How to cite: Yönter, G. & M. H. Houndonougbo, 2022. Comparison of different fulljet nozzles used in laboratory type rain simulator in terms of some rainfall characteristics. Ege Univ. Ziraat Fak. Derg., 59 (1): 33-41, https://doi.org/10.20289/zfdergi.865324

Research Article
(Araştırma Makalesi)

Ege Üniv. Ziraat Fak. Derg., 2022, 59 (1):33-41
https://doi.org/10.20289/zfdergi.865324

Comparison of different fulljet nozzles used in laboratory type rain simulator in terms of some rainfall characteristics*

Laboratuvar tipi yağış benzeticisinde kullanılan farklı fulljet başlıkların bazı yağış özellikleri açısından karşılaştırılması

Gökçen YÖNTER[1*]

Marius H. HOUNDONOUGBO[2]

[1] Ege University Agricultural Faculty Soil Science and Plant Nutrition, Bornova-Izmır/Turkey

[2] Ege University Agricultural Faculty Soil Science and Plant Nutrition, Bornova-İzmir/Turkey

***** Corresponding author (Sorumlu yazar):

gokcen.yonter@ege.edu.tr

* This article was produced by a laboratory study.

Received (Alınış): **26.01.2021** **Accepted** (Kabul Tarihi): **30.07.2021**

Keywords: Rain intensity, Christiansen homogeneity coefficient, drop diameter, terminal velocity, kinetic energy.

Anahtar sözcükler: Yağış şiddeti, Christiansen homojenlik katsayısı, damla çapı, terminal hız, kinetik enerji.

ABSTRACT

Objective: The objective of this study was to determine and compare rain intensities, Christiansen coefficients, drop diameters and kinetic energies, by using Full Jet type nozzles at different pressures.

Material and Methods: In this study, simulated rainfalls were applied on 17 cups (250 cm^3), were placed on a platform, during 5 minutes at 30, 40, 50, 60 and 70 kPa pressures by using ½ HH-36 SQ, ½ HH-40 SS and ½ HH-50 WSQ nozzles with 3 replicated. The drop diameters were determined by the flour pellet method. Rainfall intensities, Christiansen coefficients, terminal velocities, drop diameter ratio, terminal velocity ratio, moment, kinetic energy, moment per unit area, kinetic energy per unit area ratios and kinetic energy for each nozzles were calculated.

Results: It was found that average rain intensities were 97-210 mm h^{-1}, average uniformity coefficients were 85-86 %, average drop diameters were 1.89-2.11 mm, average terminal velocities were 6.35-6.79 m s^{-1} for nozzles. Average kinetic energies for each nozzles were also calculated between 16.30-23.32 J m^{-2} mm^{-1}.

Conclusions: According to this study, it was determined that the most suitable nozzle for erosion studies is Fulljet ½ HH-50 WSQ.

ÖZ

Amaç: Farklı basınçlarda Full Jet tipi başlıklar kullanılarak yağış şiddetleri, Christiansen katsayıları, damla çapları ve kinetik enerjilerin belirlenmesi ve karşılaştırılması amaçlanmıştır.

Materyal ve Yöntem: Bu çalışmada yapay yağışlar, ½ HH -36 SQ, ½ HH-40 SS ve ½ HH-50 WSQ başlıklar kullanılarak 30, 40, 50, 60 ve 70 kPa basınçlarında 5 dakika süreyle platform üzerine yerleştirilen 17 kap (250 cm^3) üzerinde 3 tekrarlı uygulandı. Damla çapları un yumağı yöntemi ile belirlendi. Yağış şiddetleri, Christiansen katsayıları, terminal hızları, damla çapı oranı, terminal hız oranı, moment, kinetik enerji, birim moment, birim kinetik enerji oranları ve her bir başlık için kinetik enerjiler hesaplanmıştır.

Araştırma Bulguları: Bu çalışmada, başlıklar için ortalama yağmur yoğunlukları 97-210 mm h^{-1}, ortalama homojenlik katsayıları % 85-86, ortalama damla çapları 1.89-2.11 mm, ortalama terminal hızları 6.35-6.79 m s^{-1} arasında bulunmuştur. Her bir başlık için ortalama kinetik enerjiler de 16.30-23.32 J m^{-2} mm^{-1} arasında hesaplanmıştır.

Sonuçlar: Bu çalışmaya göre, erozyon çalışmaları için en uygun başlığın Fulljet ½ HH-50 WSQ olduğu saptanmıştır.

