

Soil Crust Formation Influenced by the Impact of Sprinkler Irrigation Systems in Iraq

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Abstract:

Field experiment was conducted to assess the impact of sprinkler irrigation system on the surface soil crusting in the silty clay texture. Three sprinkler models were used difference in nozzle size and geometric shape. Sprinklers have been utilized to irrigate cultivated and uncultivated plots in order to determine the contribution of vegetative cover which can reduce the impact of sprinkler droplets. The size distribution of the sprinkler droplets for each model was determined at different distances from the sprinkler center. Various physical soil properties were tested and statistically analyzed to understand the contribution of sprinkler irrigation in soil crusting formation. The parameters included soil infiltration, bulk density, mean weight diameter, porosity, and micromorphological study of the thin section of soil crust. The results indicated that the impact of sprinkler irrigation did not exceed two centimeters of soil depth. The outcomes included increasing the bulk density of the soil, decreasing the infiltration rate, reducing the porosity and the mean weight diameter of the soil crust. The vegetative cover caused to aggravate the sprinkler irrigation impact compared to the uncultivated plots.

Keywords: Iraq; sprinkler irrigation; soil crust; droplet size distribution; cultivated soil

I. Introduction

Majority of Iraqi soils (62.2 %) are classified as Aridisols due to climate and soil parent. The predominant characteristics of these soils were finer texture, weak structure, a high percentage of calcium carbonate, low organic matter, and saline soil (Muhaimed, Saloom et al. 2014). These soil properties are more vulnerable to soil sealing and crusting under field conditions of rainfall or sprinkler irrigation (Lehrsch and Kincaid 2006). The droplet energy impacts from irrigation sprinklers are one of the restricted problems facing the development and expansion of sprinkler irrigation systems in the arid zone of the world (Busch, Rochester et al. 1973). Iraq is one of the arid zones that has recently used the drip and sprinkler irrigation systems to resolve the water scarcity and desertification problems (Abbas, Wasimi et al. 2018). Notwithstanding the sprinkler irrigation is considered one of the most efficient systems, but it has shortfalls regarding soil crusting, runoff, and injury to the parts of plants especially during the first stage growth (Stillmunkes and James 1982, Zhang and Zhu 2017). In addition, the sprinkler irrigation system needs operational expertise to avoid the negative impact on the soil's physical properties through

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adjusting the sprinkler nozzle and operating pressure to modify the sprinkler droplet size and prevent soil crusting. The mechanism of soil surface crusting by sprinkler droplets initiated by breaking down the surface soil aggregate due to the kinetic energy of the impact of the sprinkler droplet. Fine particles have been produced to fill the pores between aggregates in the upper few centimeters of soil surface depth and form soil crusting. (Epstein and Grant 1973). Variable parameters of sprinkler irrigation that affected the surface crusting soil include application intensity, water depth of application, and drop diameter (Sun, Kang et al. 2008). Researchers have found that sprinkler droplets break down the topsoil aggregates and compact the thin surface soil and lead to hard crust formation especially in clay soils (Ragab 1983, Adeoye 1986). Sprinkler droplet energy degrades the surface soil structure and increase the penetration resistance linearly with increasing droplet energy (Baumhardt, Unger et al. 2004). Sprinkler with larger droplets induces compaction, decreases aggregate stability, reduces soil infiltration rates and increases soil bulk density. (Santos, Reis et al. 2003). A field experiment was performed in order to learn more information about the impact of sprinkler irrigation on soil crusting under Iraqi circumstances. The objectives of this research include: first, the study of the effect of sprinkler irrigation systems on the formation of soil crusts. Second, evaluate the impacts of sprinkler irrigation on infiltration rate, soil aggregate stability and soil bulk density under bare and vegetated soil conditions. And thirdly, a morphological study of surface soil crusting under a sprinkler irrigation procedure.

