Minufiya J. Agric. Res. Vol. 28 No. 2: 589 - 610 (2003)

CHARACTERIZING SOIL PHYSICAL PROCESSES UNDER SIMULATED RAIN FOR SOME SOILS IN EGYPT

Saleh M. Aly[1] , A.M. Amer[1], M. M.I. Selem[2] and M.E. Abdullah[2]
[1]-Soil Sci. Dept. Minufiya Univ.
[2]-Agriculture Research Center, Giza, Egypt.

(Received : Mar., 9 , 2003)

ABSTRACT: ***Simulated rains of different intensities and durations were applied on six soils from Egypt having different textures and calcium carbonate contents to study the drop impact of water (rain or sprinkler) on aggregate stability, infiltration, sorptivity, percolation, surface runoff, and soil loss. The soils were subjected to rain up to two hours at 60, 90 and 120 mm/h intensities while runoff and percolation water was collected continuously at 5-minute intervals. Sediments in the collected runoff were measured as soil loss. Soil sorptivity (S) and final infiltration (A) were estimated by fitting Philip's equation (adjusted or unadjusted) to measured field infiltration. Results indicated that the highest change of MWD by rain impact was for soils with high clay or $CaCO_3$ content. The change of MWD correlated highly with soil bulk density and organic matter. Although cumulative infiltration increased with rain intensity, infiltrated water as a percent of the applied water was decreased for all soils. Infiltration correlated well either with soil porosity and fine sand for low rain intensity (60 mm/h) or with soil porosity and coarse sand for high rain intensities. S and A increased with increasing rain intensity and a reasonable fit between measured and calculated cumulative infiltration was found but less accurate fit was obtained for the infiltration rate. Using the adjustment factor significantly improved the prediction of cumulative and rate of infiltration. Initiation time of percolation increased with the increase of soil content of calcium carbonate and clay. Cumulative percolation increased with rain intensity for all soils. Generally percolation was statistically related to soil porosity, calcium carbonate and fine sand contents. Initiation time of runoff ranged between 4 – 28 minutes and decreased significantly with increasing rain intensity, calcium carbonate and clay content. Runoff was drastically increased with the increase of rain intensity, especially for soils high in calcium carbonate or clay content. Variations in runoff due to the different structure classes were not as profound as that due to the increase in rain intensity. Soil loss was low for both clay and sandy soils at the low intensity. Increasing rain intensity to 90 or 120 mm/h reversed this trend for the sandy soils especially during the second hour of rain. Clay effect on soil loss decreased with the increase of rain intensity. Soil loss averages for all soils were between (0.35-0.57), (0.8-1.6), and (2.4-3.3) ton/fed/h for the first hour of rain and between (0.48-0.92), (0.98-2.0), and (3.15-4.3) ton/fed/h for the second hour at the three rain intensities. The increase of soil loss with increasing duration of rain was much less than that due to increasing rain intensity for all soils. Soil loss started at small values for all soils and sharply increased to a maximum value, and continued undulating around the high value or slightly decreased.***

Key Words: *Aggregate stability, infiltration, sorptivity, percolation, surface runoff and soil loss.*

INTRODUCTION

A common soil feature, particularly in arid and semiarid regions is the formation of soil surface crusts and seals, especially due to the action of raindrop impact or as a result of sprinkler irrigation, (Aarstad and Miller, 1973). Soil crusts and seals reduce infiltration, increase runoff and the potential for soil erosion (Cary and Evans, 1974; Morin et al., 1981). In arid and semiarid climates, reducing runoff has the benefit of increasing profile soil moisture. Water erosion is due to the dispersion action and transporting power of water. As a result of raindrop impact, considerable splashing occurs and water becomes turbid primarily by breaking down soil aggregates or by detaching soil particles from the surface. Surface sealing is a direct result of aggregate breakdown, erosional transport and depositional processes (Hairsine and Hook, 1995), so the potential exists for using aggregate stability indices to predict the intensity of sealing and seal hydraulic properties. Structural seals result from compaction under raindrop impact and depositional seals form by deposition of detached sediments and micro-aggregates in depressions.

During the last three decades, researchers have shown great interest in modeling water infiltration, chemical transport, surface runoff, and soil loss in cultivated soils during a rainfall or sprinkler irrigation event. It has been suggested that inclusion of the effect of sealing on the processes of infiltration and runoff generation would give rise to more accurate predictions (Linden, 1979; Moore, 1981; Brakensiek and Rawls, 1983). In general, two factors are responsible for the decrease in infiltration rate with time during a rainstorm or sprinkler event (Rose, 1962); (a) a decrease in the vertical moisture gradient, and (b) the development of a thin surface seal. Moore and Larson (1979) found that, for tilled and unprotected soils, a surface seal develops fairly soon after the start of rainfall or sprinkler irrigation and becomes the dominant factor limiting infiltration. In the semiarid and arid regions, the problem of sealing appears to be the main process that controls the infiltration of rain water into bare soils (Unger, 1984). If there were no runoff, there would be no erosion. A vegetation cover is most effective in decreasing the amount of runoff either through transpiration or by being an impediment to runoff water (Baver et al., 1972).

Organic compounds natural or synthetic (such as polymers) especially PAM are being used quit effectively to stabilize soil structure, which leads to increased infiltration, reduced water use, and reduced erosion on furrow irrigated fields (Lentz and Sojka, 1994; Trout et al., 1995). PAM is often capable of stabilizing soil structure but doesn't remediate poor structure (Cook and Nelson, 1986)

In a previous study under simulated rain by Aly and Abdullah (2002), a new method for estimating soil surface seal thickness and hydraulic conductivity was introduced and the effect of polyacrylamide as a soil conditioner was also studied in the same soils. Thin section slides were examined under a microscope to observe the structural features, and soil micrographs were presented.

The objective of this work is to study the raindrop impact and water action under simulated rain of different intensities and durations on the processes of aggregate stability, infiltration and surface sealing, percolation, runoff, and soil loss for some soils in Egypt.

MATERIALS AND METHOD

Six soils of different textural classes, clay and calcium carbonate contents were chosen for the study. The soils were a loamy sand (Tahreer) from Beheira Governorate, two calcareous soils from Nubareia, a sandy (Alex) and a sandy loam (Roudah), two soils from Imbaba-Giza, a sandy loam (Abu-Ghalib) and a sandy clay loam (Nikla) in addition to a clay soil (Dueap) form Minufiya. Soil physical properties are shown in Table (1). Soil samples were collected from the top 15 cm, air dried and passed through a 2 mm sieve. They were utilized in packing soil trays that were used under rain simulator. The soils were subjected to simulated rainfall of 60, 90 and 120 mm/h intensities up to two hours to study the creation of soil surface seal and its effect on infiltration, percolation, run off and soil loss of the used soils.

Water stable aggregates were determined under drop impact according to (Young, 1984), where l0 g of air dry soil clods were placed in a Buchner funnel on filter paper. The funnel was then connected to a vacuum flask and subjected to a very low vacuum (approx. 5 cm) to avoid accumulation of water. The flask and funnel were placed under the rain simulator for 15 min at 60mm/h rain intensity. The impacted soil samples were then carefully washed onto a stack of four sieves (0.25, 0.5, 1 and 2 mm) and immediately wet sieved for a period of 3 minutes.

