THE EFFECT OF RAINFALL KINETIC ENERGY ON THE SOIL PARTICLES SPLASH UNDER SEMI-ARID CONDITIONS

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ABSTRCT

The objective of the study was to determine the effect of raindrop impact on the soil splash rate under natural precipitation. Several rainfall parameters (e.g. rainfall intensity ,raindrop kinetic energy) are being used to characterize the eroding power of the rain on the soil splash. Rainfall characteristics and soil splash were assessed on dry –wet soil conditions and on 2 %and 6% slopes by collecting splashed soil particles using splash boarder. Rainfall energy and EI-index (product of rainfall energy and its intensity),were found to be highly correlated with splash detachment. For a given value of rainfall erosivity, total splash and splash per unit area of exposed soil surface increased linearly with an increase in moisture content, and was higher in 6% than from 2% slope.

INTRODUCTION

Soil splash is the initial process in interrill erosion in the sequence leading to soil loss and sub sequent sediment transport (Kinnel 2005).Some physically based models of soil erosion processes such as EUROSEM model and the Morgan-Finney models (Morgan 2001) have incorporated soil splash detachment triggered by raindrop impact onto the soil surface .

The effect of raindrop impact on soil is commonly attributed to the kinetic energy of the drop , or its momentum, or to some combination of these. Kinetic energy has widely been used as the raindrop index controlling soil splash detachment (Nando 2006). The raindrop energy equation that has developed by Wischemeir and smith(1981) is ;

$$E = 210.3 + 89 \text{ Log } I \qquad \text{---------------------------}(1)$$

Where ;

E = raindrop kinetic energy in *M*J / ha. mm.

I = rainfall intensity in mm / hr

Raindrop energy is used in all phases of erosion especially in breakdown of soil aggregates and splashing them in the air. Kinell (2005) stated that when raindrop hits the soil particles are splashed ,two – third of raindrop energy is expended for splash the soil particles. As the rain consists both greater mass and vertical terminal velocity such that a disproportionate amount of erosion

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results from the action of as small number of large drops, the energy (E) is dependent upon the nature of the distribution of those sizes. In particular, raindrops have the energy(E) of a falling is given by;

$$E = 1/2\ MV^2 \qquad \text{-------------------------------}(2)$$

Where;

V = The terminal Velocity of Raindrop (m / s)

M = mass of the drop = T/6 PD^3 Where P is the density of water (kg /m^3)

According to Mouzai and Bouhadef (2003), the eroding pressure resulted from raindrop impact , is based on the mathematical combination of water drop characteristics such as mass, velocity and diameter of the raindrop and the area of impact. By definition , the eroding pressure (Pc) equals to the force divided by the area (A) covered by this force (F),therefore ;

$$Pc = F / A \qquad \text{---------------------------------}(3)$$

Where ;

Pc = the eroding raindrop pressure

F = the force of raindrop

A = the area of impact = Td^2 / 4d ,where d is the diameter of the drop water

As mentioned in the finding of Epema and Riezeebos (1984):

$$F = MV^2 / d \qquad \text{------------------------}(4)$$

Where;

M = mass of drop water and

V = velocity of drop water

So;

$$Pc = 4MV^2 / TD^2 \qquad \text{--} \quad (5)$$

Recent studies have advanced our understanding of the soil splash processes ,but no method has yet been proposed to accurately predict the resistance of soil to raindrop splash. Therefore , this study presented here was carried out to estimate how much soil particles have been lost by the lateral and up-down slope splash in relation to antecedent soil moisture content and slope inclination resulted from the rain impact. This quantitative measurement of soil splash due to raindrop impact is needed to a better understanding of soil erosion.

MATERIALS AND METHODS

The study was conducted under climatic condition of Mosul city located at northern Iraq. Table (1) summarize the monthly and annual rainfall depth and their erosivity (EI_{30}) for the period 1972-2002 .