INTRODUCTION

Water erosion in Turkey, where is located in Mediterranean Basin, threatens soils which are the most important resources, significantly. According to the Dynamic Erosion Model and Monitoring System (DEMMS) data, 642 million tons of soil is lost from Turkey every year (ÇEM, 2018). In the Mediterranean Basin's Countries and Turkey, a large number of erosion studies have been carried out to minimize soil erosion in field and laboratory conditions. However, erosion studies in field conditions require a long process due to climatic changes. In particular, the variability of rain intensity and duration is very effective in this respect. Very heavy rains in the Mediterranean Basin Countries as Turkey have been observed in some studies. Cerda (1997) measured the drop diameter was between 1.00 and 2.50 mm and rainfall intensity was between 1 and 120 mm h^{-1} for natural rainfall conditions in Spain. Usón &Ramos (2001) found the average rainfall intensity was 10 mm h^{-1} and the maximum rainfall intensity was 103 mm h^{-1} in NE Spain, respectively. Arnaez et al. (2007) found that the rainfall intensities in Spain were between 27.9 and 127.2 mm h^{-1} for periods of 2 to 200 years. Petan et al. (2010) measured maximum rainfall intensities were between 220 and 288 mm h^{-1} in Slovenia. Heavy rainfalls with 131 mm h^{-1} intensity have been observed in Antalya on 03/11/2017 date (MGM, 2019).

Many rain simulators were developed in recent years in terms of ease of use in field and laboratory conditions. Especially the number and usage of rain simulators working with sprayer nozzles have increased considerably. Many companies in the world produce various types of nozzles. For this reason, we propose to determine the average drop diameter, terminal velocity and kinetic energy parameters precisely in order to conduct erosion researches on the developed nozzles types.

A large number of rainfall simulators are being developed in both field and laboratory conditions, especially as it can simulate natural rainfalls (Tossell et al., 1987). Numerous nozzles have been also developed with the development of rainfall simulators. Tossell et al. (1987) stated that the continuous spray generated by the small nozzle design is also more physically realistic than the intermitted spray produced by rotating disc and some other simulator systems. Full Jet type nozzles are used, which are constantly spraying the erosion plots in the downward and static position (Agassi & Bradford, 1999). Uniformity coefficient is also used in many erosion studies to calculate the distribution of the amount of water falling on the soil surface (Christiansen, 1942). In this section, some studies with Full Jet nozzles for rainfall simulators are given. Tossell et al (1987) found that rain intensities were 17.5-200 mm h^{-1}, and average uniformity coefficients were 81.05-91.31%, using Full Jet type nozzles at different heights (0.80-1.70 m) and at pressures (48.3, 69.0 and 96.5 kPa) in Guelph type rainfall simulator (GRS-II), respectively. In another study simulated rainfall were applied (34.8-105.3 mm h^{-1}) by using the laboratory type rain simulator, and it was found drop diameter of simulated rains was 4.38-5.25 mm, terminal velocity was 6.40-6.69 m s^{-1}, and kinetic energy was 69-81%, respectively (Erpul & Çanga, 2000). Esteves et al. (2000) applied 65 mm h^{-1} of simulated rainfall at 41.18 kPa pressure with a Full Jet nozzle type (1H-106 SQ) to 5.5x5.5 m squares network, and they determined the uniformity coefficient were 78-92%. Humphry et al. (2002) applied 70 mm h^{-1} of artificial rainfall at 28 kPa with the Full Jet type (1/2 HH-50 WSQ), and they found the uniformity coefficient was 93%. Kuhn et al. (2003) applied 60 mm h^{-1} of simulated rainfall, using a Full Jet (1/2 HH-50WSQ) nozzle, and they found that the average drop diameter was 2.00 mm, the terminal velocity was 8.10 m s^{-1} and the kinetic energy was 0.33 MJ ha^{-1} mm^{-1} (19.7 MJ ha^{-1} h^{-1}), respectively. Sausa and Siqueira (2011) applied simulated rainfalls from 40 to 182 mm h^{-1} at pressures (50, 80, 110, 140 and 170 kPa) with 2 Full Jet (1/2 HH-4O SS) nozzles in a rainfall simulator, and they found that uniformity coefficients were between 68.3 and 82.2 %. Omar et al. (2014) applied 53 mm h^{-1} simulated rainfall, using a Full Jet nozzle (1/2 HH-50 WSQ) with a height of 3 m and a pressure of 10 psi, and they reported that the CU% were between 80 and 95%, the drop diameter were between 1.3 and 2.0 mm, respectively, and the rain simulator also gave 90% of the kinetic energy of similar natural rainfall. Chouksey et al. (2017) applied 100 mm h^{-1} simulated rainfall from 3 m high with 2 Full Jet nozzles (1/2 HH-50 WSQ), and they found that drop diameter was between 1 and 5 mm, CU was

