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WATER INFILTRATION AND STORAGE IN SOILS UNDER SURFACE IRRIGATION

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ABSTRACT: ***Water storage and infiltration under surface irrigation are evaluated based on initial soil water content and inflow rate. For that purpose, a field experiment was conducted using fruitful grown grape in northern Egypt at Shibin El-Kom in 2008 grape season to evaluate water storage and conductivity under partially wetted furrow irrigation compared to traditional border irrigation as a control method. Two irrigation treatments were wet and dry conditions in which water applied when available soil water (ASW) reduced to 35% and 50%, respectively. Coefficient of variation was 6.2 and 10.2% for wet and dry treatments, respectively, under furrow systems comparing with 8.5% in border. Water was deeply percolated as 11.9 and 18.9% for wet and dry furrow treatments with no deficit, respectively, compared with 11.1% for control with 5.5% deficit percentage. Application efficiency achieved as 86.2% for wet furrow irrigation that achieved high grape yield (12.9 ton/feddan).***

Key words: ***Surface irrigation, grape, soil water storage and infiltration, water use efficiency, irrigation evaluation using linear distribution.***

INTRODUCTION

Surface irrigation that has lower efficiency than other methods is the most widely and oldest used irrigation method in Egypt and world. Surface irrigation systems are currently in use to irrigate most of the traditional crops in northern Egypt where most of the old irrigated lands are located. Therefore, Egyptian farmers have to improve surface irrigation in order to obtain high irrigation efficiency and water savings. The pipelines were widely used to lessen water loss in conveyance and handle water control instead of channels of the old surface irrigation system.

Agriculture crop production is related to many environmental factors including soil, biological, and atmospheric conditions. Irrigation method is one of the most influence factors affect agriculture production. On the other hand, soil properties are the responsible indicators to determine the amount of water that should be applied per irrigation and irrigation interval. Proper irrigation scheduling with optimized crop production is required. Irrigation scheduling requires two decisions regarding timing as when to irrigate and water amount as how much to apply. These decisions can be determined based on basic computations from soil, plant, or weather measurements (Bjerkholt and Myhr, 1996). Then, they can be adjusted depending upon irrigation system uniformity and application efficiency.

In surface irrigation, it is always desirable to obtain a high water distribution. It is also desirable for lengths of the irrigation runs of furrow, border or basin to be as long as possible because of the high labor requirements of irrigating and farming short runs. These two desirable goals of furrow irrigation techniques depend on how much water losses are caused. These losses are deep seepage and runoff, which can not be avoided. Because of this, the application efficiency of surface irrigation is sometimes low.

Irrigation water is generally infiltrated into rootzone during conveyance and recession of water at the soil surface. The inlet stream size should be adjusted to meet the intake characteristics of the soil, the slope, and the entire area to provide a nearly uniform time for water to be infiltrated at all points along the length of the furrow, border, or basin. Three phenomena should be considered in surface irrigation design: (1) the intake characteristics of the soil; (2) the rate of advance of water front moving along the furrow or strip; (3) the rate of recession of water along the furrow or strip after water has been cutoff. The shape of water infiltrated with depth depends on numerous factors, such as the variability of the soil, flow channel shape, type of irrigation (furrow versus border strip), inflow rate, irrigation hydraulics, duration of the irrigation, and slope of the field (Holzapfel *et al*., 1984; Blair and Smerdon, 1988; Valiantzas *et al*., 2000).

The general surface irrigation process includes four phases: advance, storage, depletion, and recession (Holzapfel *et al*., 1984; Walker and Skogerboe, 1987; Alazba, 1999). When the inflow stream is introduced by the upstream end of the plane, water advances with a sharply defined wetting front down the slope toward the downstream end in what is referred to as the advance phase. This phase is characterized by down-field movement of the advancing water front and continues until the water reaches the downstream end of the field. After the water has advanced to the downstream end, water continues to accumulate in the field in storage phase. In this phase, water covers the entire field and inflow continues at the upstream end of the field. The storage phase ends, and the depletion phase begins when the inflow ceases. The depletion phase continues until the depth of the surface water at the upstream end reduced to zero. This phase differs from the storage phase only in the absence of inflow into the field. The horizontal recession phase begins when the depth of surface water at the upstream decreases to zero and marks the initiation of the water drying or recession front. This phase continues until no surface water remains on the field and the irrigation is complete. The time interval during which infiltration of water into the soil occurred is bounded by the advance and recession functions and is defined as the infiltration opportunity time (Holzapfel *et al*., 1984; and Foroud *et al*., 1996; Rodriguiz, 2003). Water flow, soil surface roughness, and infiltration rate affect the nonuniform and unsteady of flow pattern into root zone along furrow or border of surface irrigation. Water inflow is expressed in a