II. Materials and Methods

Description of the experimental farm:

One-hectare area of the experimental farm of the college of engineering in Abu-Graib / Baghdad / Iraq ($44^{\circ} 6' E$, $33^{\circ} 30' N$), was selected for this study. The solid set system of sprinklers was installed in a grid pattern with sufficient overlap. Three types of sprinklers were used, B60, B81, and B90 each with a single nozzle of 4.5, 6.5, and 8.0 mm in diameter, respectively. The spacing between sprinklers and laterals was 12 X 12, 18 X 18, and 18 X 18 meter for B60, B81, and B90 sprinklers, respectively (Figure 1). After two block tests, the sprinklers were installed in a rectangular configuration of 18x12 meters for B81 and B90 sprinkler models and 12x9 meters for B60 sprinkler model to increase the distribution efficiency (Figure 2). Six plots were created between sprinkler laterals. One plot for each sprinkler model was cultivated by wheat (*TriticumaestivumL.*) as vegetative land cover. Also, one plot for each sprinkler model was irrigated without vegetative cover to evaluate the land cover effect. Spilt block experiment design was used for statistical analyze the data. The water resource of the experimental farm from Abu-Graib River. At farm inlet, water is pumped into large storage tanks and then pumped again through a network of sprinkler pipe lines (Figure 2). The climatic data recorded from Al-Raeed meteorological station (500 meters from the experimental farm).

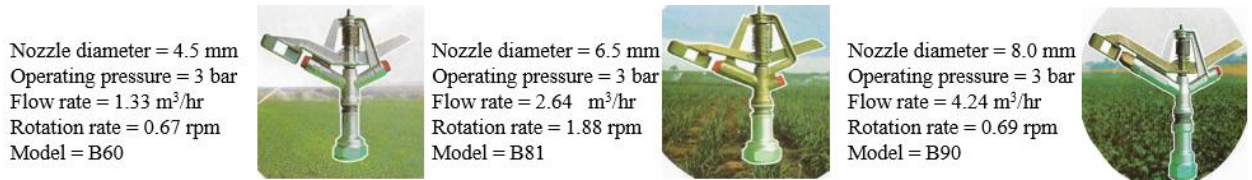


Figure 1: The sprinkler model characteristics used in field experiment.

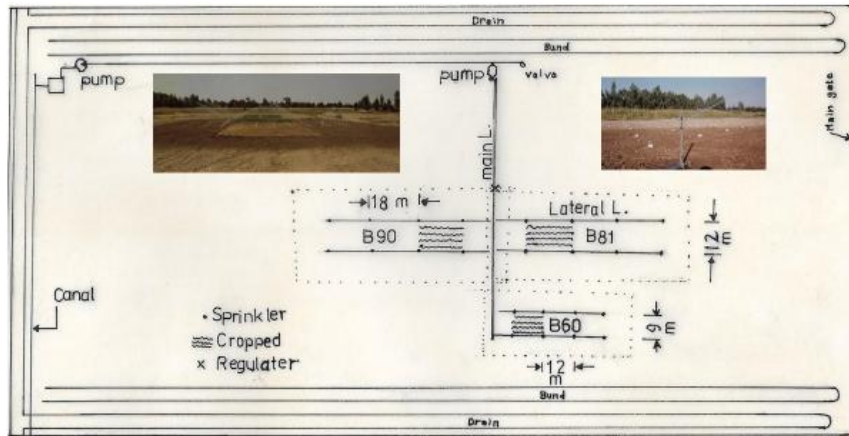


Figure 2. Schematic diagram of the experimental farm.

Physical and chemical properties of the site soil:

Five soil samples were obtained randomly from 0 – 15, 15 – 75 and 75 – 100 centimeters of soil depth at various locations on the basis of the profile horizons. Samples were aerially dried and passed through a 2 mm sieve. The soil particle analysis was performed using the pipette procedure described by Allison, Bernstein et al. (1954). Determination of soil moisture content was performed under stress conditions using a pressure membrane system as described by Fukada (1958). The bulk density was measured by using core method (Dane and Topp 2020). Soil chemical properties were determined based on American salinity laboratory proposal (Sparks, Page et al. 2020).

Soil infiltration tests:

Double ring infiltrometers were performed to measure the accumulative infiltration at different locations of the experimental farm with three replications as demonstrated by Michael (1978). The accumulative infiltration of soil was measured at the beginning of experiment and after harvesting. The basic infiltration rate (BIR) was used as an indicator for soil structure. The time required to arrive the BIR was calculated on the basis of the following equation proposed by Merriam, Keller et al. (1973).

$$T = 600 |n| \quad \text{Equation 1}$$

Where T= time to arrive BIR, and n = is the slope of the linear function between the accumulative time and infiltration rate.

