to the center of the plot.

Moreover, the equipment produces a large amount of droplets, and these are evenly distributed throughout the plot, which may compensate for the reduced size of the drops, and although the kinetic energy of a drop produced by the microsprinkler is low, results of the total kinetic energy by application area, at 0.5 bar pressure, and 0.9 and 1.2 m were satisfactory (Figures 2).

Handling (installation and application), and the maintenance of the microsprinkler is simple. Besides that, it is compact, lightweight, can be transported easily, is inexpensive (around R$ 650.00), since most of its parts are easy to purchase, with the exception of the sprinkler nozzle that was imported. The system can be coupled to a utility vehicle with reservoir of 100 liters of water, with the sprinkler pump directly connected to the vehicle battery.

Conclusion

In summary, it can be concluded that the equipment can become very useful for measurement of infiltration, runoff and soil loss. Moreover, it presents practical use, especially in areas of rural roads where space is restricted and there is the movement of vehicles, even during the simulation. The equipment can replace and/or complement the measurement of infiltration performed by ring infiltrometer, especially on rural roads that have very compacted roabed for its use.

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