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Pore size distribution of soil treated with different plowing depths and its relationship to the efficiency of water use for corn

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***Abstract*---**The soil pore size distribution is one of the propertiesthat directly affect water infiltration, hydraulic conductivity, and water holding capacity. Soil tillage often results in an unstable soil structure with an increase in the percentage of drainage pores between soil aggregates, which change with time due to the wetting and drying cycle, soil solution components, agricultural processes, and biological activity, as well as the change of water conductivity with time.In order to test the effect of the plowing depth on the soil pore size distribution, an experiment was carried out in a silty clay loam in the Nile sub-district of Babylon Governorate, south of Baghdad, Iraq, with four plowing depths. The first treatment was No-tillage (T_0), and Minimum tillage usingspike pin harrows, at a depth of 0.10 m (T_1). The chisel plowwas used for plowing with two depths of 0.20 m and 0.30 m, which represented treatments (T_2),and (T_3), respectively. Irrigation was carried out by applying three irrigation systems which are surface drip irrigation I_1, subsurface drip irrigation I_2 and basin irrigation I_3.Soil water retention curve ($\theta_{(h)}$) was estimated for field soil. Then, a computer program (RETC code) was used to match the pressure head data *h* against the volumetric watercontent θ of a non-linear relationship to estimate the van Genuchten equation parameters, [α, n, and m given that m=1-(1/n)]. Besides, The effective pore diameter (D) was calculated from the Young-Laplace equation.The results showed that whenever the depth of plowing increased, the percentage of air pores increased, as the treatments T_2 and T_3 had the largest proportion of air-filled pores, while the treatments T_0 and T_1 had the lowest percentage of air pores ranging between 0.091 and 0.165 cm^3 cm^{-3}. At the same time, it had the largest proportion of available water-filled pore, with an average rate of about 0.217 cm^3 cm^{-3}, which

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is available water tomeet water requirements for maize.The treatments T_0 and T_1 contributed to reducing the added irrigation water by 12.41% compared to the treatments T_2 and T_3, and reducing the frequency of irrigation when applying subsurface drip irrigation I_2 compared to the irrigation systems I_1 and I_3. Furthermore, it gave the highest grain yield of maize, with an average of 9000 kg.ha^{-1}, which positively affected increasing the maize wateruse efficiency, as the average water use efficiency was about 3,319 kg.m^{-3}atsubsurface drip irrigation.

***Keywords*---**no-tillage, minimum tillage, Young-Laplace equation, differential water capacity, pore diameter, van Genuchten equation.

Introduction

Agricultural management aims to provide the optimum environment for crop production. Tillage is used to improve the structural properties of the soil and modify the soil pore size distribution to create the desired properties for the movement of water,gas, chemicals, and heat to facilitate crop growth with minimal environmental degradation due to erosion and water pollution.The non-optimal use of agricultural machinery and equipment led to soil compaction, poor aeration, the destruction of its aggregates, an increase in its bulk density, and the deterioration of its other structural properties. However, there were many plowing machines and systems due to the different soils, cultivated crops, and climatic conditions (Mărunțelu, 2020). The frequent use of conventional tillage has led to the deterioration of the soil structure and its exposure to erosion and drought and its loss by erosion, which increases the proportion of out-of-investment areas, in addition to the high costs of used equipment, spent fuel, and labor. Therefore, it was necessary to search for alternative systems to conventional agricultural systems such as Conservation tillage or Zero tillage and Minimum tillage in a way that ensures the continuity of increasing agricultural production and reducing its costs (Issaka et al., 2019).

One of the principles of conservation agriculture is not to plow the soil in order to increase its ability to retain moisture, increase the stability of the aggregates, protect it from wind and water erosion, and maintain crop productivity for a long time (Jayaraman et al., 2021b,Liben et al., 2018).Corsi and Muminjanov,(2019) showed that the principle of conservation agriculture is the cultivation of the land directly without plowing and forming a permanent crop cover from the remnants of automatically renewable plants or the residues of successive annual crops. The aim is to improve the properties and structure of the soil and its natural biodiversity and protect it from degradation and erosion. Furthermore, Jassim, (2018) stated that one of the goals of conservation agriculture is to reduce the frequency of plowing, which contributes to reducing the costs of plowing, fuel, and labor. Besides, increasing productivity per unit area, maintaining soil moisture, increasing soil efficiency to carbon sequestration, and reducing its emission into the atmosphere. Plowing with spike pin harrows leaves a part of the previous plant residues at a rate of 15-30%, which contributed to increasing the ability of the soil to retain moisture and increase its content of organic matter to improve its fertility as well as protect it from erosion and reduce production costs (Krauss et al., 2020).

One of the sustainable agricultural practices to enhance land productivity is the implementation of Reduce Tillage or Minimum Tillage, which has achieved an increase in plant production and improved conditions for germination and seedling emergence, as well as improving the physical, chemical, and biological properties of the soil (Jena, 2019).The porous space is part of the total soil volume that is stripped of solid materials and isolated from it, but it is affected by the physical, chemical, and biological properties of the soil and affects it. Besides that, activities and interactions take place in this part such as the movement of water and air, dissolution, and sedimentation, it also acts as a place where roots penetrate and habitat for soil organisms (de Oliveira et al., 2021).The soil pore space is characterized by two properties: porosity and pore size distribution, and the pore size distribution is the most important because it has a close and complex relationship with other soil properties, especially with soil structure and stability of its aggregates and the particle size distribution (Lipiec et al., 2018).

