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Stabilization of Soil Surface Against Rainfall Erosivity for a Dune Soil at El- Sheikh Zuwied, North Sinai, Egypt.

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Abstract: The stabilizing effect of some locally prepared materials [Bitumen emulsion (Bit), Polyvinyl acetate butyl acrylate emulsion (PVAcBuA) and Polymeric bitumen emulsion (Bit-PVAc BuA] at the rates of 75 and 150 g (active material) m^{-2} soil for protecting soil surface against rainfall erosivity using rainfall simulator was the aim of the present study. Dune sand from El-Sheikh Zuwied region on the northern coast of Egypt (annual rainfall > 200mm) was used. The soils were exposed to three rainfall intensities i.e., 60, 90 and 120 $mm.h^{-1}$ for a time duration up to 2h. Obtained results refer to the following: Cumulative infiltration, infiltration rate, cumulative runoff, runoff rate and hydraulic conductivity increase with increasing rainfall intensity and duration. Applying Bit, PVAcBuA and Bit-PVAcBuA emulsions increase infiltrability, hydraulic conductivity and mean diameter of soil pores of stabilized soil being higher with the higher rate of application, and at the same time decrease water loss through runoff. Soil loss either splashed or through runoff decrease by stabilization of soil surface being lower with increasing the application rate of the stabilizer. In all cases stabilizing effect of studied materials could be desendingly arranged as follows: PVAcBuA emulsion > Bit-PVAcBuA emulsion > Bit emulsion.

Key words: Sandy soil; stabilizer; Rainfall Simulator; infiltration; hydraulic conductivity; runoff; soil loss.

INTRODUCTION

Rainfall is considered one of the main destructive factors that adversely affect the structure stability of soil surface. Water erosion occurs when raindrops strike bare soil, detaching particles, forming soil crusts and seals and overland flow (runoff) transports the detached soil out of the field. Bonding must occur before water begins to flow over the soil surface. Water bonds when the rainfall rate exceeds the soil infiltration rate. This increases soil loss through runoff water. Accordingly, water erosion takes several forms, depending on the concentration of the flow. Sheet or splash erosion occurs when there is little or no concentration of water flow over the surface. Rills form as water concentrates in small channels. When rills deepen, they become gullies (Morgan, 1979 and Nagat Abd-El Moaty, 2009).

Sand dunes of the Mediterraranean coast suffer from rain fall erosion. This is because it receives heavy individual storms that erode soils. Therefore, protecting soil surface against rainfall erosivity in these areas is of main priorities for soil and water conservation from one side and improving soil productivity on the other side (Elliot et.al., 1991).

There are several means for protecting soil surface against rainfall erosivity (Attia, 2004). Of these is stabilization of soil surface using synthesized stabilizers (chemical stabilization). (El-Hady, 2000).

The present research work aims at investigating the stabilizing effect of applying some locally prepared materials on protecting soil surface through modifying structure and reducing soil loss (either splashed or loss with runoff water) due to rainfall erosivity. With this respect, chosen stabilizers assemble petroleum emulsions (Bit), polymers emulsions (PVAcBuA) and petrolume emulsions modified with polymers emulsions (Bit-PVAcBuA).

MATERIALS AND METHODS

Soil:

A dune sand from El-Sheikh Zuwied region that lies on the Mediterranean coast, North Sinai of Egypt was chosen. Such choice was for the exposure of this type of soils to the highest amounts of rainfall under Egyptian conditions. Annual precipitation was in the range of 200 mm that adversely affects the stability of soil surface and consequently increasing soil loss. Table (1) presents the main analytical data of the soil that determined according to methods described by Klute (1986) and Page et al. (1982).

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Table 1: Main analytical data of El-Sheikh Zuwied soil.

