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A study on the comparison of kinetic energies calculated with some formulas using Fulljet nozzle

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Fulljet başlık kullanılarak bazı formüllerle hesaplanan kinetik enerjilerin karşılaştırılması üzerine bir çalışma

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ABSTRACT

Objective: The objective of this study was to compare kinetic energies calculated by different formulas with Rose's (reference) formula, using Fulljet type nozzle (½ HH-50 WSQ) at different pressures.

Material and Methods: A platform in the dimension of 1x1 m was used to place 17 cups (250 cm^3) and inclined at a slope of 9%. Then, artificial rainfalls (at pressures of 30, 40, 50, 60 and 70 kPa) was applied with a ½ HH-50 WSQ nozzle for 5 minutes and each experiment was triplicated. Drop diameter, rainfall intensities, terminal velocities were determined and kinetic energies were calculated with different equations.

Results: In this study, it was found that rain intensities varied between 85- and 109 mm h^{-1}, Christiansen coefficients (CU) (%) were 83-87 %, drop diameter (D_{50}) were 1.77-2.05 mm, and terminal velocities were 6.08-6.67 m s^{-1}. Average kinetic energies were also calculated between 9.94-46.59 J m^{-2} mm^{-1}, respectively.

Conclusions: The results obtained from this study (±5 %) were found to be in good agreement with the Rose (1960) formula and some kinetic energy formulas.

Keywords: Christiansen coefficients, kinetic energy, mean drop diameter, rain intensity, terminal velocity

ÖZ

Amaç: Farklı basınçlarda Fulljet tipi başlık (½ HH-50 WSQ) kullanılarak Rose (referans) formülü ile farklı formüllerle hesaplanan kinetik enerjilerin karşılaştırılması amaçlanmıştır.

Materyal ve Yöntem: %9 eğimli 1x1 m boyutunda platform üzerine 17 adet kap (250 cm3) yerleştirilmiştir. Daha sonra bu kaplara 5 dakika sürede yapay yağışlar (30, 40, 50, 60 ve 70 kPa basınçlarda), ½ HH-50 WSQ başlık ile 3 tekrarlı olarak uygulanmıştır. Damla çapı, yağış şiddetleri, terminal hızlar belirlenmiş ve kinetik enerjiler farklı eşitliklerle hesaplanmıştır.

Araştırma Bulguları: Bu çalışmada yağış şiddetleri, 85-109 mm h-1, Christiansen katsayıları (CU) (%) %83-87, damla çapları (D_{50}) 1.77-2.05 mm ve terminal hızlar 6.08-6.67 m s^{-1} belirlenmiştir. Ortalama kinetik enerjiler de sırasıyla 9.94-46.59 J m^{-2} mm^{-1} arasında hesaplanmıştır.

Sonuç: Bu çalışmada, Rose (1960) formülü ile bazı kinetik enerji formülleri arasında çok yakın (%±5) ilişkiler bulunmuştur.

Anahtar sözcükler: Christiansen katsayısı, kinetik enerji, ortalama damla çapı, yağış şiddeti, terminal hız

INTRODUCTION

Erosion studies conducted in the field and laboratory conditions, rainfall simulators are being developed, especially as they can simulate natural rainfalls (Tossell et al., 1987). Numerous nozzles have been also developed with the development of rainfall simulators as Fulljet type nozzles. Christiansen (1942) suggested a method for calculating the uniform distribution of water in sprinkler irrigation systems. Uniformity coefficient is also used in many erosion studies to calculate the distribution of rainfall. Humphry et al. (2002) applied 70 mm h^{-1} of simulated rainfall at 28 kPa with the ½ HH-50 WSQ type nozzle, and they found the uniformity coefficient was 93 %. Kuhn et al. (2003) applied 60 mm h^{-1} of simulated rainfall, using a ½ HH-50 WSQ nozzle, and they found that the mean 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. Omar et al. (2014) applied 53 mm h^{-1} simulated rainfall, using a Fulljet nozzle (½ HH-50 WSQ) with 10 psi (68.9 kPa) pressure and 3 m height, and they reported that the CU% were between 80 and 95 %, the drop diameter was between 1.30 and 2.00 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 height with 2 Fulljet nozzles (½ 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. Houndonougbo & Yönter (2020) applied simulated rainfall to the soil surface in erosion trays with Veejet and Fulljet nozzles in oscillating conditions, and researchers found that simulated rainfall intensities, Christiansen coefficients, runoff and soil losses were similar between these nozzles.