Rabot et al., (2018) demonstrated the importance of the soil pore size distribution for their impact on controlling fluid movement and storage in the soil and providing a space within the area filled with air important for the vital and physiological activity of the rhizosphere. The pore space is affected by several factors, the most important of which is the compaction of soil aggregates by agricultural work, and that the pore space is in a state of continuous change with time due to the effect of external and internal stresses of the soil system (Horn, 2021). Researchers always strive to improve the ideal porosity of the soil and keep it as stable as possible to provide plant production, and this is a major goal of soil management (Chandrasekhar et al., 2019). Several studies indicated that the stability of soil pores has a close relationship to the stability of soil structure. Moreover, the presence of organic matter or conditioner in the soil, especially its presence in soils with a fine texture, has led to a significant improvement in soil structure, which was reflected in a good pore size distribution and increasing the diameter of the effective pores (Gosh et al., 2020).

Nimmo,(2004) reviewed the methods of measuring soil pore size and showed that the most widely used method is the water retention curves. This method explains the behavior and liquid content in an unsaturated pore medium by adopting the idea of effective capillary size, which acquires or loses liquid from a certain size of pore sizes through a Drying or wetting curves for the relationship between the volumetric water content θ and the pressure head h, where as volumetric water content is a function of the pressure head [θ(h)].Vanderlinden et al., (2021) demonstrated concepts related to soil water retention curves such as macropores, micropores, air-filled pores, and field capacity, and available water is indicative of the soil pore size distribution, and the study of these concepts comprehensively gives an integrated understanding of the changes in soil pore sizes when the soil is exposed to different physical conditions. Shein et al., (2016) classified soil pore sizes quantitatively according to the concept of effective pore diameter and physically according to their action and for each range of soil pore sizes. The pores with a volumetric range greater than 50 μm are transmission pores, and those with volumetric ranges less than 50 µm are storage pores for water, salts, and various organic wastes, while pores smaller than 0.5 µm are residual pores.

To study the pore size distribution, the pore space was placed in two volumetric groups the large pores, known as air pores, and micropores are the capillary pores that hold water, and the activities are affected according to the pore size distribution. Capillary forces such as cohesion, adhesion, and water retention prevail in the microporous system to be a source for the preparation of water and dissolved substances. Whereas, the macropores system is important for drainage and soil aeration (Zhai et al., 2019). Gao et al., (2019) found that the effective pore diameter increased when conservation tillage was used compared to conventional tillage. They recommended the use of conservation tillage while keeping crop residues for the previous season to improve soil physical properties and crop yield and reduce soil erosion instead of conventional tillage. Yellow maize (Zea mays L.) is the fourth production crop in Iraq after wheat, barley, and rice. The cultivated areas amounted to 515160 and 405427 ha, with productivity of 473064 and 419,345 tons for the years 2019 and 2020, respectively. Babylon governorate ranks first in terms of the area planted with the crop at the level of Iraq, with a rate of 29.1% (Ministry of Planning - Central Statistics Agency, 2021). This research aims to evaluate the soil pore size distribution and specific water capacity when plowing the soil at different depths. Coupled with, its impact on field irrigation management, the amount of water added by applying different irrigation systems, maize yield, and the irrigation water use efficiency.

Materials and Methods of work

A field experiment was carried out in one of the fields of the Nile sub-district of Babylon Governorate, 86 km south of Baghdad, during the fall season of 2020. The experiment site is located at latitude 32° 31' 35"N, longitude44° 36'21''E, at a height of 31 m above sea level. The study area is characterized by a flat to almost flat topography, where the field soils were classified as sedimentary with a silty clay loam texture and classified under the Typictorrifluvent group according to the classification of (Soil Survey Staff, 2019). Soil samples were taken randomly from the experiment site before planting from the A_p horizon (0.00 -0.30 m) to estimate some physical and chemical properties of the soil. Table 1 shows the results of some of these properties.

Table 1
Physical, chemical, and hydraulic properties of the soil

Parameter	A_p horizon (0.00-0.30m)
Sand (gm kg^{-1})	181.00
Silt (gm kg^{-1})	471.00
Clay (gm kg^{-1})	348.00
Texture	SiCL
Bulk Density (Mg m^{-3})	1.32
Saturated hydraulic conductivity (cm hr^{-1})	3.20
Volumetric water content at 33 Kps (cm^{3}cm^{-3})	0.32
Volumetric water content at 1500 Kps (cm^{3}cm^{-3})	0.13

Available water (cm^3cm^{-3})	0.19
Electrical Conductivity (dSm^{-1})	1.70
Ph	7.60
CEC ($Cmol_c$ kg^{-1} soil)	16.83

* Properties were estimated according to methods described in [Klute, 1986; Page *et al.*, 1982]

The experiment was designed according to the distribution of the split plots using a Randomized Complete Block System (RCBD) with three replicates. The experiment included two factors, the first that represents the main plot is the tillage system (T) which includes four levels: No-tillage (T_0), Minimum tillage to a depth of 0.10 m (T_1), medium tillage by chisel plow to a depth of 0.20 m (T_2),and deep tillage by chisel plow to a depth of 0.30 m (T_3).The second factor that represents the sub plots is the irrigation systems (I), which are three systems: surface drip irrigation (I_1), subsurface drip irrigation (I_2), and surface irrigation by basins (I_3). Uni-Pc type drip irrigation pipes were used dedicated to surface and subsurface irrigation with a diameter of 0.016 m, and it has emitters with little drainage of about 4.00 lh^{-1} for the emitter. Then, the experimental units for surface and subsurface drip irrigation were supplied with seven drip tubes for each experimental unit. The length of the drip tube is 5 m, and the distance between one tube and another is 0.75 m. The number of emitters in one drip tube reached 25 emitters, as the distance between one emitter and another is 0.20 m. Subsurface drip tubes were at a depth of 0.20 m.