The rain simulator consisted of a small head (7 cm diameter) with multiple openings and a water pump to pressurize the water through the head at a height of 2.7 m from a rotating table at 5 rpm. A valve was used to control the water pressure and the rain intensity. Rain intensity was adjusted by collecting water every 5 minutes in plastic pans to measure the operating intensity. To prevent water ponding and facilitate the movement of free water at the soil surface, sample trays were placed on the rotating table at a 5° slope. The utilized trays were metal (24 x 16 x 10 cm), that allow measurements of runoff and infiltration. The soils were packed lightly in the trays to a height of about 5 cm, overlying a bed of 3 cm gravel and several layers of cheesecloth on the perforated bottom of the tray.

Table (1) Physical analysis of the six soils used in the study.

Soil	Texture	$CaCO_3$ %	O.M%	C.S%	F.S%	Silt%	Clay%	B.D g/cm^3	Poros. %
Tahreer	L. S	2.5	0.6	28.4	55.6	6	10	1.47	44.5
Alex.	S	8	0.4	44.6	46.4	3	6	1.49	43.8
Roudah	S. L	21	0.6	24.2	42.8	15	18	1.20	54.7
Abu-Ghalib	S. L	4	1.4	43	34.2	8.8	14	1.32	50.2
Nikla	S. Cl. L	5	1.7	30	31.2	11.8	27	1.24	53.2
Du eap	Cl	3	2.2	0.6	20.4	36	42	1.12	57.7

The soils were rained on for up to two hours at 60, 90 and 120 mm/h rain intensities while runoff and percolation water were collected continuously at 5-minute intervals. Sediments in the collected runoff were allowed to precipitate using $Al_2\ (SO_4)_3$ solution, and were transferred to drying pans (drying at 105 C^o) to determine soil loss. Two small pans were used to collect rain water to confirm the regularity of rain intensity during the rain event.

The kinetic energy values associated with the previously mentioned rain intensities were 27.42, 28.96, and 30.06 J/m^2/mm, calculated from the simple equation by Hudson (1971) utilizing only rain intensity ($E_k = 11.9 + 8.73 \log i$), where E_k = kinetic energy (J/m^2/mm), i = rain intensity mm/h. This formula is only used for rain intensities higher than 25 mm/h.

Philip (1957; 1969), indicated that cumulative infiltration (I) can be expressed as a series that converges rapidly for times not too large. The series that can describe infiltration over the period of interest from the initial stage out to a long time after infiltration has begun is $I = S\,t^{1/2} + A\,t + B\,t^{3/2} + \ldots$ which is usually truncated after the first two terms. The coefficients S, A, B, .. are constants depending on the soil properties and soil moisture content (surface and initial water contents) and can be evaluated by numerical analysis techniques. The coefficient S, called the sorptivity, has a wide applicability in the soil water theory. Sorptivity is a measure for the capacity of a soil to absorb water and is also known as the coefficient of the square root of time term in infiltration. The Philip model has been applied in the field by measuring cumulative infiltration at numerous times, using a double ring infiltrometer, and fitting the resulting data to find the best values of S and A. The early stage of infiltration is effectively described by the truncated equation and the infiltration rate (i) is derived by differentiating with respect to time (t) to obtain $i = \frac{1}{2}\,S\,t^{-1/2} + A$. The infiltration rate decreases as a function of time. Sorptivity is the dominant parameter in the early stage of infiltration. As time progresses, the first term becomes negligible and the importance of the final infiltration rate A, which represents the main part of the gravitational influence, increases.

The Philip's two term cumulative infiltration equation ($I = S\,t^{1/2} + A\,t$) was applied at different rain intensities to estimate sorptivity (S), and the final infiltration rate (A) for the six soils. S and A were calculated to maximize the fit between measured and calculated values of infiltration using a similar technique to that of Smith (1999) with the aid of the computer program Mathcad. The evaluated S and A were used to calculate (predict) cumulative and rate of infiltration. The best fit parameter SER (summation of error ratios, Aly, 2001) was evaluated to measure the goodness of fit between the calculated and measured values of cumulative and rate of infiltration. Soil sorptivity was also calculated as the slope of the cumulative infiltration versus the square root of time (Jury et al., 1991)

To improve the fit, an additional adjustment factor C was added to the previous equation ($I = S\, t^{1/2} + A\, t + C$), where S and A were evaluated and compared to the measured values. Due to the high error in infiltration measurements, S and A and the slope were calculated using infiltration data at times greater than 20 minutes.

Stepwise regression was carried out relating each soil physical parameter (such as infiltration, sorptivity, percolation, runoff, soil loss) to all other physical properties in table (1), and the ones with highest correlation to the studied property were listed according to their order of importance.

RESULTS AND DISCUSSION

Soil erosion is closely linked and controlled by the soil aggregate stability and the kinetic energy of the variable which induces the process. Aggregate stability of the six studied soils was measured and listed as mean weight diameter (MWD) in Table (2). A small reduction was observed for MWD values after raining for only15 minutes at rain intensity of 60 mm/h.

Table (2): MWD for the studied soils, as a measure of aggregate stability under raindrop impact for 15 min. at rain intensity of 60 mm/h.

Soil	MWD (mm)		
	Wetting only	After 15 min. of rain at 60 mm/h	Change %
Tahreer	0.34	0.30	11.76
Alex.	1.01	0.92	8.91
Roudah	0.76	0.61	19.74
Abu-Ghalib	0.50	0.42	16.00
Nikla	0.38	0.35	7.90
Dueap	0.16	0.13	18.75

In spite of the high sand content and loose structure for most of these soils (Table 1), soils with high content of calcium carbonate (Roudah and Alex.) had the largest MWD due to the cementing effect without rain impact. The difference in MWD between the two samples was used as a measure of soil aggregate susceptibility to break down by drop impact and of soil erodibility. The highest change of MWD by rain was observed for soils with high fine materials (Roudah and Dueap), as fine materials were first to detach and transport by drop impact. Stepwise regression indicated that MWD before and after exposure to rain correlated highly with both soil organic matter and fine sand content while MWD change (by drop impact) correlated highly with soil bulk density, organic matter, silt and clay content, respectively.

Infiltration

Infiltration rate, defined as the soil intake of water per unit area in a unit of time, includes both absorbed and percolated water. It is considered horizontal infiltration if the movement is lateral and entirely dominated by matric potential forces. It is considered vertical if the flow is downward and is aided by both matric and gravity potentials.

Cumulative infiltration values presented in Table (3) are summed over 1 and 2 hours of rain. Although cumulative infiltration increased with rain intensity for all studied soils, infiltrated water as a percent of the applied water was decreased for all soils at different rates. Increasing time of rain from 1 to 2 hours decreased the infiltrated water percent by 20 – 30 % for all three intensities. This was attributed to the effect of raindrop impact (kinetic energy), different properties of the formed seal in each soil, and the possible

Table (3): Cumulative Infiltration (mm) for six soils after 1 and 2 hours of rain at three rain intensities.