Assessing the droplet size distribution of sprinkler jet:

In order to maximize the efficiency of the sprinkler irrigation system, precise knowledge of the distribution of the droplet size (DSD) in actual field conditions is required. Sprinkler droplet characterization is very essential in evaluating the effect of droplets on soil and crop growth (Lehrsch, Lentz et al. 2005, Molle, Tomas et al. 2012, Zhang and Zhu 2017). One of the accessible and simpler methods in the field estimates of the DSD of sprinkler spray, is flour pellet method (Carter, Greer et al. 1974, Eigel and Moore 1983, Kathiravelu, Lucke et al. 2016). The principle of this process involves dropping water droplets of known weight into a circular container with a diameter of 21 cm and a thickness of 5 cm, which is filled with sieved wheat flour. The formed flour pellets are dried into the air and then oven-dried at 105 °C for 24 hours. Then drawing calibration curve between pellet weight and known droplet water diameter. In this study, different water droplets were weighted using filter paper and sensitive electronic scale and dropped into freshly sieved flour from different heights. Different water droplets were obtained using different tools such as pipette, micropipette, dripper, hypodermic needle, and syringe. Water droplet diameter was determined using the following equation:

$$d = \sqrt[3]{(6/\pi)W} \text{ (Equation 2)}$$

Where d is the diameter of the known water droplet in millimeters and W is the average droplet weight in milligram assume the water, density is one milligram per cubic millimeter. Many known droplet sizes were dropped into flour. Also, the average known droplets weight and pellets were calculated and represented in the calibration curve. Nine containers filled with sifted wheat flour for each sprinkler model were used for three distance (3, 9, 15 meters) from the center of sprinkler irrigation (Figure 3). The exposed duration of sprinkler water spray in the field conditions should be brief (1 to 2 seconds) to avoid duplicate droplet counts. In addition, in order to prevent splash effects, the test area should be restricted to the center of the collection container. After the samples were collected from the spray of each sprinkler model with three replicates for each distance, the formed pellets were dried and sieved in the set of sieves (4 to 0.3 mm). The flour pellets were classified, counted, and weighted. The diameter of the droplets was determined based on the calibration curve between the weight of the pellet and the diameter of the droplet. The results were statistically analyzed and represented by using Jamovi 1.2.22 software.



Figure 3. Containers of sieved wheat flour used in measuring sprinkler droplets.

Soil aggregate stability

Undisturbed soil samples were randomly collected at different locations of the treatments with three replications. The samples were aeri ally dried and passed through 9 and 4 mm sieves. Aggregates diameters of 9 to 4 mm were dried in oven over 48 hours under calcium chloride to allow samples to arrive at isotropy matric potential. These aggregates were used to estimate the aggregate stability by wet sieving method which proposed by Kemper and Chepil (1965). The results of the soil aggregates were represented by mean weight diameter and the calculations were completed based on the basis of protocol suggested by Youker and McGuinness (1957).

Micromorphological characteristics of surface crusting soil

After harvesting, soil crust samples from the surface were collected for various treatment locations and carefully packed in cardboard containers in the laboratory of the Geological and Mineral Survey Directorate in Iraq. The soil crust samples were oven-dried at 105-110 ° C, then saturated with epoxy. Thin sections were designed for a 30 micrometer thick crusting of the soil surface. The thin sections were pasted on slideshow by canadabalsem material (Cady, Wilding et al. 1986). These slides were analyzed by microscopy and photomicrographs were prepared for each slide. (Evans and Buol 1968). The photomicrographs were printed and labelled. The point counting method was used to estimate the porosity for depth, as suggested by Carver (1971).

III. Results and discussion

Physical and chemical properties of the site soil:

The results of morphological description of soil profile and physical and chemical analysis in (Table 1) indicated that the soil is sedimentary parent, silty clay texture, and weak structure. The results of soil chemical

properties (Table 2) illustrated that the soil was contained a high percentage of calcium carbonate, low organic matter, and very low salinity. This outcomes was agreed with Alzubaydi and Alamar (2016).