continuity equation and an equation of motion (Cahon *et al*., 1995). Wu (1971) studied individual inflow as water advance effects on water outflow. His derivations of infiltrated water into soil along furrow were based on advance and storage stages of surface irrigation interrelation with soil infiltration rate.

Warrick (1983) examined six statistical distributions of depth of water infiltrated for surface irrigation. He found uniformity coefficient UC as well as lower quarter distribution uniformity DU is related analytically to the coefficient of variation CV. The distributions were the normal, log normal, uniform, a specialized power, beta and gamma distributions. He demonstrated that the specialized power function is exact for basin irrigation provided the surface water advance is proportional to a power of time and the intake has approached a constant value before recession. The results lend credibility to the general approximations as: UC = 1- 0.8 CV and DU = 1-1.3 CV.

The aim of this work is to study the effect of using furrow irrigation system compared with border method on the storage and infiltration of water in a clay loam soil cultivated with grape. Soil water conductivity, grape yield and efficiency of irrigation applied as well as water use efficiency were also evaluated.

Theory

Evaluation of surface irrigation based on measurements of advance and recession phase and an independent measurement of soil infiltration is affected by inlet flow, soil type, furrow slope, length, shape, time of cutoff irrigation and cultivated crop all of which are design parameters Alternatively, The three preceding functions are responsible to shape infiltrated water distribution curve. Soil infiltration rate I is an empirical power function (Rodriguiz, 2003) describing the rate in mm/min as a function of opportunity time in minute and expressed as:

$$I = k\ t_o^{n-1} \quad ---- \quad (1)$$

Where I is infiltration rate in mm/min, t_o is an opportunity time in minute, k and n are empirical coefficients.

The cumulative infiltrated depth as a function of opportunity time can be derived by integrating the right side of Eq. (1) respect to opportunity time and expressed as:

$$Z = \frac{k}{n}\ t_o^{n} \quad ---- \quad (2)$$

Where Z is cumulative infiltrated depth in mm and n is infiltration power coefficient which ranges from 0.8 to 0.2 for most soil types.

Water advance and recession functions combine to define the infiltration opportunity time along furrow or strip length as shown in Fig. (1). The two functions can be defined as advance or recession time versus distance ℓ along the furrow or strip and formulated as empirical power equations (Elliot

and Walker, 1982; Walker and Skogerboe, 1987; Scaloppi *et al*., 1995; Rodriguiz, 2003) as follows:

$$t_\ell = a\ \ell^{m} \qquad ------ \quad (3)$$

$$t_r = c\ \ell^{x} \qquad ------ \quad (4)$$

Where t_ℓ is advance time in min, t_r is recession time in min, and ℓ is furrow or strip length in meter, and a, c, m, and x are empirical coefficients in the equations.