Soil	60 mm/h		90 mm/h		120 mm/h	
	1 h	2h	1 h	2h	1 h	2h
	Infiltrated water, mm					
Tahreer	44.0	64.7	56.0	84.6	62.8	97.3
Alex.	37.2	55.2	48.6	77.3	54.8	83.7
Roudah	28.9	41.7	38.7	53	43.8	57.2
Abu-Ghalib	36.5	51	42.7	60	49.7	69.2
Nikla	36.3	48.3	42.4	58.6	48.5	65.7
Dueap	29.9	39.7	39.5	53.2	44.1	55.7
	Infiltration, % of applied water					
Tahreer	73.3	53.9	62.2	47.0	52.3	40.5
Alex.	62.0	46.0	54.0	42.9	45.7	34.9
Roudah	48.2	34.8	43.0	29.4	36.5	23.8
Abu-Ghalib	60.8	42.5	47.4	33.3	41.4	28.8
Nikla	60.5	40.3	47.1	32.6	40.4	27.4
Dueap	49.8	33.1	43.9	29.6	36.8	23.2

disruption of the formed seal layer in some cases. The sudden increase of cumulative or rate of infiltration with rain intensity can occur, as the disruption of the formed seal layer occurs. Infiltration was highest for soils having high content of sand (Tahreer and Alex) except for that of high content of calcium carbonate (Roudah) which had the lowest values. Infiltration decreased as the content of clay or silt was high and correlated well either with soil porosity and fine sand for low rain intensity (60 mm/h) or with soil porosity and course sand for high rain intensities.

Figure (1) for infiltration rate (mm/h) with time (5-minute intervals) increased with increasing rain intensity and decreased with time. The infiltration rate representative lines for all soils at 60 mm/h rain intensity appeared always below those at 90 and 120 mm/h intensities. The decrease with time was relatively higher for the soils with more fine materials (clay, silt and calcium carbonates) such as Dueap (42% clay) and Roudah (21% $CaCO_3$). This was explained by the decrease in the vertical moisture gradient, and the development of a thin surface seal. The reduction rate in infiltration was sharp (approx. 50 %) during the first 30 minutes of rain, afterwards infiltration reduction was gradual.

Infiltration rates (mm/h) under water head of 1 cm without exposure to rain were much higher than that of the soils after exposure to rain. Results of Tahreer and Alex soils (sandy) were the highest (~ 113 mm/h after 1hour). Although Roudah soil is sandy, infiltration rate was intermediate (63 mm/h after 1hour) due to the high content of calcium carbonate. The Dueap clay soil exhibited the lowest infiltration rate after one hour of infiltration time (43 mm/h). The soils that were rained on for two hours at the three intensities had infiltration rates as low as 10 mm/h, clearly indicated the great effect of drop impact on infiltration rate.

Calculated values of sorptivity (S) and final infiltration (A) presented in Table (4) were evaluated at three rain intensities and only presented for the low intensity of 60 mm/h. S and A increased with increasing rain intensity due to the relative increase of rain kinetic energy that caused more soil compaction, reduced the size of soil pores, reduced vertical infiltration and in the same time increased soil water content. All these reasons led to the increase of the horizontal S and A.

Sorptivity values as the slope of the cumulative infiltration vs. the square root of rain time for the soils Tahreer, Alex., Roudah, Abu-Ghalib, Nikla and Dueap without exposure to rain were 215.98, 223.19, 121.93, 136.71, 89.48 and 85.31 mm/h½ respectively. These values were calculated from infiltration data under constant water head, 1 cm. Sorptivity for all soils were drastically decreased after exposure to rain for two hours at different intensities.

Sorptivity calculated to maximize the fit between measured and calculated values of infiltration was higher than the slope of the relationship of the cumulative infiltration vs. the square root of time only for soils with high clay content (Nikla and Dueap) using the unadjusted infiltration equation but was higher for all soils with the addition of the adjustment factor C. Sorptivity was lower for soils with high content of calcium carbonate (Roudah and Alex).

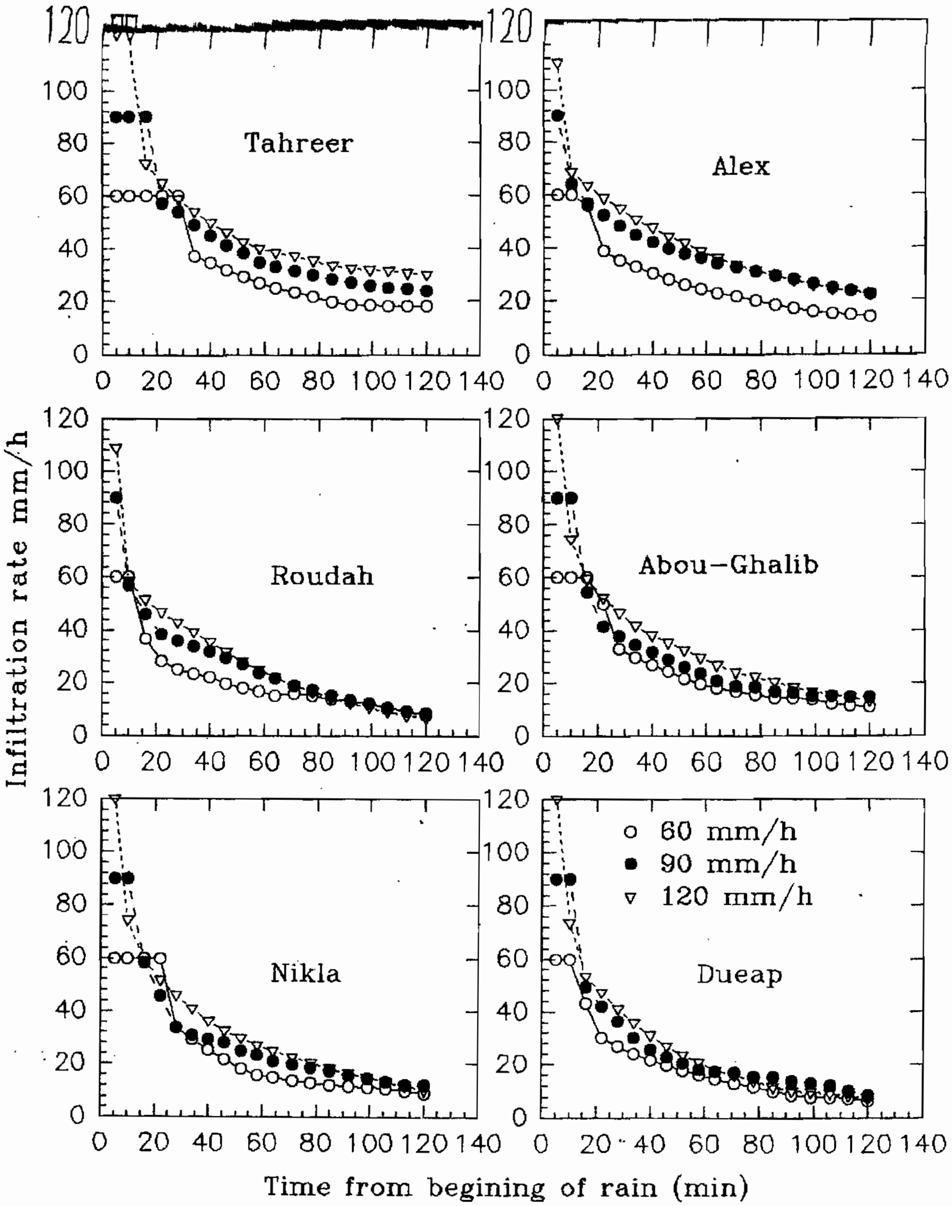

Fig. 1. Infiltration rate with time (5–min. intervals) for six soils under simulated rain at three rain intensities.

