Int. Agrophysics, 2000, 14, 1-7

EFFECT OF WIND ON SIZE AND ENERGY OF SMALL SIMULATED RAINDROPS: A WIND TUNNEL STUDY

G. Erpul[1], *D. Gabriels*[1, 2], *D. Janssens*[1]

[1]Department of Soil Management and Soil Care, University of Ghent, Coupore Links 653, B 9000 Ghent, Belgium
E-mail: donald.gabriels@rug.ac.be
[2]Fund for Scientific Research, Flanders, Belgium

Accepted May 25, 1999

Abstract. A series of tests to evaluate the effect of wind on drop size distribution and impact energy were carried out in a wind tunnel with rainfall simulation facility. Horizontal wind speed of 5.7, 10.0, and 12.1 m s^{-1} was applied with high intensity rainfall (97.2 - 143.0 mm h^{-1}) with different raindrop size distributions created by adjusting the nozzle for the operating pressures. The median drop size d_{50} ranged from 1.00 to 1.63 mm.

Drop size distribution changed with wind. The median drop diameter was becoming larger in wind-driven rain compared to windless rain. Wind accompanying rainfall increased the amount of sand splash from splash cups which indicated higher kinetic energy, especially with winds higher than 10.0 m s^{-1}. Differences in kinetic energy levels between wind-driven and windless rain are ascribed to the higher impact velocity resulting from the vectorial sum of the applied horizontal wind speed and the initial drop velocity created by the spray nozzle, rather than to the change in drop size.

Keywords: wind speed, raindrop size, kinetic energy; raindrop impact velocity

INTRODUCTION

The size and impact velocity of raindrops determine its erosive power [23,26]. Lal *et al.* [15] showed that erosivity of wind-driven rain could differ drastically from the rain falling in windless conditions to wind in dry conditions. An increasing angle of deviation from vertical with increasing wind speed brings about an increased total splash [32,31]. The net soil transport under oblique rainfall was experimentally observed by Moeyersons [25] and Poesen [28]. Wright [33] modelled the effect of oblique rainfall by changing the values of the parallel and normal components of the incident drop velocity. De Lima [2] emphasized the importance of wind in raindrop splash anisotropy.

Lyles *et al.* [20] found that up to 66% more soil detachment occurred at 13.4 m s^{-1} wind velocity than without wind at the same rainfall intensity, duration of exposure, and with clods of the same size. Also Disrud [4] observed that more clods were destroyed by wind-driven rain than by in windless conditions. Disrud and Krauss [5] mentioned the wind shear stress as an independent variable affecting soil loss.

Some explanations of both wind effects on rainfall and rainfall effect on wind erosion were given by Lyles [18,19]. In the first case, wind altered the angle of raindrop impact, and increased detaching capacity of the drops by adding a horizontal component to the drop velocity (thus increasing the kinetic energy of rainfall). In the latter case, rainfall increased (or decreased) the ability of wind to cause movement and abrasion of soil.

Jungerius *et al.* [14] recorded appreciable wind erosion on dunes during rainy days, and noticed that a lot of material was shifted down-slope during rainfall. A combined action of raindrop splash causing upward movement of sand particles followed by wind drag was observed by Rutin [30] and Jungerius and Dekker [13]. De Lima *et al.* [3] dealt with field measurements of particle movement during periods in which rainfall and wind coincide. Their results showed an increase of particle movement during rainfall. This was attributed to the combined action of saltation and rainfall -induced uplift of soil particles and subsequent transport by wind.

Pedersen and Hasholt [27] measured soil splash erosion on an event-based scale under natural rainfall. Kinetic energy of precipitation was calculated according to a model that incorporates horizontal terminal velocities of raindrops induced by wind speed.

In our study experiments were carried out in a wind tunnel with rainfall simulation to evaluate the effect of different wind speed levels on raindrop size distribution of small raindrops and related raindrop energy at high rain intensity levels.

MATERIALS AND METHODS

The tests were carried out in a wind tunnel with rainfall simulation facility of the International Center for Eremology (I.C.E), University of Ghent, Belgium. A description of the I.C.E wind tunnel is given by Gabriels *et al.* [10].

