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CHANGES OF SOME SOIL PHYSICAL AND HYDROPHYSICAL CHARACTERISTICS IN RESPONSE TO DIFFERENT SPRINKLER TYPES AND NOZZLE SIZES

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ABSTRACT

Soil characteristics' degradation had been considered as one of the most important problems that face the agricultural development processes under arid and semi-arid conditions due to non-suitability of the applied technologies and techniques, attributed to management considerations. Consequently, higher crop yield and quality reduction had been occurred due to the degradation of the plant healthy media (soil). Therefore, the goal of this investigation was to monitor the change detection of some soil physical and hydrophysical characteristics under sprinkler irrigated agriculture. However, the terminal objectives were to evaluate and monitor some soil characteristics changes (soil bulk density, hydraulic conductivity and soil penetration resistance) under different mode of action of sprinkler types (rotating and impact sprinkler) and corresponding nozzle sizes (small and large sizes). Hereby, field experiments were carried out for two seasons (2006 and 2007) in the Desert Experimental Farm of Faculty of Agriculture, Ain Shams University which is located at El-Bustan region, Behaira Governorate. Results revealed that soil characteristics were highly affected with the sprinkler mode of action and corresponding nozzle sizes. However, a power function proportion of soil penetration resistance with respect to applied rotating and impact sprinkler types and corresponding small and large nozzle sizes, had been observed and analyzed. Therefore, data analysis speculated that, selection of the appropriate sprinkler types under diverse field conditions and situations such as: crop type and design criteria of sprinkler irrigation systems, have to be considered for good agricultural development processes under Egyptian newly reclaimed regions.

INTRODUCTION

Egyptian agriculture community, in general, and agricultural water sector, in particular, is overwhelmed with various problems due to potential natural environmental changes and socio-economical considerations. Therefore, Egypt adopted several policies towards rationalizing agricultural water and maximizing irrigation water unit productivity and net return. These policies based on legilisations that pressurized irrigation methods and systems are the only allowable technologies for providing crop with its suitable and stable water requirements under newly reclaimed soils. Due to these policies, sprinkler irrigation method and attributed systems are widely used under Egyptian conditions at certain status of newly reclaimed soils with about 75% of the total irrigated areas (1.5 million feddan of about 2 million feddan reclaimed). With the point of view of sprinkler irrigation method, water spreading from a single sprinkler over a large area reduces the instantaneous application

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rate and impact energy per unit area maybe reduced. Therefore, design of sprinkler irrigation system and attributed management criteria, requires a thorough knowledge of sprinkler types and nozzle sizes, as well as of the velocity and displacement of sprinkler droplets. Thus, the suitability and performance analyses of sprinkler irrigation systems should be evaluated closely and properly designed and managed, under diverse field conditions and status.

Soil densification (capping) is a worldwide problem and occurs under a wide range of soils and climatic conditions. Soil surface densification is characterized by few large pore, greater density, orientation of different sized materials, high penetration resistance than underlying soils, low saturated hydraulic conductivity and limited infiltration rate, hereby, restricted emergence of crop seedling may appear.