Table 1: Physical properties of the site soil.

cm	%				pw%				gm/cm ³
soil depth	sand	silt	clay	texture	0.33 bar	15 bar	AW	50% of AW	BD
0 - 15	4.90	53.40	41.70	silty clay	31.00	16.00	15.00	23.50	1.37
15 - 75	4.00	55.60	40.40	silty clay	32.00	16.00	16.00	24.00	1.54
75 - 100	4.00	49.00	47.00	silty clay	33.00	18.00	15.00	25.50	1.53

Table 2: Chemical properties of the site soil.

Centimeter	ds/m	pH	%			meq / 100 gm soil						
soil depth	EC		CaCO ₃	CaSO ₄	OM	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁼
0 - 15	3.30	8.1	23.00	0.46	1.40	1.40	15.00	23.50	1.37	1.57	0.10	2.49
15 - 75	8.00	7.7	25.00	0.45	0.60	1.87	16.00	24.00	1.54	3.71	0.07	2.29
75 - 100	12.30	8.0	26.50	1.20	0.50	1.56	15.00	25.50	1.53	1.71	0.10	6.27

Droplet size distribution of sprinkler jet:

The regression plot was created between the average known droplet diameter and average flour pellet as a reference to estimate the droplet size of sprinkler jet at different distances from the sprinkler center as shown in (Figure 4). Statistically, it was highly correlated ($r^2=0.9806$). The results showed that the smaller droplets were falling closer to the center of sprinkler and the largerdroplets were falling further away from the center of sprinkler (Table 3). This distribution of sprinkler droplets was accompanied by a kinetic energy effect, which increased with regard to the mass of the droplets. Also, the proportion of larger droplets increased as the sprinkler nozzle increased. Therefore, the distribution of largerdroplets (> 2 mm) was33%,41%, and 58% at 9 meters from the sprinkler center of model B60, B81, and B90, respectively,as shown in (Figure 7). The size of the droplet has been increased due to an increase in the size of the nozzle.This result was agreed with Kohl and DeBoer (1984) and Kohl (1974).. The statistical results analysis of JAMОВI software, showed that there wasa significant difference ($p < .01$) between 3

and 9 meters distance from sprinkler center. There was also a significant difference ($p < .001$) between 3 and 15 meters. Although there was no significant difference between 9 and 15 meters as shown in (Figure 7) There was a significant difference ($p < .05$) between sprinkler models B60 and B90 for the impact of the sprinkler model. There was also a significant difference ($p < .01$) between B81 and B90 sprinkler models. Whereas there was no significant difference between the B60 and 81 sprinkler models(Figure 7).

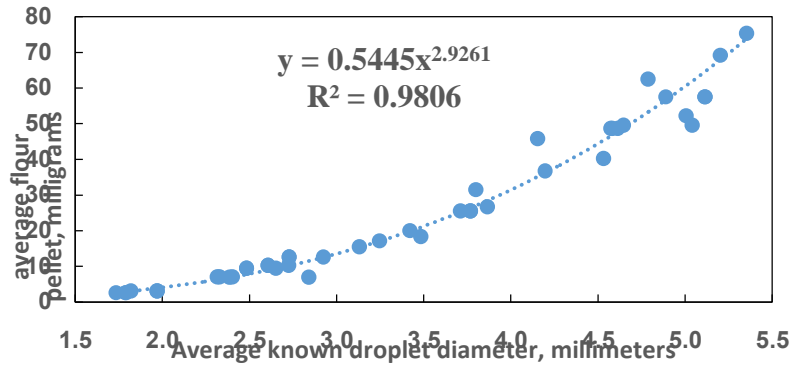


Figure 4: Association between average flour (milligram) and average known droplet diameter (millimeter)

Table 3: The statistical summarized results of droplet size distribution of sprinkle jets.

statistical description of droplet size distribution of sprinklers						percent droplet diameter more than 2mm		
Sprinkler	median	Mean	variance	minimum	maximum	3 meters	9 meters	15 meters
B60	1.25	1.38	0.72	0.4	2.8	0	33%	50%
B81	1.25	1.37	0.54	0.4	2.6	0	41%	31%
B90	2.00	2.16	1.94	0.5	5.5	0	58%	65%