Rainfall was simulated with a continuous spray system of downward oriented nozzles installed in the central pipe line of the rainfall simulator. The nozzle employed gave axial flow, and was a wide angle, full cone type. Operating pressures were limited and kept at 0.75, 1.00, and 1.50 bars, enabling to simulate high intensity rains. Below an operating pressure of 0.75 bar drops would not form and at pressures greater than 1.50 bar the drops were too small. Three wind speeds were applied: 5.7 (low), 10.0 (medium), and 12.1 m s^{-1} (high). The highest intensities were obtained with the highest pressure applied (1.50 bar), resulting in the smallest raindrops. According to the distribution function relating intensity to drop size distribution, raindrop size increases with increasing rainfall intensity [22]. At the high intensities produced with the rain simulator in the wind tunnel, according to the Marshall and Palmer's model, the d_{50} values for natural rain would be about twice the values produced by the simulator. The general idea that high intensity rains are characterised by large drops is misleading as the median drop size can decrease for high rain intensity levels higher than 100 mm h^{-1} [12].

Table 1 reports the rainfall intensities obtained for different operating pressures and different horizontal wind speeds.

Drop size distribution was determined by the stain method [11]. Absorbent paper was dyed with 1 M $CuSO_4$ and dried to make spot permanent and easier to measure. Dry $CuSO_4$ was white but after exposure to rainfall, each raindrop made a light blue circular stain. The absorbent paper was exposed to simulated rainfall in the wind tunnel for a second only to prevent several drops falling on the same spot. Light blue stains were marked, measured, and counted very carefully. To calibrate stain size to that of the drops, drops of a known size produced by the hypothermic needles were allowed to fall on the dyed absorbent paper, and the size of the resultant stains was determined.

Kinetic energy of rainfall was determined by the splash cup technique [8]. The technique involved exposure of a cup packed with sand of a certain particle size (range) to rainfall. The amount of sand which is splashed out of the cup is a measure of kinetic energy of the oblique rainfall.

Before the study on the oblique rain in the wind tunnel, a calibration study was carried out with another rainfall simulator creating vertical rain and described by Gabriels and De Boodt [9]. The calibration study aimed at establishing a linear relationship between the amount of splash (S_p) of a standard sand and the kinetic energy (E) of the rainfall. A standard graded tertiary dune sand obtained as a sieve fraction of 100 - 200 μm was packed in 7 cm diameter cups. A correction for the amount of splashed sand was made [1] for splash depths greater than 2 mm [12]. The terminal vertical fall velocity of

Table 1. Rainfall intensities for windless and wind-driven rains

Wind speed u (m s^{-1})	Operating pressure (bar)	Rainfall intensity* I (mm h^{-1})	ci**
0.0	0.75	97.2	$93.9 \leq I \leq 100.5$
	1.00	98.5	$92.7 \leq I \leq 104.3$
	1.50	143.0	$141.2 \leq I \leq 144.8$
5.7	0.75	113.3	$109.1 \leq I \leq 117.5$
	1.00	116.4	$113.6 \leq I \leq 119.2$
	1.50	124.0	$120.9 \leq I \leq 127.1$
10.0	0.75	108.0	$100.9 \leq I \leq 115.1$
	1.00	110.9	$108.6 \leq I \leq 113.2$
	1.50	136.6	$132.0 \leq I \leq 141.2$
12.1	0.75	110.0	$104.3 \leq I \leq 115.8$
	1.00	115.4	$113.4 \leq I \leq 117.4$
	1.50	139.1	$136.1 \leq I \leq 142.1$

*The spatial distribution of the intensity in the wind tunnel was measured with small collectors (rain gauges), 11 cm in diameter and 13.5 cm in depth (collecting surface = 95.03 cm^2). 240 collectors placed in the testing area were exposed to 15 min rainfall, **95% confidence interval (ci) on mean rainfall intensity.

the raindrops was derived from the monograph of Laws [16]. The linear relationship between splash amounts (S_p) and the kinetic energy (E) was:

$$E = 20.364\, S_p + 2.6009 \quad (R^2 = 0.96)$$

with E in J m^{-2} and S_p in g cup^{-1}.

RESULTS AND DISCUSSION

Effect of wind on drop size distribution

Figure 1 compares the rain drop size distribution without and with wind. From Fig. 2 illustrating the cumulative frequency of drop sizes, the median drop size d_{50}, the "spreading coefficient" d_{75}/d_{25} and the "sorting coefficient" $(d_{75}-d_{25})/d_{50}$ are derived (Tables 2 and 3).