Seeds of yellow corn (*Zea mays* L.), a hybrid Euphrates variety from the Dutch company Monarch, were sown on 23/07/2020. The planting was carried out in the form of rows inside the plots with a direction from south to north, and each plot included 7 rows, the distance between one row and another was 0.75 m, and between one hole and other 0.20 m, by 25 holes per row. Three seeds were placed in each hole at a depth of 0.04 - 0.05 m, thinning to one plant after two weeks of germination to obtain a plant density (6.6 plant m^{-2}, 66666 plant ha^{-1}). Corn stem borer (Sesamiacriteca) was controlled using the granular insecticide diazinon at a concentration of 10% (6 kg ha^{-1}) in the heart of the plant at two dates, the first after 24 days of germination and the second 15 days after the first date (Al-Roumi et al., 2018). The crop service continued from weeding and removing the weeds by hand throughout the trial period, where plants were harvested on November 20, 2020. (Growing season 120 days). Fertilizers were added according to the fertilizer recommendation for yellow corn: 200 kg N, 78.5 kg P, and 120 kg $K.ha^{-1}$(Al-Halafi and Al-Tamimi, 2017).Also, fertilizer DAP (18%N and 23.3%P) and potassium sulfate (41.5% K) were used. At planting, DAP fertilizer and potassium sulfate were added, after 25 days of planting, the first batch of urea fertilizer (46% N) was added, while the second batch was added after 60 days with the beginning of flowering.

The relation was estimated between volumetric water content(θ) and pressure head (h) for the soil samples. Sintered – Glass Funnels have been used with a specification soil moisture equipment group to measure the moisture content at water potentials between -1 to-100 Kps, and a pressure plate apparatus in the range -250 to -1500 Kps. The soil water functions were described using the van

Genuchten equations (1980). Equation 1 was used to describe the relation between θ and h as follows:-

$$\theta=\theta_r+(\theta_s-\theta_r)[1+(\alpha h)^n]^{-m} \qquad (1)$$

Where θ is volumetric water content (cm^3 cm^{-3}) at any value of h,θ_s and θ_r are the saturated and residual volumetric water content of the soil, respectively (cm^3 cm^{-3}),h pressure head (cm).α (related to the inverse of the air-entry value),n (related to the slope of moisture retention curve which depends on pores size distribution), andm are the fitting parameters of van Genuchten's model. The differential of eq.1 was used to find the slope of SWRC ($\frac{d\theta}{dh}$), it is called differential water capacity or specific water capacity (SWC). The differential formula of SWC is (van Genuchten, 1980):

$$\frac{d\theta}{dh}=\frac{-\alpha n m(\theta_s-\theta_r)(\alpha|h|)^{n-1}}{[1+(\alpha|h|)^n]^{m+1}} \qquad (2)$$

To evaluate the diameter (D) of pores sizes can be calculated by the equation of Young-Laplace as given in equation, Eq.3 (Stingaciu*et al.*, 2010).

$$D=\frac{4\sigma\cos\beta}{\rho_w g h} \qquad (3)$$

Where D is effective pore diameter (cm) and it's a function of pore volume, σ is a water surface tension (at 20°C= 72.7 g s^{-2}), cosβ= 1, (β is the contact angle between soil pore wall and water its 0 for a wetted surface), ρ_w water density (at 20°C= 0.998 g cm^{-3}), andg is the acceleration due to gravity (980 cm s^{-2}). The substituting the values above in eq. 3, eq. 4was produced to evaluate effective pore diameter(Mahdi and Naji, 2016).

$$D=\frac{0.298}{h} \qquad (4)$$

Soil water contents of plant root depth were determined by gravimetric method before irrigation water application and monitored gravimetrically in 0.3 m depth during emergence and vegetative stages. The depth increment to 0.6 m during flowering and grain maturity stages. Irrigation operations were carried out after depleting 50% of the available water. Irrigation water productivity was evaluated for all treatments. Field water use efficiencies (WUE*f*) were used to promote the efficiency of irrigation water at the crop production level (Howell, 2003).

$$WUE_f = \frac{yield}{I} \quad (5)$$

Where WUE_f is the field water use efficiencies (kg ha^{-1} mm^{-1}), yield (kg ha^{-1}), and I is the applied irrigation water depth (mm).

Results and Discussion

Soil water retention curve at different plowing depths

Figure 1 shows the soil water retention curves (SWRC) for the tillage depth treatments (T_0, T_1, T_2, and T_3). There were differences between the water retention curves with different plowing treatments. The soil water holding capacity increased for T_0 and T_1 at different pressure head levels (0 to 15000 cm). Upon saturation, the volumetric water content was 0.484, 0.492, 0.452, and 0.425 cm^3cm^{-3} for treatments T_0, T_1, T_2, and T_3, respectively. This difference in the amount of water at saturation is because the amount of water retained in the soil depends mainly on the total porosity and the soil pore size distribution that is affected by the soil structure. In this case, almost all the pores are saturated with water, as well as plowing negatively affects the volumetric water content at these ranges because of its effect on reducing the total porosity when the soil structure is broken and leads to a reduction in the large pores volume and a decrease in the water content at saturation and this is within the low-pressure head ranges. Different amounts of water were lost in soil models for tillage treatments when the pressure head changed from 0.1 to 330 cm.

Also, the volumetric water content θ that the soil retained at the pressure head of 330 cm differed from one treatment to another according to the change in soil structure due to the tillage systems. The amount of water retained ranged from 0.349 to 0.300 cm^3cm^{-3}.In the case of changing the pressure head to 15000 cm, the volumetric water content at the wilting point θ_{pwp} was similar for all experimental treatments and the reason for this is that the high ranges of the pressure head depend mainly on the specific surface area of soil particles and soil texture. Thus, the soil water retention in these cases will have an effect resulting from the soil texture. and not from its structure, and the texture has not changed. The solid line in Figure 1 refers to the best fitting of data of pressure head (h) against θ according to the Van Genuchten equation (eq.1). Eq. 1 shows good fitting between the observed data and fitted data, since the determination coefficient (R^2) value was more than 0.930 for soil samples, and declines the residual mean square of θ (RMSθ), it was less than 2.25×10^{-2} $(cm^3\ cm^{-3})^2$. In the same role Table, 2 shows eq. 1 parameters which are θ_s, θ_r, α, n, and m.