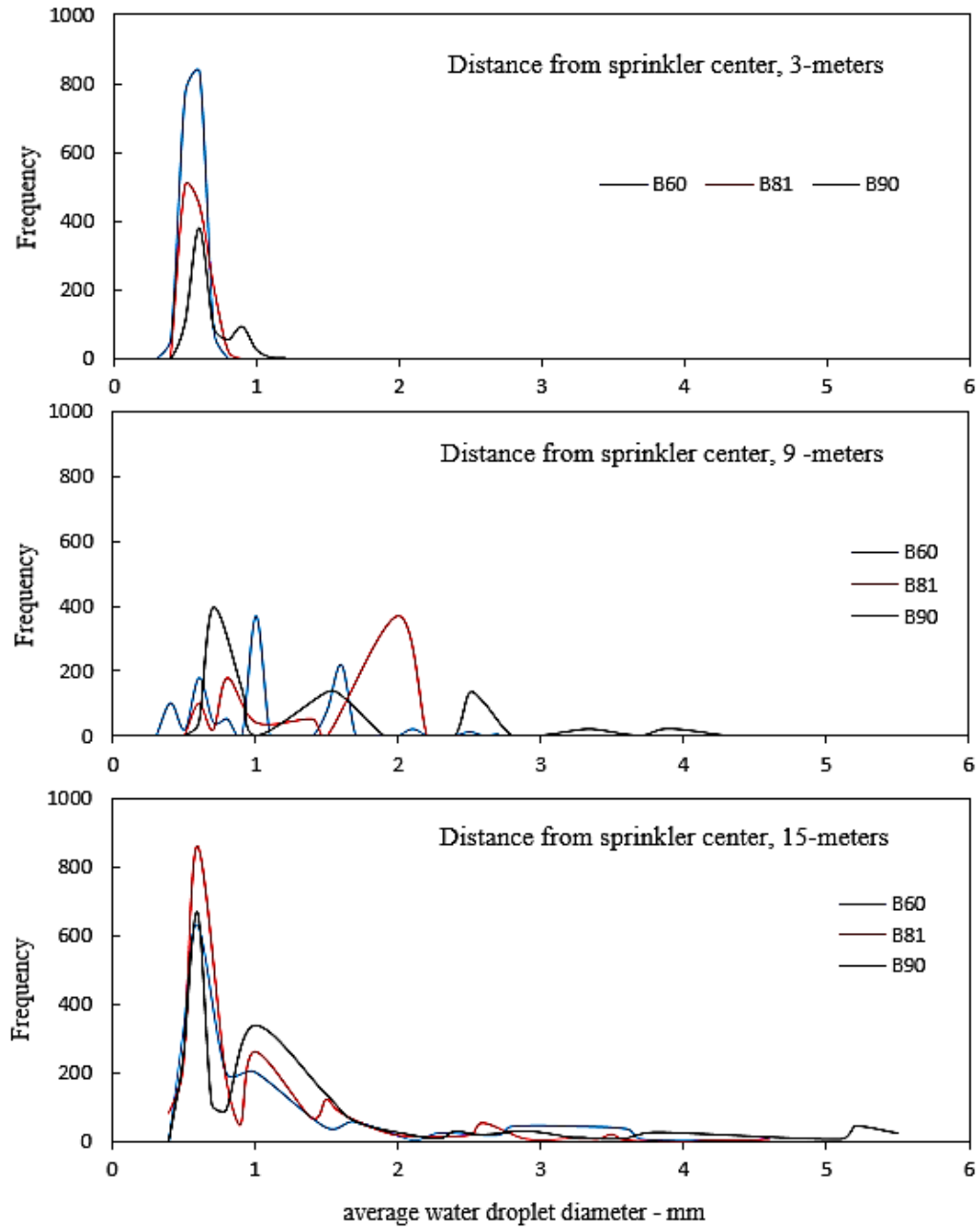


Figure 5: Droplet size distribution from sprinkler jets B60, B81, and B90.