Without wind, the simulated rainfall had rather low d_{50} ranging between 1.00 mm for the highest rainfall intensity (143.0 mm h^{-1}) and 1.32 mm for the 98.5 mm h^{-1} rainfall intensity. The corresponding d_{25} and d_{75} also had the lowest values. On the other hand the highest "spreading" and "sorting" coefficients were obtained in windless conditions. When horizontal wind was introduced, a change in raindrop characteristics occurred. At all wind speeds and all rainfall intensities the d_{25}, d_{50}, and d_{75} increased compared to the windless rainfalls. This could be attributed to the formation of larger drops because of turbulence in the wind tunnel. Collisions between small drops will occur more frequently as a result of their greater number per unit volume of air. This would be expected to result in an increase in the mean drop size. For large drops, however, this would not be expected as large drops are less stable and the effect of wind would be to cause some of them to break up into smaller drops.

There was no significant difference in the median drop sizes for the different wind speeds. Also remarkable was the lower "spreading" and "sorting" coefficients for wind-driven rainfall compared to the windless rainfall. This means that the raindrop size of the wind-driven rainfall had a narrow range around the d_{50} (between 1.54 and 1.63 mm). The narrow spreading around d_{50} and low sorting coefficient would indicate that d_{50} could be used as a representative characteristic of the raindrop size distribution. Research by Laws and Parsons [17], Zanchi and Torri [34], and Lal *et al.* [15] showed a good relationship between d_{50} and rainfall intensity. In those studies the wind speed was not mentioned and there was no indication if rains were windless or wind-driven.

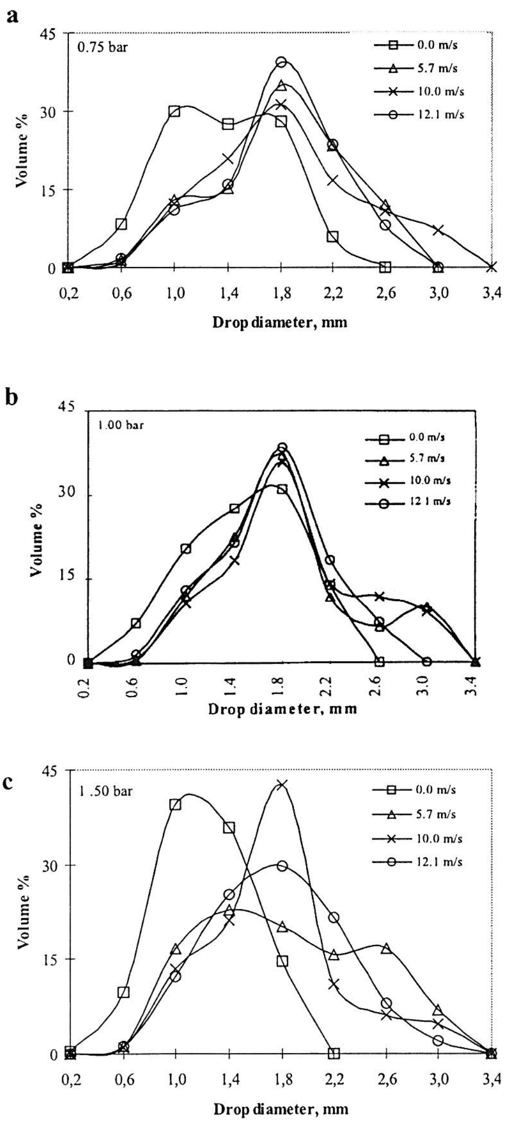

Fig. 1. Drop size distributions for windless rains and for rains driven by 5.7, 10.0, and 12.1 m s^{-1} wind speed at: 0.75 (a), 1.00 (b) and 1.50 (c) bars operating pressures.