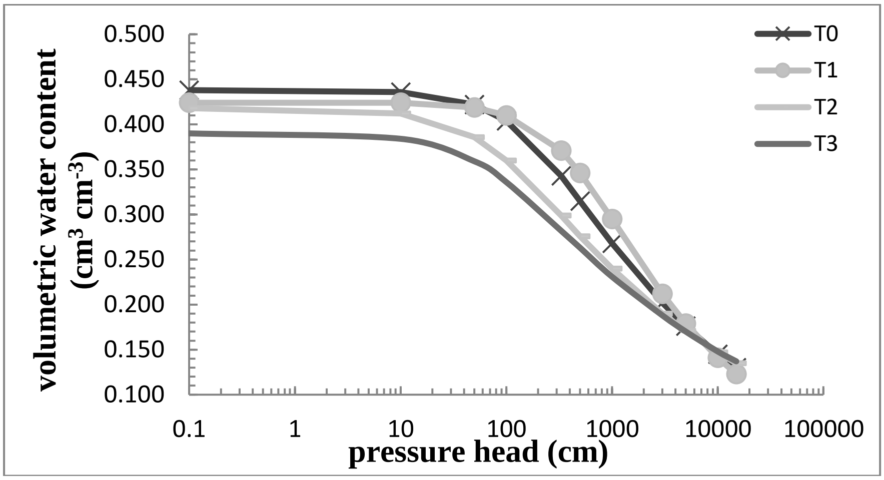

Fig. 1. Soil water retention curves for treated soils with different plowing depths.

Table 2
The values of van Genuchten equation parameters (θ_s, θ_r, α, n, and m), and the values of best-fitting parameters (R^2, RMSθ) for soils treated with different plowing depths

Treatments	θ_s $cm^3\ cm^{-3}$	θ_r $cm^3\ cm^{-3}$	α cm^{-1}	n	m	R^2	RMSθ $(cm^3\ cm^{-3})^2$
T_0	0.434	0.062	0.0058	1.259	0.206	0.962**	2.25×10^{-2}
T_1	0.420	0.071	0.0021	1.346	0.257	0.930**	2.24×10^{-2}
T_2	0.408	0.058	0.0094	1.225	0.184	0.966**	1.87×10^{-2}
T_3	0.383	0.055	0.0123	1.194	0.162	0.948**	2.08×10^{-2}

** significance at 0.01

Pores size distribution of soil, air-filled pores, and water-filled pores

Figure 2 shows the air pore volume and the water-filled pore volume for soil samples subjected to a water tension of 330 cm water. The difference in water content between 0.1 and 330 cm water pressure heads represents the air-filled porosity of the soil, which are the pores with a size greater than 9.03 µm as the effective diameter of soil pores.Whereas, the difference between the water content between 330 and 15,000 cm water pressure head represents the water holding capacity of the soil, which is equivalent to the depth of available water, which are water-filled poresand its size is less than 9.03 µm (Silva et al., 2019). The same Figure showed that treatments T_0 and T_1 had the largest percentage of air-filled pores, with an average rate of 0.142 cm^3cm^{-3}. Though, treatment T_3 had the lowest air-filled pores, which amounted to 0.118 cm^3cm^{-3}, while pores filled with available water they were the lowest in treatment T_3 to reach 0.117 cm^3cm^{-3}compared to other tillage treatments.This is because the soil of this treatment lost more water at the pressure head of 330 cm water, and the retained and residual water is less.Besides, it has a weak soil structure, high bulk density, low total porosity, and a large volumetric distribution of its pores, and this was the result of deep plowing.

The treatments T_0 and T_1 were characterized by the largest percentage of pores filled with available water, with an average ratio of about 0.217 cm^3cm^{-3}. This is because these two treatments have good soil structure, low bulk density, and high total porosity and the distribution of their pore sizes was of a small type. This is caused by no-tillage and minimum tillage which preserved soil structure and aggregate stability from degradation as well as improved other soil physical properties.It is clear from the above that the soil'sability to lose water increased with the increase in the plowing depth, which had an important role in the disintegration of the structure units and the dispersal of the soil aggregates, and the increase in the soil poressize. Therefore, its ability to hold water decreased and the amount of water lost at the same water pressure head that the soil is exposed to increased compared to other plowing treatments, which can be explained by the slope of the water retention curves. Then, the soil lost more water when the slope of the water retention curves increased, as the slope of the waterretention curves increased with the increase in the plowing depth. This means soils that have been deeply tilled lose more water than soils that are not tilled (no-tillage) and soils that have been tilled (minimum tillage) when exposed to the same water pressure head.

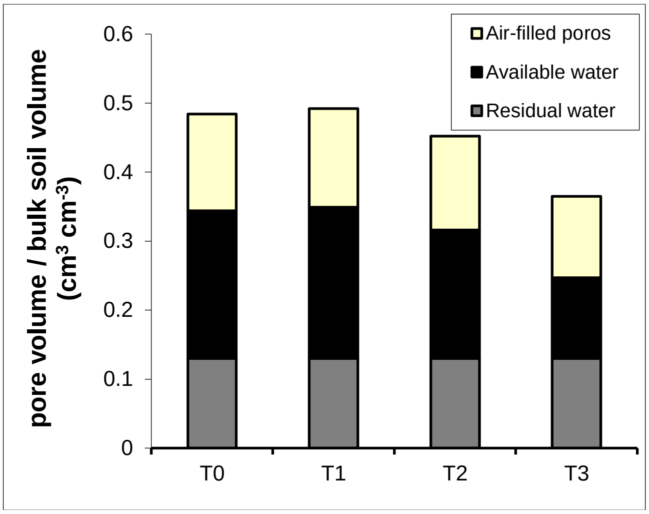

Fig. 2. Air and water distribution for soils treated with different plowing depths, Air-filled pore volume (pores > 9.03 µm diam.) and water-filled pore volume (pores < 9.03 µm diam., available water + residual water)

