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Soil surface Seal Induced by Rainfall and its effect on Properties of soil of the North western Coast of Egypt.

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Abstract

The current work aims at evaluating the effect of soil surface seal caused by rain on properties of recently reclaimed calcareous soils in the northwestern coast, Egypt. Soils were taken from the 0-30 cm surface layer, representing 3 textural classes: clay loam, loam, and sandy loam, and three $CaCO_3$ contents: 250-300 g kg^{-1}, 300-350 g kg^{-1}, and > 400 g kg^{-1}. Soils were packed into stainless steel pots with dimensions of diameter and 20 cm height 15 cm exposed to three main artificial rainstorms 60 mm 30 min^{-1}, 120 mm 30 min^{-1} and 180 mm 30 min^{-1} for two different durations 10 and 30 min with two sloping grades 9 and 2%. There was a positive correlation between seal development and rainstorm intensity and duration. Soil fine particle content, exchangeable sodium percentage (ESP), and soil compaction were the main factors controlling the rate of sealing and its severity. Sloping grade restricted maximization of manifestation of seal development. There was a positive correlation between seal development and, soil erosion, salinization, and surface compaction, and negative correlation with irrigation water storage by soil.

Keywords: *Seal Induced Rainfall, Calcareous Soils, Runoff, Soil Degradation.*

Introduction

Factors affecting soil surface seal induced by rainfall include rainfall. Rain is characterized by the following parameters i) intensity; ii) raindrop diameter, iii) final velocity of raindrops. **Moncada et al., (2013); Wick et al., (2014); Gelaw et al., (2015)** development of surface seal depends on the extent of breakdown of surface aggregates, depends on soil structure stability which is directly related to the kinetic energy of raindrops rain intensity and duration of rainstorm. **Armenise, et.al., (2018)** found that 60% reduction occurred in unsaturated hydraulic conductivity of soil surface soils between2 and 9 minutes of rainfall. They added that; increasing rainfall duration by 2 to 14 minutes caused increases in seal thickness in sandy loam soils exponentially by 1.56 to 5.4 mm. Rainfall duration affected the depth of reduced porosity formed below the sealed surface. Soil texture affects the rate of sealing through effects on aggregate stability **Wakindiki and Ben-Hur, (2002)**, **Lado et al., (2004a)** found that soils which contains 63 to 80 % clay exhibited aggregate stability increase and less sealing, while soils with 22 to 40% clay were susceptible to seal formation, **Levy et.al., (1994)** noted that more than 70% of seal formations are related to salinity and sodicity of soil. Since salinity increases infiltration while sodicity decreases infiltration. **Abrol et al., (2016). Poesen, (1986)** reported a negative correlation between soil surface slope and surface sealing which has adverse effects on infiltration, and causes excessive water loss by runoff, slope reduces macroporosity of soil surface (**Assouline, 2004)**. Thickness and bulk density of soil surface is strongly related to rainfall characteristics and with the initial bulk density of the soil despite the marked change in the density of the consolidated layer. Largest changes in bulk density were reported to occur within the first 10 minutes of the rainstorm, and changes were inversely correlated with the initial conditions of soil (**Jakab, et al., 2013). Di Prima, et al., (2018)** found that soil sealing increased soil bulk density by 39 to 42%, depending on the type of soil. Soil erosion involves two major processes: (i) detachment of soil particles from the soil surface, and (ii) transport of sediments, mainly by surface runoff (**Korkanç, 2018)**.

Materials and Methods

The study area was represented by four sites; Borg El-Arab site, Swani Jaber site, El-Kasr site, and Sidi Barrani. In each site, one representative soil profile was selected. Soil taken from the 0-30 surface soil layer soil air dried, gently crushed then sieved through a 2mm sieve.The physical analysis of soils contained particle size distribution by **Klute, (1986)**. Chemical analysis included electrical conductivity and soluble salts **(Richard, 1954).** Textural classes were clay loam,

loam, and sandy loam, the soil was packed in pots of 15 cm diameter and 20 cm height. The initial bulk densities were (1.2 to 1.5 Mg m^{-3}) .Three main artificial rainstorms (60 mm 30 min^{-1}, 120 mm 30 min^{-1} and 180 mm 30 min^{-1}) for two different durations (10-30 min) with sloping grades (2 - 9%) were tested. After rainstorms ended the simulator was halted and soil samples were taken and the plastic bottles were disconnected from the funnels then contents were exposed to centrifuging and the runoff water was separated from soil sediments. Runoff water and soil sediments were determined, and the final bulk density was measured.