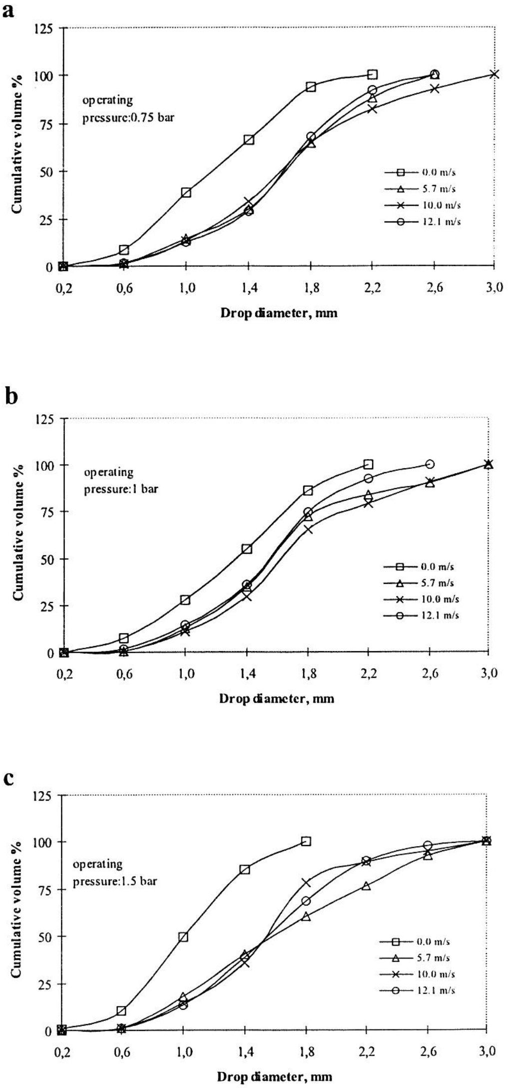

Fig. 2. Cumulative frequency of drop sizes of windless rains and for rains driven by 5.7, 10.0, and 12.1 m s^{-1} wind speed at: 0.75 (a), 1.00 (b) and 1.50 (c) bars operating pressures.

Effect of wind on rainfall kinetic energy

The kinetic energy values for windless and wind-driven rain as determined from the sand splash amount are reported in Table 4. From the kinetic energy, a corresponding impact velocity was calculated.

The highest rainfall intensities produced at the highest operating pressure (bar) resulted in the lowest kinetic energy and hence the lowest corresponding impact velocities at all wind speeds. As the rainfall intensities for all the tests were in the same order of magnitude, the large differences in sand splash amount and corresponding kinetic energy between windless and wind-driven rainfalls are due to factors other than rainfall intensity. The exponential relationships between the kinetic

Table 2. Raindrop characteristics for windless and wind-driven rains

Operating pressure (bar)	Rainfall intensity I (mm h^{-1})	Wind speed u (m s^{-1})	d_{25} (mm)		d_{50} (mm)		d_{75} (mm)	
			Mean	ci*	Mean	ci	Mean	ci
0.75	97.2	0.0	0.85	$0.73 \leq d_{25} \leq 0.97$	1.19	$1.11 \leq d_{50} \leq 1.26$	1.51	$1.44 \leq d_{75} \leq 1.57$
0.75	113.3	5.7	1.28	$0.97 \leq d_{25} \leq 1.60$	1.63	$1.59 \leq d_{50} \leq 1.67$	1.98	$1.95 \leq d_{75} \leq 2.01$
0.75	108.0	10.0	1.25	$1.15 \leq d_{25} \leq 1.34$	1.62	$1.53 \leq d_{50} \leq 1.71$	2.04	$1.88 \leq d_{75} \leq 2.21$
0.75	110.0	12.1	1.31	$1.20 \leq d_{25} \leq 1.43$	1.62	$1.55 \leq d_{50} \leq 1.68$	1.92	$1.87 \leq d_{75} \leq 1.97$
1.00	98.5	0.0	0.95	$0.93 \leq d_{25} \leq 0.97$	1.32	$1.29 \leq d_{50} \leq 1.36$	1.65	$1.64 \leq d_{75} \leq 1.67$
1.00	116.4	5.7	1.25	$1.13 \leq d_{25} \leq 1.36$	1.57	$1.48 \leq d_{50} \leq 1.66$	1.85	$1.32 \leq d_{75} \leq 2.39$
1.00	110.9	10.0	1.32	$1.04 \leq d_{25} \leq 1.61$	1.63	$1.43 \leq d_{50} \leq 1.83$	2.06	$1.74 \leq d_{75} \leq 2.38$
1.00	115.4	12.1	1.20	$1.10 \leq d_{25} \leq 1.31$	1.55	$1.48 \leq d_{50} \leq 1.62$	1.82	$1.78 \leq d_{75} \leq 1.85$
1.50	143.0	0.0	0.75	$0.73 \leq d_{25} \leq 0.77$	1.00	$0.97 \leq d_{50} \leq 1.04$	1.29	$1.27 \leq d_{75} \leq 1.30$
1.50	124.0	5.7	1.30	$1.19 \leq d_{25} \leq 1.41$	1.61	$1.38 \leq d_{50} \leq 1.84$	2.00	$1.77 \leq d_{75} \leq 2.23$
1.50	136.6	10.0	1.20	$1.17 \leq d_{25} \leq 1.24$	1.54	$1.50 \leq d_{50} \leq 1.57$	1.77	$1.75 \leq d_{75} \leq 1.79$
1.50	139.1	12.1	1.18	$1.10 \leq d_{25} \leq 1.26$	1.54	$1.51 \leq d_{50} \leq 1.57$	1.91	$1.76 \leq d_{75} \leq 2.07$