Rain drop diameter, rainfall intensity and kinetic energy are the most important parameters on soil erosion. Some researchers reported that kinetic energy can be used a parameter of rainfall to detach soil, but, rainfall kinetic energy cannot be measured directly from meteorological parameters without disdrometers which is very expensive system, and it's usually estimated from rainfall intensity, therefore some kinetic energy formulas have been developed to calculate the kinetic energies of rainfall according to rain intensity (Salles et al., 2002; Petan et al., 2010). In this study, the objective was (1) to determine simulated rainfall intensities, uniformity coefficients, median drop diameters and kinetic energy ratios, using a ½ HH-50 WSQ type nozzle at different pressures (30, 40, 50, 60 and 70 kPa) and 2.00 m height, and (2) to compare kinetic energies calculated using formulas given by Wischeimer & Smith (1958), Hudson (1965), Carter et al. (1974), McGregor & Mutchler (1976), Park et al. (1980), Zanchi & Torri (1980), Kinnell (1981), Bollinne et al. (1984) Rosewell (1986), Onaga et al. (1988), Brandt (1990), McIsaac (1990), Sempere-Torres et al. (1992), Smith & De Veaux (1992), Coutinho & Tomas (1995), Renard et al. (1997), Cerro et al. (1998), Uijlenhoet & Stricker (1999), Jayawerdena & Rezaur (2000), Steiner & Smith (2000), Uson & Ramos (2001), Petan et al. (2010) with the ones calculated according to Rose's (reference) formula for this nozzle, and (3) to reveal the kinetic energy formulas that give the similar results according to the drop diameter and precipitation intensity measured in laboratory conditions.

MATERIAL and METHODS

Material

In this study, a laboratory type rain simulator (Bubenzer & Meyer, 1965) and a ½ HH-50 WSQ type nozzle that was mounted on it was used (Figure 1). ½ HH-50 WSQ nozzles apply rainfall in a square. In addition, these nozzles can apply drops in the range of 1.00-5.00 mm (Anonymous, 2019). 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 (Taysun, 1985). 17 aluminum containers (volume: 250 cm^3, height: 5 cm and diameter: 9 cm) were used to determine rainfall intensities in the experiment (Tossell et al., 1987).

Figure 1. Full Jet type (1/2 HH-50WSQ) spraying nozzle, laboratory type rainfall simulator and cups of used in experiment.

Şekil 1. *Full Jet tipi (1/1 HH-50 WSQ) püskürtücü başlık, laboratuvar tipi yağış simulatörü ve denemede kullanılan kaplar.*

Method

In this study, 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 at each pressure. The amount of water collected in containers was weighed on a scale with an accuracy of ± 0.01 g and recorded. Each experiments was triplicated. The amount of water obtained from the experiment was converted to rain intensities with the following formula (Tossell et al., 1987).

$$I_p = 10\left[\frac{\left(\frac{\sum Vi}{A_g}\right)}{n} \times \frac{60}{t}\right] \qquad (1)$$

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

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

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

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

The mean drop diameters and terminal velocities for natural rainfalls were taken from Kohnke & Bertnard (1959)'s tables. The terminal velocities of simulated rainfall were calculated by Uplinger (1981)'s formula as given below.

$$V = 4.854\ De^{(-0.195\ D)} \qquad (3)$$

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

Meyer (1965) stated that median drop diameter ratio ($D = \frac{Ds}{Dn}$), terminal velocity ratio ($V = \frac{Vs}{Vn}$), moment ($M = Vx100$), kinetic energy ($KE = V2x100$), moment per unit area ($Mu = DxVx100$) and kinetic energy per unit area ($KEu = DxV2x100$) to compare simulated rainfall and natural rain, respectively.

Where, D_s is mean drop diameter of simulated rainfall (mm), D_n is mean drop diameter of natural rain (mm), V_s: terminal velocity of simulated rainfall (m s^{-1}), V_n: terminal velocity of natural rain (m s^{-1}).

In the 3th stage, the kinetic energies of natural rains with the same rain intensities of simulated rainfalls were calculated using some formulas as tabulated in Table 1. Kinetic energies of natural rains were multiplied and kinetic energies of simulated rainfalls were calculated as in the following.

$$KEs = KE\ (\%)\ x\ KEn \quad (4)$$

Where, KE % is kinetic energy per cent, I: Rainfall intensity (mm h^{-1}), KE_s: Kinetic energy of simulated rainfall (J m^{-2} h^{-1}), and KE_n: Kinetic energy of natural rainfall (J m^{-2} h^{-1}).

In this study, Rose formula given below was chosen as the reference formula due to measured intensity, mean drop diameter by methods of the flour pellet and terminal velocity of simulated rainfall, easily.

$$KE = \frac{1}{2}\ I.V^2 \quad (5)$$

where, KE: Kinetic energy (J m^{-2} h^{-1}), I: Rainfall intensity (mm h^{-1}), and V: Terminal velocity (m s^{-1}).