79%, and terminal velocity was between 3.30 and 6.00 m s^{-1} , respectively. De Sausa Junior et al. (2017) applied between 40 and 182 mm h^{-1} simulated rainfalls, using a Full Jet nozzle (1/2 HH-40 SS) from 3 m height, and they determined that the average drop diameter was 2.12 mm and kinetic energy was 22.52 J m^{-2} mm^{-1} (90.12 % of the kinetic energy of natural rainfall) and CU were 87.80 %, respectively. Houndonougbo & Yonter (2020) applied simulated rainfall to the soil surface in erosion trays with Vee jet and Full jet nozzles in oscillating conditions, and they compared rain intensity, Christiansen coefficient, runoff and soil losses and found similar results between these nozzles.

Some equations were developed to calculate the kinetic energies of the Mediterranean Basin rainfall (Petan et al., 2010). Some researchers have reported that the most appropriate kinetic energy formula in the Mediterranean basin was developed by Sempere-Torres et al. (1992) (Usón & Ramos, 2001; Petan et al., 2010). Kinetic energy can be expressed with the formula $KE_A = c \times I \times KE_B$ depending on the rainfall time and rainfall height (Rosewell, 1986). In this formula, c is a coefficient, KE_A: J m^{-2} h^{-1} and KE_B: J m^{-2} mm^{-1}, respectively.

The objective of this study was to determine rain intensities, uniformity coefficients, drop diameters and kinetic energy ratios, using Full Jet type nozzles (½ HH-36 SQ, ½ HH-40 SS and ½ HH-50 WSQ) at different pressures (30, 40, 50, 60 and 70 kPa) and 2.00 m height. Additionally to compare kinetic energies were calculated by Sempere-Torres et al. (1992) formula for these nozzles, respectively.

MATERIAL and METHODS

Material

In this study, a laboratory type rain simulator (Bubenzer & Meyer, 1965) and Full Jet type nozzles (½ HH-36 SQ, ½ HH-40 SS and ½ HH-50 WSQ) that can be mounted on it used (Figure 1). These spray nozzles are designed to spray conically in a vertical direction. ½ HH-36 SQ and ½ HH-40 SS nozzles apply rain in a circular and ½ HH-50WSQ nozzles apply rain in a square. In addition, these nozzles can apply drops in the range of 1.00-5.00 mm (Anonymous, 2019). Application pressures and flow rates of these nozzles were given Table 1. In the rain simulator, there is a 500 L water reservoir fed from the network, a motor pump, a pressure reducing regulator, 3 manometers measuring the inlet-outlet pressures to the system, plastic hoses that transmit water, and an electric motor controlling them. A total of 25 aluminum containers (volume: 250 cm^3, height: 5 cm and diameter: 9 cm) were used to determine rain intensities in the experiments.

Figure 1. Full Jet type spraying nozzles, laboratory type rainfall simulator and cups used in experiment.

Şekil 1. *Full Jet tipi püskürtücü başlıklar, laboratuvar tipi yağış simulatörü ve denemede kullanılan kaplar.*

Table 1. Performance data of Full Jet nozzles (Spraying Sys. Co. CAT 75 HYD)

Çizelge 1. *Full Jet Başlıkların Performans Verileri (Spraying Sys. Co. CAT 75 HYD)*

Nozzle Type	Capacity Size	Orifice Diameter (mm)		Flow Rate (l min^{-1})								Spray Angle (^{0})		
												0.5	1.5	6
				Pressure (bar)								Pressure (bar)		
½ HH	36 SQ	6.35	P	34.5	48.3	69	138	276	552	690	1035	48.3	138	552
			Q	9.8	11.7	13.6	18.9	25.7	35.6	39.4	47.3	295	310	284
½ HH	40 SS	6.35	P	34.5	48.3	69	138	276	552	690	1035	48.3	138	552
			Q	11.0	12.9	15.1	20.8	28.8	39.4	43.5	52.6	333	344	314
½ HH	50 WSQ	6.76	P	34.5	48.3	69	103.5	138	276	552	-	34.5	69	552
			Q	14.0	16.3	18.9	22.7	25.7	34.8	47.3	-	394	416	386

(P: Pressure-bar; Q: Flow rate -l min^{-1})

Method

In the research, the method was applied in 3 stages. In the 1st stage; the position of nozzles is centered with a platform of 1x1 m square at a standard slope of 9 % (Tossell et al., 1987). Rainfall simulator were adjusted to 30, 40, 50, 60 and 70 kPa pressures, by controlling manometers and 5 minutes of rain was applied for each pressure with 3 replicated. The amount of water collected in containers was weighed on a sensitive scale (0.01 g) and recorded. The amount of water obtained from the experiment was converted to rain intensities with the following formula (Tossell et al., 1987).