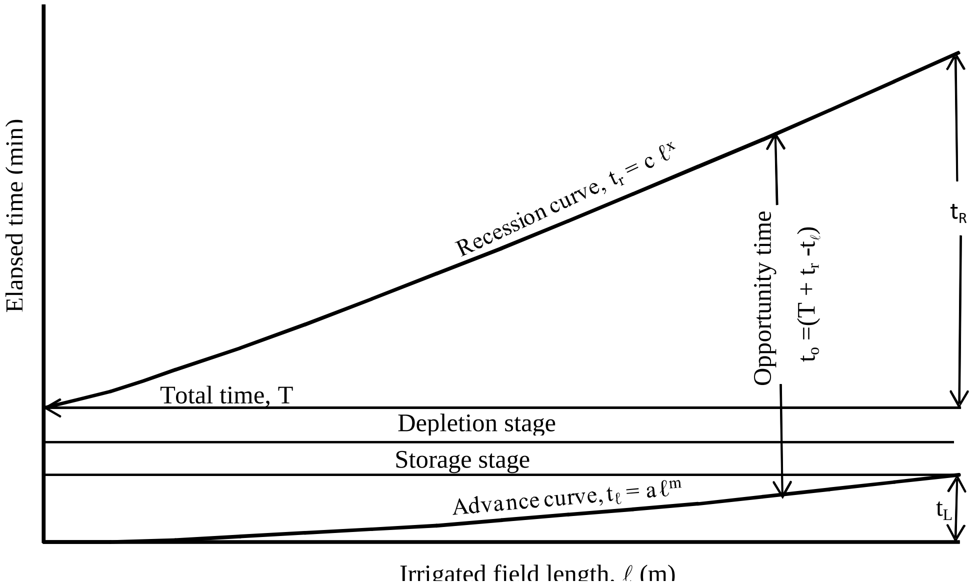

Fig. 1: Infiltrated water depth by surface irrigation using water advance and recession.

The water infiltration opportunity time along furrow or strip length which is the difference between the last time when water disappeared to the first time when water started at the same point along furrow or strip can be determined as follows:

$$t_o = T + t_r - t_\ell \quad ---- \quad (5)$$

Where t_o is opportunity time when water depth along furrow or strip totally infiltrated into the root zone in minute and T is total time of advance, storage, and depletion (duration time that started from water turn on and ended when the water at the upstream end disappeared) in minutes as shown in Fig. (1). When storage and depletion has not occurred, total time T is taken from water turn on to cutoff.

The advance depth, Z_ℓ, which is infiltrated during advance time, can be formulated as follows:

$$Z_\ell = \frac{k}{n}(T - t_\ell)^n \quad ----- (6)$$

The storage depth, Z_s, along furrow that infiltrated when water is cut off can be formulated as follows:

$$Z_s = \frac{k}{n}(T_{off} - t_\ell)^n \quad ---- (6)$$

The depletion, Z_d, along furrow that infiltrated at the end of depletion stage can be formulated as follows:

$$Z_d = \frac{k}{n}(T - t_\ell)^n \quad ---- (7)$$

1.2. Infiltrated water depth along irrigated field

The infiltrated water depth Z along furrow was formulated according to Amer (2007) by incorporating Eqs. (3) and (4) into Eq. (5), subsequently applying Eq. (2) as follows:

$$Z = \frac{k}{n}(T + c\,\ell^x - a\,\ell^m)^n \quad ---- (8)$$

Infiltrated water depth along furrow can be profiled using Eq. (8) as shown in Fig. (2). The desired water depth d which soil can keep it in rootzone divides the area in underirrigation condition into three divisions which are A_1 represents the water stored into rootzone, A_2 represents the water of deep seepage beyond the rootzone, and A_3 represents the water deficit in rootzone.

Deep seepage area, A_2, can be formulated as follows:

$$A_2 = kT^{n-1}\int_0^{L_d}\left(\frac{T}{n} + t_r - t_\ell\right)\cdot d\ell - d\cdot L_d \quad --- (9)$$

Water usable by plant area, A_1, , can be formulated as follows:

$$A_1 = \overline{Z}\cdot L - A_2 \quad ----- (10)$$

Deficit area, A_3, can be formulated as follows:

$$A_3 = L\cdot d - A_1 \quad ----- (11)$$

The infiltrated water depth Z can be formulated from Eq. (8) in a simple form by using binomial expansion and keeping only first two terms without significant deference occurred as follows:

$$Z = \frac{k}{n}\sum_{p=0}^{1} C_p^n\, T^{n-p}(t_r - t_\ell)^p = kT^{n-1}\left(\frac{T}{n} + t_r - t_\ell\right) + \quad --- (12)$$

where C represents the combination and p is integral number of terms.