Table (1) : Mean monthly rainfall depth and EI_{30} at the experiment site

Rainy months	Jan.	Feb.	Mar	Apr	May	Oct.	Nov	Dec.
Rain (mm)	62.3	65.6	69.9	40.1	15.6	11.5	40.3	65.1
EI_{30} (metric unit)*	18.8	19.7	21.9	6.4	2.8	1.1	11.9	17.4

*(100 t . Cm . ha^{-1} h^{-1})

The soil chosen for this study belong to great group of Calciorthid and had a textured of silty clay. Some related physical and chemical properties of this soil are given in table (2). Air- dry soil which had passed through a 2 mm sieve was placed in the center of manufactured splash boarder which was used to asses the amount and the spatial distribution of soil transported by splash.

Table (2) : Physical and chemical properties of the studied soil

CaCO3	O.M.	EC	pH	Texture	Sand	Silt	Clay
%		dS/m			%		
36.5	1.60	0 .24	7.3	Silty Clay	16.59	41.86	41.55

The splash boarder consisted of a central metallic cane of 77*mm in diameter, which was filled with a selected soil and surrounded by the adjacent compartments with diameters up to 50 cm (Fig. 1). The cane was opened from one side and closed from the other side. The closed side has a fine holes for moistened the soil by capillary movement through the bottom of the cane by placing inside a pan which containing water. Some of these cans were wetted and the other left dry .The cane was placed in the center of splash boarder and was leveled at 2% and 6% . The base of the splash boarder was made to get a sufficient amount of soil in each compartment for size-distribution and to prevent the formation of a water layer. The spatial distributions of fraction, average splash lengths have been computed to analyze the splash distribution of each fraction of the soil particles.

The experiment was exposed to the natural rainfall of a single rainstorm event on December of season of 2008-2009 . Data on rainfall energy and soil splash was

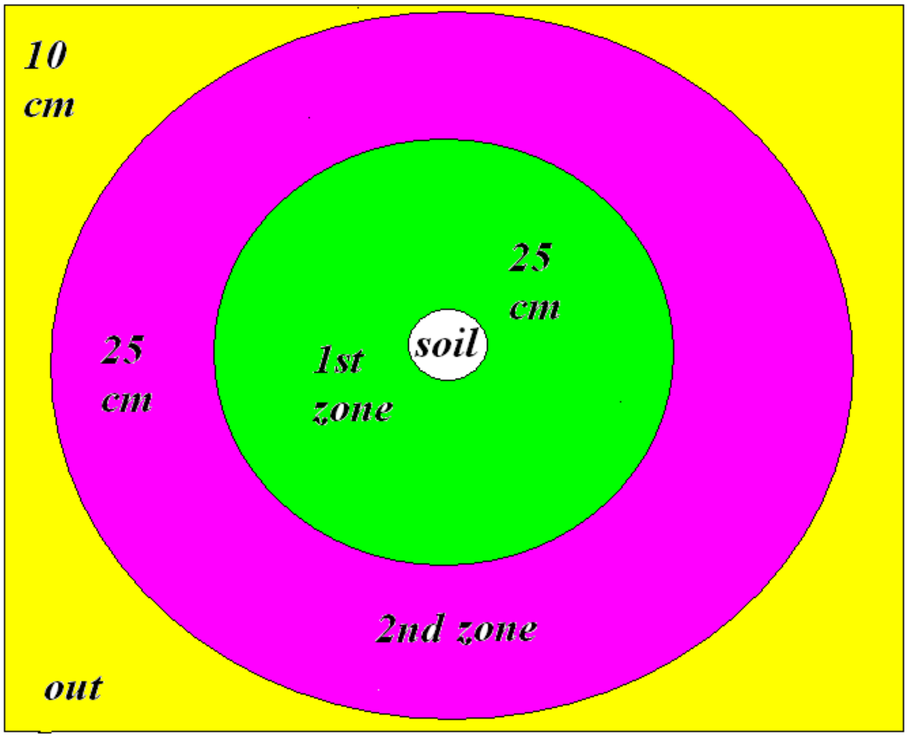

Fig.1 : Schematic diagram of the soil boarder used in the study

obtained from rainfall duration of 5.15 hours. All splashed soil particles was collected, dried at 105 C and weighed. The weight of splashed particles into different
zones of splashed board ,was measured as in the following.;

$$X = \sum n \; M_i X_i \; I \; \sum n \; M_i \qquad \text{-------------------------------- (6)}$$

Where;

Xi = The distance from the soil cane to the zone of splashed board.
Mi = The weight of soil particles in the zone of splash boarder
n = number of soil boarder zones