Table 1. Relationships between kinetic energy and rain intensity (Sales et al, 2002; Petan et al, 2010)

Çizelge 1. *Kinetik enerji ve yağış şiddeti arasındaki ilişkiler (Sales et al, 2002; Petan et al, 2010)*

Reference	KE (J m^{-2} h^{-1})-I (mm h^{-1}) relation	Location	Range of I (mm h^{-1})
Wischeimer & Smith, 1958	$I (11.87+8.73 \log_{10} I)$	Washington, USA	n.a
Rose, 1960	$½\ I\ V^2$	England	n.a
Hudson, 1965	$29.86 (I–4.29)$	Zimbabwe	n.a
Carter et al., 1974	$11.32 I+0.5546 I^2-0.5009x10^{-2} I^3+0.126x10^{-4} I^4)$	South Central, USA	1-250
McGregor & Mutchler, 1976	$I (27.3+21.68 e^{-0.048 I}-41.26 e^{-0.072 I})$	Mississippi, USA	n a
Park et al., 1980	$21.1069 I^{1.156}$	USA	n.a
Zanchi & Torri, 1980	$I (9.81+11.25 \log_{10} I)$	Italy	n.a
Kinnell, 1981	$I (17.124+5.229 \log_{10} I)$	Miami, Florida	1.89-309
//	$30.132 (I-5.484)$	//	//
//	$29.31 I (1-0.281 e^{-0.018 I})$	//	//
//	$I (9.705+9.258 \log_{10} I)$	Rhodesia	18.5-228.6
//	$29.863 (I-4.287)$	//	//
//	$29.22 I (1-0.894 e^{-0.0477 I})$	//	//
Bollinne et al., 1984	$12.32 I+0.56 I^2$	Belgium	0.27-38.6
Rosewell, 1986	$29 I (1-0.596 e^{-0.0404 I})$	Gunnedah, Australia	1-145.9
//	$26.35 I (1-0.669 e^{-0.0349 I})$	Brisbane, Australia	1-161.2
//	$24.48 (I-1.253)$	Melbourne, Australia	n.a
//	$24.80 (I-1.292)$	Cowra, Australia	n.a
Onaga et al., 1988	$I (9.81+10.6 \log_{10} I)$	Okinawa, Japan	n.a
Brandt, 1990	$I (8.95+8.44 \log_{10} I)$	USA	n.a
McIsaac, 1990	$28.8 I (1-0.45 e^{-0.033 I})$	Panama	1.5-194

Table 1. Relationships between kinetic energy and rain intensity (Sales et al, 2002; Petan et al, 2010) (continued)

Çizelge 1. *Kinetik enerji ve yağış şiddeti arasındaki ilişkiler (Sales et al, 2002; Petan et al, 2010) (devamı)*

Reference	KE (J m^{-2} h^{-1})-I (mm h^{-1}) relation	Location	Range of I (mm h^{-1})
Sempere-Torres et al., 1992	34 I-190	Cevennes, France	20-100
Smith & De Veaux, 1992	13 $I^{1.21}$	Oregon, USA	n.a
//	11 $I^{1.23}$	Alaska, USA	n.a
//	18 $I^{1.24}$	Arizona, USA	n.a
//	11 $I^{1.17}$	New Jersey, USA	n.a
//	10 $I^{1.18}$	North Carolina, USA	n.a
//	11 $I^{1.14}$	Florida, USA	n.a
Coutinho & Tomas, 1995	35.9 I (1-0.559 $e^{-0.034\ I}$)	Portugal	0-120
Renard et al., 1997	29 I (1-0.72 $e^{-0.05\ I}$)	USA	n a
Cerro et al., 1998	38.4 I (1-0.538 $e^{-0.029\ I}$)	Barcelona, Spain	n.a
Uijlenhoet & Stricker, 1999	7.20 $I^{1.32}$	Based on Marshall & Palmer parameterization	n.a
//	8.53 $I^{1.29}$	//	//
//	8.46 $I^{1.17}$	//	//
//	8.89 $I^{1.28}$	//	//
//	10.8 $I^{1.06}$	//	//
//	7.74 $I^{1.35}$	//	//
Jayawerdena&Rezaur,2000	36.8 I (1-0.691 $e^{-0.038\ I}$)	Honk Kong	0-150
Steiner & Smith, 2000	11 $I^{1.25}$	Northern Mississippi, USA	n.a
Uson & Ramos, 2001	23.4 I-18	NE, Spain	<20
Petan et al, 2010	29.4 I (1-0.60 $e^{-0.085\ I}$)	Koseze, Slovenia	0.1-230

In the next step, calculated kinetic energies were converted to J m^{-2} mm^{-1} unit according to Rosewell 1986 formula.

$$KEh = c.I.KEmm \qquad (6)$$

where, KE_h: kinetic energy (J m^{-2}h^{-1}), c: coefficient, I: rainfall intensity (mm h^{-1}) and KE_{mm}: kinetic energy (J m^{-2}mm^{-1}), respectively.