The average infiltrated depth of low quarter, $\overline{Z}_{LQ}$, can be derived as follows:

$$\overline{Z}_{LQ} = \frac{4kT^{n-1}}{L}\int_{0.75L}^{L}\left(\frac{T}{n}+t_r-t_\ell\right)\cdot d\ell$$

$$\overline{Z}_{LQ} = kT^{n-1}\left(\frac{T}{n}+\frac{4t_R}{x+1}[1-0.75^{x+1}]-\frac{4t_L}{m+1}[1-0.75^{m+1}]\right) -- (13)$$

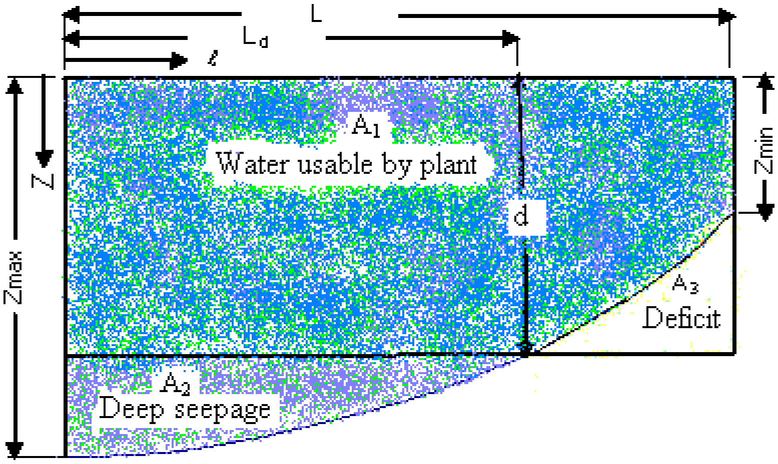

Fig. 2: Water distribution depth profile.

1.3. Irrigation efficiencies

Percentage of water deep seepage P_{DS} defined as the ratio of irrigation water drained beyond the rootzone to the total applied water can be formulated as follows:

$$P_{DS} = \frac{A_2}{A_1+A_2} \quad ------- \; (14)$$

Percentage of water deficit P_D defined as the ratio of water deficit to the water needed into the rootzone can be formulated as follows:

$$P_D = \frac{A_3}{A_1+A_3} \quad ------- \; (15)$$

Water uniformity for surface irrigation profile can be determined by measuring infiltrated water along furrow or strip in systematical stations. Uniformity coefficient as well as distribution uniformity evaluates the design of irrigation systems. Uniformity coefficient UC as a parameter that shows how water uniformly distributed along furrow can be defined as follows:

$$UC = 1 - \frac{\sum\left|Z - \bar{Z}\right|}{N\,\bar{Z}} \quad ---- \quad (16)$$

where Z is water depth measured at each station in mm, $\bar{Z}$ is mean of water depth measured at all locations in mm, and N is total number of locations.

Distribution uniformity DU defined as the ratio of average low quarter depth of water infiltrated $\bar{Z}_{LQ}$ to the mean of water depths $\bar{Z}$ along strip can be expressed as:

$$DU = \frac{\bar{Z}_{LQ}}{\bar{Z}} \quad ---- \quad (17)$$

Application and storage efficiencies evaluate the design of the system synchronizing with the irrigation scheduling. Application efficiency E_a with no tail water runoff defined as the ratio of infiltrated water stored in the rootzone to the total water applied can be expressed as:

$$E_a = \frac{A_1}{A_1 + A_2} \quad ---- \quad (18)$$

Storage efficiency E_S defined as the ratio of infiltrated water stored to the water needed into rootzone can be expressed as:

$$E_S = \frac{A_1}{A_1 + A_3} \quad ---- \quad (19)$$

1.4. Irrigation evaluation using linear distribution

In practicality, irrigation systems apply water with a degree of non-uniformity. If schedule irrigation depth (d) was considered in between minimum and maximum depths of water distribution ($Z_{min} \le d \le Z_{max}$), then the area wetted by irrigation system was divided into surplus and deficit areas (Amer, 2005). Then, the situation was called underirrigation condition. When $d \ge Z_{max}$, the whole area was deficit irrigated. For $d \le Z_{min}$, the whole area was surplus-irrigated.

Schedule parameter α specified the deviation of schedule irrigation depth d to average of water distribution depth $\bar{X}$ in terms of CV was formulated as follows:

$$\alpha = \frac{1}{CV}\left(\frac{d}{\bar{Z}} - 1\right) \quad ---- \quad (20)$$

Where d was the water depth expressing the plant water requirement and $\bar{Z}$ was average water distribution depth applied.

