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## BALLISTIC MODEL TO ESTIMATE MICROSPRINKLER DROPLET DISTRIBUTION

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**ABSTRACT:** Experimental determination of microsprinkler droplets is difficult and time-consuming. This determination, however, could be achieved using ballistic models. The present study aimed to compare simulated and measured values of microsprinkler droplet diameters. Experimental measurements were made using the flour method, and simulations using a ballistic model adopted by the SIRIAS computational software. Drop diameters quantified in the experiment varied between 0.30 mm and 1.30 mm, while the simulated between 0.28 mm and 1.06 mm. The greatest differences between simulated and measured values were registered at the highest radial distance from the emitter. The model presented a performance classified as excellent for simulating microsprinkler drop distribution.

**Key words:** irrigation, modeling, simulation

## MODELO BALÍSTICO PARA ESTIMAR A DISTRIBUIÇÃO DE GOTÍCULAS APLICADAS POR MICROASPERSORES

**RESUMO:** A determinação experimental dos diâmetros de gotas em sistemas de microaspersão é trabalhosa e demorada. Essa determinação pode, entretanto, ser obtida empregando-se modelos balísticos. O objetivo do presente estudo foi comparar valores medidos experimentalmente com valores simulados de diâmetros de gotas aplicadas por microaspersores. Os dados experimentais foram obtidos empregando-se o método da farinha. As simulações foram realizadas usando o modelo balístico adotado pelo programa computacional SIRIAS. Os diâmetros médios de gotas determinados experimentalmente variaram entre 0,30 mm e 1,30 mm, enquanto que os simulados ficaram entre 0,28 mm e 1,06 mm. As maiores diferenças entre valores medidos e simulados foram registradas nas maiores distâncias em relação ao microaspersor. O modelo apresentou um desempenho classificado como ótimo na simulação da distribuição de gotas em microaspersores.

**Palavras-chave:** irrigação, modelagem, simulação

### INTRODUCTION

Sprinkler and microsprinkler droplet size distribution evaluation is useful in evaporation and wind drift loss studies and to establish models to simulate water distribution. This evaluation can be achieved employing different methods, the flour method being one of the most common because of its simplicity, low cost and good precision, even when compared to the more sophisticated laser method (Kohl et al., 1985; Vilela, 1995; Kincaid et al., 1996; DeBoer et al., 2001).

Many studies were developed to determine sprinkler droplet size distribution (Kohl, 1974; Kohl & DeBoer, 1984; Dadio & Wallender, 1985; Carvalho, 1991; Oliveira, 1991; Mergulhão, 1992; Matsura, 1993; Li et al., 1994). However, there is no similar study carried out specifically for microsprinkler systems.

Droplet size experimental determination is arduous and time-consuming. Many authors used mathematical models based on ballistic theories to estimate sprin-

kler droplet size as a function of the distance from the emitter (Bernuth & Gilley, 1984; Hills & Gu, 1989; Seginer et al., 1991; Tarjuelo et al., 1994; DeBoer et al., 2001).

The present study aimed to determine microsprinkler droplet diameters for different microsprinkler nozzles and, using a ballistic model, to compare simulated and experimental values.

### MATERIAL AND METHODS

Experimental evaluations were performed indoor, in Piracicaba, SP, Brazil, using self-compensating microsprinklers operating at 250 kPa, with a jet angle of 17° and nominal flows of 28 L h<sup>-1</sup> (gray nozzle); 35 L h<sup>-1</sup> (brown nozzle); 47 L h<sup>-1</sup> (blue nozzle); 55 L h<sup>-1</sup> (green nozzle); 70 L h<sup>-1</sup> (orange nozzle); and 95 L h<sup>-1</sup> (yellow nozzle). The respective nozzle diameters were 1.00 mm (gray), 1.10 mm (brown), 1.25 mm (blue), 1.33 mm (green), 1.48 mm (orange), and 1.75 mm (yellow). The

gray and brown nozzles used a black swivel, that resulted in a wetted area of smaller radius, while the others had a blue swivel for a larger profile. Microsprinkler were fixed 0.38 m above soil surface.