Tukey Post-Hoc Test – droplet-mm

		3	9	15
3	Mean difference	—	-1.05 **	-1.320 ***
	p-value	—	0.003	< .001
9	Mean difference		—	-0.272
	p-value		—	0.476
15	Mean difference			—
	p-value			—

Note. * p < .05, ** p < .01, *** p < .001

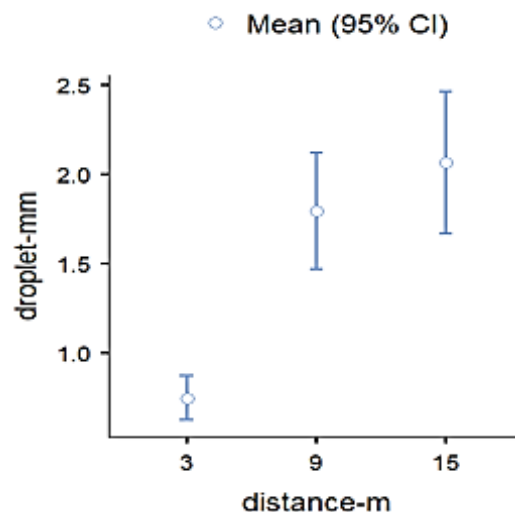


Figure 6: The effect of distance from the sprinkler center on the droplets size distribution according to JAMOVI software.

Tukey Post-Hoc Test – droplet-mm

		B60	B81	B90
B60	Mean difference	—	0.0113	-0.777 *
	p-value	—	0.999	0.014
B81	Mean difference		—	-0.788 **
	p-value		—	0.008
B90	Mean difference			—
	p-value			—

Note. * p < .05, ** p < .01, *** p < .001

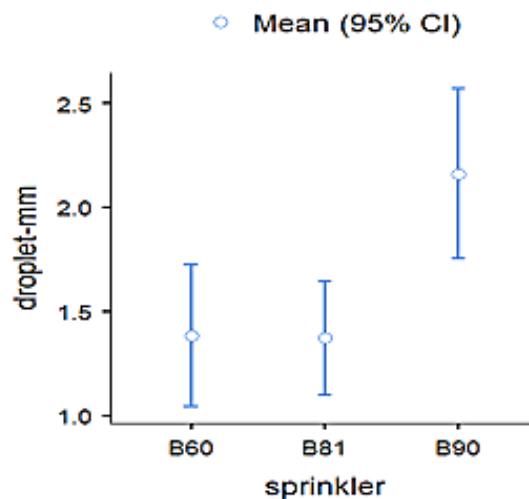


Figure 7: The effect of sprinkler model on the droplets size distribution according to JAMOVI software.

Soil infiltration tests

The result (

Table 4) showed that cultivated plots for all sprinkler models had a highly reduction in the infiltration capacity and infiltration rate due to agricultural processes and a smaller organic content (Yimer, Messing et al. 2008). The findings indicated that the reduction in infiltration rate (IR) was significantly difference ($P < .01$) between cultivated and uncultivated plots (Figures 8, 9, and 10)). The sprinkler model B60 (Figure 5 and Table 3) had the

lowest reduction effect on infiltration rate for all treatments compared to the other sprinkler models due to the droplets size distribution. This outcome was agreed with Lehrsch and Kincaid (2006).

Table 4: The summarized results of the percentage reduction in soil infiltration rate (mm / hr).

Sprinkler	BI	AHU	AHC	R-AHU %	R-AHC %
B60	31.1	25.1	23.3	19.4	25.2
B81	31.1	20.9	12.8	32.8	58.8
B90	31.1	23.3	12.4	25.2	60.1

Where BI = before irrigation, AHU = after harvesting in uncultivated plots, AHC = after harvesting in cultivated plots, R-AHU = percentage reduction in uncultivated plots relative to BI, R-AHC = percentage reduction in cultivated plots relative to BI.

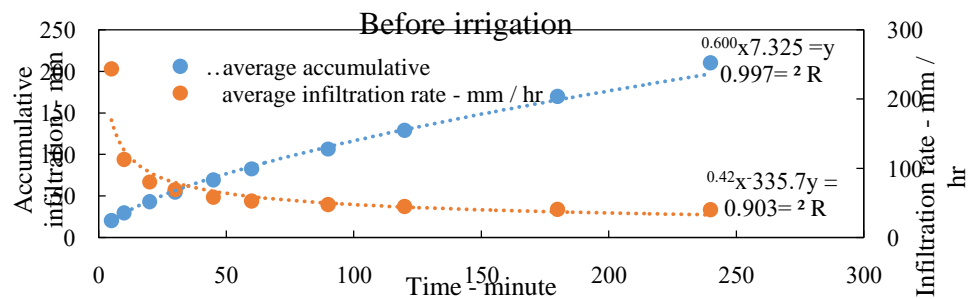


Figure 8: Average soil infiltration capacity of the site before starting the experiment.