Results in Table (4) show a reasonable fit between measured and calculated cumulative infiltration, but the prediction of the infiltration rate i was relatively less accurate [high values of SER(i)] using the unadjusted equation, especially shortly after infiltration has commenced. Using the adjustment factor significantly improved the prediction of cumulative and rate of infiltration as the values of SER(I) and SER(i) were significantly lower (better fit).

Table (4): Calculated soil sorptivity, final infiltration and best fit parameter SER for cumulative (I) and rate (i) of infiltration in six soils at 60 mm/h rain intensity using Philip's equation with and without the adjustment factor c and sorptivity calculated as the slope of I vs. $t^{0.5}$.

Treatment (Soil)	Sorptivity (S) $mm/h^{0.5}$	Final k (A) mm/h	Slope as Sorptivity	SER(I)	SER(i)	Factor C
Tahreer	39.771	4.5155	49.811	0.17134	1.6479	--
Tahreer +c	65.487	-7.4103	49.811	0.02572	0.9697	-13.288
Alex.	31.749	5.6401	44.246	0.22929	1.9663	--
Alex.+c	61.617	-8.2113	44.246	0.03299	0.4547	-15.434
Roudah	27.331	1.9029	31.619	0.13386	1.7718	--
Roudah +c	41.191	-4.5243	31.619	0.04729	0.9997	-7.1615
Abu-Ghalib	31.941	0.5937	33.488	0.13380	1.3472	--
Abu-Ghalib +c	47.307	-6.5324	33.488	0.01919	0.5474	-7.9402
Nikla	42.265	-5.6855	30.428	0.08926	1.0322	--
Nikla +c	52.356	-10.365	30.428	0.06208	1.1824	-5.2142
Dueap	33.087	-3.2101	26.738	0.22422	2.4363	--
Dueap +c	56.452	-14.046	26.738	0.02607	0.8553	-12.074

The final infiltration rate calculated from the unadjusted infiltration equation produced positive values that decreased with increasing clay content to became negative for Nikla and Dueap soils. The adjusted equation produced negative values for all soils with the two soils Nikla and Dueap having the largest negative numbers while the lowest negative number was associated with the calcareous soil Roudah (-4.52 mm/h).

Percolation

Water that passes through the soil during the infiltration process is called percolation water, It is usually collected after a while from the beginning of the infiltration process. This time lag can be called the initiation time of percolation. Initiation time of percolation (Table 5) increased with the increase of soil fine materials (calcium carbonate, silt and clay) as the highest values were observed with the clay soil (Dueap) and the calcareous soil (Roudah). Tahreer soil was the first to percolate at the three intensities due to its coarse texture and low content of calcium carbonate. Increasing rain intensity from 60 to 90 mm/h decreased initiation time for all soils, while the increase to 120 mm/h produced inconsistent results, as initiation time was decreased, increased or remained unchanged. This result depended on the possibility of surface seal cracking under this high rain intensity with time. Initiation time of percolation was statistically dependent on soil content of silt, calcium carbonate and coarse sand, respectively.

Table (5): Initiation time of percolation (min.) for six soils at three rain intensities

Soil	60 mm/h	90 mm/h	120 mm/h
Tahreer	26	17	13
Alex.	58	46	46
Roudah	78	64	71
Abu-Ghalib	46	40	46
Nikla	46	40	40
Dueap	95	90	84

Cumulative percolation (Table 6) increased with the increase of rain intensity, but not at the same rate for all soils. High content of clay or calcium carbonate delayed percolation, as no percolation was observed during the first hour in both Dueap and Roudah soils at all intensities. Alex soil of moderately high calcium carbonate and very high content of sand, percolated as much water as that of Abu-Ghalib (14% clay). The highest percolation was obtained for the sandy soil (Tahreer) and was almost 44 mm after two hours of rain at the high intensity of 120 mm/h. Percolation as percent of applied water increased with time and was higher after two hours than one hour of rain for all soils except for the sandy soil (Tahreer) where it was slightly decreased. This indicates that the only soil that reached its maximum capacity of percolation before one hour of rain was the sandy soil without calcium carbonate. The lowest percolation as percents of the applied water was observed with the heavy clay soil (Dueap) at all three rain intensities. Generally percolation was statistically related to soil porosity, calcium carbonate and fine sand contents.

Table (6): Cumulative percolation (mm) for six soils after 1 and 2 hours of infiltration time at three rain intensities.

Soil	60 mm/h		90 mm/h		120 mm/h	
	1 h	2h	1 h	2h	1 h	2h
	percolated water, mm					
Tahreer	17.5	33.1	21.1	37.9	24.5	44.3
Alex.	3.2	20.3	7.1	26.7	8.0	32.3
Roudah	0.0	5.0	0.0	5.6	0.0	6.8
Abu-Ghalib	2.3	15.0	5.0	19.4	7.8	24.2
Nikla	5.3	14.9	7.0	18.0	8.0	20.3
Dueap	0.0	3.3	0.0	4.3	0.0	4.9
	Percolation, % of applied water					
Tahreer	29.2	27.6	23.4	21.1	20.4	18.5
Alex.	5.3	16.9	7.9	14.8	6.7	13.5
Roudah	0.0	4.2	0.0	3.1	0.0	2.9
Abu-Ghalib	3.8	12.5	5.6	10.8	6.5	10.1
Nikla	8.8	12.4	7.8	10.0	6.7	8.5
Dueap	0.0	2.8	0.0	2.4	0.0	2.1

Rate of percolation presented in Figure (2) decreased with time for all soils at all rain intensities. A similar pattern was observed for all soils, where representative lines of 60 mm/h rain intensity were always below the other lines beside the lines for 120 mm/h were always on top. Percolation rates for all soils decreased by as much as 50 % during the first 20 to 30 minutes of percolation. This was attributed to the structural changes of these soils under the continued impact of rain drops with the presence of fine materials and the formation of surface seals. The lowest results were observed for Dueap and Roudah followed by Nikla, where they contained 42%, 18% and 27% clay contents and Roudah also contained 21% calcium carbonates. Although Alex had more sand than Tahreer, percolation was less for Alex than Tahree due to its lower calcium carbonate content. The effect of increasing rain intensity (increasing drop impact) on soil surface was manifested clearly in the Tahreer soil, where the representative percolation lines for the three intensities appeared far from each other more than for the other soils due to the easy movement of fine materials downward forming patches of seals.