Droplet size distribution was determined using the flour method. This method needs previous calibration to obtain the relationship between the dried ball masses and the previous known droplet diameters. However, relations obtained by different authors resulted in very close droplet diameter values for the correspondent ball masses (Table 1). Any of the presented relations allows to obtain droplet diameter evaluations with differences only at the second decimal place, when expressed in millimeters. For this reason, the present study used only one of these relations, with no previous experimental calibration.

The mean droplet diameters were, therefore, determined using the expression  $d = 1.257 m^{0.353}$ , obtained by Oliveira (1991), with  $d$  being the droplet diameter (mm) and  $m$  the dried flour ball mass (mg). Droplet catch pans were distributed along three perpendicular microsprinkler radii at distances of 0.80 m, 1.20 m, 1.60 m, 2.00 m, 2.40 m, 2.80 m, and 3.20 m from the emitter. Pan contents collected at the same radial distance were grouped in a composite sample.

The droplet collecting time was near five seconds for each tested nozzle, avoiding droplet overlapping on the pans. The microsprinkler was covered with a PVC can that was removed at the beginning and replaced at the end of the test. The sieving and drying procedure was similar to that presented by Oliveira (1991). The droplet percent numbers, relative to each radial distance, were calculated considering the collected emitter profile and the circular ring area corresponding to each catch pan. Each circular ring, corresponding to the pan radial distances from the emitter, represented an area directly proportional to the square of the radius. Using the mean droplet diameters and the percent value of each diameter, considering the correspondent circular area, the percent applied water volumes were calculated, referring to the various droplet diameters for each nozzle, since the droplets were considered spherical.

Droplet simulations were made using the SIRIAS software (SIMulación de Riego por ASpersión), developed by Carrion et al. (2001) for sprinkler systems, on Delphi language for Windows 95, and theoretically based on the ballistic model presented by Tarjuelo et al. (1994). In this model the equations describing the droplet movement can be written as follows:

$$\frac{dV_x}{dt} = -C_2 (V_x^2 + V_y^2)^{0.5} V_x \quad (1)$$

$$\frac{dV_y}{dt} = -C_2 (V_x^2 + V_y^2)^{0.5} V_y - g \quad (2)$$

where  $V_x$  and  $V_y$  are, respectively, the horizontal and vertical components of the droplet speed;  $t$  is the droplet trajectory time;  $C_2$  is the aerodynamic drag coefficient; and  $g$  is the gravitational acceleration.

The SIRIAS software solves equations 1 and 2 using the fourth order Runge-Kutta method. Input variables consisted of the operational emitter characteristics, like the service pressure and the jet angle inclination. In the case of self-compensating microsprinklers the regulating membranes modify the pressure, preventing its use as an input variable. The pressure values employed in the simulations were, therefore, those corresponding to emitter nominal flows and were obtained by the pressure-flow curves for the different nozzles operating without the self-compensating membranes.

The differences between the measured and simulated values were quantified by the determination coefficient ( $R^2$ ). A confidence coefficient ( $c$ ), proposed by Camargo & Sentelhas (1997), was also used. This coefficient corresponds to the product of the correlation coefficient ( $r$ ) by the exactness coefficient ( $d$ ) (Willmott et al., 1985, mentioned by Camargo & Sentelhas, 1997). The ( $d$ ) values were calculated using the expression:

$$d = 1 - \left[ \frac{\sum (P_i - O_i)^2}{2} \right] \quad (3)$$

where  $P_i$ ,  $O_i$  and  $O$  are the estimated, measured, and average values, respectively.

Table 1 - Relationships between droplet diameters and dried flour ball masses obtained by different authors.