The splashed rates Mr (g / m^2/ min.) resulted from the rain impact were calculated as the mass (g) from each boarder zone of radius R (m) divided by its surface area A (m^2) is related to the average soil splash time (T) and the actual detachment rate M (g / m ^{2}) expressed by the following equation called fundamental splash distribution function (Nanda 2006);

$$Mr = \{ 1- ex \left(- \frac{T}{2} \; \frac{R}{A} \right) \frac{2}{T} \; \frac{A}{R} \; M \qquad \text{--------- (7)}$$

The calculation of the rain erosivity in this study is based on the analysis of rainfall chart for rainstorm measurements .Rainfall charts of this rainstorm, were analyzed for unit kinetic energy ($J. m^{-2} . mm^{-1}$) , the kinetic energy per unit area and unit volume of rainstorm to calculate throughfall kinetic energy ,maximum rainfall intensity at 30-minut and the combination of them (EI_{30}). This calculation is performed by the division of rainstorm into segments of uniform intensity .The kinetic energy is calculated for each segment and multiplied by the rainfall during that segment, it gives the total kinetic energy of the segment .The sum of kinetic energies of all segments gives the factor of rainstorm erosivity ($R = EI_{30}$) of the USLE. The factor of rainstorm erosivity is calculated based on the equation of Wischmeir and Mannering (1978)as in the following;

$$R = EI_{30} = \frac{(210.3 + 0.89 \operatorname{Log} I) * I_{30}}{100} \qquad (8)$$

Where :

$R = EI_{30}$ = The rainstorm erosivity factor ($100\ t . Cm . ha^{-1} h^{-1}$)

I = The rainstorm intensity ($Cm . h^{-1}$)

I_{30} = Maximal thirty – minute intensity ($Cm. h^{-1}$)

The soil erodibilty prediction was used to estimate the soil erodibility factor (K-factor) for the soil of the USLE. Information required to predict K value (as shown in table 3) include , percent of sand , very fine sand , organic matter content , soil structure code and soil permeability code (Wischmeir et al.1978).

Table (3) ; Soil erodibility factor (K) and soil dependent –properties

Sand**	Vfs* + Silt	Organic matter	Structure Code	Permeability	K-factor
%				Cm / hr	$Mg . h . MJ^{-1} mm^{-1}$
8.8	49.2	1.60	4	4	0.27

** without very fine sand *very fine sand

The soil – erodibility prediction equation is ;

$$K = 27.66 * M^{1.14} * 10^{-8} * (12 - A) + 0.0043 (B-2) + 0.0033 (C-3) \qquad (9)$$

Where;

K = Soil erodibility value ($Mg . h . MJ^{-1} mm^{-1}$)

M = (Percent silt and sand) = (100 – percent clay)
A = Percent organic matter
B = The soil structure code ,and
C = The soil permeability code

Soil erodibility (K–factor) was determine to assess the relative suscepility of the soil to loss. The relative soil loss (A) hazard was assessed by the R * K formula. The sediments–rainfall energy and sediment–rainfall erosivity were analyzed statistically using SAS soft ware package.

RESULTS AND DISCUSSION

Table (4) showed the detailed analysis of the selected rainstorm used in the study. The analysis includes the calculations of their intensity (I), kinetic energy (E) and erosivity (EI_{30}) based on the analysis of rainfall charts of this rainstorm. It showed that the rainfall kinetic energy and rainfall erosivity of the selected storm equal to 263.8 t-m/ha and 0.94068 metric unit respectively .

These indexes primarily designed for estimation of the soil loss caused by individual rainfall event. As the rainfall is regarded as one of the fundamental factor governing soil erosion , the erosivity of the rain will thus related to the maximum intensity at 30-minut(I_{30})and kinetic energy of the rain. Individual storm values of these interaction term are nearly always less than 100 and highly correlated with soil loss.