Surface runoff

Whenever the rate of water supply to the soil surface, whether rain or irrigation, exceeds the rate of infiltration and doesn't accumulate on the

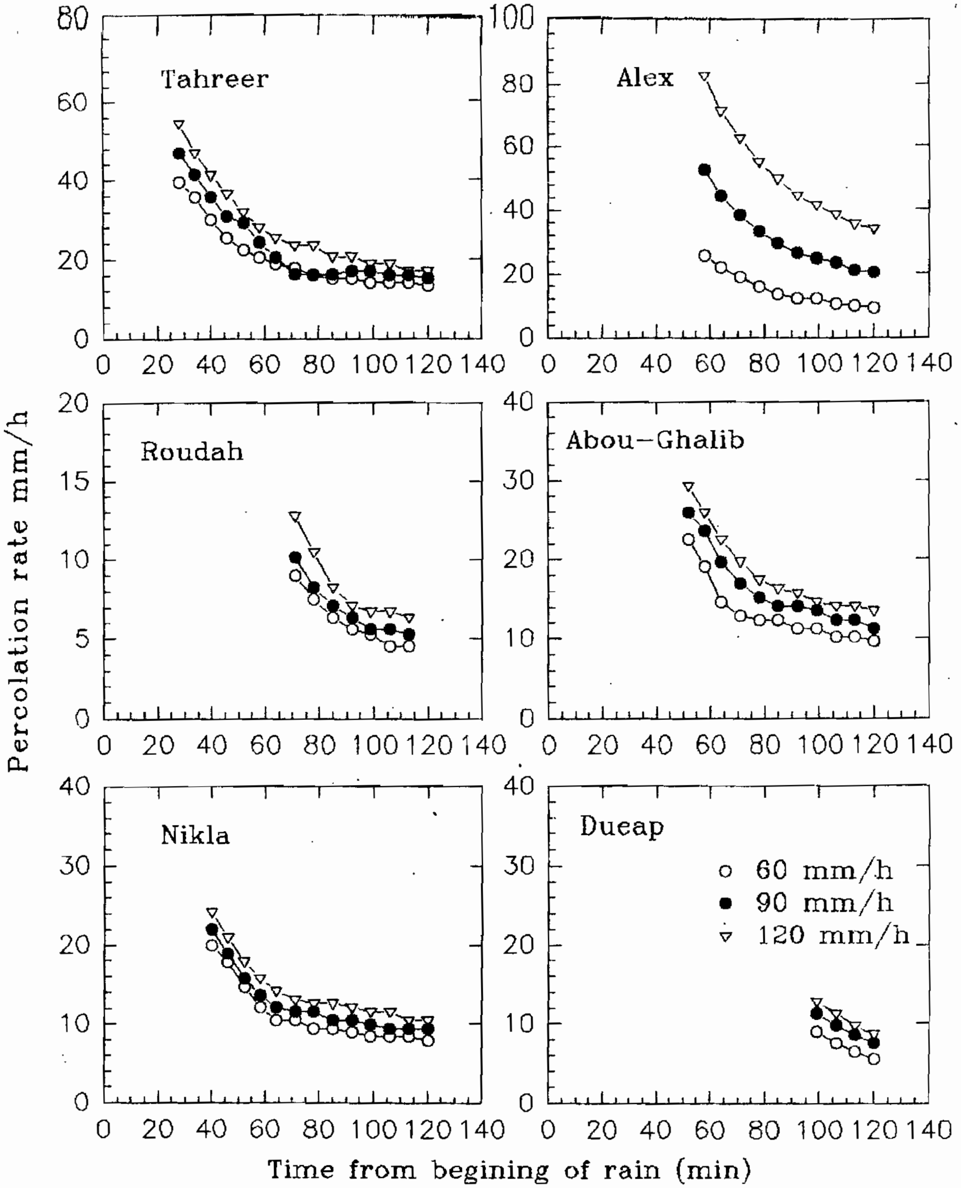

Fig. 2. Percolation rate with time (5-min. intervals) for six soils under simulated rain at three rain intensities.

surface, water will runoff. Soil erosion takes place during the runoff process and valuable top soil is removed to streams, reservoirs and lakes which become polluted with sediments (Baver et al., 1972).

Initiation times of runoff at different rain intensities are presented in Table (7) for the six studied soils. It ranged between 4 and 28 minutes. It decreased significantly with increasing rain intensity, calcium carbonate or clay content. Soils with high content of calcium carbonate (Roudah and Alex) exhibited the lowest values of initiation time which indicates high susceptibility to runoff and crusting or surface seal formation, especially at high rain intensities. It was statistically related to soil contents of calcium carbonate, fine sand and organic matter, respectively.

Table (7) Initiation time of runoff (min) for six soils at three rain intensities.

Soil	60mm/h	90mm/h	120mm/h
	Initiation time of runoff, min.		
Tahreer	28	17	10
Alex.	15	6	4
Roudah	12	6	4
Abu-Ghalib	22	12	6
Nikla	20	12	6
Dueap	13	10	5

Cumulative runoff after 1 and 2 hours of rain are presented in Table (8). Runoff was drastically increased with the increase of rain intensity, especially for soils high in calcium carbonate or clay content (Roudah and Dueap). Runoff after two hours was significantly higher than after one hour of rain. Differences between runoff values for different soils during the second hour were smaller as compared to that for the first hour. These differences were attributed to the variations in runoff initiation times and the sealing effect in all soils. Variations in runoff due to the different structure classes were not as profound as that due to the increase in rain intensity.

Runoff as percent of applied water followed the same trends as that obtained for absolute values of runoff for all soils. The lowest runoff values were obtained for the sandy soil (Tahreer). Runoff was statistically related mainly to soil porosity in addition to soil content of calcium carbonate, fine sand at low rain intensity and coarse sand and silt at high rain intensities, respectively.

Figure (3) for runoff rates (mm/h) at 5-minute intervals show that all soils followed similar trends. The differences between soils were very small except for the sandy soil (Tahreer). Generally, runoff rates increased steadily with increasing rain intensity. The obtained runoff values, even with the lowest rain intensity (60 mm/h) were considered relatively high which indicates that