Author	Dried ball mass (mg)					
	0.01	0.05	0.10	0.20	0.60	1.00
	----- mm -----					
Carter et al. (1974)	0.267	0.457	0.576	0.726	1.046	1.241
Kohl (1974)	0.247	0.437	0.558	0.713	1.052	1.261
Hills & Gu (1989)	0.268	0.461	0.582	0.734	1.062	1.261
Oliveira (1991)	0.247	0.437	0.558	0.712	1.050	1.257
Matsura (1993)	0.269	0.458	0.576	0.724	1.042	1.234
Average	0.260	0.450	0.570	0.722	1.050	1.251
CV (%)	4.439	2.657	1.969	1.286	0.717	0.999

To evaluate data performance in relation to the confidence coefficient ( $c$ ), a scale based on Camargo & Sentelhas (1997) was utilized, with some alterations. The performance was classified as excellent for values higher than 0.85; very good between 0.76 and 0.85; good between 0.66 and 0.75; regular between 0.51 and 0.65; bad between 0.41 and 0.50; and very bad for values lower than 0.40.

## RESULTS AND DISCUSSION

Microsprinkler experimental mean droplet diameters, corresponding to the different radial distances, varied between 0.30 mm and 1.30 mm, (1.0-mm range). Lower droplet diameters could be formed during the water application and had precipitated mainly over the pans located near the microsprinkler. However, the methodology used to determinate droplet diameter allows to measure only values higher than 0.30 mm.

The conventional sprinkler droplet diameters fall, usually, within a larger range in comparison to those determined for microsprinklers. Kohl & DeBoer (1984) obtained, for low pressure sprinklers, droplet diameters be-

tween 0.33 mm and over 5.00 mm. Solomon et al. (1985) observed droplet diameters between 0.20 mm and 1.90 mm for central pivot spray sprinklers. These diameters approached the values found in the present work.

Carvalho (1991), using medium pressure sprinklers, determined droplet diameters between 0.58 mm and 5.22 mm. Oliveira (1991) obtained, for different fixed sprinkler nozzles using flat and serrated plates, mean droplet diameters between circa 0.50 mm and 2.50 mm. Employing high pressure sprinklers, Mergulhão (1992) found mean droplet diameters between 0.77 mm and 4.07 mm, according to the sprinkler model and the operational pressure. Matsura (1993) also studied the droplet diameter distribution for a high pressure sprinkler, and obtained values between 0.60 mm and 4.70 mm.

The ballistic model-simulated values fell close the experimental collected values, between 0.28 mm and 1.06 mm. The highest differences were found, in most cases, for the largest distances from the microsprinkler (Figure 1). This increasing difference between simulated and measured data, in relation to the radial distance, was also obtained for conventional sprinklers by other authors (Hills & Gu, 1989; DeBoer & Monnens, 2001).