Mechanical analysis				
Coarse sand (> 200µ) %	Fine sand (200-20µ) %	Silt (20-2 µ) %	Clay (< 2 µ) %	Textural class
7.7	87.2	2.6	2.5	Sand

Chemical analysis				
pH 1:2.5	EC dS/m	$CaCO3$ %	OM %	CEC cmol / kg
7.88	1.68	5.05	0.18	4.67

Soluble cations me/l (1:5 extract)				Soluble anions me/I (1:5 extract)			
Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	$CO3^{--}$	$HCO3^{-}$	$SO4^{--}$
8.20	1.66	4.57	2.05	5.40	-	4.54	6.54

Hydrophysical analysis					
Bulk density $Mg.m^{-3}$	Total porosity %	Water holding capacity (w/w) %	Field capacity (w/w) %	Wilting percentage (w/w) %	Hydraulic conductivity $m.day^{-1}$
1.45	45.3	17.8	8.8	2.7	1.16

Examined Stabilizers:

1- Bitumen Emulsion (Bit):

A cationic slow setting bitumen emulsion (50% active material) was prepared at the Egyptian Petroleum Research Institute (EPRI), Cairo, Egypt. Bitumen of penetration (120/140) produced by Amria petroleum Company was chosen for : a) Its easiness of emulsification (Ezzat, 1985), b) Its high content of oils and resins which raises its compatibility with either emulsified polymers of latex emulsions (Sitz et al., 1991, Carol Brooks 1991 and Newcomb et al., 1992) c) Its high penetration value where the soften the bitumen is, the easier it is for the emulsion to penetrate soil surface and to form stable structural units without adverse effect on soil penetrability to air, water and fertilizers solution (Abou Zeid, 1984) Redicot EM 76 was used as a cationic emulsifier based on polyamine derivatives produced by AKZ0 Noble surface chemistry, Cairo. The optimum percentage of emulsifier to be mixed with the aqueous phase and asphalt to get the best bitumen emulsion was examined to be 2.5% (wt %). Water was wormed up to 90^{0}C. The emulsifier was added while stirring. The pH of the aqueous phase was adjusted to pH 4.5 using HCl followed by hot bitumen (140̊C). Stirring was continued until the emulsion became completely homogeneous.(El-Hady et al,2002).

2.Polyvinyl Acetate Butyl Acrylate Emulsion (PVAcBuA):

The emulsified polymer polyvinyl acetate butyl acrylate (50% active material) was prepared in the Polymer and Pigments Department, National Research Centre, Cairo, Egypt by emulsion polymerization of polyvinyl acetate and butyl acrylate (1:1). Polymerization conditions were: a) polymerization was carried out under nitrogen atmosphere i.e. in the absence of air. b) Initiator used was the redox pair initiator system i.e. sodium bisulphite ($NaHSO_3$) and potassium per sulphate ($K_2S_2O_8$) at the ratio of 1:2.5. Initiator: monomer (w/w) was 0.5%. c). Emulsifying agent was 0.5% polyvinyl alcohol solution of b.p 120 ^{0}C and mol-wt.700.000 and d) The temperature used and time of polymerization were 60^{0}C and 8 h. respectively (El–Hady and Abd El-Hady, 2001).

3. Polymeric Bitumen Emulsion (Bit-PVAc BuA):

Polyvinyl acetate butyl acrylate emulsion (PVAcBuA) 50% (active material) was used as the modifier for the prepared Bit. (**El- Hady *et al,* 2002**) At room temperature, PVAcBuA emulsion was added to the prepared asphalt emulsion (Bit) while stirring until getting a completely homogeneous emulsion taking into consideration that Bit-PVAcBuA was 4:1 (wt%). The pH of the obtained modified emulsion was similar to the original emulsion because the pH of PVAcBuA emulsion is equal to 4.5 **(Sitz *et al,* 1991)**. The original emulsion (Bit) and the modified emulsion (Bit-PVAcBuA) were examined according to ASTM D244.Table (2) presents their main constituents and specifications.

It is noteworthy that mentioning trade and firm names is for the information and convenience of the reader and do not constitute an official endorsement of the products.

Rainfall Simulator. The Rain Simulator Used Consisted of:

1- Water supply: water pump was used to pressurize the water to a tank of 0.25 m^3 size having a float to adjust the water surface at a constant head of 0.8m.

2- The spraying system: The nozzle dripper used was carrying nozzles of 1 mm openings which is placed at a height of 1.5m from the soil surface in the experimental trays. A valve was used to control the water pressure and the rain intensity. Rain intensity was adjusted by collecting rain regularly in plastic pans to measure the operating intensity and confirm the regularity of rain intensity during the work.