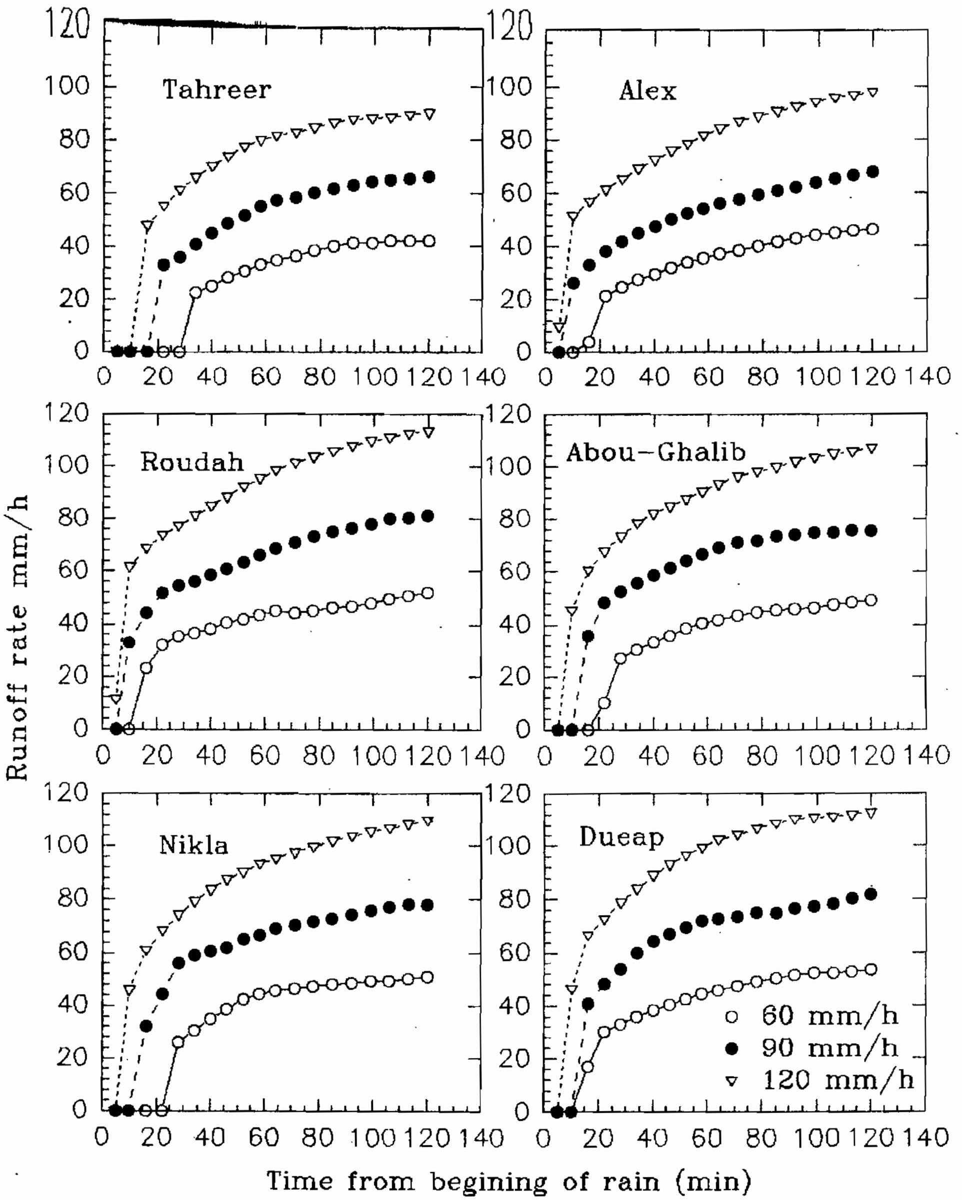

Fig. 3. Runoff rate with time (5-min. intervals) for six soils under simulated rain at three rain intensities.

this intensity can have deleterious effects, especially for the fine textured soils.

Table (8): Cumulative runoff (mm) for six soils after 1 and 2 hours of rain at three rain intensities.

Soil	60 mm/h		90 mm/h		120 mm/h	
	1 h	2h	1 h	2h	1 h	2h
			Runoff water, mm			
Tahreer	15.2	55.3	32.9	95.5	55.9	142.7
Alex	22.0	64.8	40.8	102.7	64.0	156.3
Roudah	30.6	78.3	50.6	127.0	75.5	182.8
Abu-Ghalib	22.9	69.0	46.5	120.0	69.4	170.8
Nikla	23.0	71.7	46.9	121.4	70.7	174.3
Dueap	29.7	80.3	49.9	126.8	75.3	184.3
			Runoff, % of applied water			
Tahreer	25.3	46.1	36.6	53.1	46.6	59.5
Alex	36.7	54.0	45.3	57.1	53.3	65.1
Roudah	51.0	65.3	56.2	70.6	62.9	76.2
Abu-Ghalib	38.2	57.5	51.7	66.7	57.8	71.2
Nikla	38.3	59.8	52.1	67.4	58.9	72.6
Dueap	49.5	66.9	55.4	70.4	62.8	76.8

Soil loss under simulated rain

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 hit the soil water surface, considerable splashing occurs and water becomes turbid primarily by breaking down soil aggregates or by detaching soil particles from the surface (Baver et al., 1972).

Soil loss data indicated low soil loss for both Dueap and Tahreer soils at the low intensity, especially during the first hour, Table (9). Although the two soils were different in texture, the low values for Dueap soil were attributed to the high clay content and high resistance to erosion. Whereas the low values for Tahreer soil was due to the high infiltration rate and initiation time of runoff which reduced soil loss during the early times. Increasing rain intensity to 90 or 120 mm/h reversed this trend for the sandy soils especially during the second hour of rain. Clay effect on soil loss decreased with the increase of rain intensity as resistance of stable aggregates to breake down decreased with the increase of rain intensity (kinetic energy). The high content of sand made soil more prone to erosion. Generally soil loss for all soils increased with the increase of rain intensity which is in agreement with Morin et al. (1981) and Aly (1993).

Cumulative and average soil loss rate for the second hour of rain at the three intensities were higher than that of the first hour for all soils, Table (9). Soil loss averages for all soils were between 0.35-0.57, 0.8-1.6, and 2.4-3.3 ton/fed/h for the first hour of rain and between 0.48-0.92, 0.98-2.0, and 3.15-4.34 for the second hour at the 60, 90, and 12 mm/h rain intensities, respectively. The average increase in soil loss due to the increase of intensity to 90 and 120 mm/h were 270 and 630% during the first hour and 210 and 520% during the second hour of that at 60 mm/h. Increasing duration time to a second hour at the three intensities increased soil loss by 150, 120 and 130%, respectively.

Table (9): Cumulative and average rate of soil loss for the six studied soils during the 1st and 2nd hour of rain at three intensities.

Soil	60 mm/h		90 mm/h		120 mm/h	
	1st h	2nd h	1st h	2nd h	1st h	2nd h
	Cumulative soil loss, $g/m^2/h$.					
Tahreer	96	172	369	481	792	1033
Alex	121	199	362	471	763	1005
Roudah	114	116	342	319	751	877
Abu-Ghalib	135	220	280	343	733	852
Nikla	119	192	253	294	588	750
Dueap	82	114	189	233	569	756
	Soil loss, ton/fedd./h.					
Tahreer	0.403	0.722	1.550	2.020	3.326	4.339
Alex	0.509	0.836	1.520	1.978	3.205	4.221
Roudah	0.479	0.487	1.436	1.340	3.155	3.683
Abu-Ghalib	0.567	0.924	1.177	1.441	3.079	3.578
Nikla	0.499	0.806	1.063	1.235	2.470	3.150
Dueap	0.345	0.479	0.794	0.979	2.389	3.175

Soil loss increase with increasing the duration of rain were much less than that due to increasing rain intensity for all soils. Erodibility rates increased with time and the soil surface became less resistant to erodibility as rain intensity and duration increased. For this reason soil loss is one of the main factors to be considered when choosing the sprinkler irrigation intensity.

Simple correlation indicated that soils having high contents of coarse and fine sand were more susceptible to erosion (positively correlated), whereas soils having high contents of silt, clay or organic matter were less prone to erosion (negatively correlated with soil erosion), Table (10). Coarse sand was the only significant factor associated with low rain intensity.

Table (10) Simple correlation coefficient (r) between some soil parameters and cum. soil losses after raining for 1and 2 hours.