El-Nakib and Fouad (1990) mentioned that the penetration force almost linearly increased with soil depth. Also, soil penetration resistance depended upon soil compaction and texture, and showed that soil compaction increased with depth. **Trout and Neibling (1993)** stated that hydraulic forces of moving water and soil factors such as aggregate stability and particle size determine erosion and sedimentation. With sprinkler irrigation, water drop energy detaches particles, some of which may be transported down slope by shallow interfile flow if the water application rate exceeds the soil infiltration rate. Hereby, **Bjorneberg *et al* (2000)** reported that improving soil physical and hydro-physical characteristics could be an important tool for controlled runoff; erosion due to irrigation water and both fertilizer and water unit use efficiencies. Therefore, management choices should depend on overall costs and control needed to meet water quality and production goals. Another assessment issue is to apply polyacrylamide (PAM). Data of this technique revealed that the ability of PAM to influence surface soil conditions of specific soils can be used to reduce the environmental risks associated with the intensive use of sprinkler irrigation. However, it offers a safe, practical and non-intrusive management alternative to current costly, labor- and energy-intensive practices of increasing the number of machine turns and building storage basins to control runoff and soil erosion **(Santos *et al* 2003)**. Moreover, **Tayel *et al* (2001**) studied the sandy hydrophysical soil characteristics viz. mechanical, water retention, bulk density, total porosity, pore size distribution and water intake rate in relation to exposed time of water application under El-Falouga conditions, Egypt. The average soil water percentage (v/v) in B-3, O-13, D-17 and M-28 ranged from 11.7-13.4, 12.5-17.2, 12.6-15.6 and 11.0-12.6, respectively. The bulk density ranged from 1.49-1.51 gm/cm^3. The total soil porosity of B-3, O-13, D-17 and M-28 ranged from 29.55-32.25, 31.29-35.67, 31.08-35.25 and 28.61-31.23%, respectively. **Walker and Lin (2008)** stated that although soil properties have changed through the decades of irrigation, the wastewater spray irrigation system remains functional in this area and the soils are still performing reasonably well. However, some concerns about reduced soil functionality need to be addressed from a landscape perspective in order to sustain this system.

Therefore, the goal of this investigation was to monitor the change detection of the soil physical and hydrophysical characteristics under sprinkler irrigated agriculture. However, the terminal objectives were to evaluate and monitor the soil characteristics change (soil bulk density, hydraulic conductivity and soil penetration resistance) under different mode of action of sprinkler types (rotating and impact) and attributed nozzle sizes (small and large).

MATERIALS AND METHODS

Field experiments were carried out during 2006 and 2007 in the Desert Experimental Farm of Faculty of Agriculture, Ain Shams University at El-Bustan region (which represents sandy soil conditions) in the western desert of Egypt. Some initial soil physical, hydrophysical and chemical characteristics of the studied soil were determined and tabulated in **Tables (1 and 2)** as described by **Klute (1986)** and **Page (1982)**. However, chemical analysis of irrigation water at the studied area was conducted according to the standard procedures and presented in **Table (3)**. In order to study the effect of sprinkler types and nozzle sizes on the attributed soil characteristics such as soil penetration resistance, samples of sandy soil were collected from different locations along sprinkler lateral line (0-4, 4-8, 8-12m). The penetration resistance and pore size distribution of the collected soil samples had been measured as initial status (tender), and under different investigated sprinkler types and corresponding nozzle sizes, by using penetrometer at range of soil moisture content of about 8.5 – 9%. However, the initial data of the soil penetration resistance at different soil depths are tabulated in **Table (4).**

Table 1. Some physical and hydro-physical properties of the investigated soil

Sample Depth, cm	Particle Size Distribution, %				F.C., (33 kPa) %	P.W.P., (15000 kPa) %	B.D., g/cm^3	Texture Class
	C. Sand	F. Sand	Silt	Clay				
0-30	52.8	41.4	4.1	1.7	9.4	4.3	1.7	Sandy
30-60	50.0	43.5	5.0	1.5	8.5	4.4	1.6	Sandy

Table 2. Some chemical properties of the investigated soil

Sample Depth, cm	pH (1.25) water	EC, dS/m	Soluble cations, meq/l				Soluble anions, meq/l			
			Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	SO_4^{--}	Cl^{-}
0-30	8.2	1.27	2.9	2.8	5.1	0.6	0.0	3.6	2.0	6.1
30-60	8.3	1.22	2.9	2.1	5.2	0.7	0.0	3.7	2.1	6.3

Table 3. Chemical analysis of irrigation water

pH	EC, dS/m	Soluble cations, meq/l				Soluble anions, meq/l			SAR
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{--}	Cl^{-}	
7.74	0.55	1.03	0.74	8.01	0.42	1.95	4.52	3.73	8.51

Table 4. Initial soil penetration resistance (N/mm^2)

Soil depth (cm)	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
Penetration resistance (N/mm^2)	4	4	4	4.8	5.2	6	4.8	4	4	4.4