Figure 3 shows the relationship of effective pore diameter (d) calculated from applying equation 3 with the volumetric water content θ for different experimental treatments. It is observed that when the effective pore diameter increases, the water content of the soil increases, but it varies from one treatment to another. For example, when the effective pore diameter is less than 30 µ, the water content of the soil is similar in all treatments. The reason for this is that the water content in such conditions depends mainly on the specific surface area of the soil particles and the soil texture. Thus, the soil water holding, in this case, will have an effect resulting from the soil texture and not from its structure, and the experiment treatments did not change the soil texture because it is a constant physical characteristic of one type of soil. With an increase in the effective pore diameter (greater than 50 µm and up to 300 µm), the moisture content increased at the treatments T_0 and T_1which is due to the increase in the soil porosity in these treatments, as the total porosity increased in the no and minimum tillage. Figure 3 represents the distribution curves of soil pore volumes. It is noted that the pore volume increases sharply when the pore diameter decreases. The pore volume in soil models can be inferred from the amount of water content retained by the soil when exposed to specific water stress, and this represents the soil pores with a diameter less than 9.03 µm, which corresponds to a pressure head of 330cm.The ratio of the water-retaining pore volume when soil models were subjected to this pressure ranged between 0.480 and 0.830 as a relative water content at the moisture range $0<\Theta<1$ ($\Theta = \frac{\theta-\theta_r}{\theta_s-\theta_r}$). While the pore volume with an effective diameter greater than 9.03 µm it is between 0.170 and 0.520 and this equals $(1-\frac{\theta-\theta_r}{\theta_s-\theta_r})$ within the moisturerange $0<\Theta<1$.

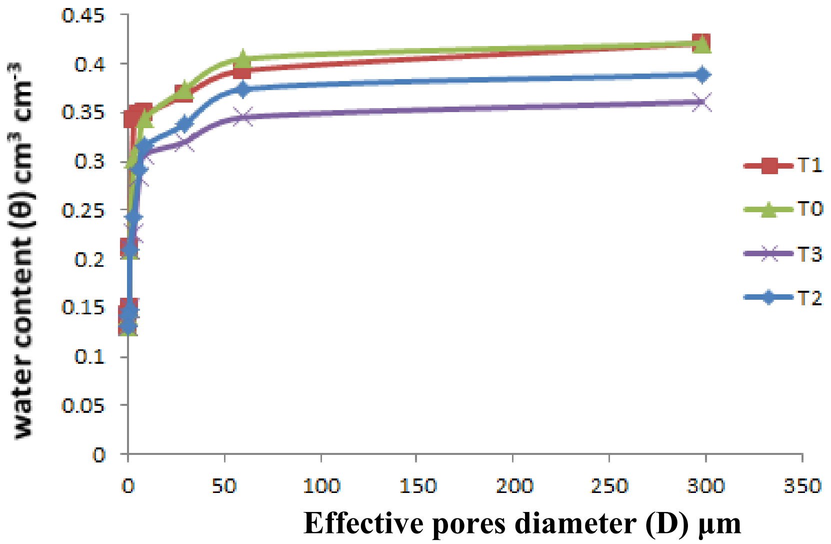

Fig. 3. Relationship between effective pores diameter D and water content θfor soils treated with different plowing depths

It is clear from the above that the air-filled pores system is of the type of mesopores, which are water-carrying pores from that water drains when the soil is exposed to a pressure head of 330 cm water, where the percentage of these pores ranged between 27.8 and 30.1%. The water-storing pores are the pores that retain water when the soil is exposed to a pressure head of 330 cm water, their percentage ranged between 69.9 and 72.2% of the total void volume. This distribution of soil pore sizes is important to determine the soil's water and biological environment, as some experiment treatments possessed a good percentage of water-storing pores, which are important to meet the water requirements of the plant. Therefore, T_0 and T_1 treatments were characterized by good water storage due to the increase in the proportion of storage pores, which amounted to nearly two-thirds of the porous system volume compared to other treatments.

Specific (or differential) water capacity

The specific water capacity of soil C was estimated by applying equation 2, where Figure 4 shows the relationship of the absolute value of the water retention curves slope $\left|\frac{d\theta}{d\Psi}\right|$ and the pressure head (h), as the highest slope occurred at the pressure head 330cm. water. The figure shows that the function slope increases with an increase in pressure head until reached the highest peak of the slope, as the highest slope occurred at the pressure head of 330cm.Furthermore, treatment T_3 had the highest peak, followed by treatment T_2 and T_0, then treatment T_1. After that, the slope decreased to 15,000 cm of water, bringing its value close to zero in the high range of pressure head and for all treatments. The highest value was in the capillary region of the curve, as the slope is steeper. The variance in the absolute value of the water retention curves slope and the variance at the top of the slope function curves is a result of the tillage treatments effect on the pore size distribution. It was found that whenever the plowing depth increased, more water was lost from these soils compared to the no and minimum plowing treatments when the stress applied to the soil pressure head increased.