*95% confidence interval (ci) on the mean.

energies or impact velocities and the applied wind speeds are illustrated in Fig. 3. The kinetic energies and the impact velocities considered are the means of the values for each wind speed applied. It is clear that at the present stage of research the exponential relationships between the kinetic energy or impact velocity and the wind speed are valid for the conditions in which the experiments were carried out.

Wind-driven rain attained larger drops which hit the sand surface with higher impact velocities and at an angle from the vertical because of the combination of horizontally applied wind acting on the initial vertical drop velocity created by the nozzle [4,6,21,27,31]. This facilitated sand splash [25,28,31-33] and increased the sand removal from the splash [3,13-15,18,19].

Although there is a clear difference in d_{50} between rains without wind, and rains with wind, but no significant difference in d_{50} for the different wind speeds. For wind speeds between 0 and 5.7 m s^{-1}, the increase in energy is in response to the increasing drop velocity. To determine the form of response, measurements at wind speeds below 5.7 m s^{-1} are needed. For wind speeds higher than 5.7 m s^{-1} the increase in energy can be attributed to the increase in drop impact velocity.

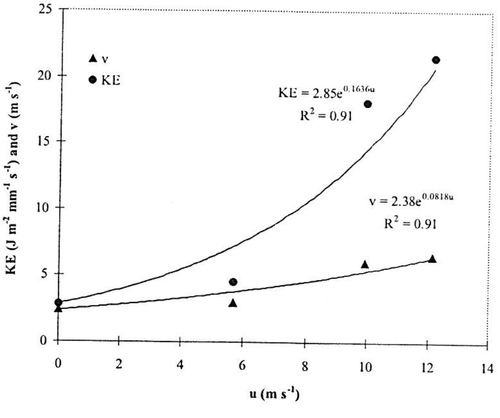

Fig. 3. Impact velocities (v) and kinetic energies (E) of simulated rainfall affected by different horizontal wind speeds (u) (d_{50} between 1.00 and 1.63 mm).

Table 3. Spreading and sorting coefficients for windless and wind-driven rains

See Figure	I (mm h^{-1})	u (m s^{-1})	d_{25} (mm)	d_{50} (mm)	d_{75} (mm)	d_{75} / d_{25}	(d_{75} - d_{25}) / d_{50}
1a &2a	97.2	0.0	0.85	1.19	1.51	1.78	0.55
1a &2a	113.3	5.7	1.28	1.63	1.98	1.55	0.43
1a &2a	108.0	10.0	1.25	1.62	2.04	1.63	0.49
1a &2a	110.0	12.1	1.31	1.62	1.92	1.47	0.38
1b &2b	98.5	0.0	0.95	1.32	1.65	1.74	0.53
1b &2b	116.4	5.7	1.25	1.57	1.85	1.48	0.38
1b &2b	110.9	10.0	1.32	1.63	2.06	1.56	0.45
1b &2b	115.4	12.1	1.20	1.55	1.82	1.52	0.40
1c &2c	143.0	0.0	0.75	1.00	1.29	1.72	0.54
1c &2c	124.0	5.7	1.30	1.61	2.00	1.54	0.43
1c &2c	136.6	10.0	1.20	1.54	1.77	1.48	0.37
1c &2c	139.1	12.1	1.18	1.54	1.91	1.62	0.47

Table 4. Kinetic energies (E) and corresponding impact velocities (v) of windless and wind-driven rains