For comparing KE_{mm}, deviation from the reference KE_{mm} was found with the following formula (Petan et al., 2010).

$$df\ \% = \frac{KEeq-KEref}{KEref}\ x\ 100 \qquad (7)$$

where, KE_{eq}, are calculated with formulas, KE_{ref} is calculated by Rose's ($KE_{ref} = \frac{1}{2}\ I.V^2$) references formulas.

RESULTS and DISCUSSION

Rainfall intensities, uniformity and variation coefficients, drop diameters, terminal velocities, moments, kinetic energies, as erosion forming powers (Taysun, 1985) moments per unit area and kinetic energies per unit area and their energies (J m^{-2} mm^{-1}) are given in Table 2 and 3, respectively. In addition, average kinetic energies (J m^{-2} mm^{-1}) calculated with different formulas of simulated rainfalls by using the Fulljet nozzle were given Table 4.

According to Table 2, rain intensity increased from 85 mm h^{-1} to 109 mm h^{-1}, uniformity coefficient increased from 83 % to 87 %, mean drop diameter of the simulated rainfall increased from 1.77 mm to 2.05 mm, the terminal velocity increased from 6.08 m s^{-1} to 6.67 m s^{-1}. According to Table 3, the kinetic energy ratio increased from 64 % to 77 %, respectively. On the contrary, variation coefficients decreased from 18 % to 16 % in this experiment.

According to Table 4, the kinetic energies were calculated between 9.94 J m^{-2} mm^{-1} and 46.59 J m^{-2} mm^{-1}. In some studies, it was determined that rainfall intensity was between 53 mm h^{-1} and 100 mm h^{-1}, drop diameter was between 1.00 mm and 5.00 mm, uniformity coefficient was between 79 % and 95 %, terminal velocity was between 3.30 m s^{-1} and 8.10 m s^{-1}, kinetic energy ratio was 90 % and kinetic energy was 33.00 J m^{-2} mm^{-1}, respectively (Humpry et al., 2002; Kuhn et al., 2003; Omar et al., 2014; Chouksey et al., 2017). There are similarities between the results of this study and the ones obtained in the literature. The t test results of the experiment are given in Table 5. According to Table 5, the lowest t tests and mean difference values are taken from formula of Renard et al. (1997) in this experiment.

Table 2. Rain intensities, uniformity and variation coefficients, dropp diameters and terminal velocities in the experiment

Çizelge 2. *Denemede Fulljet Başlığın Yağış Şiddetleri, Uniformite ve Varyasyon Katsayıları, Damla Çapları ve Terminal Hızlar*

	½ HH-50 WSQ										
	P kPa	I mm h^{-1}	Std.	CU %	CV %	D_s mm	D_n mm	D	V_s m s^{-1}	V_n m s^{-1}	V
	30	85	15	85	18	1.85	2.85	0.65	6.26	7.47	0.84
	40	93	18	83	19	2.05	2.93	0.70	6.67	7.55	0.88
	50	97	16	86	16	1.83	2.97	0.62	6.22	7.59	0.82
	60	101	17	86	17	1.77	3.01	0.59	6.08	7.63	0.80
	70	109	17	87	16	1.97	3.09	0.64	6.51	7.71	0.84
Mean	50	97	17	86	17	1.89	2.97	0.64	6.35	7.59	0.84

Table 3. Moment and Kinetic Energy of Fulljet Nozzle, Moment Per Unit Area and Kinetic Energy per Unit Area in the experiment

Çizelge 3. *Denemede Fulljet Başlığın Moment ve Kinetic Enerji, Birim Alana Düşen Moment ve Birim Alana Düşen Kinetik Enerjisi*

Erosion Forming Power (%)						
Parameters						Mean
M	84	88	82	80	84	84
KE	71	77	67	64	71	70
M_u	54	62	51	47	54	54
KE_u	46	55	42	38	46	45

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

Table 4. Average kinetic energies (J m^{-2} mm^{-1}) calculated with different formulas of simulated rainfalls by using the Fulljet nozzle

Çizelge 4. *Fulljet başlık kullanılarak yapay yağış şiddetlerinin farklı formüllerle hesaplanan ortalama kinetik enerjileri (J m^{-2} mm^{-1})*

Kinetic Energy Formulas	KE (J m^{-2} mm^{-1})	Deviation from the reference (%)	Kinetic Energy Formulas	KE (J m^{-2} mm^{-1})	Deviation from the reference (%)
W-S (1958)	20.44	1.34	S-T (1992)	22.42	11.16
H (1965)	19.97	-0.99	S-DV1 (1992)	23.76	17.80
Crt (1974)	20.59	2.08	S-DV2 (1992)	22.03	9.22
MG-M (1976)	19.23	-4.66	S-DV3 (1992)	37.74	87.11
Prk (1980)	30.14	49.13	S-DV4 (1992)	16.75	-16.96
Z-T (1980)	22.50	11.55	S-DV5 (1992)	15.94	-20.97
K1 (1981)	19.25	-4.56	S-DV6 (1992)	14.60	-27.62
K2 (1981)	19.89	-1.39	C-T (1995)	24.59	21.91
K3 (1981)	19.50	-3.32	Rnd (1997)	20.18	0.05
K4 (1981)	19.66	-2.53	Cer (1998)	25.98	28.81
K5 (1981)	19.97	-0.99	U-S 1 (1999)	21.76	7.88
K6 (1981)	20.26	0.45	U-S 2 (1999)	22.48	11.45
Blln (1984)	46.59	130.99	U-S 3 (1999)	12.88	-36.14
Rsw 1 (1986)	20.05	-0.59	U-S 4 (1999)	22.38	10.96