1- Mode of action of the investigated sprinklers

Two mode of action of sprinklers types (rotating and impact), had been investigated with different nozzle sizes (small and large), based on the hydraulic and operating test analyses under different conditions, as presented in **Fig. (1)**. Selection of the investigated sprinkler types and nozzles was based on the spreading percentage of the sprinkler under Egyptian conditions, and the desired policies for providing Egyptian markets with new products which help in rationalizing irrigation water, improving irrigation efficiencies and maximizing irrigation water unit net return. An area of about 0.61 feddan was divided into three parts (24 x 36 m^2 for each plot) for rotating sprinkler, small nozzle impact and large nozzle impact sprinkler.

i -Rotating sprinkler

The rotating sprinkler depends on gear-driven technology, rotary type. The epicyclic gear train for the sprinkler includes a sun gear coupled to an impeller for rotation about a central axis. A planetary gear has a single set of teeth meshing with the teeth of the sun gear for revolving about the central axis while pivoting about a revolving planetary gear axis. A first ring gear is fixed relative to the sprinkler housing and has teeth meshing

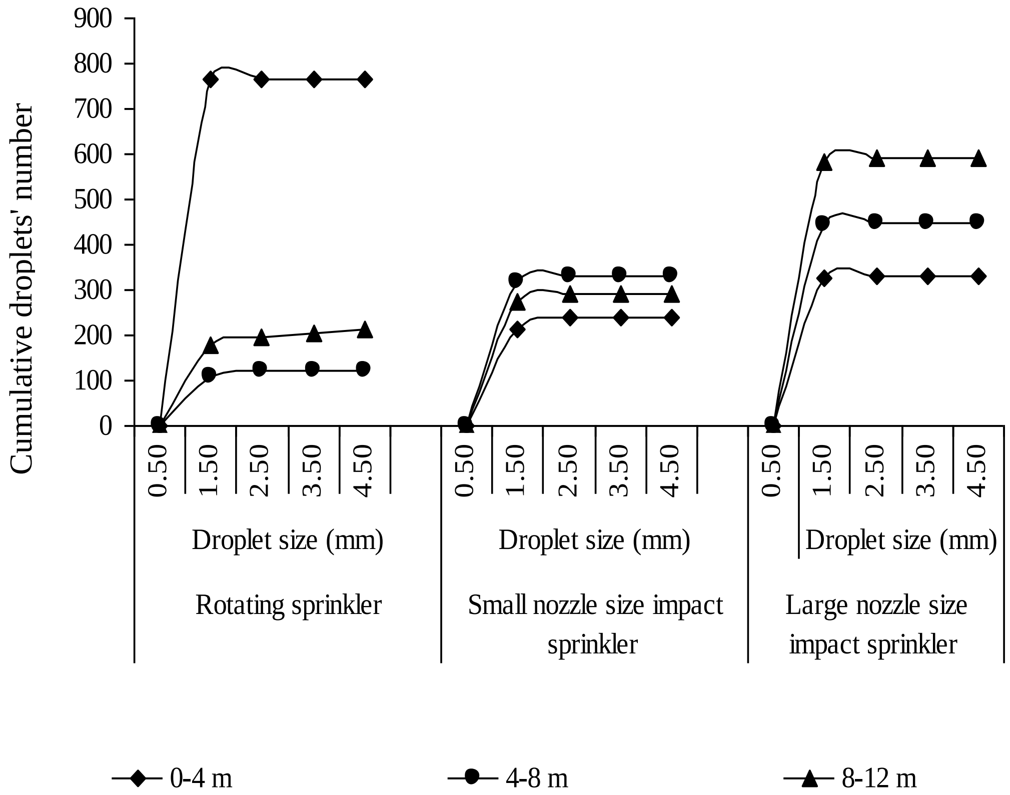

Fig. 1. Cumulative droplet's number along sprinkler lateral lines

with the teeth of the planetary gear. Second and third ring gears are adjacent to the first ring gear and rotate about the central axis. The respective teeth of the second and third ring gears, mesh with the planetary gear teeth. A drive pin is mounted to the sprinkler spray head adjacent to the outer surfaces of the second and third ring gears, which it contacts a protrusion of the second ring gear without contacting the protrusion of the third ring gear, and a second position in which it contacts a protrusion of the third ring gear without contacting the protrusion of the second ring gear.