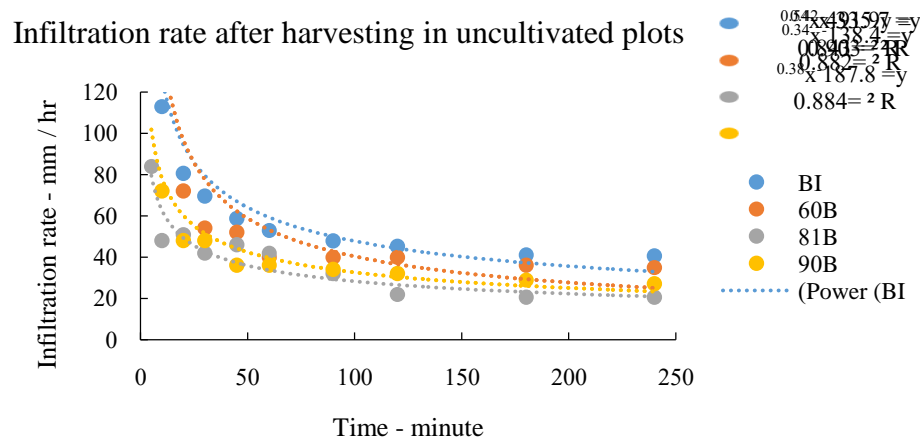


Figure 9: The average infiltration rate at the end of the experiment in uncultivated plots.

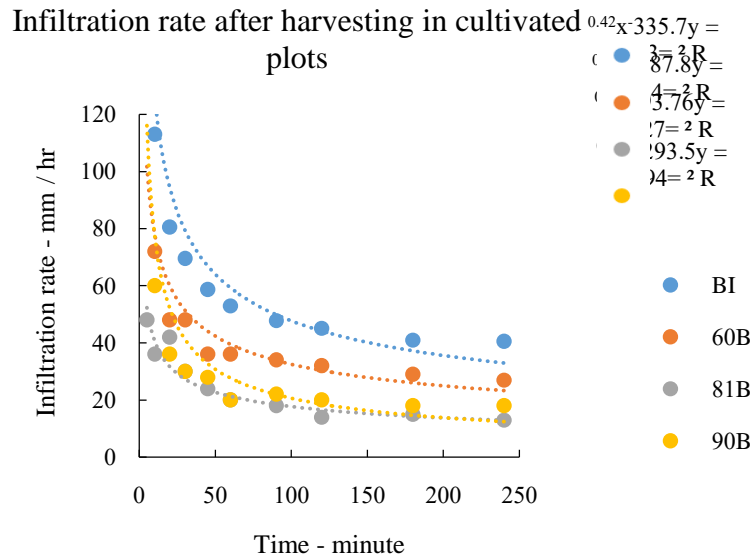


Figure 10: The average infiltration rate at the end of the experiment in cultivated plots.

Soil aggregate stability:

The results in (Table 3) showed that the B81 sprinkler provided a high percentage increase in bulk density and a decrease in the MWD of the surface soil crust of both cultivated and uncultivated plots compared to the soil below. This may be due to a combination of application time and a higher percentage of droplet size. And these outcomes have been agreed with Sun, Kang et al. (2008). The surface crusted soil (Table 5) was characterized by an increase in bulk density and a decrease in MWD for cultivated plots compared to uncultivated plots. This outcome also has been agreed with Duley (1940) and Willardson, Ertsgaard et al. (1974).

Table 5: Physical properties of the crusted surface soil and its underside.