Table 2: Main constituents and specifications of the original (Bit) and cationic modified bitumen (Bit-PVAcBuA) emulsions.

property	Original emulsion	Modified emulsion	Standard method
Consituents			
Solid content %	50.0	50.0	
EM 76 wt%	2.5	2.5	
PVAcBuA wt%	-	20	
HCl%	1.0	1.0	
Water content %	47.5	47.5	
Properties			ASTM D44
Color of emulsion	Brown	Brown	
pH of emulsion	4.5	4.5	
Particle charge test	+ve	+ve	
Viscosity, Saybolt Fural at 77F(25C),S.	92	120	
Storage stability test, 24h, %	1.0	1.0	
Settlement, wt% (5days).	1.1	1.9	
Resistance to water	Pass	Pass	
Resistance to sea water	Pass	Pass	

Soil Trays:

The utilized soil trays were stainless steel (50× 35 × 10 cm) and divided by quite thick barrier 8 cm height to allow the movement of runoff to the small part (10 × 35 × 8 cm) which has a hole in the bottom for collecting runoff and also having a movable cover to prevent the falling of rain in it and mixes with runoff. The large part (40 × 35 × 8) cm has a perforated bottom for collecting infiltrated water. Openings diameter are 1 mm. The soils were packed lightly in the large part to a depth of 5 cm height and bulk density of 1.45 Mgm^{-3} on a bed of 3 cm gravels (3-7mm) overlaying several layers of cheesecloth on the perforated bottom to prevent closing of drainage holes. Plastic sheets were put in a position for collecting splashed soil and at the same time to prevent the splashed soil particles to go back again to the tray. The soil trays were placed at 5^0 slope during rainfall to prevent bonding and facilitate the movement of free water at the surface.

Procedure:

1-since the application rates of the stabilizers i.e 75 and 150g (active material) m^{-2} soil, the optimum conditions for stabilizing process such as suitable initial (5% w/w) and final moisture content (8% w/w)and the appropriate emulsion dilution was taken into consideration to obtain an optimal soil aggregation and stability (El-Hady and Tayel,1981). The soils in the trays were left for a few hours to dry to be sure that the formed thick crust (8-10mm thickness) is completely insoluble in the applied rain.

2-The soils were exposed to rainfall for 2 hours at intensity of 60, 90, and 120 mmh^{-1} and during that time infiltrated and runoff water were collected continuously at 5 minutes intervals. Sediments in the collected runoff water were allowed to precipitate before transferring to drying pots (drying at 105 °C) to obtain soil loss. Splashed soils over the plastic sheets were collected and dried.

3- At the end of each rainstorm i.e. after 2h rainfall, soil cores were collected from the trays to estimate hydraulic conductivity (Klute, 1986) and to calculate mean diameter of soil pores (El-Hady, 1979).

RESULTS AND DISCUSSION

1. Cumulative Infiltration and Infiltration Rate:

Cumulative infiltration (mm) for the untreated soil and those stabilized with the examined materials when exposed to three rain intensities (60, 90 and 120mm. h^{-1}) after 1 and 2h of rain is shown in table (3-a). In all cases cumulative infiltration increases with increasing rainfall intensity up to 120mm h^{-1}. In other words, infiltrated water increases by increasing the kinetic energy of rain. According to **Hudson's equation (1971)** that describes the relation between the rainfall intensity and its kinetic energy, kinetic energy increases as rain intensity increases. Applying such equation:

Ek =11.9+8.73 log i where E_k=kinetic energy $Jm^{-2}mm^{-1}$ and i rain intensity $mm.h^{-1}$

Kinetic energy values for the three used rain intensities 60, 90 and 120mmh^{-1} are 27.42, 28.96 and 30.06 Jm^{-2} mm^{-1}, respectively. With this respect, increasing rain intensity from 60 to 90 mmh^{-1} increases the cumulative infiltration after 2h of rainfall by 24.2%. Relevant value when rain intensity was raised to be 120 mm h^{-1} was 56.3%.