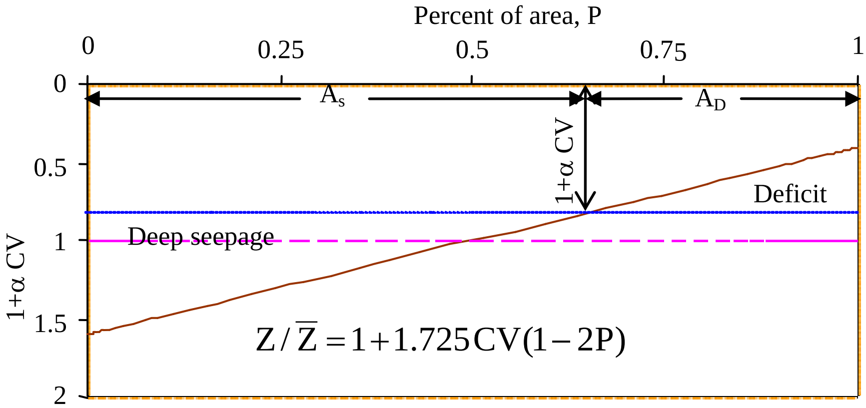

Fig. 3: Linear cumulative frequency curve with relative required depth (1+α CV) for CV=0.3 (After Amer, 2005).

In underirrigation condition, the relative schedule depth (1+αCV) in Fig. (3) intersected with water distribution curve $(Z/\overline{Z})$ shows both deep seepage area A_S and deficit area A_D which defined both deep seepage (P_{DS}) and deficit (P_D) percentages, respectively.

The percent of area under deep seepage was defined as:

$$A_S=\frac{1.725-\alpha}{3.45} \quad ------(21)$$

The percent of area under deficit was defined as:

$$A_D=\frac{1.725+\alpha}{3.45} \quad ------(22)$$

In underirrigation condition, the deficit percentage is defined as the ratio of water deficit to the required water into the root zone. It is formulated using linear distribution for water applied under irrigation system according to Amer (2005) and determined as follows:

$$P_D=\frac{(1.725+\alpha)^2\,CV}{6.9(1+\alpha CV)} \quad ----(23)$$

Where CV is system's coefficient of variation and α is schedule parameter. Deep seepage fraction P_{DS} in underirrigation is described as follows:

$$P_{DS}=\frac{(1.725-\alpha)^2\,CV}{6.9} \quad ----(24)$$

In complete overirrigation, when P_D equals zero and α ≤ -1.725, the overirrigated fraction is as follows:

$$P_{DS}=-\alpha CV=1-\frac{d}{\overline{Z}} \quad ---(25)$$

In complete deficit, when P_D equals zero α ≥ 1.725, the deficit fraction was as follows:

$$P_D = \frac{\alpha CV}{(1+\alpha CV)} = 1 - \frac{\bar{Z}}{d} \quad --- (26)$$

Application and storage efficiencies used to evaluate the design of the system synchronizing with the irrigation scheduling. Application efficiency (E_a) defined as the ratio of water stored in the rootzone to the total water applied calculated as follows:

$$E_a = 1 - P_{DS} ---- (27)$$

Storage efficiency E_S defined as the ratio of amount of water stored to the water needed into rootzone is calculated as follows:

$$E_s = 1 - P_D \quad ---- (28)$$

Distribution uniformity DU is expressed in linear distribution as follows:

$$DU = 1 - 1.27\,CV \quad ---- (29)$$

Uniformity coefficient UC is expressed in linear distribution as follows:

$$UC = 1 - 0.798\,CV \quad ---- (30)$$

MATERIALS AND METHODS

Field experiment was conducted in a field cultivated with grape in clay loam soil located at an arid site in northern Egypt (Shibin El-Kom area, 17.9 m above sea level, $30^o\ 32^/$ N, $31^o\ 03^/$ E) in one season started on 25 February 2008 and ended on 11 July 2008. The soil of the studied area is clay loam in texture (49.5% clay, 31.9% silt, and 18.6% sand), non-saline and non-alkali (EC_e = 2 dS/m, SAR =7.5, and pH = 7.6). The average soil bulk density is 1.28 g/cm^3 for one meter soil depth. The studied area is irrigated by Nile water having EC = 0.65, SAR = 2.4, and pH = 8.2. The soil particle size distribution and some hydrophysical properties of the soil were determined according to Klute (1986). The chemical properties of soil as well as irrigation water used in the study were determined according to Page (1982). As shown in Table (1), the volumetric soil water content at field capacity was increased from 39.4% in first twenty centimeters of surface soil to 43.3% in the second twenty centimeters of the soil, then, it decreased to 38.9% in soil depth from 80 to 100 cm. Average of volumetric soil content was almost 41.02% for one meter depth. It seemed that bulk density was increased from 1.23 g/cm^3 in soil surface to 1.32 g/cm^3 in one meter depth.

A randomized complete-blocks design with irrigation types as main block and two different techniques of irrigation scheduling as random treatments within furrow irrigation compared with border irrigation treatment were established as shown in Fig.(4).There were three replicates in each treatment. Plot size was 54 × 15 m with 2.5 m row width and a 2 m spacing between plants within rows as shown in Fig.(4). Plants were adequately watered in first using border irrigation. Irrigation water treatments were wet and dry furrow treatments compared to dry border treatment. Wet treatment was by applying irrigation water when available soil water (ASW) was reduced to almost 65%

in the upper 1 m of the soil profile (26.33%) gravimetric water content when soil reference (ψ) was 1bar. Dry furrow treatment was applying water when soil water reached to almost 50% from available soil water almost in 23.9% gravimetric water content when soil potential (ψ) was in between 3.5 bar. Only dry treatment with two replicates was applied under border irrigation as a control when ASW was less than 50% almost 22.6% soil water content by weight.

Table (1): Variation of soil field capacity, soil permanent wilting point and soil bulk density with soil depth.

Soil depth, cm	Field capacity, cm^3/cm^3, %	Permanent wilting point cm^3/cm^3, %	Bulk density g/cm^3
0 - 20	39.40	20.10	1.23
20 - 40	43.30	20.30	1.26
40 - 60	42.50	18.64	1.29
60 – 80	41.00	18.60	1.30
80 – 100	38.90	18.60	1.32
Average	41.02	19.25	1.28

Water distribution along furrow was mathematically gotten and compared with control treatment by border. Linear distribution was used to determine deep seepage, water deficiency, storage efficiency, and application efficiency.

Initial soil moisture content was measured before measuring the infiltration rate. Infiltration rate of the soil was measured using double ring method before irrigation for more than a location along furrow. The two rings were driven into the soil to 7 cm depth by a hammer and a short wooden plank was used to prevent damage of the edges of the metal cylinders. A plastic sheet was put first inside the inner ring and the water was totally added. Then the plastic sheet was removed and the disappeared depth was recorded with interval time.

Furrow shape was as 54 m in length and 0.7 m in width with blocked-ends. Figure 4 showed the shape of the furrow and border experiment. The field slope was measured using water level tube and recorded as 0.12%. Water advance and recession time were recorded each 4.5 m along furrow length for two different soil water contents. Soil water content along furrow was measured for 1 m soil depth in nine stations using soil sample in which taken by augur. The water advance time was recorded for each 4.5 m length during irrigation time. The total flow time T which including the time of water advance, storage, and depletion was recorded from the time of the water turned on to the moment of water disappeared at upstream end. Water recession time functioned of furrow length was recorded in an empirical equation. Inflow rate of a 2.1 m^3/h was measured using flow meter for furrow treatments and 7.5 m^2/h per unit width for border treatment. The collected data were used to find out the power equations as shown in Eqs. 3 and 4.