$$I_p = 10\ [\frac{(\frac{\Sigma Vi}{Ag})}{n}\ \frac{60}{t}] \quad (1)$$

Where, I_p is rain intensity (mm h^{-1}); V_i is amount of water collected in the container (cm^3); A_g is cross sectional area of the container (cm^2); t is rain application time (minutes); n is number of cups; 10 is coefficient used to convert cm h^{-1} to mm h^{-1}. The uniformity coefficient was calculated according to the formula Christiansen (1942).

$$CU\ (\%) = 100\ (1- \frac{\Sigma[Ii-Im]}{n\ Im}) \quad (2)$$

Where, CU is uniformity coefficient (Christiansen, 1942); I_i is rain intensity collected in each container (mm h^{-1}); I_m is average rain intensity (mm h^{-1}).

In the 2nd stage; the drop diameters of simulated rain for calculating terminal velocities were determined according to the flour pellet method (Navas et al., 1990). In this method, a 25.4 cm diameter plate containing an uncompact layer of flour (2.54 cm thick) was exposed to rainfall for 1-4 s. The small flour balls were dried for 24 h at 105^{0}C, and sieved (5000, 3000, 2000, 1000 and 250 µm) the fractions were weighted, respectively.

Cerda (1997)'s formula was used to calculate the average drop diameters for natural rainfalls in the Mediterranean basin as follows formula;

$$D_{50} = 0.46 + 0.02\ I \quad (3)$$

Where, D_{50} is average drop diameter (mm), I is rain intensity (mm h^{-1}).

Terminal velocities of simulated and natural rains were calculated by the formula proposed by Uplinger (1981).

$$V = 4.854\ D\ e^{(-0.195\ D)} \quad (4)$$

Where, V is terminal velocity (m s^{-1}.), D is average drop diameter (mm).

Meyer (1965) explained that drop diameter ratio (D = $\frac{Ds}{Dn}$), terminal velocity ratio (V = $\frac{Vs}{Vn}$), moment (M = V x 100), kinetic energy (KE = V^2 x 100), moment per unit area (M_u = D x V x 100) and kinetic energy per unit area (KE_u = D x V^2 x 100) to compare simulated rains and natural rains. Where, D_s is average drop diameter of simulated rain (mm), D_n is average drop diameter of natural rain (mm), V_s: terminal velocity of simulated rain (m s^{-1}), V_n: terminal velocity of natural rain (m s^{-1}).

In the 3rd stage, the kinetic energies of natural rains with the same rain intensities were calculated using the formula developed by Sempere-Torres et al. (1992) for the Mediterranean basin. For each Full Jet nozzle, kinetic energy values of natural rains were multiplied by kinetic energy ratios (%), and kinetic energy values of simulated rains were calculated.

$$KEn(h) = 33.38 \, x \, I - 186.12 \quad (5)$$

$$KEn(mm) = \frac{(33.38 \, x \, I - 186.12)}{I} \quad (6)$$

$$KEs(mm) = KE\ (\%) \, x \, KEn(mm) \quad (7)$$

Where, $KE_{n(h)}$ is kinetic energy natural rain (J m^{-2} h^{-1}), I: Rain intensity (mm h^{-1}), $KE_{n(mm)}$: Kinetic energy of natural rainfall (J m^{-2} mm^{-1}), KE (%): kinetic energy ratio, and KEs(mm): Kinetic energy of simulated rainfall (J m^{-2} mm^{-1}). In the next step, calculated kinetic energies were converted to J m^{-2} mm^{-1} unit according to Rosewell (1986) formula. Data were analyzed statistically by SPSS statistical software package (Anonymous, 1999).

RESULTS and DISCUSSION

Average rain intensities, uniformity and variation coefficients, average drop diameter, terminal velocity, moment, kinetic energy, moment per unit area and kinetic energy per unit area and their energies are tabulated in Table 2, respectively. According to Table 2, while moment and kinetic energy (%) gave the best simulation in all three titles, moment per unit area and kinetic energy per unit area (%) gave weak simulation, respectively. The similar findings were found by Erpul & Canga (2000).