Result and Discussion

Basic physical and chemical properties of the studied soils

Table 1 shows results of soil samples taken from New Borg El-Arab, Swani Jabber, El-Kasr, and Sidi Barrani, i.e. soils1, 2, 3 and 4.The textural class ranged between clay loams (soil1), sandy loam (soil 2 and 3), and loam (soil 4). All soils were highly calcareous.

Table 1. Some basic characteristics of the studied soils

Sample No.	Sand %	Silt %	Clay %	Texture Class	$CaCO_3$ g kg^{-1}	D_b Mg m^{-3}
1	25.85	39.24	34.91	*	333.6	1.20
2	76.36	13.5	10.14	**	479.5	1.52
3	57.82	24.61	17.57	**	271.0	1.51
4	46.46	32.73	20.81	***	291.9	1.36

***** **Clay Loam**
****** **Sandy Loam**
******* **Loam**

Considering the chemical analysis; Table 2 shows that pH ranged from 8.0 to 8.61 and EC ranged from 1.63 to 112.1 dS m^{-1}, soils 1, 3 and 4 are saline, while soil 2 was non-saline. The dominant soluble cations were sodium followed by calcium, magnesium and potassium. The dominant anions were chloride followed by bicarbonate and sulphates. Soils 1 and 4 were sodic and soil 3 was moderately sodic, soil 2 was slightly sodic.

Table 2. Chemical analyses of the studied soil

Soil No.	pH	EC dS m^{-1}	Soluble Cations and Anions mmolc.								ESP
			Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	$CO3^{--}$	$HCO3^{-}$	$SO4^{--}$	
1	8.61	112.10	353.45	212.55	1126.24	11.52	1668.87	0.0	18.13	16.76	49.30
2	8.35	1.63	4.79	4.21	6.45	1.18	9.00	0.0	6.30	1.33	3.12
3	8.00	12.71	51.39	43.61	64.00	5.28	140.61	0.0	17.39	6.28	11.04
4	8.08	17.23	52.77	49.23	121.27	7.10	205.46	0.0	13.54	9.37	19.18

"Rainfall-induced seal" was on the uppermost layer of soil with low porosity, high bulk density and poor hydraulic conductivity which enhances runoff generation **(Carmi and Berliner, 2008; Davis et al., 2010; Sela et al., 2012).** Runoff water volume expresses seal strength. Increasing runoff water volume is an important indicator for seal development **(Sajjadi, and Mahmoodabadi, 2015).** Table 3 shows surface runoff volume generated due to seal development on the upper layer of soils. Increased seal development was related to rainstorm intensity from 60 mm 30 min^{-1} to 180 and from duration of 10 - 30 minutes. The increase varied according to the soil properties. Seal development was correlated positively with rain storms intensity and durations, **Moncada et al., (2013); Wick et al., (2014); Gelaw et al., (2015); Shin et.al. (2016), and Armenise, et.al. (2018).** After surface sealing the intensity exerted by excess rainfall occurred. Soil 1 which has the highest content of fine particles showed the strongest surface seal. In contrast; soil 2 gave the weakest surface seal, due to its low content of fine particles, soils 3 and 4 showed medium strength due to their physical and chemical properties. Work by **Lado et al., (2004a); Lado et al., (2004b) and Mamedov et.al, (2006); Wuddivira et al., (2009) and Abrol et al., (2016)** indicated that soil properties effect surface sealing.

Table 3. Comparative effects of rainstorms characteristics and soil properties on runoff water (m^3 hm^{-2}) as indicator of soil seal development