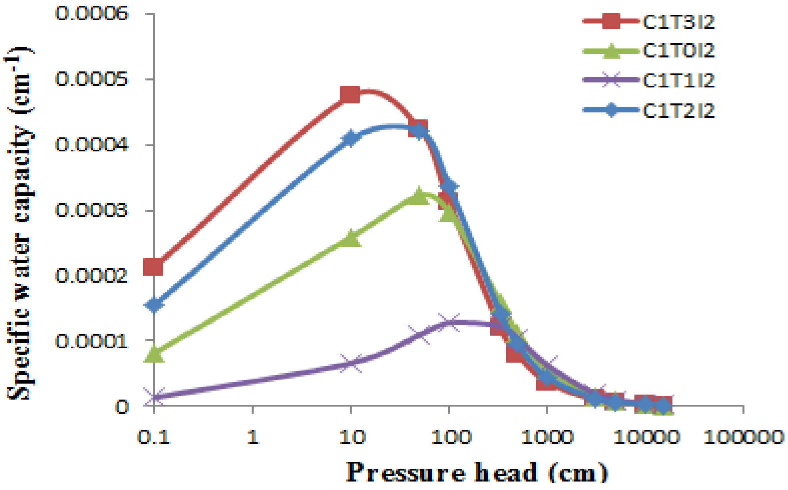

Fig. 4. The relationship of SWC (cm^{-1}) with pressure head (cm) for soils treated with different plowing depths

It was possible to convert the pressure head values on the x-axis in the above figure to the values of the pore volumes in terms of diameter (D, µm) when using equation 4 for capillary height. Since the relationship between pressure head and pore volume is inverse, according to the equation, this flips the shape of the slope curve (water capacity) to the so-called frequency distribution function of pore sizes. Figure 5 showed that most of the pores have sizes ranging between 59.6-119.2 µm for all soil treatments, and there are relatively few small and large pores distributed on both sides of the curve. The top of the curve represents the pore volume region of the maximum pore space of the soil responsible for the water retention and loss activities from the pressure head change (Terleev et al., 2021).

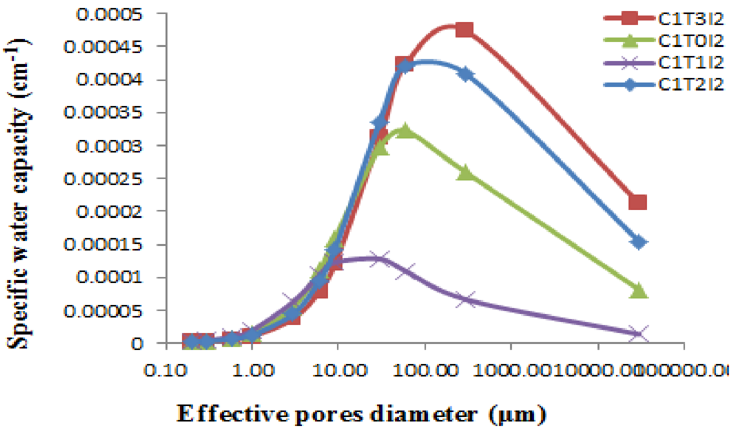

Fig. 5. The relationship of SWC (cm^{-1}) with effective pores diameter (µm) for soils treated with different plowing depths

The effect of the pores size distribution of soil on the depth of applied irrigation water and the water use efficiency

The quantities of irrigation water applied m^3ha^{-1}, differed during the growing season of maize according to the plowing depth and the applied irrigation systems. Table 2 shows that treatments T_0 and T_1 have contributed to reducing the amount of irrigation water applied compared to treatments T_2 and T_3, by 12.41% of the arithmetic mean. This decrease is attributed to the soil's ability in the two treatments T_0 and T_1 to retain water and save it, as the porous system was of a medium and small type, a system that retains water and does not lose it easily when the water stress changes, it is a good percentage of water-holding pores that meet the water requirements of maize.

Table 2
Total applied water (m^3 h^{-1}), Yields (kg h^{-1}), and Water use efficiency (kg m^{-3}) for different plowing depths and irrigation systems

Treatment	Total applied water (m^3 h^{-1})	Yields (kg h^{-1})	Water use efficiency (kg m^{-3})
T_0 I_1	3973.20	6000	1.51
T_0 I_2	3044.40	10467	3.44
T_0 I_3	5826.40	10550	1.81
T_1 I_1	4274.50	6110	1.43
T_1 I_2	3161.50	10550	3.34
T_1 I_3	6186.50	10190	1.65
T_2 I_1	4659.00	5680	1.22
T_2 I_2	3359.00	8583	2.56
T_2 I_3	6449.00	8760	1.36
T_3 I_1	5487.20	4880	0.89
T_3 I_2	3694.20	7486	2.03
T_3 I_3	6569.00	7620	1.16
$LSD_{0.05}$		0.36	0.021

Therefore, treatments T_0 and T_1 were characterized by good water content, and the percentage of water-holding pores was more than 50%, and this was proved by the soil pore size distribution of these two treatments. This contributed a lot to delaying the irrigation decision and thus reducing the frequency of irrigation, so the total result at the end of the growing season was less water consumption compared to the two tillering treatments T_2 and T_3. As for the qualitative effect of irrigation systems on the amount of added water, sub-surface drip irrigation showed the least consumption of added water, and the treatment T_0 I_2 consumed the least added water, which amounted to about 3044.40 m^3ha^{-1}. However, the largest amount of water consumed was in the treatment of traditional surface irrigation T_3 I_3, which amounted to about 6569.00 m^3ha^{-1}, with an increase of nearly double the quantity.