Rain intensities for ½ HH-36 SQ and ½ HH-40 SS type nozzles are higher than the rainfall intensity for ½ HH-50 WSQ nozzle (Table 2). In the Mediterranean region, natural rain intensities similar to the rain intensities for ½ HH-36 SQ and ½ HH-40 SS type nozzles, were determined by some researchers (Petan et al., 2010; MGM, 2019). In addition, natural rain intensities similar to the rain intensities of the ½ HH-50 WSQ nozzles were also determined by some researchers (Cerda, 1997; Uson and Ramos, 2001, Arnaez et al., 2007). For the ½ HH-36 SQ type nozzle, 30-70 kPa pressure increases increased the rain intensity from 204 mm h^{-1} to 211 mm h^{-1}. In the research, uniformity coefficient of the nozzle was determined as 79-87%. Variation coefficients decreased from 25% to 15% in response to pressure increases. For a series to be homogeneous, the coefficient of variation must be less than 20% (Anonymous, 1999). According to these results, the most suitable pressure for ½ HH-36 SQ nozzle was determined as 40-70 kPa. It was found that the drop diameter of simulated rain was between 1.82 and 2.34 mm, terminal velocity between 6.23 and 7.17 m s^{-1} and kinetic energy ratio range between 46 and 62 %, respectively. Kinetic energies for ½ HH-36 SQ nozzle were calculated to vary between 14.94 and 20.12 J m^{-2} mm^{-1}. In some studies, with ½ HH-20-160 SQ type nozzles, it was found that rain intensity was between 55 and 114 mm h^{-1}, drop diameter was between 1.34 and 3.57 mm, uniformity coefficient was between 78 and 92 % and kinetic energy ratio was between 60 and 70 %, respectively (Esteves et al., 2000). The results given in the literature support the findings of this research. Rain intensity for ½ HH-40 SS type nozzle increased between 196 and 224 mm h^{-1} due to pressure increase. Uniformity coefficient was determined between 83 and 86% in this research. Variation coefficients decreased from 24% to 19% depending on the pressure increase. The optimum pressure for ½ HH-40 SS nozzle was determined between 50 and 70 kPa. For ½ HH-40 SS type nozzle, it was found that drop diameter between 1.64 and 2.16 mm, terminal velocity between 5.78 and 6.89 m s^{-1} and kinetic energy ratio between 40 and 58%, respectively. The kinetic energies for ½ HH-40 SS nozzle were calculated between 13.00 and 18.80 J m^{-2} mm^{-1}. In some studies, with ½ HH-40 SS type nozzles, rain intensity was determined between 40 and 182 mm h^{-1}, drop diameter was determined 2.12 mm and kinetic energy was determined 22.52 J m^{-2} mm^{-1}, respectively (Sausa and Siqueira, 2011; De Sausa Junior et al., 2017). There is a similarity between the results given in the literature and the results obtained from this research. For ½ HH-50 WSQ type nozzle, rain intensity increased between 85 and 109 mm h^{-1} due to pressure increase. Uniformity coefficient was determined between 83 and 87%. Variation coefficients decreased from 18% to 16% depending on the pressure increase. The most suitable pressure for ½ HH-50 WSQ nozzle was between 30 and 70 kPa. For ½ HH-50 WSQ nozzle, it was found that the drop diameter of the simulated rainfall between 1.77 and 2.05 mm, the terminal velocity was between 6.05 and 6.67 m s^{-1} and the kinetic energy ratio between 66 and 86%, respectively. The kinetic energies for ½ HH-50 WSQ nozzle were calculated between 20.80 and 25.88 J m^{-2} mm^{-1}. In some researches with 1/2 HH-50 WSQ nozzles, it was determined that rainfall intensity between 53 and 100 mm h^{-1}, drop diameter was between 1.00 and 5.00 mm, uniformity coefficient was between 79 and 95%, terminal velocity between 3.30 and 8.10 m s^{-1}, kinetic energy ratio was 90% and kinetic energy was 33.00 J m^{-2} mm^{-1} (Kuhn et al., 2003; Omar et al., 2014; Chouksey et al., 2017). There is a parallel between the results of this research and the literature.

Table 2. Rain intensities, uniformity and variation coefficients, moment, kinetic energy, moment in unit area and kinetic energy in unit area of Full Jet nozzles in the experiment

Çizelge 2. *Denemede Full Jet başlıkların yağış şiddetleri, yeknesaklık ve değişim katsayıları, moment, kinetic enerji, birim alana moment ve birim alana kinetik enerjileri*