Soil Parameter	60 mm/h		90 mm/h		120 mm/h	
	1h	2h	1h	2h	1h	2h
C.S.	0.869*	0.911*	----	----	----	----
F.S.	----	----	0.965**	0.956**	0.845*	0.931*
Silt	----	----	- 0.815*	- 0.841*	----	----
Clay	----	----	- 0.917**	- 0.931**	- 0.915*	- 0.903*
O. M	----	----	- 0.988**	- 0.927**	- 0.912*	- 0.919**

Figure (4) illustrates the rates of soil loss (g/m^2/min) for the studied soils at the three rain intensities. At 60 mm/h rain intensity, soil loss started after 28 minutes from the beginning of rain for the Tahreer soil due to it's high infiltrability, while for the other five soils it was started within 12 – 20 minutes. At this intensity, soil losses were relatively small for all soils and variations were even smaller between soils. The highest soil loss rate was observed for Abu-Ghalib and was about 5 g/m^2/min after one hour from the beginning of rain. The lowest soil loss was obtained for Dueap and Roudah soils. The representative soil loss lines appeared parallel to the x axis, reflecting almost an average constant rate ranging from 1.8 – 3.5 g/m^2/min for the different soils .

Increasing rain intensity to 90 or 120 mm/h shortened the initiation time of soil loss for all soils especially the rich in calcium carbonate (Roudah and Alex). Soil loss started at small values for all soils and sharply increased to a maximum value, in a short time after soil loss has commenced. Then it continued undulating around the high value for the sandy and clay soils (Tahreer, Alex, Roudah and Dueap) or slightly decreased as for Abu-Ghalib and Nikla. The average high value ranges for all soils are 3.7 – 8.3 g/m^2/min at 90 mm/h and 11-4 – 16.6 g/m^2/min at 120 mm/h. For both intensities the highest values were observed for Tahreer and Alex while the lowest were for Dueap and Nikla, respectively. The increase in soil loss for sandy soils is attributed to the loose structure and the presence of coarse sand that weakens the cohesive forces. The decrease in soil loss is due to soil compaction by raindrop impact with high kinetic energy that enhances cohesion forces between soil fine particles with rain time, and increases resistance to erodibility.

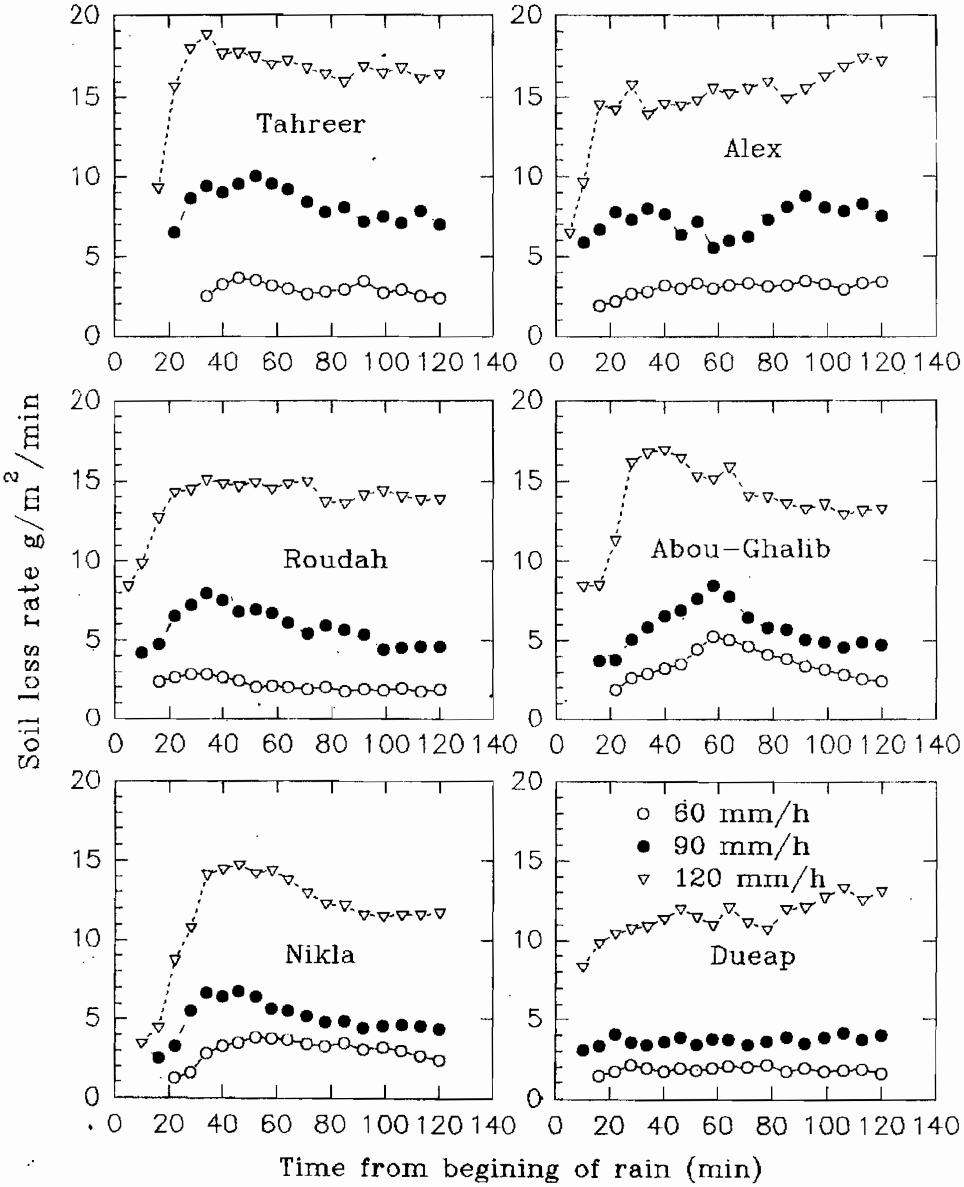

Fig. 4. Soil loss rate with time (5-min. intervals) for six soils under simulated rain at three rain intensities.

REFERENCES

Aarstad, J. S. and D. F. Miller (1973). Soil management practices for reducing runoff under center pivot sprinkler systems. J. Soil and water Cons. 28:171-173.

Aly. S. M. (1993). Polymers effect on water erosion and infiltration rate of erosion prone soil. Minufiya J. Agric. Res., vol. 18 No. 2:1371 –1386.

Aly, S. M. (2001). Evaluation of four models for predicting water retention in soils and a new best fit parameter. Egypt J. Soil Sci., 41 (1-2) : 43-63.

Aly, S. M. and M.E., Abdullah (2002). Evaluation of thickness and hydraulic conductivity of soil surface seal in PAM treated soils. Minia 1st Conference for Agricultural and Environmental Sciences (MCAES 1st) March, 25-28, Minia, Egypt.

Baver, L.D., W.H. Gardner and W.R. Gardner (1972). Soil Physics. Fourth edition. Wiley Eastern Limited, New Delhi, Bangalore, Bombay.

Brakensiek, D. L., and W. J. Rawls (1983). Agricultural management effects on soil water processes. Part II. Green and Ampt parameter for crusting soil. Trans. ASAE 25:1753-1757.