Table 4. Average kinetic energies (J m^{-2} mm^{-1}) calculated with different formulas of simulated rainfalls by using the Fulljet nozzle (continued)

Çizelge 4. *Fulljet başlık kullanılarak yapay yağış şiddetlerinin farklı formüllerle hesaplanan ortalama kinetik enerjileri (J m^{-2} mm^{-1}) (devamı)*

Kinetic Energy Formulas	KE (J m^{-2} mm^{-1})	Deviation from the reference (%)	Kinetic Energy Formulas	KE (J m^{-2} mm^{-1})	Deviation from the reference (%)
Rsw 2 (1986)	18.01	-10.71	U-S 5 (1999)	9.94	-50.72
Rsw 3 (1986)	16.91	-16.16	U-S 6 (1999)	26.83	33.02
Rsw 4 (1986)	17.13	-15.07	J-R (2000)	25.29	25.38
O (1988)	21.59	7.04	S-S (2000)	24.14	19.62
Brnt (1990)	17.99	-10.81	U-R (2001)	16.25	-19.43
McI (1990)	19.78	-1.93	P (2010)	20.58	2.03
Rose (1960) Reference formula = 20.17 (mm h^{-1})					

(W-S: Wischeimer & Smith; R: Rose; H: Hudson; Crt: Carter et al.; MG-M: McGregor & Mutchler; Prk: Park et al.; Z-T: Zanchi & Torri; K: Kinnell; Blln: Bolline et al.; Rsw: Rosewell; B-F: Brown & Foster; O: Onaga et al.; Brnt: Brandt; McI: Mc Isaac; Rnd: Renard; S-T: Sempere-Torres et al.; S-DV: Smith & DeVeaux; C-T: Coutinho & Tomas; Cer: Cerro et al.; U-S: Uijlenhoet & Stricker; J-R: Jayawerdena & Rezaur; S-S: Steiner & Smith; U-R: Uson & Ramos; P: Petan et al).

Table 5. The t test results of the experiment

Çizelge 5. *Denemeye ait t testi sonuçları*

Formulas	N	Mean	Std. Deviation	Std. Error Mean	Test Value = 20.17					
					t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
									Lower	Upper
R	15	20.17	1.40459	0.36266	0.00	14	1.000	0.00000	-0.7778	0.7778
WS	15	20.44	1.27265	0.32860	0.82	14	0.425	0.27000	-0.4348	0.9748
H	15	19.97	1.27099	0.32817	-0.60	14	0.556	-0.19800	-0.9019	0.5059
Crt	15	20.59	1.47213	0.38010	1.11	14	0.288	0.42000	-0.3952	1.2352
MGM	15	20.50	3.70740	0.95725	0.35	14	0.734	0.33200	-1.7211	2.3851
Prk	15	30.14	1.87043	0.48294	20.65	14	0.000	9.97200	8.9362	11.0078
Z-T	15	22.46	1.42918	0.36901	6.21	14	0.000	2.29000	1.4985	3.0815
K1	15	19.25	1.21192	0.31292	-2.93	14	0.011	-0.91800	-1.5891	-0.2469
K2	15	19.89	1.25849	0.32494	-0.86	14	0.407	-0.27800	-0.9749	0.4189
K3	15	19.50	1.22557	0.31644	-2.11	14	0.053	-0.66800	-1.3467	0.0107
K4	15	19.65	1.22346	0.31590	-1.63	14	0.126	-0.51400	-1.1915	0.1635
K5	15	19.97	1.27099	0.32817	-0.60	14	0.556	-0.19800	-0.9019	0.5059
K6	15	20.26	1.28884	0.33278	0.28	14	0.782	0.09400	-0.6197	0.8077
Blln	15	46.59	3.75260	0.96892	27.27	14	0.000	26.42200	24.3439	28.5001
Rsw1	15	20.05	1.27618	0.32951	-0.37	14	0.717	-0.12200	-0.8287	0.5847
Rsw2	15	18.01	1.13346	0.29266	-7.37	14	0.000	-2.15800	-2.7857	-1.5303
Rsw3	15	16.91	1.09202	0.28196	-11.55	14	0.000	-3.25600	-3.8607	-2.6513
Rsw4	15	17.13	1.10384	0.28501	-10.67	14	0.000	-3.04200	-3.6533	-2.4307
O	15	21.59	1.34061	0.34614	4.12	14	0.001	1.42600	0.6836	2.1684
Brnt	15	17.99	1.11839	0.28877	-7.55	14	0.000	-2.18000	-2.7993	-1.5607
McI	15	19.78	1.25144	0.32312	-1.21	14	0.245	-0.39200	-1.0850	0.3010
S-T	15	22.42	1.41967	0.36656	6.14	14	0.000	2.25000	1.4638	3.0362
S-DV1	15	23.76	1.46892	0.37927	9.47	14	0.000	3.59200	2.7785	4.4055
S-DV2	15	22.03	1.36069	0.35133	5.31	14	0.000	1.86400	1.1105	2.6175
S-DV3	15	37.74	2.33140	0.60196	29.18	14	0.000	17.56800	16.2769	18.8591
S-DV4	15	16.75	1.03654	0.26763	-12.79	14	0.000	-3.42200	-3.9960	-2.8480
S-DV5	15	15.18	2.11805	0.54688	-9.11	14	0.000	-4.98400	-6.1569	-3.8111
S-DV6	15	14.60	0.91086	0.23518	-23.68	14	0.000	-5.56800	-6.0724	-5.0636
C-T	15	24.59	1.55309	0.40101	11.03	14	0.000	4.42200	3.5619	5.2821
Rnd	15	20.10	1.29500	0.33437	0.02	14	0.981	0.00800	-0.7091	0.7251
Cer	15	25.99	1.63046	0.42098	13.82	14	0.000	5.81800	4.9151	6.7209