½ HH-36 SQ														
P kPa	I mm h^{-1}	D_s mm	Std.	CU %	CV %	D_n mm	D	V_s m s^{-1}	Vn m s^{-1}	V	M %	KE %	M_u %	KE_u %
30	204	2.28	50	79	25	4.54	0.50	7.13	9.05	0.79	79	62	40	31
40	206	2.07	37	85	18	4.58	0.45	6.74	9.13	0.74	74	55	33	25
50	209	2.06	33	86	16	4.64	0.44	6.70	9.16	0.73	73	53	32	23
60	209	1.82	32	87	15	4.64	0.39	6.23	9.16	0.68	68	46	27	18
70	211	2.34	31	87	15	4.68	0.50	7.17	9.14	0.78	78	61	39	31
½ HH-40 SS														
P kPa	I mm h^{-1}	D_s mm	Std.	CU %	CV %	D_n mm	D	V_s m s^{-1}	Vn m s^{-1}	V	M %	KE %	M_u %	KE_u %
30	196	2.16	47	83	24	4.38	0.50	6.89	9.09	0.76	76	58	38	29
40	204	1.84	46	83	23	4.54	0.41	6.23	9.05	0.69	69	48	28	20
50	209	2.08	42	85	20	4.64	0.45	6.70	9.16	0.73	73	53	33	24
60	215	1.64	41	86	19	4.76	0.34	5.78	9.12	0.63	63	40	21	14
70	224	2.02	43	85	19	4.94	0.41	6.64	9.18	0.72	72	52	30	21
½ HH-50 WSQ														
P kPa	I mm h^{-1}	D_s mm	Std.	CU %	CV %	D_n mm	D	V_s m s^{-1}	Vn m s^{-1}	V	M %	KE %	M_u %	KE_u %
30	85	1.85	15	85	18	2.16	0.86	6.27	6.89	0.91	91	83	78	71
40	93	2.05	18	83	19	2.32	0.88	6.67	7.18	0.93	93	86	82	76
50	97	1.83	16	86	16	2.40	0.76	6.20	7.28	0.85	85	72	65	55
60	101	1.77	17	86	17	2.48	0.71	6.05	7.45	0.81	81	66	58	47
70	109	1.97	17	87	16	2.64	0.75	6.54	7.70	0.85	85	72	64	54

P: Pressure; I: Rain intensity; Std.: Standard deviation; CU: Uniformity coefficient; CV: Variation coefficient; Ds: Simulated rain drop diameter; Dn: Natural rain drop diameter; D: Drop diameter ratio; Vs: Simulated rainfall velocity; Vn: Natural rainfall velocity; V: Velocity ratio; M: Moment; KE: Kinetic energy; M_u: Moment in unit area; KE_u: Kinetic energy in unit area)

In general, according to the results of the research, the rain intensities in Full Jet (1/2 HH) nozzles were sorted from large to small ½ HH-40 SS> ½ HH-36 SQ> ½ HH-50 WSQ (Table 1). In some studies, rain intensities of SS and SQ type nozzles were found higher (Sausa and Siqueira, 2011; De Sausa Junior et al., 2017) than ½ HH-50 WSQ type nozzle. Although the pressure increase was the same, rain intensities were determined differently in each nozzle. It was reported that the rain intensity varied according to the type of the nozzle, the pressure applied and the height of the nozzle from the plot (Tossel et al., 1987; Agassi and Bradford, 1999). Uniformity coefficients were found close and high in all 3 nozzles (Table 1). Similar results were reported by some researchers (Esteves et al., 2000; Humpry et al., 2002; Omar et al., 2014). In all 3 nozzles, the drop diameters of simulated rain did not increase regularly depending on the rain intensity. The drop diameters were listed from large to small ½ HH-36 SQ> ½ HH-40 SS> ½ HH-50 WSQ. Agassi and Bradford (1999) emphasized that the maximum drop size did not increase with intensity as under natural storms. The terminal velocities of the nozzles also had the same trend in the drop diameter, respectively. The highest kinetic energy ratio and kinetic energy (Table 3) were obtained from ½ HH-50 WSQ nozzle in this research. The similar results were reported by other researchers (Erpul and Çanga, 2000; Kuhn et al., 2003; Omar et al., 2014). The results from correlation analysis are given in Table 4. The correlations between drop diameter, terminal velocity and kinetic energy of simulated rainfalls for each nozzle were found positive at p>0.01 significance level.