Cary, J.W. and D. D. Evans (ed.) (1974). Soil crusts. Tech. Bull.214. Univ. of Arizona, Tucson, AZ.

Cook, D. F. and S. D. Nelson (1986). Effect of polyacrylamide on seedling emergence in crust – forming soil. Soil Sci. 141:328 – 333

Hairsine, P. B. and R. A. Hook (1995). Relating soil erosion by water to the nature of the soil surface. P. 77 – 91. In H. B. So et al. (ed). Sealing, sealing and hardsetting soils: Productivity and conservation. Aust. Soc. Soil Sci., Brishane.

Hudson, N. W. (1971). Soil Erosion. Cornell University Press, Ithaca, New York, USA.

Jury, W.A., W.R. Gardner and W.H. Gardner (1991). Soil Physics. Fifth edition. John Wiley & Sons, Inc., New York, Chichester, Brisbane, Toronto, Singapore.

Lentz, R. D. and R. E. Sojka (1994). Field results using polyacrylamide to manage furrow erosion and infiltration. Soil Soc. 158:274–282.

Linden, D. R. (1979). A model to predict soil water storage as affected by tillage practices. Ph. D. diss. Univ. of Minnesota, St. Paul (Diss. abstr. 80 – 11844).

Moore, I. D. (1981). Effects of surface sealing on infiltration. Trans. ASAE 24: 1946 - 1552.

Moore, I. D. and C. L. Larson (1979). Effects drainage projects on surface runoff from small depressional watershed in the North Central region. WRRC, University of Minnesota Grad. School. Bull. 99.

Morin. J., Y. Benyamini, and A. Michaeli (1981). The dynamics of soil crusting by rainfall impact and the water movement in the soil profile. J. Hydrol. 52:321 – 335.

Philip, J. R. (1957b). The theory of infiltration. Soil Science 83:345-357.

Philip, J. R. (1969). Theory of infiltration. Adv. Hydrosci. 5:215- 05. Academic Press. N.Y.

Rose, C. W. (1962). Some effects of rainfall, radiant drying, and soil factors on infiltration under rainfall into soils. J. Soil Sci. 13:286 – 298.

Smith, R. E. (1999). Technical Note: Rapid Measurements of Soil Sorptivity. Soil Sci. Soc. Am. J. 63:55 – 57.

Trout, T. J., R. E. Sojka, and R. D. Lentz (1995). Polyacrelamide effect on furrow erosion and infiltration. Trans. ASAE 38:761 – 765.

Unger, P. W. (ed.) (1984). Tillage system for soil and water conservation. Food and Agriculture Organization Soils Bull. 54. FAO , Rome.

Young, R.A. (1984). A method of measuring aggregate stability under water drop impact. ASAE paper No. 83 -2134. Transactions of the ASAE – 1984.P. 1351 - 1354.

توصيف العمليات الطبيعية السائدة تحت نظام المطر الصناعي في بعض الأراضي المصرية

صالح محمد علي[1] – عبد المنعم عامر[1] – محمود سليم[2] – محمد السيد عبد الله[2]
١ – قسم علوم الأراضي – كلية الزراعة – جامعة المنوفية
٢ – مركز البحوث الزراعية – الجيزة

الملخص العربي

تم في هذا البحث تعريض ستة من الأراضي المصرية المختلفة في القوام ونسبة كربونات الكالسيوم لمطر صناعي بدرجات شدة و أزمنة مختلفة وذلك بغرض دراسة تأثير المياه سواء بواسطة المطر أو من الرشاشات علي بعض معاملات التربة مثل درجة ثبات الحبيبات- التشرب – الإمتصاصية – الرشح – الجريان السطحي – فقد التربة. وقد استخدم المطر لمدة ساعتين بثلاثة درجات لشدة المطر هي ٦٠، ٩٠، ١٢٠ مم/ساعة حيث جمعت مياة الجريان السطحي و الرشح كل ٥ دقائق كما تم جمع الرواسب في مياه الجريان السطحي واعتبارها مساوية لفقد التربة. كما تم تقدير الإمتصاصية ومعدل الرشح النهائي من تطابق التشرب التجميعي المقاس من الحقل مع ذلك المحسوب من معادلة Philip (المعدلة والغير معدلة). أوضحت النتائج أن أعلي تغير في قيمة القطر المتوسط الموزون MWD بواسطة المطر حدث في الأراضي ذات النسبة المرتفعة في الطين أو كربونات الكالسيوم وقد ارتبط MWD بكل من الكثافة الظاهرية للتربة وكذلك كمية المادة العضوية بها. بالرغم من أن التشرب التجميعي ازداد بزيادة شدة المطر إلا أن نسبته من كمية مياه الري المستخدمة قلت في جميع الأراضي. وقد وجد ارتبط إحصائي بين التشرب والنفاذية وكذلك كمية الرمل الناعم عند شدة المطر المنخفضة أو النفاذية ونسبة الرمل الخشن في حالة شدة المطر العالية. ازدادت كل من الإمتصاصية ومعدل الرشح النهائي بزيادة شدة المطر وقد وجد تطابق معقول بين التشرب التجميعي المقاس و المحسوب بينما معدل التشرب كان تطابقه أقل دقة وقد تحسن التطابق بدرجة كبيرة لكل من التشرب ألتجميعي ومعدل التشرب عند إضافة معامل تصحيح لمعادلة Philip . ازداد زمن بداية الرشح بزيادة كل من شدة المطر والمحتوي من الطين أو كربونات الكالسيوم كما زاد الرشح التجميعي بزيادة شدة المطر في كل الأراضي حيث ارتبط إحصائيا

بالنفاذية وكربونات الكالسيوم والرمل الناعم. تراوح زمن بداية الجريان السطحي بين ٤- ٢٨ دقيقة حيث قل بدرجة كبيرة بزيادة كل من شدة المطر ونسبة الطين أو كربونات الكالسيوم. كانت الاختلافات في قيمة الجريان السطحي كنتيجة لتغير قوام التربة أقل كثيرا من تلك الناتجة عن زيادة شدة المطر أما فقد التربة فقد كان قليلا في كل من الأراضي الرملية والطينية عند شدة المطر المنخفضة بينما أدت زيادة شدة المطر إلي عكس نتائج الأرض الرملية خاصة في الساعة الثانية من المطر كما انخفض تأثير الطين بزيادة شدة المطر وتراوح متوسط فقد التربة في الأراضي بين (٠,٣٥-٠,٥٧) ، (٠,٨-١,٦) ، (٢,٤-٣,٣) طن/فدان/ساعة وذلك خلال الساعة الأولي ، (٠,٤٨-٠,٩٢) ، (٠,٩٨-٢,٠) ، (٣,١٥-٤,٣) طن/فدان/ساعة وذلك خلال الساعة الثانية من المطر عند شدة المطر الثلاث المستخدمة. وقد كانت زيادة فقد التربة بزيادة مدة التعرض للمطر أقل من تلك الناتجة عن زيادة شدة المطر في جميع الأراضي حيث بدأ الفقد قليلا ثم ازداد بسرعة إلي حد أقصي حيث استمر متذبذبا حول هذه القيمة المرتفعة أو قل قليلا.