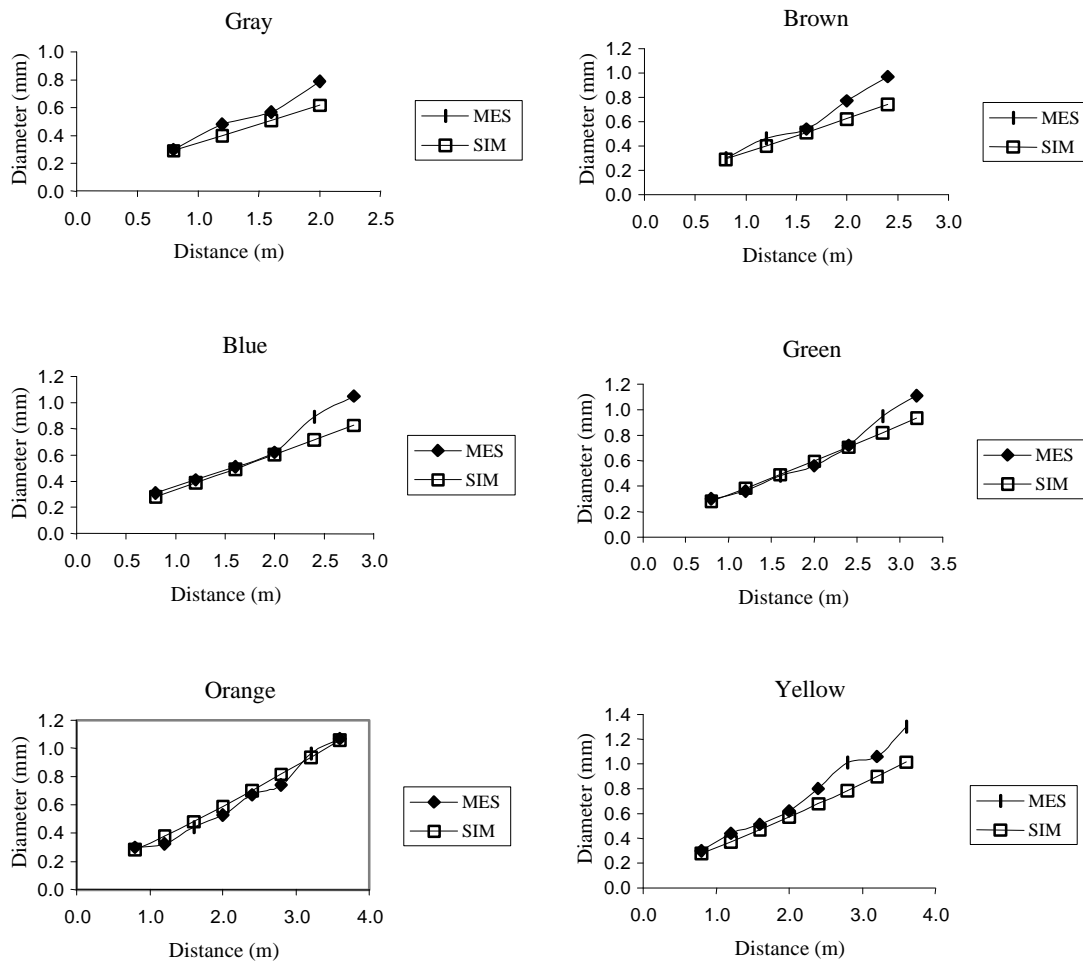


Figure 1 - Mean droplet diameters measured (MES) and simulated (SIM) in relation to the radial distance for different microsprinkler nozzles.

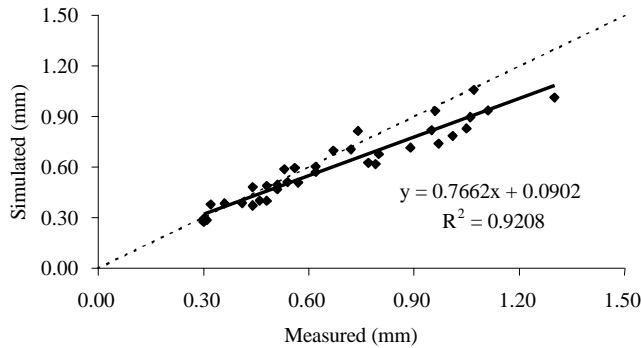


Figure 2 - Relationship between microsprinkler measured and simulated droplet diameter values.

These differences at the largest distances are related to the fact that the model considers only one droplet diameter for each radial distance, and this behavior does not occur in a real situation. Matsura (1993) noticed that, in spite of the fact that droplet diameters usually present a proportional relation to the emitter wet radius, small drops were also observed at greater distances because of drop break during their trajectory. This was also observed in the microsprinkler essays.

In a general way the ballistic model presented a tendency of underestimating the experimental values, as it can be observed in relation to the 1:1 line (Figure 2). Anyway, the correlation between measured and simulated values was high, with a determination coefficient ( $R^2$ ) of 0.92 (Figure 2), which corresponds to a correlation coefficient ( $r$ ) equal 0.96. The exactness coefficient ( $d$ ) was 0.95 which, multiplied by ( $r$ ), resulted in a confidence coefficient ( $c$ ) equal 0.91, corresponding to an excellent performance, according to the Camargo & Sentelhas (1997) scale.

As a conclusion, the ballistic model is an useful tool to estimate microsprinklers droplet diameters.

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