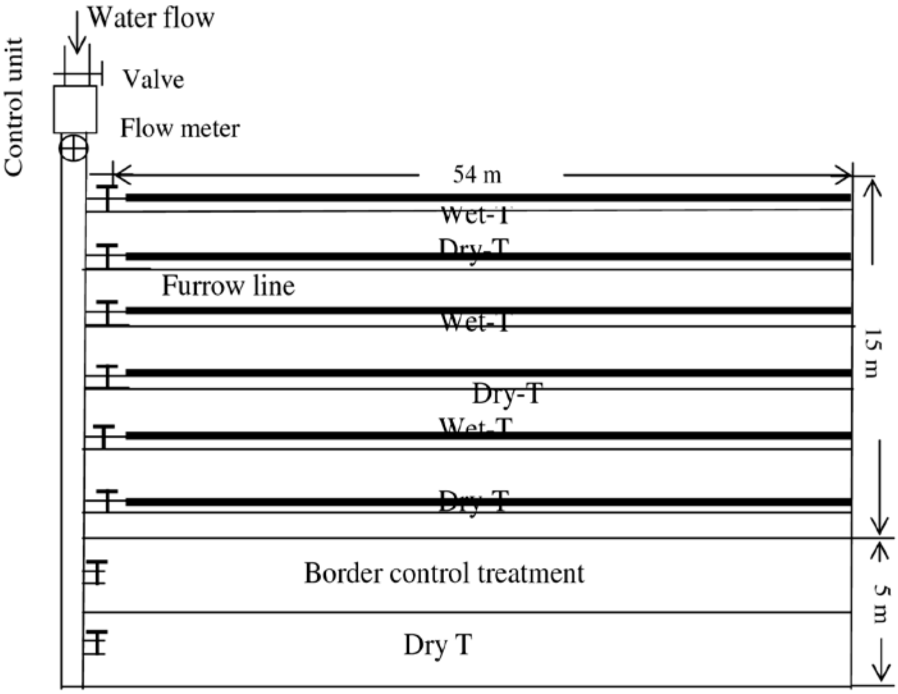

Fig. 4: Experimental layout.

Irrigation schedule depth (d) was determined using water balance as follows:

$$d = (\theta_f - \theta_i) D \quad ---------- \quad (31)$$

Where θ_f and θ_i are average volumetric water content after and before irrigation in m^3/m^3, and D is wetted soil root depth in m.

Average width of flow in the border was 2.5 m as equal to the strip width. Nevertheless, the average width of flow in the partially wetted furrows (w) was determined as follows:

$$w = \frac{Q T_{off}}{\bar{Z} L} \quad ---- \quad (32)$$

where w is average width of flow in furrow in m, Q is furrow inflow rate in m^3/h, T_{off} is water cutoff time in h, $\bar{Z}$ is average of cumulative infiltrated depth in m, and L is furrow length in m.

Pore size distribution was determined according to De Leenheer and De Boodt (1965) as follows:

$$\Delta p = \frac{2\sigma}{r} \cos \beta \quad ----- \quad (33)$$

where p is the pressure in Pa, σ is water surface tension in N m^{-1} and equals to 73 N m^{-1} when water temperature at 20 ^{o}C, r is the pore radius in m, and β is the contact angle in degree.

Unsaturated hydraulic conductivity was determined using the following equation by Campbell (1974):

$$K = K_S \left(\frac{\theta}{\theta_S} \right)^{2b+3} \quad ----- \quad (34)$$

Where K and K_s are, respectively, unsaturated and saturated hydraulic conductivities in mm/h, θ and $θ_s$ are, respectively, unsaturated and saturated volumetric soil moisture content in cm^3/cm^3, and b is empirically determined constant (slope) of moisture characteristic curve (absolute value).

Gape yield was determined by evaluating average yield per plant in kg and multiplying that by number of plants in feddan (840 trees/feddan). Water use efficiency WUE was determined by dividing grape yield in kg/feddan by water applied in m^3/feddan.

RESULTS AND DISCUSSIONS

Infiltration rate

Field infiltration rates were obtained with the double ring infiltrometer as presented in the curves in Fig. 5. The soils at the three locations were moderately dry at the surface prior to infiltration was about 23.9% initial water moisture content by weight for Dry treatment. Initial soil moisture was 26.33% in Wet T when soil infiltration was measured. Measured intake rates for individual infiltration runs were obtained at 2- to 10-minute intervals for the duplicate measurement locations at each of three sites. The average points in the figure were taken from duplicate measured curves (different locations) at regular time intervals; the vertical bar at each point showed the difference between duplicate curves at a given time. The precision of these measurements was excellent considering reference soil variation between measurement locations at a given site and the likelihood of errors in infiltration measurements. Infiltration rate (I in cm/h) as fitted to power equation was found in the experimental field. It was functioned to opportunity time t_o in minute for the clay loam soil as $I = 36\ t_o^{-0.498}$ with $r^2=0.9881$ and $I=19\ t_o^{-0.4}$ with $r^2=0.966$ for Dry and Wet treatments, respectively. The minimum value of 1.8 cm/h infiltration rate found for both treatments and considered as saturated hydraulic conductivity. Cumulative infiltrated depth Z in cm was integrated from infiltration rate function and reported as $Z = 1.2\ t_o^{0.502}$ and $Z = 0.528\ t_o^{0.6}$, respectively, where Z in cm and t_o in min