Table 5. The t test results of the experiment (continued)

Çizelge 5. *Denemeye ait t testi sonuçları (devamı)*

Formulas	N	Mean	Std. Deviation	Std. Error Mean	Test Value = 20.17					
					t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
									Lower	Upper
U-S1	15	21.76	1.35655	0.35026	4.54	14	0.000	1.59000	0.8388	2.3412
U-S2	15	22.48	1.39313	0.35970	6.42	14	0.000	2.31000	1.5385	3.0815
U-S3	15	12.85	0.77933	0.20122	-36.39	14	0.000	-7.32200	-7.7536	-6.8904
U-S4	15	22.38	1.38568	0.35778	6.18	14	0.000	2.21000	1.4426	2.9774
U-S5	15	9.94	0.62842	0.16226	-63.01	14	0.000	-10.22400	-10.5720	-9.8760
U-S6	15	26.83	1.68658	0.43547	15.30	14	0.000	6.66200	5.7280	7.5960
J-R	15	25.29	1.60099	0.41337	12.40	14	0.000	5.12400	4.2374	6.0106
S-S	15	24.14	1.49234	0.38532	10.31	14	0.000	3.97200	3.1456	4.7984
U-R	15	16.25	1.05082	0.27132	-14.45	14	0.000	-3.92000	-4.5019	-3.3381
P	15	20.57	1.33280	0.34413	1.17	14	0.260	0.40400	-0.3341	1.1421

(W-S: Wischeimer & Smith; R: Rose; H: Hudson; Crt: Carter et al.; MG-M: McGregor & Mutchler; Prk: Park et al.; Z-T: Zanchi & Torri; K: Kinnell; Blln: Bolline et al.; Rsw: Rosewell; B-F: Brown & Foster; O: Onaga et al.; Brnt: Brandt; McI: Mc Isaac; Rnd: Renard; S-T: Sempere-Torres et al.; S-DV: Smith & DeVeaux; C-T: Coutinho & Tomas; Cer: Cerro et al.; U-S: Uijlenhoet & Stricker; J-R: Jayawerdena & Rezaur; S-S: Steiner & Smith; U-R: Uson & Ramos; P: Petan et al).

Table 4 showed that while the lowest KE were obtained from Uijlenhoet & Stricker (1992) formula, the highest KE were obtained from Bollinne et al. (1984) formula, respectively. Salles et al. (2002) reported that Bollinne et al. (1984)'s formula predicted unrealistically high KE.

According to deviation from the reference (%), Wischmeier & Smith (1958), Hudson (1965), Carter et al. (1974), McGregor &Mutchler (1976), Kinnell (1981), 1st Rosewell (1986), McIsaac (1990), Renard et al. (1997), and Petan et al. (2010) formulas showed very good performances within the range of ±5% (Figure 2). According to this range, whereas the lowest KE was calculated from Renard et al. (1997) formula, the highest KE was calculated from McGregor & Mutchler (1976) formula.