Table 3. Kinetic energies (KEs: J m^{-2} h^{-1}) calculated using Sempere-Torres et al., (1992) formula for Full Jet nozzles

Çizelge 3. *Full Jet başlıklar için Sempere-Torres ve ark., (1992)'nın formülü kullanılarak hesaplanan kinetik enerjiler*

	36 SQ			40 SS			50 WSQ		
P	I	KE_A	KE_B	I	KE_A	KE_B	I	KE_A	KE_B
30	204	4105	20.12	196	3685	18.80	85	2200	25.88
40	206	3678	17.85	204	3178	15.58	93	2509	26.98
50	209	3598	17.22	209	3598	17.22	97	2197	22.65
60	209	3122	14.94	215	2795	13.00	101	2101	20.80
70	211	4182	19.82	224	3790	16.92	109	2485	22.80
Average	208	3737	17.99	210	3410	16.30	97	2229	23.82

(P: kPa; I: mm h^{-1}; KE_A: J m^{-2} h^{-1}; KE_B: J m^{-2} mm^{-1})

Table 4. The correlations of pressure, rain intensity, drop diameter, terminal velocity and kinetic energy of simulated rainfalls in the experiment

Çizelge 4. *Denemede yapay yağışların, basınç, yağmur şiddeti, damla çapı, terminal hızı ve kinetik enerjilerine ait ikili ilişkileri*

½ HH-36 SQ					
Parameters	P	I	Ds	Vs	$KEs_{(mm)}$
P	1.000	0.969**			
I		1.000			
Ds			1.000	0.997**	0.984**
Vs				1.000	0.994**
$KEs_{(mm)}$					1.000
½ HH-40 SS					
Parameters	P	I	Ds	Vs	$KEs_{(mm)}$
P	1.000	0.995**			
I		1.000			
Ds			1.000	0.998**	0.987**
Vs				1.000	0.988**
$KEs_{(mm)}$					1.000
½ HH-50 WSQ					
Parameters	P	I	Ds	Vs	$KEs_{(mm)}$
P	1.000	0.990**			-0.769**
I		1.000			-0.679**
Ds			1.000	0.996**	0.672**
Vs				1.000	0.674**
$KEs_{(mm)}$					1.000

(P: Pressure-kPa; I: Rain intensity-mm h^{-1}; Ds: Drop diameter of simulated rainfalls-mm; Vs: Terminal velocity of simulated rainfall-m sec^{-1}; KEs: Kinetic energy of simulated rainfalls-J m^{-2} mm^{-1})

CONLUSIONS

According to the results obtained from this study, the increase of applied pressures increased rain intensity of Full Jet ½ HH-36 SQ, ½ HH-40 SS and ½ HH-50 WSQ nozzles, respectively. The pressures increased the uniformity coefficients in all 3 nozzles, it decreased the coefficient of variation. Kinetic energy was determined at the highest ½ HH-50 WSQ nozzle. The closest rain intensities to the Mediterranean climate rain intensities were determined under the ½ HH-50 WSQ nozzle. According to the research results, ½ HH-50 WSQ nozzle can be used up to 120 mm h^{-1} rain intensity, and ½ HH-40 SS and ½ HH-36 SQ nozzles can be used easily in rainfalls higher than 200 mm h^{-1}.

REFERENCES

Agassi, M. & J.M. Bradford, 1999. Methodologies for interrill erosion studies. Soil and Tillage Research, 49: 277-287.

Anonymous, 1999. SPSS 9 for Windows User's Guide. Copyright 1999 by SPSS Incorporation SPSS, Chicago, IL.

Anonymous, 2019. CAT 75 HYD., Wheaton, IL 60187-7901 USA. http://spraying systems co., Erişim tarihi: 20.04.2020.

Arnaez, J., T. Lasanta, R. Ruiz-Flano & L. Ortigosa, 2007. Factors affecting runoff and erosion under simulated rainfall in Mediterranean vineyards. Soil and Tillage Research, 93: 324-334. https:// doi.10.1016/j.still.2006.05.013.

Bubenzer, G.D. & L. D. Meyer, 1965, Simulation of rainfall and soils for laboratory research. Transaction of American Society of Agricultural Engineers, 8: 73-75.

ÇEM, 2018. Dinamik Erozyon Modeli ve İzleme Sistemi (DEMİS) Türkiye Su Erozyonu İstatistikleri, Teknik Özet. T.C. Tarım ve Orman Bakanlığı Çölleşme ve Erozyonla Mücadele Genel Müdürlüğü, Ankara, TÜRKİYE.

Cerda, A., 1997. Rainfall drop size distrubution in the Western Mediterranean basin, Valencia, Spain. Catena 30: 169-182. https://doi.org/10.1016/S0341-8162(97)00019-2.

Chouksey, A. V. Lambey, B. R. Nikam, S. P., Aggarvald & S. Dutta, 2017. Hydrolgical modelling using a rainfall simulator over an experimental hillslope plot. Hydrology 4: 17. https://doi. 10.3390/hydrology4010017.

Christiansen, J. E., 1942. Irrigation by sprinkling. University of California Agricultural Experiment Station Bulletin, No: 670.