ii -Impact sprinkler

Impact sprinkler comprises a device for connecting the pressurized water column to a rotating joint, which supports a rotating assembly which is formed by a tubular body with a nozzle for generating a jet, an oscillating arm and deflection element mounted at the end of the arm so as to interact with the jet. The deflection element comprises at least one main deflector which oscillates elastically in a direction which is transverse to the arm between a central equilibrium position, in which the surface affected by the jet is minimal, and at least one lateral abutment position, in which the surface affected by the jet is maximal. The change from the minimally effected surface to the maximal one is sudden, so as to instantly increase withdrawal of energy from the jet and generates impulsive forces on the deflector. The axle is of high-grade steel. A special spring steel, which does not fatigue, was for the coil spring. This constantly ensures the rotation movement of sprinkler.

2- Technical specifications of the investigated sprinklers

Technical specifications of the investigated sprinkler types and corresponding nozzle sizes, as well as, the hydraulic performance analysis had been conducted according to the standard procedures of **ASAE Standards (2004)**, as shown in **Table (5).**

Table 5. Technical hydraulic performance of the investigated sprinkler types and sizes under different operating pressures

Sprinkler type	Nozzle size	Operating pressure (bar)	Radius (m)	Flow rate (l/h)
Rotating	Small (4mm)	2	11	840
		2.5	12	1008
		3	14	1188
		3.5	15	1368
Impact	Small (4.4mm)	2	10.1	995.7
		2.5	11.9	1114
		3	12.8	1231.5
		3.5	13.6	1462.5
	Large (9.6mm)	2	12.5	6048
		2.5	13.5	6480
		3	14	7560
		3.5	15	9000

3- Soil physical and hydro-physical characteristics

i- Soil physical properties

Particle size distribution was determined by using Pipette method and sodium hexametaphosphate was used as dispersing agent. Soil bulk density was determined by core method. Core dimensions were 5cm in diameter and 5cm in height as described by **Klute (1986).**

ii- Soil penetration resistances

Soil penetration resistance was determined by penetrometer T-5001, manufactured by J.J. Lioyd Instruments Ltd., Southampton, England in the soil physics Laboratory, Soil Sciences Department, Faculty of Agriculture, Ain Shams University. Soil sample was placed on the fixed crosshead and below the probe which was into contact with the soil surface as the moving crosshead was driven downwards. The force was measured from 0.05 to 5000 N with the accuracy of 0.5 or 1% by means of the stiff load cells of different ratings, ranging from 5N to 5000 N. The penetration resistance recorded and drawn by using P13 instrument for the first 5 cm through the soil sample. Moreover for reducing the uncertainty degree, another penetrometer type (Proctor penetrometer device) had been used.

iii- Soil moisture retention curve

Determination of soil moisture equilibrium values were obtained by using pressure cooker at 0.1, 0.33 and 1.0 atmosphere; and the pressure membrane at 3.0, 5.0, 10.0 and 15.0 atmosphere. Soil moisture content was expressed on dry weight basis (w) and volume basis using values of soil bulk density. Soil moisture tension and content could be expressed as an algorithm linear relationship by using the following equation:

$$\theta = aT^{-b}$$

Where: θ is soil moisture content in volume basis; T is the soil moisture tension (atom.) and a,b are constants that depends on soil types and investigated depth. In order to determine a and b values, an equilibrium phase of the abovementioned equation was used. Pore size distribution was calculated using data of soil moisture characteristics curve as described by **Baruah and Barthakur (1997)**.

$$Q.D.P = \theta_0 - \theta_{0.1} \; ; \; S.D.P = \theta_{0.1} - \theta_{0.33} \; ; \; W.H.P = \theta_{0.33} - \theta_{15} \text{ and } F.C.P = \theta_{15}$$

Where: Q.D.P is quick drainable pores; S.D.P is slowly drainable pores; W.H.P is water holding pores; and F.C.P is fine capillary pores.