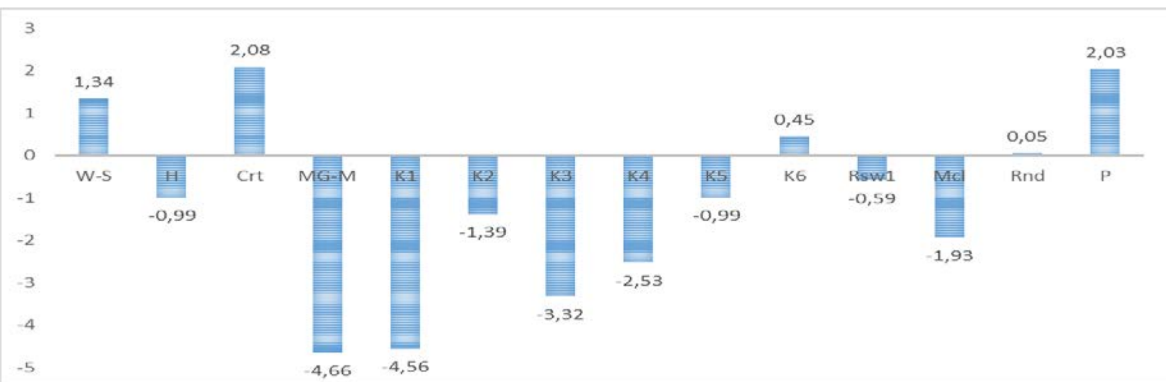

Figure 2. Kinetic energies relative to ± 5 % deviation in this study. (W-S: Wischeimer & Smith; R: Rose; H: Hudson; Crt: Carter et al.; MG-M: McGregor & Mutchler; K1, 2, 3, 4, 5, 6:Kinnell; Rsw1: Rosewell; McI: Mc Isaac; Rnd: Renard; P: Petan et al).

Şekil 2. *Bu çalışmada ± 5 % sapmaya göre kinetik enerjiler.*

Onaga et al. (1988), 2nd Smith & De Veaux (1992), and 1st Uijlenhoet & Stricker (1999) formulas showed good performances within the range of ±10% (Figure 3). According to this range, whereas the lowest KE was calculated from Onaga et al. (1988) formula, the highest KE was calculated from Smith & De Veaux (1992) formula.

Zanchi and Torri (1980), 2nd, 3nd and 4th Rosewell (1986), Brandt (1990), Sempere-Torres et al. (1992), 1st and 4th Smith & De Veaux (1992), 2nd and 4th Uijlenhoet and Stricker (1999), Steiner and Smith (2000), and Uson and Ramos (2001) formulas showed poor performances and underestimated the range of ±20% (Figure 4). According to this range, whereas the lowest KE was calculated from Rosewell (1986) and Brandt (1990) formulas, the highest KE was calculated from Uson & Ramos (2001) formula.

Park et al., (1980), Bollinne et al. (1984), 3nd, 5th and 6th Smith and De Veaux (1992), Coutinho and Tomas (1995), Cerro et al. (1998), 3nd, 5th and 6th Uijlenhoet & Stricker (1999), and Jayawardena & Rezaur (2000) formulas showed poor performances within overestimate the range of ±20% (Figure 5), respectively. According to this range, whereas the lowest KE was calculated from Smith & De Veaux (1992) formula, the highest KE was calculated from Bolline et al. (1984) formula.

According to this study, it was found that very closed relationships (0.05 %) between Rose (1980) and Renard et al., (1997) formulas for calculating kinetic energies in ½ HH-50 WSQ nozzle. Similar findings were found by Petan et al. (2010).

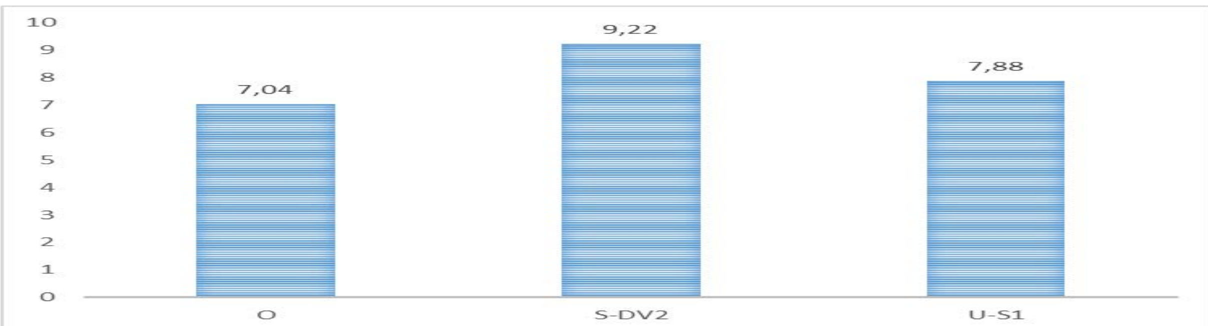

Figure 3. Kinetic energies relative to 5-10 % deviation in this study. (O: Onaga et al.; S-DV2: Smith & DeVeaux; U-S1: Uijlenhoet & Stricker).