	Before irrigation	After harvesting											
Cultivation	initial soil	Cultivated area						Non cultivated area					
Sprinkler		B60	B60	B81	B81	B90	B90	B60	B60	B81	B81	B90	B90
Status		SC	BSC	SC	BSC	SC	BSC	SC	BSC	SC	BSC	SC	BSC
Soil depth-	0 - 10	0-	10-	0-	10-	0-10	10-	0-	10-	0-	10-	0-	10-

cm		10	15	10	15		15	10	15	10	15	10	15
BD gm/cm ³	1.32	1.41	1.35	1.55	1.38	1.49	1.38	1.39	1.36	1.47	1.28	1.45	1.36
MWD mm	0.40	0.31	0.4	0.25	0.43	0.28	0.41	0.36	0.45	0.17	0.43	0.18	0.3

Where BD = Bulk density, MWD = mean weight diameter, SC = soil crust, BSC = beneath soil crust

Micromorphological characteristics of surface crusting soil

The thin section of soil crust, which formed by the impact of sprinkler droplets provided a visual examination of the layers building of the soil crust. The micromorphology examination indicated the intrinsic factors of crustability and pore size distribution of the soil crust (Valentin 1985). The severe degradation of soil aggregates were occurred in the two centimeters of soil crust thickness (Table 6) (Busch, Rochester et al. 1973). Based on Jamovi statistical analysis software, there was no significant difference between (0 – 1) and (1 – 2) cm soil crust depth, but there were highly significant difference between (0 – 1) and (4 – 6) cm soil crust depth. Sprinkler B81 was observed to be strongly influenced by soil crust relative to other sprinklers. (Figure 11). The sprinkler model B60 demonstrated the lowest effect on the porosity of the soil crust due to its size distribution and application rate, as agreed with Sun, Kang et al. (2008).

Table 6: The porosity of soil crust formation as influenced by the impact of sprinkler droplets.

Soil depth-cm	0 - 1	1 - 2	2 - 4	4 - 6
B60	12.5	14.4	21.9	22.5
B81	8.5	10.4	17.2	23.8
B90	9.0	12.0	22.8	23.6

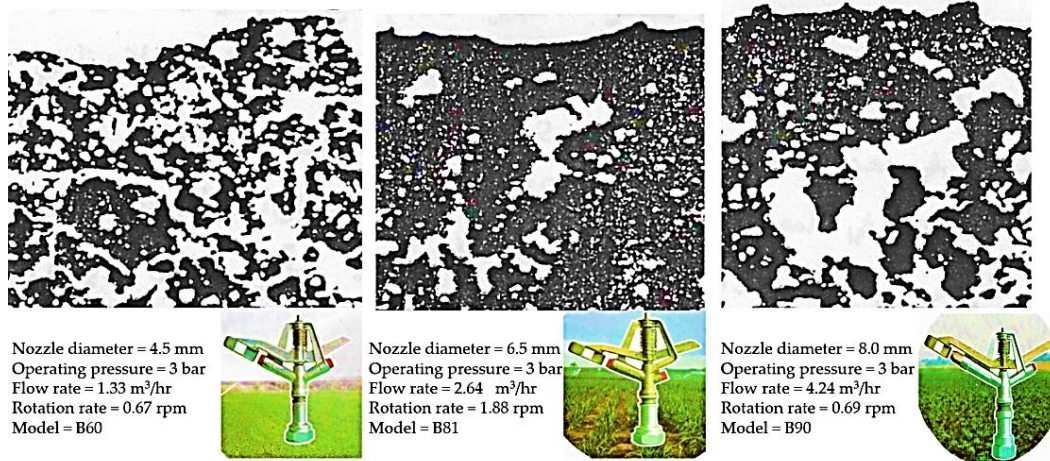


Figure 11: The microscopic thin section of soil crust formed by sprinkler models.

IV. Conclusion

The application rate, application time, and the droplets size distribution of sprinkler irrigation are to be variable parameters formed the soil crust, unless they are modified for a good performance. Iraqi soil is more vulnerable to soil sealing and crusting under field conditions of sprinkler irrigation due to its texture and lower organic content. The vegetative cover did not reduce the impact of sprinkler on the soil crusts, contrary to what is expected due to the interaction between agricultural processes and factors affecting soil crusts. Micromorphological investigation of the soil crust was enhanced and visualized the formation of the soil crust layers, which affected by sprinkler irrigation. Overall, sprinkler irrigation caused an increase in bulk density, a decrease in porosity and a low intake rate of the surface soil crust in all treatment plots with by varying proportions that did not exceed two centimeters of soil depth.

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