Wind speed u (m s^{-1})	Operating pressure (bar)	Rainfall intensity I (mm h^{-1})	d_{50} (mm)	E* (J m^{-2} mm^{-1})	ci**	v (m s^{-1})
0.0	0.75	97.2	1.19	3.28	$2.97 \leq E \leq 3.58$	2.56
0.0	1.00	98.5	1.32	3.03	$2.77 \leq E \leq 3.29$	2.46
0.0	1.50	143.0	1.00	2.25	$1.96 \leq E \leq 2.53$	2.12
				2.85		**2.38**
5.7	0.75	113.3	1.63	5.34	$4.67 \leq E \leq 6.00$	3.27
5.7	1.00	116.4	1.57	4.33	$3.89 \leq E \leq 4.78$	2.94
5.7	1.50	124.0	1.61	3.88	$3.34 \leq E \leq 4.41$	2.79
				4.52		**3.00**
10.0	0.75	108.0	1.62	21.10	$20.25 \leq E \leq 21.95$	6.50
10.0	1.00	110.9	1.63	18.53	$18.00 \leq E \leq 19.07$	6.06
10.0	1.50	136.6	1.54	14.67	$14.06 \leq E \leq 15.28$	5.42
				18.10		**5.99**
12.1	0.75	110.0	1.62	24.03	$23.25 \leq E \leq 24.82$	6.93
12.1	1.00	115.4	1.55	22.47	$21.14 \leq E \leq 23.79$	6.70
12.1	1.50	139.1	1.54	17.90	$17.49 \leq E \leq 18.31$	5.98
				21.50		**6.54**

* Kinetic energy is normalized by rainfall intensity x duration of measurement (10 min = 0.167 h). ** 95% confidence interval on mean kinetic energy.

CONCLUSIONS

Because of the occurrence of possible collisions between small drops as a result of their greater number per unit volume and the greater effect of the wind on the drops, an increase in d_{50} was observed in wind-driven rains. However for large drops this would not be expected. Large drops are less stable and the effect of wind would be to cause some of the drops to break up into smaller drops. This shows conclusively that the effects of wind on large drop sizes would not be as great as the effects on small drops. Disintegration of large drops depending on the wind turbulence may actually lead to a reduction in drop size and possibly kinetic energy. Therefore, the results of this laboratory work are limited to the drop size distributions studied (with d_{50} between 1.00 and 1.63 mm), and are valid for the conditions (wind speed and rain intensities) in which the experiments were carried out.

An increase in energy is in response to the increasing drop velocity for the wind speeds between 0 and 5.7 m s^{-1}. For the wind speeds higher than 5.7 m s^{-1} the increase in energy can be attributed to the increase in drop impact velocity.

As the probability for the wind to accompany rainfall is very high, the wind effect on rainfall characteristics should be taken into consideration when assessing the rainfall erosivity. Sand splash amounts and related kinetic energies could be indicators of this erosivity.