I	D	P_1				Means of I	P_2				Means of I
		S_1	S_2	S_3	S_4		S1	S2	S3	S4	
I_1	D_1	50.02	10.07	13.75	12.57	21.603	74.98	12.49	20.05	17.56	31.27
	D_2	200.06	62.46	162.48	137.52	140.63	312.51	135.1	200.03	177.47	206.28
Means of P		125.04	36.265	88.115	75.045	81.116	193.75	73.795	110.04	97.515	118.77
I_2	D_1	150.01	62.49	112.52	87.47	103.12	237.55	90.03	165.07	145.08	159.43
	D_2	650.01	275.07	445.06	422.53	448.17	887.52	400.02	675.09	662.5	656.28
Means of P		400.01	168.78	278.79	255	275.65	562.54	245.03	420.08	403.79	407.86
I_3	D_1	250.06	162.57	225.06	212.5	212.55	412.51	237.48	262.49	247.56	290.01
	D_2	1162.5	800.02	925.03	907.02	948.65	1475	1000.1	1237.6	1225.1	1234.4
Means of P		706.29	481.295	575.05	559.76	580.6	943.77	618.78	750.03	736.33	762.23
G. Means of P		410.45	228.78	313.98	296.6		566.68	312.53	426.72	412.54	
Means of D											
D_1		150.03	78.37667	117.11	104.18	112.42	241.68	113.33	149.2	136.73	160.24
D_2		670.86	379.1833	510.86	489.02	512.48	891.69	511.73	704.23	688.35	699

Notes (I) Rainstorm intensity (I_1, I_2, I_3 = 60, 120, 180 mm $30min^{-1}$)
(D) Rainstorm duration (D_1, D2 = 10, 30 min)
(P) Slope (P_1, P_2 = 2, 9%)
(S) Soil (S_1, S2, S3, S4 = Soils. 1, 2, 3 and 4 respectively.

Table 4 shows the amounts of eroded soil material caused by seal development. Soil 1 showed the highest soil loss and soil 2 showed the lowest, which reveals direct relationship between soil erosion and seal development. The minimal amount of eroded soil by seal was by soil 2: 0.02 Mg h^{-1}, whilst soils 3 and 4 lost 0.05 and 0.39 Mg h^{-1} respectively. This may be due to the physical and chemical effects of each. These were associated with the soil seal severity by increasing the effect of rainstorm intensity and duration, and soil slope. In general increasing of slope means more efficiency for gravity in moving of solid soil particles and runoff water. Gravity affects runoff water movement since increasing runoff caused more speed with increased slope. These findings are supported by **Schmidt, (2010); Asadi et al. (2011) and Sajjadi and Mahmoodabadi, (2015).**

Table 4. Comparative efficiency of seal development on soil loss (Mg ha^{-1})

I	D	P_1				Means of I	P_2				Means of I
		S_1	S_2	S_3	S_4		S_1	S_2	S_3	S_4	
	D_1	1.25	0.02	0.05	0.39	**0.43**	2.17	0.18	0.29	0.47	**0.78**
	D_2	2.12	0.15	0.69	0.51	**0.87**	8.21	1.19	1.62	1.53	**3.14**
Means of P		**1.68**	**0.08**	**0.37**	**0.45**	**0.65**	**5.19**	**0.69**	**0.95**	**1.00**	**1.96**
I_2	D_1	3.44	0.57	1.73	1.82	**1.89**	29.55	4.96	14.43	15.90	**16.21**
	D_2	30.70	5.26	15.07	17.41	**17.11**	54.02	9.18	25.39	28.98	**29.39**
Means of P		**17.07**	**2.92**	**8.40**	**9.62**	**9.50**	**41.78**	**7.07**	**19.91**	**22.44**	**22.80**
I_3	D_1	4.75	1.30	3.77	3.85	**3.41**	41.77	14.21	20.79	20.99	**24.44**
	D_2	42.56	15.52	22.94	23.21	**26.06**	70.87	26.10	35.96	39.35	**43.07**
Means of P		**23.65**	**8.41**	**13.36**	**13.53**	**14.74**	**56.32**	**20.16**	**28.37**	**30.17**	**33.75**
G. Means of P		**14.13**	**3.80**	**7.37**	**7.86**		**34.43**	**9.30**	**16.41**	**17.87**	
Means of D											
D_1		**3.14**	**0.63**	**1.85**	**2.02**	**1.91**	**24.50**	**6.45**	**11.84**	**12.45**	**13.81**
D_2		**25.13**	**6.98**	**12.90**	**13.71**	**14.68**	**44.37**	**12.16**	**20.99**	**23.29**	**25.20**

Notes (I) Rainstorm intensity (I_1, I_2, I_3 = 60, 120, 180 mm $30min^{-1}$)
(D) Rainstorm duration (D_1, D2 = 10, 30 min)
(P) Slope (P_1, P_2 = 2, 9%)
(S) Soil (S_1, S2, S3, S4 = Soils. 1, 2, 3 and 4 respectively)