Şekil 3. *Bu çalışmada 5-10 % sapmaya göre kinetik enerjiler.*

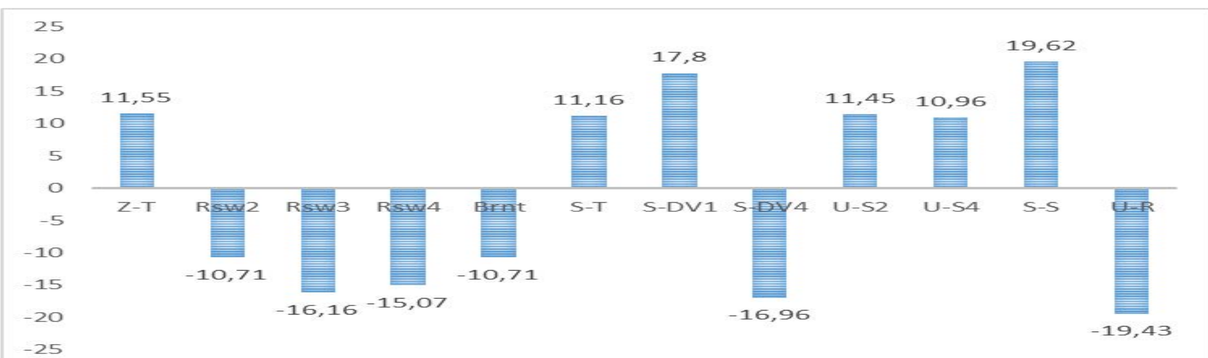

Figure 4. Kinetic energies relative to 10-20 % deviation in this study. (Z-T: Zanchi & Torri; Rsw2, 3, 4: Rosewell; Brnt: Brandt; S-T: Sempere-Torres et al.; S-DV1, 4: Smith & DeVeaux; U-S2, 4: Uijlenhoet & Stricker; S-S: Steiner & Smith; U-R: Uson & Ramos).

Şekil 4. *Bu çalışmada 10-20 % sapmaya göre kinetik enerjiler.*

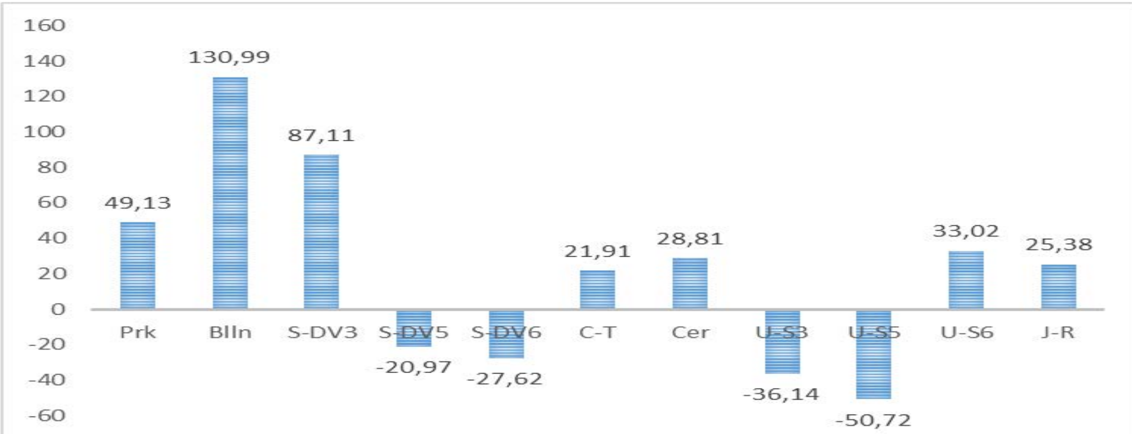

Figure 5. Kinetic energies relative to >20 % deviation in this study. (Prk: Park et al.; Blln: Bolline et al.; S-DV3, 5, 6: Smith & DeVeaux; C-T: Coutinho & Tomas; Cer: Cerro et al.; U-S3, 5, 6: Uijlenhoet & Stricker; J-R: Jayawerdena & Rezaur).

Şekil 5. *Bu çalışmada >20 % sapmaya göre kinetik enerjiler.*

CONCLUSIONS

It is very difficult to measure the kinetic energy of natural rainfall directly today without disdrometers. Therefore, kinetic energy can be calculated with some empirical formulas depending on the rain intensity. For rainfall simulators and the nozzles used, it is very important to determine the kinetic energies of rainfall with the most accurate and appropriate methods. Therefore, it is important to make comparisons with the formulas used in the calculation of kinetic energies. In this study, Rose equation was chosen as the reference equation because the drop diameter, terminal velocity and rain intensity of artificial rainfall were obtained at the time of treatment, easily. According to this study, it was found that some equations gave close results. However, it is clear that the kinetic energies of the nozzles used in rain simulators can change. Therefore, determination of the kinetic energies for each nozzle will help erosion studies.

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