The Table also showed that the tillage systems had a significant effect on the average grain yield, as the treatmentT_0 had the highest value of the average grain yield of 9007.2 kg ha^{-1}. Though, the treatment T_3gave the lowest average grain yield amounting to 6663.5 kg ha^{-1}, and the yield decreased by 14.74 and 26.02 % for treatments T_2 and T_3 compared to treatment T_1respectively.The reason for this is that the increase in the plowing depth destroyed the soil structure and changed the soil's physical properties, including the lack of water holding due to the increase in the percentage of capillary pores as mentioned previously in Figure 2. It likewise caused a decrease in the available water that affected the processes of water absorption and the transfer of nutrients from the shoot to stems and leaves, and this affected plant growth and the formation of the maize yield. It is noteworthy that the treatments T_0 and T_1 did not differ significantly in the yield of maize grains. As for the interaction effect of plowing depths and irrigation systems, the two treatments T_0I_3 and T_1I_2 gave the highest grain yield, which amounted to 10552 kg ha^{-1}, respectively, while the lowest grain yield was in the treatment T_3 I_1, which reached 4880 kg ha^{-1}.

The field water use efficiency differed according to the experimental treatments. The tillage treatments had a significant effect on the average field water use efficiency, and the treatment T_0 achieved the highest average field water use efficiency of 2.169 kg m^{-3}.Thoughthe lowest average field water use efficiency was at treatment T_3 with a decrease of 4.78, 33.31, and 60.78% for the tillage treatmentsT_1, T_2, T_1 and in order from the treatment T_0.The reason for this decrease is attributed to the role of deep plowing in increasing the water use compared to the treatment of no-tillage, as no-tillage worked to retain and conserve soil water for the maximum possible period in an appropriate manner. This achieves the principle of conservation cultivation or conservation tillage because it preserves the soil structure and a large percentage of small-sized pores (<9.03 µm), which are water-storing pores.

The effect of the bilateral interaction between the tillage and irrigation systems was significant in the values of field water use efficiency, as the treatment T_0I_2 achieved the highest field water use efficiency, reaching 3.319 kg m^{-3}. Besides, it exceeded the treatments T_0I_1 and T_0I_3 by 132.26 and 88.47%, respectively, where the treatment T_1I_2 also gave the highest field water use efficiency, which was 3.50 kg m^{-3}. Even though the treatment T_2I_2 recorded the highest value for the field water use efficiency, which amounted to 2.347 kg m^{-3}, it increased than the treatments T_2I_1 and T_2I_3 by 104.62 and 69.09%, respectively. As for the treatment T_3I_2, it was also the highest in the field water use efficiency value, amounting to 1.896 kg m^{-3}. Whereas the treatments T_3I_1 and T_3I_3 gave the lowest field water use efficiency, reaching 0.890 and 1.160 kg m^{-3}, respectively. The reason for the low productivity of these two treatments it is the deep plowing that causes the loss of water in a short time faster than the non-plowed soil. This effect increases with the increase in the plowing depth, and thus the quantities of added water increase, but with a lower yield compared to other treatments.

Conclusions

This experiment showed that no-tillage and minimum tillage treatments caused an increase in the amount of retained water in the soil at the pressure head of 330 cm water. That is, an increase in the water content at the field capacity, which increased the depth of the available water that would meet the water need of the plant, and this is a result of increasing the percentage of water-filled pores with a size less than 9.03 µm. However, there was a reduction in the water-holding pores and an increase in the air pores for deep plowing treatments, and the depth of the available water decreased, which had a negative impact on the management of field irrigation and an increase in irrigation frequency. It was found that the increase in the plowing depth caused the loss of more water quantities compared to the no-tillage and minimum-tillage treatments when the applied pressure head was increased, and this is due to it having the highest specific water capacity. The increase of water holding for no-tillage and minimum-tillage treatments improved the management of maize irrigation by delaying irrigation time and reducing irrigation frequency, especially for micro-irrigation systems such as surface and sub-surface drip irrigation. Irrigation scheduling data showed a significant decrease in the amount of irrigation water applied when no-tillage and minimum-tillage using micro-irrigation systems, which contributed to saving irrigation water and reducing water addition and distribution losses in the field and this is important in the economics of water resources at the country level, at the same time there was a significant increase in the yield of yellow corn for these two treatments, which made them have the highest field water use efficiency, and this is one of the conservation agriculture objectives to be sustainable use of natural and water resources alike.

References

1. Al-Hilfy, I. H. H., and A. H. Al-Temimi. 2017. Response of three synthetic maize (*Zea mays* L.) cultivars to different fertilizers for growth traits and biological yield. Iraqi J. of Sci. and Tech. 8(3): 21-32.
2. Al-Roumi, A. H., H. A. Naas and A. A. Kubba. 2018. The effect different levels of diazenon on sesamiacriteca in different time for farieties of Zea mays L. J. of Kerbala Univ. 16(4): 213-223.
3. Chandrasekhar, Parvathy, Janis Kreiselmeier, Andreas Schwen, Thomas Weninger, Stefan Julich, Karl-Heinz Feger, and Kai Schwärzel. 2019. SPorDyn: A Python code for modeling the evolution of soil pore size distribution after tillage. MethodsX 6, 2118-2126.
4. Corsi, Sandra, and Hafiz Muminjanov. 2021. Conservation Agriculture: Training guide for extension agents and farmers in Eastern Europe and

Central Asia. Food and Agriculture Organization United Nations.Pp 122. chap. 3: 25-34.