The total soil splashed by rainfall event as a function of drying and wetting of soil surface are shown in table (5).It shows that soil splash increases after wetting of the soil surface. The totals for the two soils are approximately the same at first and as much as wet it showed more movement by rain splash. The increase in soil splash rate was more rapid with wet soil surface and high rainfall kinetic energy. The high rainfall kinetic energy produced two times more soil loss than low rainfall kinetic energy under wet state soil surface, while the minimal soil splash occurs when rains are gentle and fall on a dry state soil surface. The splashed soil caught on the each zone of splash boarder is an indication of the size of soil fraction that caught in the field with out being carried away in the runoff.

Most of the splashed materials were either very small aggregates or single soil particles. The difference between the two soils (dry and wet) were larger than the differences among treatment. Furthermore the diffrence was in the opposite direction

Table(4): The analysis of the selected rainstorm which is soil exposed to it

Rainfall duration		Duration (min)	Rainfall Depth (Cm)	Uniform Intensity (Cm/hr)	Unit energy (t-m/ha./Cm)	Energy Increment (t-m/ha)
Starting time hr : min	Terminal time hr : min					
1:50	2:15	25	0.18	0.432	177.5	31.9
2:15	2:30	15	0.23	0.920	206.7	47.5
2:30	3:!5	45	0.20	0.260	157.9	31.5
3:15	3:20	05	0.34	4.080	264.3	89.8
3:20	3:50	30	0.18	0.360	170.5	30.6
3:50	3:70	195	0.29	0.080	112.3	32.5
Total		315	1.42			263.8

$$EI_{30} = \frac{263.8 * 0.36}{100} = 0.94068 \left(100 \frac{t}{ha.} \frac{cm}{h} \right)$$

from the difference between the two soils in the materials splashed .Wet soil had an
average of 1.5 times much soil movement by splash as in the dry soil. The most soil splashed in wet stat are were driven far to fall out of soil boarder (4.2%) in comparison to dry soil (2.9 %). On the other hand, the quantity of splashed soil particles that is lost during rainfall event is presented in table (6). This loss in soil is a function to kinetic energy of the rainstorm that impacts the soil surface at slope of 2%

Table(5) : Soil loss as a function of soil splash for dry and wet states.

Soil State	Weight of soil (g)		Soil loss by evaporation		Soil in the splash boarder				Soil out of splash boarder	
	Before rainstorm	After raistorm	g	%	In the 1st zone		In the 2nd zone			
					g	%	g	%	g	%
Dry	238	227.20	11.19	4.9	0.52	0.22	3.59	1.58	7.08	2.9
Wet	238	226.52	11.87	5.2	0.49	0.21	1.73	0.72	9.64	4.2

and 6% . Measurement of soil particles splash by raindrop showed that the slope 6% averaged more soil splashed than 2% .

Because the soil surface has a slope, then splashed soil particles in the 6 % travels
further than particles splashed in 2 % slope , resulting in the 6 % net migration of detached materials. In 2 % slope (approximately the soil has no slope), raindrop
splash moves the detached soil particles radically away from the site of detachment and the soil particles splashed away from the point of impact of one drop is replaced by material splashed by other drops in the surrounding area of splash itself and soil
particles move only short distances. This results indicated that the migration of soil particles increases as the slope gradient increases. On sloping surfaces more soil splashed down slope than up, so more erosion as slope gradient increase (Van Dijk 2003)

Table (6) :Soil loss as a function of soil splash for 2% and 6 % slope

Slope %	Weight of soil (g)		Soil loss by evaporation		Soil in the splash boarder				Soil out of splash boarder	
	Before rainstorm	After Rainstorm	g	%	In the 1st zone		In the 2nd zone			
					g	%	g	%	g	%
2 %	238.4	227.8	10.58	4.4	4.75	0.20	3.59	1.51	10.11	4.20
6%	234.8	226.38	12.01	5.1	5.46	0.23	1.73	0.74	11.46	4.88

The effect of slope gradient on the net slope transport of soil material by splash has been observed to be linear in some cases and non-linear in others (Grosh and Jarrett, 1994).

The interpretation of this behavior that when splashing is driven by the energy derived from raindrops impacting the soil surface, raindrop energies used to overcome the bonds that hold particles in the soil surface and may also be used in the transport of the detached particles away from the site of drop impact. From table (7) the mass of soil splashed per unit area (M) and soil loss per unit area per unit time (Mr) for the treatments show that wet soil moisture condition at slope of 2 % has a sol loss by splashing than other treatments included in the study.