Regarding stabilized soils, cumulative infiltration increases being higher by doubling the application rates of the stabilizer from 75g (active material) m^{-2} soil to be 150g (active material) m^{-2}soil.

Values of infiltration rate (mm h^{-1}) that describe the soil intake of water per unit area in a unit time (table 3-b), increase with rain intensity and decrease with time duration of rainfall. Soil stabilization increases the infiltration rate of the soil being also higher by doubling the application rate of the stabilizer. With this respect, and similar to that of cumulative infiltration applied stabilizers could be arranged assendingly as follows:

Bit emulsion <Bit-PVAcBuA emulsion<PVAcBuA emulsion.

It is noticed that the difference between the values of infiltration rates of soils treated with the higher application rate of the stabilizers and that treated with the lower ones don't exceed 3% This refers to the economics of using the lower application rates.

Table 3: Influence of the prepared stabilizers on soil infiltrability after 1and2 h of rain at three rain intensities.

Examined stabilizers	Application rate g (active (material)m^{-2} soil	Rain intensity (mm h^{-1})					
		60		90		120	
		1h	2h	1h	2h	1h	2h
a. Cumulative infiltration (mm).							
Untreated	0	47.3	72.3	61.0	89.8	73.0	113.0
Bit	75	48.8	74.6	68.3	93.3	78.8	115.7
	150	49.7	77.4	68.9	97.6	81.1	118.7
PVAcBuA	75	49.8	77.2	70.4	96.1	82.9	119.6
	150	50.0	80.8	72.8	104.6	83.7	123.6
Bit -PVAcBuA	75	49.7	76.4	69.6	95.1	81.4	117.9
	150	49.8	79.2	73.1	100.4	82.2	121.6
b. infiltration rate (mm h^{-1})							
Untreated	0	47.3	36.2	61.0	45.0	73.0	56.5
Bit	75	48.8	37.3	68.3	46.7	78.8	57.9
	150	49.7	38.8	68.9	48.8	81.1	59.4
PVAcBuA	75	49.8	38.6	70.4	48.1	82.9	59.8
	150	50.0	40.5	72.8	52.4	83.7	61.8
Bit -PVAcBuA	75	49.7	38.3	69.6	47.6	81.4	59.0
	150	49.8	39.6	73.1	50.2	82.2	60.9

2. Soil Hydraulic Conductivity and Mean Diameter of Soil Pores:

The infiltration rate is the velocity at which water percolates into the soil and usually decreases the longer water is in contact with the soil. It will reach a relativity steady value (final infiltration rate) equal to the permeability or hydraulic conductivity of water through the soil. In the case of coarse textured soils both values i.e. infiltration rate and hydraulic conductivity are usually high and decrease with the fine fractions in the soil (Boudelaire, 1973). Such water transmitting parameters were classified as: very low, low, medium and high for soils with final infiltration rates of less than 0.1 inch (<0.25 cm).h^{-1}; 0.1-0.5 inch (0.25-1.25cm).h^{-1}; 0.5-1.0 inch (1.25-2.5cm).h^{-1} and greater than 1.0 inch (>2.5cm) h^{-1}, respectively. The 1^{st} group (very low) is soils that are very high in percentage of clay. Most of the soils of the 2^{nd} group (low) are shallow, high in clay or low in organic matter. Soils in the 3^{rd} group (medium) are loams and silts. The soils of the 4^{th} group (high) include deep sands, deep well aggregated silt loams and some virgin black clays that have abundant water – stable aggregates (Donahue et al, 1977).

Hydraulic conductivity values (m day^{-1}) for the untreated soil or those treated with the examined materials after exposing the soil to three rain intensities (60,90 and 120mmh^{-1}) for 2h are presented in Table 4. Generally, soil stabilization increase hydraulic conductivity values. More increase was obtained by doubling the application rate of the stabilizer.

According to Donahue et al, 1977; soil permeability values can be considered high (>25 mmh^{-1}) even with high rate of the applied stabilizers. This means that stabilized soils with such materials don't cause problems with respect to water movement through them.

The effect of soil stabilizers on the mean diameter of soil pores (Fig.1) took the same trend as that of hydraulic conductivity. Moreover, high application rates yield higher values of mean diameter of soil pores. Also, the arrangement of the applied stabilizers on their effect on mean diameter of soil pores is the same as that of soil infiltrability.