5. de Oliveira, J. A., Cássaro, F. A., and Pires, L. F. (2021). Estimating soil porosity and pore size distribution changes due to wetting-drying cycles by morphometric image analysis. Soil and Tillage Research, 205, 104814.
6. Gao, L., B. Wang, S. Li, H. Wu, X. Wu, G. Liang, D. Gong, X. Zhang, D. Cai, and A. Degré. 2019. Soil wet aggregate distribution and pore size distribution under different tillage systems after 16 years in the Loess Plateau of China. Catena 173: 38-47.
7. Gosh, T., P. P. Maity, T. K. Das, A. Krishnan, A. R. T. I. Bhatia, P. Bhattacharya, and D. K. Sharma. 2020. Variation of porosity, pore size distribution and soil physical properties under conservation agriculture. Indian J. Agric. Sci 90, 2051-2058.
8. Horn, R. F. 2021. Soils in agricultural engineering: Effect of land-use management systems on mechanical soil processes. Hydrogeology, chemical weathering, and soil formation. chap. 10A. 187-199.
9. Howell. T.A. 2003. Irrigation efficiency. Encyclopedia of Water Science, published by Marcel Dekker, New York. USA. 10:467-472.
10. Iraqi Ministry of Planning Central Statistical Organization. Agricultural Statistics Department. 2021. Cotton, maize and potato production report for the year 2020. Republic of Iraq. 1-18.
11. Issaka, F., Z. Zhang, Z. Zhao, E. Asenso, J. Li, Y. Li, and J. Wang. 2019. Sustainable conservation tillage improves soil nutrients and reduces nitrogen and phosphorous losses in maize farmland in southern China. Sustainability 11(8): 1- 13.
12. Jassim, A. A. 2018. Plowing and Soil Fragmentation Equipment and Machines. Al-DaarAljamieia. Baghdad University. Ministry of Higher Education and Scientific Research. Second Edition. P 326.
13. Jayaraman, S., R. C. Dalal, A. K. Patra, and S. K. Chaudhari. 2021. Conservation Agriculture: A Sustainable Approach for Soil Health and Food Security. 23-50.
14. Jena, P. R. 2019. Can minimum tillage enhance productivity? Evidence from smallholder farmers in Kenya. Journal of Cleaner Production, 218: 465-475.
15. Klute., A. (eds.) 1986. Methods of Soil Analysis: Part 1- Physical and Mineralogical Methods. ASA and SSSA. SSSA Book Series No. 5. Madison, WI: Soil Sci. Soc. Am. p 1188.
16. Krauss, M., A. Berner, F. Perrochet, R. Frei, U. Niggli, and P. Mäder. 2020. Enhanced soil quality with reduced tillage and solid manures in organic farming–a synthesis of 15 years. Scientific reports 10(1): 1-12.
17. Liben, F. M., B. Tadesse, Y. T. Tola, C. S. Wortmann, H. K. Kim, and W. Mupangwa. 2018. Conservation agriculture effects on crop productivity and soil properties in Ethiopia. Agronomy Journal 110(2): 758-767.
18. Lipiec, J., R. Świeboda, J. Chodorowski, M. Turski, and M. Hajnos, 2018. Pore size distribution and stability of ortstein and overlying horizons in podzolic soils under forest. Geoderma, 310: 138-142.
19. Mahdi, N. T. and H. S. Naji. 2016. Soil pore size distribution at different carbonate minerals content. The Iraqi J. of Agric. Sci. 47(5): 1312 – 1320.
20. Mărunțelu, I. 2020. Optimization of Agriculture Technologies for the Preparation of the germinative bed in experimental field and small Individual farms.Pp 196-201.

21. Nimmo, J.R. 2004. Porosity and pore size distribution. In Hillel, D. (ed.) Encyclopedia of Soils in the Environment: London, Elsevier. 3: 295-303.
22. Page, A. L., R. H. Miller, and D. R. Kenney. 1982. Methods of Soil Analysis .Part 2. Chemical and Microbiological Properties. USA. Am. Soc. Agron. Inc. Publisher, Madison, Wisconsin. USA.
23. Rabot, Eva, M. Wiesmeier, S. Schlüter, and H-J. Vogel. 2018. Soil structure as an indicator of soil functions: A review. Geoderma 314: 122-137.
24. Silva, B. M., G. C. Oliveira, M. E. Serafim, É. A. Silva, P. T. G. Guimarães, L. B. B. Melo, L. D. Norton, and N. Curi. 2019. Soil moisture associated with least limiting water range, leaf water potential, initial growth and yield of coffee as affected by soil management system." Soil and Tillage Research 189, 36-43.
25. Soil Survey Staff .2019. Soil Survey Manual (U.S. Department of Agriculture Handbook No. 18). Chap. 1: 1-18.
26. Stingaciu, L. R., L. Weihermuller, S. Haber- Pohlmeier, S. Stapf, H. Vereecken and A. Pohlmeier. 2010. Determination of pore size distribution and hydraulic properties using nuclear magnetic resonance relaxometry: A comparative study of laboratory methods. Water Resour. Res. 46(11):1-6.
27. Terleev, V. V., R. S. Ginevsky, V. A. Lazarev, A. G. Topaj, and E. A. Dunaieva. 2021. Functional Description of Water-Retention Capacity and Relative Hydraulic Conductivity of the Soil Taking into Account Hysteresis. Eurasian Soil Science, 54(6): 888-896.
28. van Derlinden, K., Y. Pachepsky, A. Pedrera-Parrilla, G. Martinez, A. Espejo-Pérez, F. Perea, and J. Giráldez. 2021. Water retention and field soil water states in a vertisol under Long-Term direct drill and conventional tillage. European Journal of Soil Science 72(2): 667-678.
29. van Genuchten, M.Th. 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Sci. Soc. Am. J. 44:892-898.
30. Zhai, Q., H. Rahardjo, A. Satyanaga, and G. Dai. 2019. Role of the pore-size distribution function on water flow in unsaturated soil. J. of Zhejiang University-Science. 20(1): 10-20.
31. Suryasa, I. W., Rodríguez-Gámez, M., & Koldoris, T. (2021). Health and treatment of diabetes mellitus. *International Journal of Health Sciences*, *5*(1), i-v. https://doi.org/10.53730/ijhs.v5n1.2864
32. Gandamayu, I. B. M., Antari, N. W. S., & Strisanti, I. A. S. (2022). The level of community compliance in implementing health protocols to prevent the spread of COVID-19. International Journal of Health & Medical Sciences, 5(2), 177-182. https://doi.org/10.21744/ijhms.v5n2.1897