RESULTS AND DISCUSSION

1- Some Soil Physical Characteristics as Affected with Sprinkler Types and Nozzle Sizes

The effect of different sprinkler types and attributed nozzle sizes due to its droplet impact, on some physical soil characteristics such as soil bulk density, had been laboratory investigated along lateral sprinkler line, are presented in **Table (6).**

With the point of view of the initial soil bulk density at the area of different sprinkler types and nozzle sizes, data indicated that, there is a steep position trend of soil penetration resistance with increasing soil depths, with respect to all point of examination along sprinkler later line and tender ones. However, the highest soil bulk density (1.78 g/cm^3) was obtained at examination point (4-8m).This may be due to that soil is considered as fallow soil for two years ago (at least) before cultivation. Also, this may be due to the variation of soil structure and texture fraction among the investigated depths.

With respect to the examination of soil depths, data analysis speculated that there is a positive proportional trend between investigated soil depths (2 up to 6cm) and attributed soil bulk density (g/cm^3) along sprinkler lateral lines, except for data obtained at 4- 6cm (soil depth) at 4-8m spacing from sprinkler position with small nozzles impact sprinkler.

With the point of view of soil bulk density along sprinkler lateral line, it can be concluded that the highest values varied with respect to the investigated sprinkler types and attributed nozzle sizes, as well as the examination points along sprinkler lateral lines. This may be due to the effect of droplet sizes distributions and its impact energies effect on soil texture.

2- Soil penetration resistance

The influence of sprinkler types and sizes due to droplet impact on some physical soil characteristics, such as soil penetration resistance and soil moisture tension (SMT), had been laboratory investigated along lateral sprinkler line and are presented in **Fig. (2).** Taking into consideration of the initial soil penetration resistance at the area of different sprinkler types and nozzle sizes, data indicated that, there is a steep position trend of soil penetration resistance with increasing soil depths, with respect to all point of examination along sprinkler later line and tender ones. However, the highest soil penetration resistance were obtained at examination point (0-4m), at either tender area other investigated areas of the investigated sprinkler types and associated nozzle sizes. However, the mean soil penetration resistance values were 7.5, 9.75, 11.25 and 11.85 N/mm^2 under tender, rotating, small nozzle impact and large nozzle impact sizes respectively, with an increment percentage of 30, 50 and 58% of the investigated sprinkler types and nozzle sizes compared with tender status, with the abovementioned. This may be due to that soil is considered as fallow soil for two years ago (at least) before cultivation. Also, this may be due to the variation of soil structure and texture fraction among the investigated depths.

With respect to the examination soil depths, data analysis speculated that there is a positive proportional trend between investigated soil depths (2 up to 6cm) and attributed soil penetration resistance (N/mm^2) along sprinkler lateral lines, except for data obtained at 0- 4m spacing from sprinkler position with small nozzles impact sprinkler. The mean values of soil penetration resistance were 9.1 N/mm^2 for rotating sprinkler, 10.2 N/mm^2 for small nozzle impact sprinkler and 10.3 N/mm^2 for large nozzle impact sprinkler mean, while it was 5.3 N/mm^2 for the tender ones. This may be due to the droplet distribution patterns and its impacts kinetic energy, as well as the correct and deformed droplet percentages and its effect on soil characteristics as soil aggregates and fragments in different stage of decomposition.

Considering of soil penetration resistance along sprinkler lateral line, it can be concluded that the highest value was 18 N/mm^2 at 0-4m from the sprinkler position obtained with rotating sprinkler and the lowest value was 2 N/mm^2 obtained at the same conditions, as presented in **Fig. (2).**

Generally, from the approach analysis of the obtained results, it can be concluded that soil penetration could be estimated as a function of attributed affected soil characteristics and may be expressed according to the following equations **(Table, 7)**. With respect to the crop yield reduction coefficient, which represents an indication of droplet size distribution (correct and deformed percentages) due to the difference in sprinkler mode of action and nozzle sizes, which revealed to be a power function.