Table 4: Influence of the prepared stabilizers on hydraulic conductivity of soils (m day^{-1}) after 2h of rainfall.

Examined stabilizers	Application rate g (active material) m^{-2} soil	Rain intensity (mm h^{-1})			
		60	90	120	Mean
Untreated	0	0.87	1.08	1.36	1.10
Bit .	75	0.90	1.12	1.39	1.14
	150	0.94	1.17	1.43	1.18
PVAcBuA	75	0.94	1.16	1.44	1.18
	150	0.97	1.26	1.49	1.24
Bit -PVAcBuA	75	0.92	1.15	1.42	1.16
	150	0.95	1.21	1.46	1.21

3. Surface Runoff and Runoff Rate:

Whenever the rate of water supply to the soil surface exceeds the rate of infiltration and doesn't accumulate on the surface, water will run down slope and eventually collect in channels variously called rills or gullies. These channels generally form a tree like Pattern leading to larger and larger streams. Soil erosion takes place during the runoff process and valuable top soil is removed to streams, reservoirs and lakes which become polluted with sediments.

Cumulative runoff data (mm) and runoff rate (mmh^{-1}) for the untreated soil and those stabilized with the examined materials when exposed to three rain intensities (60, 90 and 120 mmh^{-1}) for 1 and 2h are shown in table 5-a and b, respectively. After an hour of rainfall, runoff water was 17.6% that of applies water. With increasing the rain intensity, runoff water increase to be 28.2 and 32.2% that of applied water under the rain intensity of 90 and 120 mmh^{-1}, respectively. At the end of rainfall duration i.e. after 2h, increasing rainfall intensity from 60 to 90 and to 120 mmh^{-1} increased runoff water to be 2.1 and 3.1 times that of runoff at 60 mmh^{-1} rainfall, in sequence.

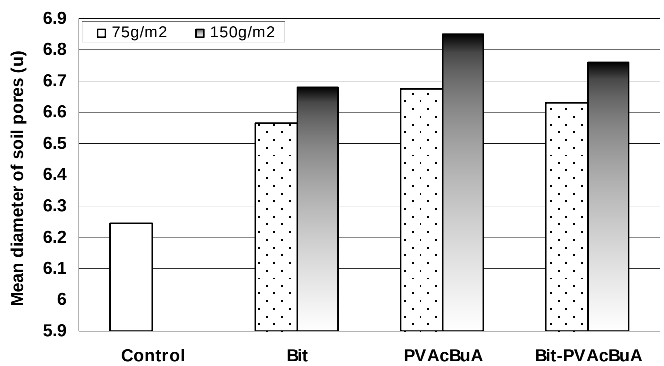

Fig. 1: Mean diameter of soil pores for El- Sheikh Zouied soil under different rates of stabilizers.

Table 5: Influence of the prepared stabilizers on water runoff after 1 and 2 hours of rain at the three rain intensities.

a. cumulative runoff (mm)							
Examined stabilizers	Application rate g (active material)m^{-2} soil	Rain intensity (mm h^{-1})					
		60		90		120	
		1h	2h	1h	2h	1h	2h
Untreated	0	10.5	39.6	25.4	84.9	38.6	122.6
Bit	75	8.4	36.5	15.5	80.2	30.8	118.9
	150	7.2	32.7	14.7	74.4	27.7	114.8
PVAcBuA	75	7.0	33.0	12.7	76.4	25.3	113.6
	150	6.6	28.1	9.5	64.9	24.2	108.2
Bit -PVAcBuA	75	7.2	34.0	13.7	77.7	27.3	115.9
	150	7.0	30.2	9.0	70.6	26.2	110.9
b.runoff rate (mm h^{-1})							
Untreated	0	10.5	19.8	25.4	42.4	38.6	61.3
Bit	75	8.4	18.3	15.5	40.1	30.8	59.5
	150	7.2	16.3	14.7	37.3	27.7	57.4
PVAcBuA	75	7.0	16.6	12.7	38.2	25.3	56.8
	150	6.6	14.0	9.5	33.1	24.2	54.2
Bit -PVAcBuA	75	7.2	17.0	13.7	38.9	27.3	58.0
	150	7.0	15.2	9.0	35.3	26.2	55.4

Regarding the effect of soil stabilization on the cumulative runoff and run off rate, applying Bit, PVAcBuA and Bit- PVAcBuA reduce surface runoff water on the soil. More reduction in surface runoff was obtained by doubling the application rate of the stabilizers. The effect of applied stabilizers on decreasing surface runoff from the soil and run off rate could be descendingly arranged as follows.