REFERENCES

1. **Bisal F.**: Calibration of splash cup for soil erosion studies. Agr. Eng., 31, 621-622, 1950.
2. **De Lima J.L.M.P.**: Raindrop splash anisotropy: slope, wind and overland flow velocity effects. Soil Technology, 2, 71-78, 1989.
3. **De Lima J.L.M.P., Van Dijk P.M., Spaan W.P.**: Splash-saltation transport under wind-driven rain. Soil Technology, 5, 151-166, 1992.
4. **Disrud L.A.**: Magnitude, probability, and effect on kinetic energy of winds associated with rains in Kansas. Trans. Kans. Acad. Sci., 73(2), 237-246, 1970.
5. **Disrud L.A ., Krauss R.K.**: Examining the process of soil detachment from clods exposed to wind-driven simulated rainfall. Trans. ASAE, 14, 90-92, 1971.
6. **Disrud L. A., Lyles L., Skidmore E.L.**: How wind affects the size and shape of raindrops. Agr. Eng., 50 (10), 617, 1969.
7. **Ekern P.C.**: Raindrop impact as a force initiating soil erosion. Soil Sci. Soc. Am. Proc., 15, 7-10, 1950.
8. **Ellison W.D.**: Soil erosion studies. (7 parts). Agr. Eng. 28: 145-146; 197-201; 245-248; 297-300; 349-351; 407-408; 447-450, 1947.
9. **Gabriels D., De Boodt M.**: A rainfall simulator for soil erosion studies in the laboratory. Pedologie, 2, 80-86, 1975.
10. **Gabriels D., Cornelis W., Pollet I., Van Coillie T., Ouessar M.**: The I.C.E. wind tunnel for wind and water erosion studies. Soil Technology, 10, 1-8, 1997.
11. **Hall M.J.**: Use of stain method in determining the drop size distributions of coarse liquid sprays. Trans. ASAE, 13(1), 33-41, 1970.
12. **Hudson N.W.**: The influence of rainfall mechanics on soil erosion. M.Sc. Thesis, University of Cape Town, 1965.
13. **Jungerius P.D., Dekker L.W.**: Water erosion in dunes. Caten Suppl., 18, 185-193, 1990.
14. **Jungerius P. D., Verheggen A.J.T., Wiggers A.J.**: The development of blowouts in ' De Blink ', a coastal dune area near Noordwijkerhout. Earth Surface Processes and Landforms, The Netherlands, 6, 375-396, 1981.
15. **Lal R., Lawson T.L., Anastase A.H.**: Erosivity of tropical rains. In: Assessment of erosion. (Eds M. De Boodt, D. Gabriels).Wiley, Chichester, 143-151, 1980.
16. **Laws J.O.**: Measurements of the fall velocity of water drops and raindrops. Trans. Amer. Geophys. Union 22, 709-721, 1941.
17. **Laws J.O., Parsons D.A.**: The relation of raindrop size to intensity. Trans. Amer. Geophysical Union, 24, 452-459, 1943.
18. **Lyles L.**: Soil detachment and aggregate disintegration by wind-driven rain. SCSA Special Publ., n. 21, 152-159, 1977a.
19. **Lyles L.**: Wind erosion: process and effects on soil productivity. Trans. ASAE, 20, 880-884, 1977b.
20. **Lyles L., Disrud L.A., Woodruff N.P.**: Effects of soil physical properties, rainfall characteristics, and wind velocity on clod disintegration by simulated rainfall. Soil Sci. Soc. Am. Proc., 33(2), 302-306, 1969.
21. **Lyles L., Dickerson J.D., Schmeidler N.F.**: Soil detachment from clods by rainfall: Effects of wind, mulch cover, and initial soil moisture. Trans. ASAE, 17, 697-700, 1974.
22. **Marshall J.S., Palmer W.M.**: The distribution of raindrops with size. J. Meteor., 5, 165-166, 1948.
23. **Meyer L.D.**: Symposium on simulation of rainfall for soil erosion research. Trans. ASAE, 8(1), 66-67, 1965.
24. Mihara, Y., Raindrop and soil erosion. Bull. Nat. Inst. Agr. Sci., Tokyo, Series A, No. 1, 1952.
25. **Moeyersons J.**: Measurements of splash-saltation fluxes under oblique rain. In: Rainfall simulation and runoff and soil erosion. (Ed. J. de Ploey), Catena Suppl., 4, 19-31, 1983.
26. **Park S.W., Mitchell J.K., Bubenzer G.D.**: Splash erosion modeling: Physical analyses. Trans. ASAE, 25(2), 357-361, 1982.
27. **Pedersen H.S., Hasholt B.**: Influence of wind speed on rainsplash erosion. Catena, 24, 39-54, 1995.
28. **Poesen J.**: Field measurements of splash erosion to validate a splash transport model. Z. Geomorph., Suppl.-Bd., 58, 81-89, 1986.
29. **Rose C. W.**: Soil detachment caused by rainfall. Soil Sci., 89, 28-35, 1960.
30. **Rutin J.**: Erosion on a coastal sand dune, De Blink, Noordwijkerhout. Laboratory of Physical Geography and Soil Science, University of Amsterdam, The Netherlands, 35, 144, 1983.
31. **Umback C.R., Lembke W.D.**: Effect of wind on falling water drops. Trans. ASAE, 9, 805-808, 1966.
32. **Van Heerden W.M.**: Splash erosion as affected by the angle of incidence of raindrop impact. Unpublished Ph. D. thesis, Purdue University, Lafayette, Ind., 1964.
33. **Wright A.C.**: A physically-based model of the dispersion of splash droplets ejected from a water drop impact. Earth Surface Processes and Landforms, 11, 351-367, 1987.
34. **Zanchi C., Torri D.**: Evaluation of rainfall energy in Central Italy. In: Assessment of Erosion. (Eds M. De Boodt and D. Gabriels), Wiley, Chichester, 133-142, 1980.