3- Some soil hydrophysical characteristics

Generally, drainable pores are decreased under the effect of applying water irrigation using small and large nozzle impact sprinklers compared with the rotating one **(Tables 8 and 9).** On the

Table 6. Soil bulk density along sprinkler lateral line under different sprinkler types and nozzle sizes

Sprinkler type and tender	Nozzle sizes (mm)	Soil depth (cm)	Distance along lateral line (m)		
			0-4	4-8	8-12
Tender	-	2	1.71	1.72	1.73
		4	1.72	1.75	1.74
		6	1.74	1.78	1.77
Rotating	Small	2	1.72	1.74	1.74
		4	1.77	1.77	1.75
		6	1.79	1.78	1.77
Impact	Small	2	1.75	1.76	1.74
		4	1.77	1.78	1.76
		6	1.78	1.77	1.78
	Large	2	1.73	1.74	1.74
		4	1.77	1.78	1.75
		6	1.78	1.79	1.78

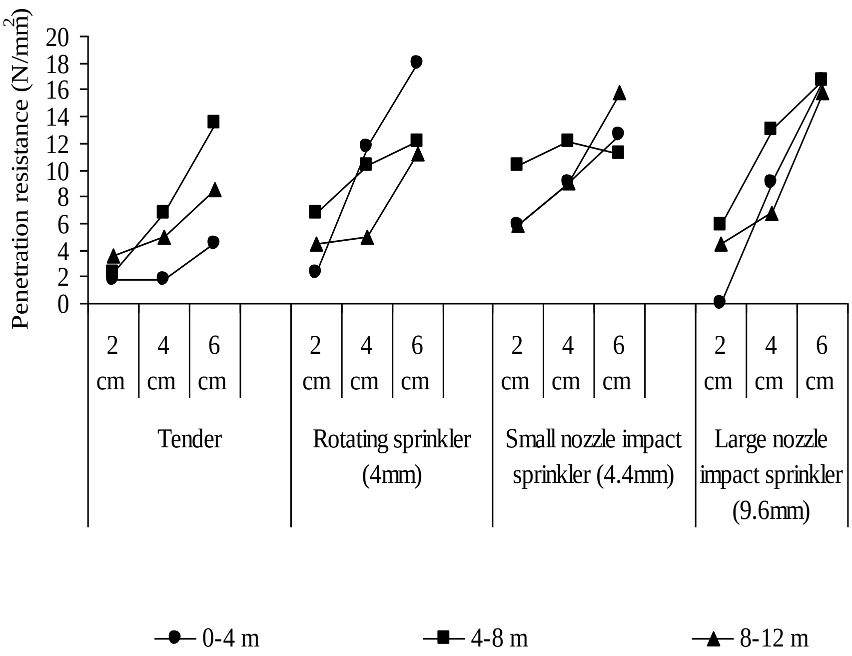

Fig. 2. Effect of sprinkler type and nozzle size on soil penetration resistance along sprinkler lateral line

Table 7. Estimated soil penetration resistance along sprinkler lateral line under different sprinkler types and nozzle sizes

Sprinkler types	Observed equations*	R^2
Rotating Sprinkler	$Y_{r\ 0\text{-}4} = 2.4398\ x^{1.9451}$	0.9693
	$Y_{r\ 4\text{-}8} = 6.8425\ x^{0.5438}$	0.9887
	$Y_{r\ 8\text{-}12} = 4.0066\ x^{0.759}$	0.7007
Small nozzle impact sprin-kler	$Y_{si\ 0\text{-}4} = 25.7755\ x^{0.6901}$	0.9937
	$Y_{si\ 4\text{-}8} = 10.622\ x^{0.0926}$	0.4118
	$Y_{si\ 8\text{-}12} = 5.5832\ x^{0.8713}$	0.9502
Large nozzle impact sprinkler	$Y_{li\ 0\text{-}4} = 4.922\ Ln(x) - 0.362$	0.9894
	$Y_{li\ 4\text{-}8} = 6.0539\ x^{0.9742}$	0.9779
	$Y_{li\ 8\text{-}12} = 4.102\ x^{1.0805}$	0.8818