PVAcBuA emulsion > Bit- PVAcBuA emulsion>Bit emulsion.

In other words, after 2h of rainfall, either cumulative runoff or runoff rate reached 92.6, 94.5 and 97.0% for the lower application rate of the stabilizers for PVAcBuA, Bit- PVAcBuA and Bit emulsions, respectively. Relevant value for the higher one i.e. 150g m^{-2} soil were 88.2, 90.5, and 93.6%.

4.Soil Loss:

Water erosion is due to the dispersion action and transporting power of water. When a raindrop hits a dry soil surface, the raindrop is absorbed and the soil becomes moist. As more drops fall and strike the bare soil surface, considerable splashing occurs and water becomes turbid primarily by breaking down soil aggregates or detaching soil particles from the surface. Overland flow carries the detached soil from the field. Depending on the concentration of water flow (rainfall intensity), water erosion takes several forms. Sheet or splash erosion occurs when there is little or no concentration of water flow over the soil surface. Rills forms as water concentrates in small channels. When rills deepen, they become gullies. Therefore, raindrop detachment and overland flow transport are the two main parts of soil erosion by water.

Soil loss either splashed or through the runoff water (g m^{-2}) for untreated soil or those stabilized with the examined materials after exposing the soil to 2h of rainfall at three rain intensities (60, 90 and 120 $mm.h^{-1}$) are illustrated in Fig.2. Moreover, soil loss as a % of the untreated soil is shown in Table (6).

Table 6: Influence of the prepared stabilizers on soil loss as % of untreated soil.

Examined stabilizer	Application rate (gm^{-2})	Rain intensity (mmh^{-1})					
		60		90		120	
		*	**	*	**	*	**
Untreated	0	100	100	100	100	100	100
Bit	75	20.3	39.7	21.4	40.4	21.5	40.7
	150	14.9	18.9	17.0	24.4	19.6	30.2
PVAc BuA	75	15.9	29.6	18.6	31.4	18.9	31.8
	150	10.8	13.5	14.0	18.6	17.6	23.9
Bit-PVAc BuA	75	18.7	37.2	19.4	38.4	20.1	39.2
	150	12.7	14.3	15.0	21.3	17.7	25.3

*Splashed soil **Soil Loss through runoff.Bit= bitumen emulsion, PVAc BuA=polyvinyl acetate butyl acrylate, Bit-PVAc BuA= bitumen emulsion modified by polymer.