Table (7): Total soil loss and total soil loss rate for the treatments .

Treatments	Dry	Wet	2 %	6 %	Estimated Soil loss
	Measured Soil loss				
Soil loss M (g /m2)	2444.0	2620.6	2398.8	1905.5	2539.8
Soil loss rate Mr (g/m2/min.)	7.76	8.32	7.62	6.05	8.06

The slope of the splash which soil particles are driven (as shown in Fig.2) describing the average splash length as a function of size fraction of soil particles. The mass and the horizontal drift of detached soil particles increase rapidly with soil particles of smallest size of < 50 *M*m (Silt and Clay size fraction) and decrease to reach a minimum for coarsest particle size fraction of 50 to 2000 *M*m (Sand size fraction). The length of soil Particles movement by raindrop splash usually most noticeable and greatest splash angle due to raindrop impact of soil in splash boarder..A large splash angle causes the detachment particle to fall relatively close to the point of impact

The three angles 1, 2 and 3 (in Fig.2) represent the splash angles of soil particles at 1st and 2nd zones and out of splash boarder. This figure shows that the collecting splash soil in each zone of splash boarder is a function of single soil particle diameter. On the horizontal surfaces , particles splashed back and forth and a layer of loose previously detached particles forms. Previously detached soil particles protect the soil surface from detachment. The possibility of collecting all the splash soil particles for a single drop decreases as the target area and the splash angle with the horizon increases.

Finally, the most important interactions that influence splash detachment and splash transport are soil water content × kinetic energy and slope × kinetic energy respectively. Significant interactions show that the these factors are not independent of each other; the simple effects of a factor differ, and the magnitude of any simple

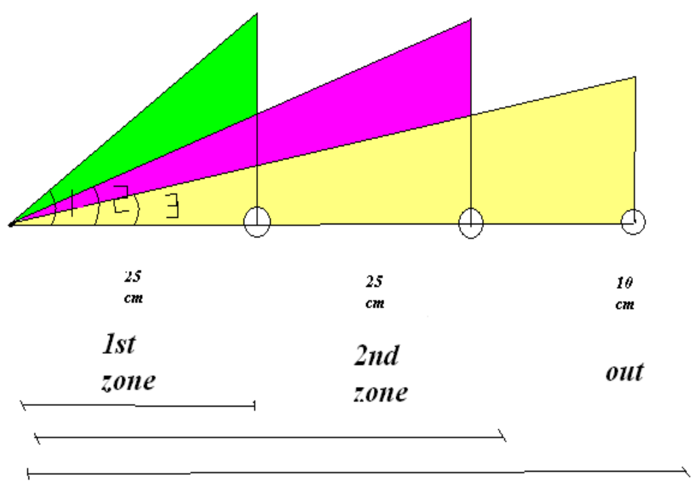

Fig 2 ; Splash angles of the splash boarder zones

effect varies according to the level of the other factors of the interaction term. Analyses of data also indicated that when factors other than rainfall are held constant, soil loss by raindrop splash in the water erosion is directly proportional to a rainfall factor composed of total storm kinetic energy (E) times the maximum 30-min intensity (I_{30}) and particle size distribution (ratio of fine to coarse soil particles) of soil

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تا ثير الطاقة الحركية للمطر على معدل تناثر دقائق التربة
تحت الظروف شبه الجافة

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الخلاصة

استهدفت الدراسة تحديد تاثير قطرات المطر على معدل تناثر دقائق التربة تحت ظروف التساقط الطبيعي باستخدام معيار الشدة المطرية والطاقة الحركية لوصف القوى المعرية للمطر في حالتي الجفاف والترطيب وتحت مستويين من الميل % 2 و % 6 حيث تم جمع دقائق التربة المتناثرة باستخدام لوح التناثر.

اشارت النتائج الى ان طاقة المطر ودليل قابلية المطر على التعرية يرتبط ارتباطا شديدا مع تناثر الدقائق ومعدل تفكيكها .وان معدل التفكيك \ وحدة المساحة وكذلك معدل التفكيك \ وحدة المساحة \ وحدة زمن ازداد خطيا مع زيادة المحتوى الرطوبي للتربة ودرجة ميل سطحها.