*** Y is the soil penetration resistance (N/mm^2) and X is the soil depth (cm)**

Table 8. Water retention data, soil bulk density (ρb) and hydraulic conductivity (k_s) values under different sprinkler types and nozzle sizes

Soil water retention (h, mbar)	Theta (θ)			
	Tender	Rotating	Small nozzle impact	Large nozzle impact
0.001	34.71	33.96	33.58	32.83
10.00	22.89	22.56	22.48	21.56
30.00	19.84	19.75	19.68	19.66
60.00	17.64	17.55	17.33	17.21
100.00	14.66	14.05	14	14.11
330.00	10.21	11.5	12.33	12.41
500.00	8.14	8.18	8.21	9.11
1000.00	7.12	7.25	7.31	8.25
3000.00	6.21	6.28	6.29	7.12
5000.00	5.84	5.88	5.78	6.05
10000.00	4.75	4.68	4.77	5.08
15000.00	4.3	4.3	4.3	4.3
K_s, cm/hr	945.22	866.45	798.24	777.59
Pb, g/cm^3	1.73	1.75	1.76	1.78
Available water, %	**5.91**	**7.20**	**8.03**	**8.11**

Table 9. Pore size distribution as affected by different sprinkler types and corresponding nozzle sizes

Pore size indices	Tender	Investigated sprinkler types and corresponding nozzle sizes		
		Rotating (4mm)	small nozzle impact (4.4mm)	large nozzle impact (9.6mm)
Q.D.P	20.05	19.91	19.58	20.42
S.D.P	4.45	2.55	1.67	1.7
W.H.P	5.91	7.2	8.03	8.11
F.C.P	4.3	4.3	4.3	4.3

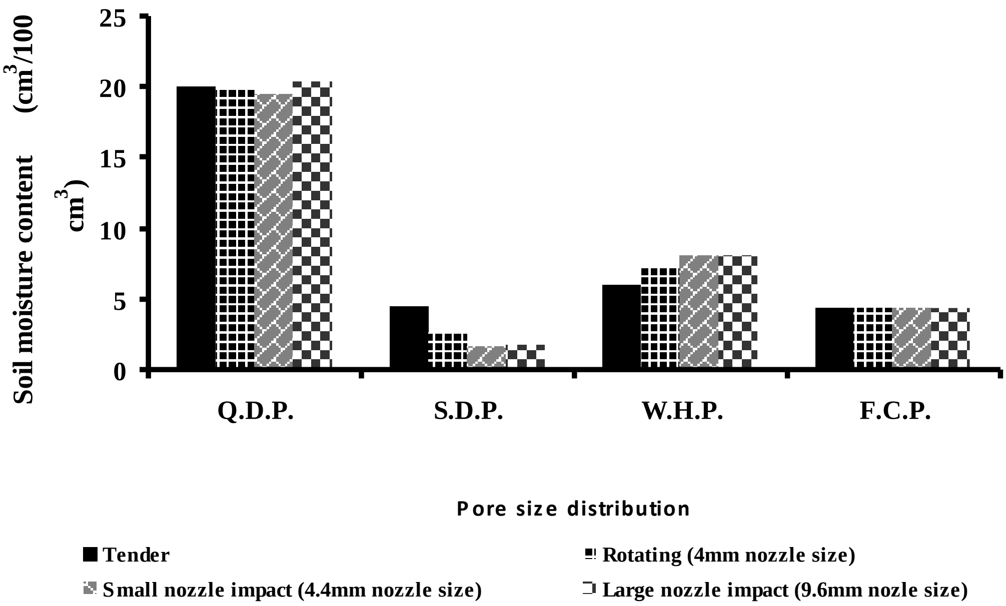

Fig. 3. Pore size distribution as affected by different sprinkler types and nozzle sizes

other hand, **Fig. (3)** revealed that the use of impact sprinkler type resulted increase enhancement of the soil capability in holding water. This action is a benefit on the short time. This may be due to redistribution of soil particles as a result of sprinkler atomization theories and nozzle sizes, as well as, droplet distribution pattern along sprinkler lateral line.

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