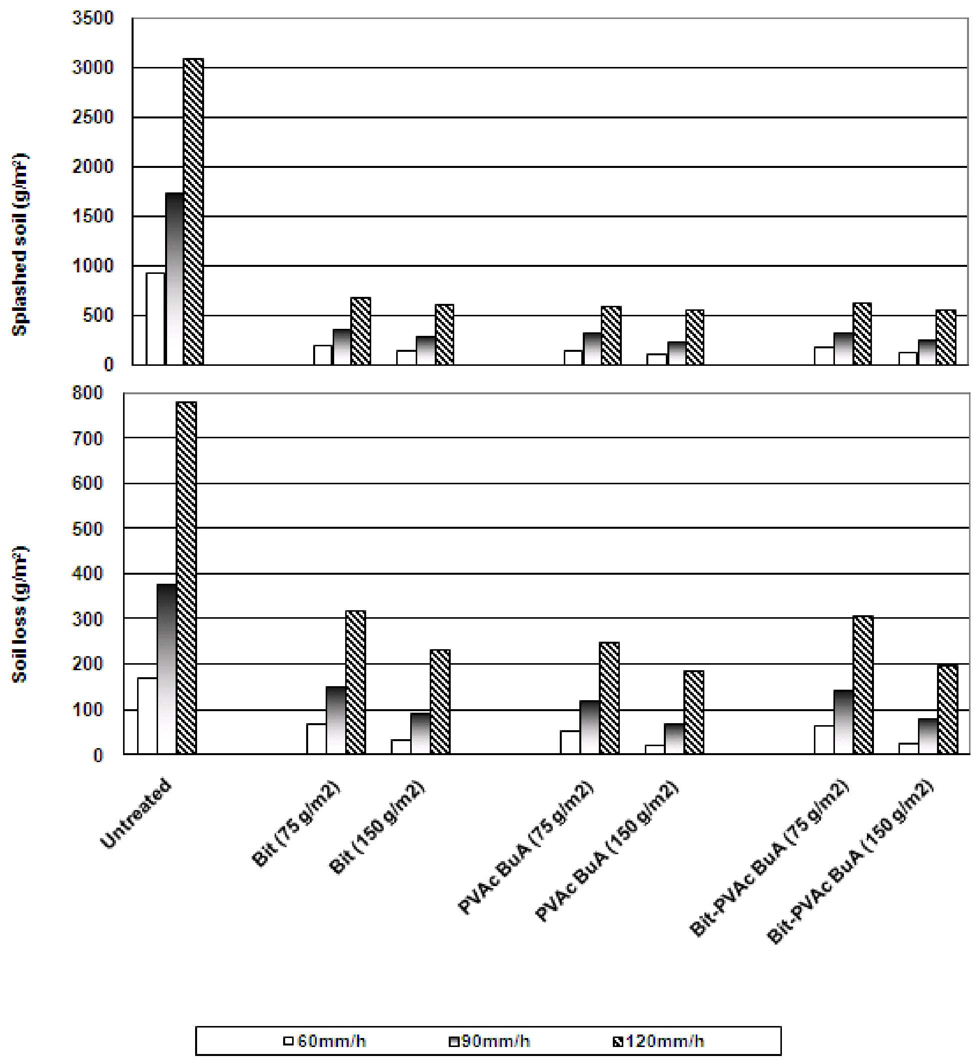

Fig. 2: Splashed soil and soil loss through runoff of El-Sheikh Zuwied soil as affected by the prepared stabilizers after 2 h of rainfall at three rain intensities.

In all cases either in the untreated soil or those stabilized with the examined materials soil loss increases with the increase of rainfall intensity up to 120 mmh^{-1}. This is also previously mentioned when discussing the Influence of rain intensity on infiltration and runoff. The higher the rainfall intensity is, the more is the kinetic energy exerted on the soil. Soil loss as a manifestation of soil erosion is closely linked and controlled by the kinetic energy of rain.

Therefore, the higher the kinetic energy of rain is, the higher is the soil loss (USDA, 1978; Gaber, 1989 and Attia 1999 and 2004).

Values concerned with the untreated soils refer to the high soil loss from the soil. This is due to the structure features of it that adversely affect their stability against rainfall erosivity.

Regarding stabilized soil, examined emulsions reduced to a great extent soil loss. Moreover much reduction was obtained by doubling the application rate of the stabilizers to reach in some cases one seventh that of the non-stabilized soil.

On Conclusion:

Cumulative infiltration and infiltration rate, cumulative runoff and runoff rate and hydraulic conductivity increase with increasing rainfall intensity and duration. Applying Bit, PVAcBuA and Bit-PVAcBuA emulsions increase infiltrability, hydraulic conductivity and mean diameter of soil pores of stabilized soil being higher with the higher rate of application, and at the same time decrease water loss through runoff. Soil loss either splashed or through runoff decrease by stabilization of soil surface being lower with increasing the application rate of the stabilizer. In all cases stabilizing effect of studied materials could be desendingly arranged as follows:
PVAcBuA emulsion > Bit-PVAcBuA emulsion > Bit emulsion.

Taking into consideration the stabilizing effect of applied materials on one hand and the prices of materials used and cost of application on the other hand, bitumen emulsions modified with polymer emulsions may be preferable. In all cases, economic evaluation must be considered.

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