Depressions are places for accumulating and harvesting runoff water. Land of depression does not harvest runoff water along with the solids and dissolved salts in the water. This may lead to salinization. Table 5 shows total dissolved salts translocated to depressions. The lowest effect of seal was in soil 1 causing a translocation of 0.05 Mg salts ha^{-1}. This was lower in soil 2 which showed 0.007 Mg ha^{-1}. Soils 3 and 4 showed moderate amounts of around 0.01 Mg ha^{-1}. High amounts are associated with severe seals and intensive rainstorms as well as long duration of a storm soil salinity **Cui, et al. (2017).**

Table 5. Comparative efficiency of seal development on translocation of dissolved salts (Mg h^{-}1)

I	D	P_1				Means of I	P_2				Means of I
		S_1	S_2	S_3	S_4		S_1	S_2	S_3	S_4	
	D_1	0.05	0.007	0.01	0.01	**0.02**	0.15	0.02	0.02	0.01	**0.05**
	D_2	0.19	0.05	0.07	0.06	**0.09**	0.61	0.06	0.10	0.09	**0.21**
Means of P		**0.12**	**0.03**	**0.04**	**0.04**	**0.06**	**0.38**	**0.04**	**0.06**	**0.05**	**0.13**
	D_1	0.24	0.04	0.05	0.05	**0.10**	0.80	0.07	0.08	0.08	**0.26**
	D_2	0.53	0.20	0.26	0.25	**0.40**	1.12	0.34	0.35	0.38	**0.63**
Means of P		**0.38**	**0.17**	**0.23**	**0.21**	**0.25**	**0.96**	**0.27**	**0.30**	**0.25**	**0.44**
	D_1	0.58	0.06	0.07	0.09	**0.20**	1.91	0.10	0.11	0.10	**0.55**
	D_2	1.20	0.30	0.40	0.38	**0.48**	3.13	0.41	0.52	0.48	**1.05**
Means of P		**0.89**	**0.13**	**0.16**	**0.17**	**0.34**	**2.52**	**0.22**	**0.23**	**0.24**	**0.80**
G. Means of P		**0.46**	**0.11**	**0.14**	**0.14**		**1.29**	**0.18**	**0.20**	**0.18**	
						Means of D					
D_1		**0.29**	**0.04**	**0.04**	**0.05**	**0.10**	**0.95**	**0.06**	**0.07**	**0.06**	**0.29**
D_2		**0.64**	**0.18**	**0.24**	**0.23**	**0.32**	**1.62**	**0.29**	**0.32**	**0.29**	**0.63**

Notes (I) Rainstorm intensity (I_1, I_2, I_3 = 60, 120, 180 mm 30min^{-1})
(D) Rainstorm duration (D_1, D2 = 10, 30 min)
(P) Slope (P_1, P_2 = 2, 9%)
(S) Soil (S_1, S2, S3, S4 = Soils. 1, 2, 3 and 4 respectively)

Top soil bulk density in (Table 6) did not give a clear trend due to variation of initial bulk density of the soil. These results were used to calculate the percent of change in the initial bulk density. Soil 1 was the most affected by rainstorms, the high increase in bulk density 33.83% was associated with the lightest rainstorm and shortest duration. Soil 3 recorded a low increase of 7.15 % and soil 2 showed 17.51% increase and soil 4 showed 22.04 increases. Increasing rainstorms intensity and duration increased bulk density due to the impact of raindrops on the soil surface. The effect of slope on bulk density was negative and the high (9%) as well as the low (2%) slope showed rather similar effects. These findings agree with **Jakab, et al. (2013) and Di Prima, et al. (2018).**

Table 6. Comparative efficiency of seal development on increasing top layer bulk density change (%)