De Sausa Junior, S. F., T.A. Mendes & E. Q. De Siqueirra, 2017. Development and calibration of a rainfall simulator for hydrological studies. Brazilian Journal of Water Resources, 22 (59): 2017. https://doi.org/10.1590/2318-0331.0217170015.

Erpul, G. & M. R. Çanga, 2000. Doğal yağışların laboratuvar tipi yapay yağışlar ile karşılaştırılması. Tarım Bilimleri Dergisi, 6 (1): 32-35.

Esteves, M., O. Planchon, J. M. Lapetite, N. Silvera & P. Cadet, 2000. The" EMIRE" large rainfall simulator: Design and Field Testing. Earth Surface Processes and Landforms, 25: 681-690. https://doi.10.1002/1096-9837(200007)25:73.0.CO;2-8.

Houndonougbo, M. & G. Yönter, 2020. Farklı basınçlarda veejet ve fulljet başlıkların yağış şiddeti, Christiansen katsayısı, yüzey akış ve toprak kayıpları üzerine etkilerinin kıyaslanması üzerine bir ön çalışma. Ege Üniv. Ziraat Fak. Derg., 57 (2):209-217. https://doi.org/10.20289/zfdergi.553142.

Humphry, J. B., T. C. Daniel, D. R. Edwards & A. N. Sharpley, 2002. A portable rainfall simulator for plot-scale runoff studies. Applied Engineering in Agriculture, 18 (2): 199-204. https://doi. 10.13031/2013.7789.

Iramu, E. T., 2012. A Critical Evaluation of the Effects of Plant Extract Formulations Against Two Generalized Insect Pests of *Abelmoschus manihot* (L.) Medik (Family: Malvaceae). School of Agriculture and Food Sciences, the University of Queensland, (Unpublished) PhD Thesis, Queensland, Australia, 198 pp.

Kuhn, N. J., R. B. Bryan & J. Novar, 2003. Seal formation and interrill erosion on smectite-rich Kastanozem from NE Mexico. Catena, 52: 149-169. https://doi. 10.1016/S0341-8162(02)00091-7.

Meyer, L. D., 1965. Simulation of rainfall for soil erosion research. Transaction of American Society of Agricultural Engineers, 8: 63-65.

MGM, 2019. T. C. Tarım ve Orman Bakanlığı, Meteoroloji Genel Müdürlüğü. http://www.mgm.gov.tr/veridegerlendirme/il-ve-ilçeleristatistik.aspx. Erişim tarihi: 16.04.2020.

Navas, A., F. Alberto, J. Machin & A. Galan, 1990. Design and operation of a rainfall simulator for field studies of runoff and soil erosion. Soil Technology, 3: 385-397. https://doi.org/10.1016/0933-3630(90)90019-Y.

Omar, M. A., Z. A. Rahaman & W. R. Ismail, 2014. Sediment and nutrient concentration from different land use and land cover of Bukit Merah Reservoir (BMR) Catchment, Perak, Malaysia. Geografı, 2 (2): 52-65.

Petan, S., S. Rusjan, A. Vidmar & M. Mikos, 2010. The rainfall kinetic energy-intensity relationship for rainfall erosivity estimation in the Mediterranean part of Slovenia. Journal of Hydrology, 391: 314-321. https://doi.10.1016/j.jhydrol.2010.07.031.

Rosewell, C. J., 1986. Rainfall kinetic energy in eastern Australia. Journal of Climate and Applied Meteorology, 25: 1695-1701. https://doi.org/10.1175/1520-0450(1986)025<1695:RKEIEA>2.0.CO;2

Sausa Junior, S. F & E. Q. Siqueira, 2011. Development and Calibration of a Rainfall Simulator for Urban Hydrology Research. 12th International Conference on Urban Drainage, Porto Alegre, Brazil, 11-16 September 2011.

Sempere-Torres, D., C. Salles, J. D. Creutin & G. Delrieu, 1992. Quantification of soil detachment by raindrop impact: performance of classical formulae of kinetic energy in Mediterranean storms. Erosion and Sediment Transport Monitoring Programmes in River Basins (Proceedings of the Oslo Symposium, August 1992). IAHS Publ., No. 210, 1992.

Tossell, R. W, W. T. Dickinson, R. P. Rudra & G. J. Wall, 1987. A portable rainfall simulator. Canadian Agricultural Engineering, 29: 155-162.

Uplinger, C. W., 1981. A new formula for raindrop terminal velocity. In: Abstracts of 20th Conference of Radar Meteorology. American Meteorogical Society, Boston, USA, pp. 389-391.

Usón, A. & M. C. Ramos, 2001. An improved rainfall erosivity index obtained from experimental interrill soil losses in soils with a Mediterranean climate. Catena, 43: 293-305.