I	D	P_1				Means of I	P_2				Means of I
		S_1	S_2	S_3	S_4		S_1	S_2	S_3	S_4	
I_1	**D_1**	33.83	17.51	7.15	22.04	**20.13**	28.96	11.62	3.26	17.61	**15.36**
	D_2	45.51	22.86	21.44	24.37	**28.55**	37.4	14.84	11.26	22.39	**21.47**
Means of P		**39.67**	**20.19**	**14.30**	**23.21**	**24.34**	**33.18**	**13.23**	**7.26**	**20.00**	**18.42**
I_2	**D_1**	57.2	26.82	22.8	23.74	**32.64**	45.97	12.09	10.49	18.76	**21.83**
	D_2	81.95	31.99	29.59	35.94	**44.87**	68.21	26.37	21.58	28.95	**36.28**
Means of P		**69.58**	**29.41**	**26.20**	**29.84**	**38.75**	**57.09**	**19.23**	**16.04**	**23.86**	**29.05**
I_3	**D_1**	62.13	38.43	30.54	38.58	**42.42**	44.64	25.99	20.13	25.95	**29.18**
	D_2	96.1	49.96	40.32	49.15	**58.88**	81.58	38.46	32.38	41.1	**48.38**
Means of P		**79.12**	**44.20**	**35.43**	**43.87**	**50.65**	**63.11**	**32.23**	**26.26**	**33.53**	**38.78**
G. Means of P		**62.79**	**31.26**	**25.31**	**32.30**		**51.13**	**21.56**	**16.52**	**25.79**	
						Means of D					
D_1		**51.05**	**27.59**	**20.16**	**28.12**	**31.73**	**39.86**	**16.57**	**11.29**	**20.77**	**22.12**
D_2		**74.52**	**34.94**	**30.45**	**36.49**	**44.10**	**62.40**	**26.56**	**21.74**	**30.81**	**35.38**

Notes (I) Rainstorm intensity (I_1, I_2, I_3 = 60, 120, 180 mm 30min^{-1})
(D) Rainstorm duration (D_1, D2 = 10, 30 min)
(P) Slope (P_1, P_2 = 2, 9%)
(S) Soil (S_1, S2, S3, S4 = Soils. 1, 2, 3 and 4 respectively)

Summary and Conclusion

Surface runoff water volume could be used to express the strength of surface seal, rainstorms intensity and duration representing the physical act in soil surface sealing and controlling of the amount of rainfall excess runoff. Soil properties had the main role in sealing development. Fine particles in soil increases surface seal. Texture and ESP effects sealing, High initial soil bulk density enhances developing strong seals. Soil surface slope restricts sealing. Surface seals affect soil capability for irrigation water storage. Development of seals decreases soil permeability. Consequently, the rate of water entry into the soil for storage is decreased. Soil erosion is associated with surface sealing, since seals increase surface water runoff and its effect on separating and transporting soil particles. Increased salinity and sodicity in soil could happen due to of surface runoff. The rate of salinization is high in soils of initial salinity. Soil compaction by the physical impact of raindrops has a great effect on the soil sealing.

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الختم السطحى الناشئ عن الأمطار وتأثيره على خصائص التربة في الساحل الشمالي الغربي ,مصر.

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يهدف العمل الحالي إلى تقييم تأثير تكوين الختم السطحى الناجم عن سقوط الأمطار على خصائص التربة الجيرية المستصلحة حديثًا في الساحل الشمالي الغربي بمصر ، حيث تم جمع عينات التربة من الطبقة السطحية (0–30 سم) لتمثل 3 درجات للقوام: الطميية الطينية ، الطميية ، والرملية الطميية ، وثلاثة درجات لمحتوى التربة من كربونات الكالسيوم 250–300 جرام كجم $^{-1}$، 300–350 جرام كجم $^{-1}$و > 400 جرام كجم $^{-1}$. حيث تم تعبأة التربة في أواني من الصلب غير القابل للصدأ بأبعاد 20 × 20 × 15 سم و تم تعريضها لثلاث عواصف مطرية صناعية ذات كثافات60 مم 30 دقيقة $^{-1}$ و 120 مم 30 دقيقة $^{-1}$ و 180 ملم 30 دقيقة $^{-1}$ لمدتين مختلفتين 10 و 30 دقيقة على درجتى إنحدار 2 و 9 ٪. وقد أظهرت النتائج ارتباطا إيجابيا بين معدلات تطور الختم وكثافة ومدة العواصف المطرية ،ومحتوى التربة من الجسيمات الدقيقة، نسبة الصوديوم المتبادل (ESP) وإنضغاط التربة. حيث كان لهذه العوامل دورا رئيسيا فى التحكم في معدل تكون الختم و شدته ، بينما إقتصر تأثير درجة الميل على زيادة معدلات حدوث الظواهر المرتبطة بتكون الأختام. كما أظهرت النتائج أيضا أن هناك ارتباط إيجابي بين تطور الختم وتآكل التربة والتملح فضلا عن إنضغاط الطبقة السطحية , كما أظهرت أيضا الارتباط السلبي بين تكون الأختام ومعدل تخزين مياه الري بالتربة.