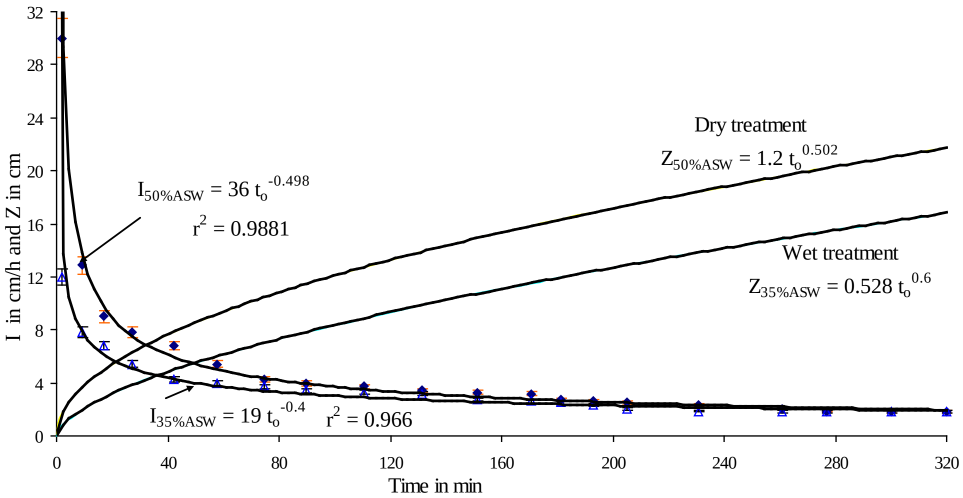

Fig. 5: Field infiltration rate I and accumulated infiltrated depth Z for Dry and Wet treatments.

Pore size distribution and its unsaturated hydraulic conductivity, K

Pore size distribution was calculated from the results of soil moisture characteristics presented in Table (2). Soil water characteristic curve which clarified the relationship between soil potential against volumetric moisture content was shown in Fig. (6). The curve showed that the saturation degree was 69.3% by volume at 0.0 bar soil potential. The field capacity and permanent wilting moisture contents by volume were 40 and 19.8% and were occurred at 0.33 and 15 bar soil potential, respectively.

As soil characteristic curve could be drawn in a relationship between pF in which defined as a logarithm of pressure head ($\log_{10}$ h) where h was applied pressure head in cm against volumetric soil moisture content θ as shown in Fig. (7). This curve showed the pore size distribution that classified as follows: volume of drainable pores (VDP) that included quickly drainable pores (QDP) and slowly drainable pores (SDP), water holding pores (WHP) that included part of coarse capillary pores (CCP), and fine capillary pores (FCP), which having the diameters of > 8.62 µ (θ at ψ ranged from 0.0 to 0.33 bar), > 28.8 µ (θ at ψ ranged from 0.0 to 0.1 bar), 28.8 – 8.62 µ (θ at ψ ranged from 0.1 to 0.33 bar), 8.62 – 0.19 µ (θ at ψ ranged from 0.33 to 15 bar), 28.8 – 0.19 µ (θ at ψ ranged from 0.1 to 15 bar), and >0.19 µ (θ at ψ > 15 bar), respectively. Results of pore size distribution are shown in Table (3).

Table (2): Soil physical characteristics in 30 cm surface soil depth.

Water potential bar	Gravimetric water content gm/gm, %	Volumetric water content cm^3/cm^3 , %
0	55.4	69.3
0.33	32	40
1	26.5	33.1
5	21.6	27
10	18.2	22.8
15	15.8	19.8

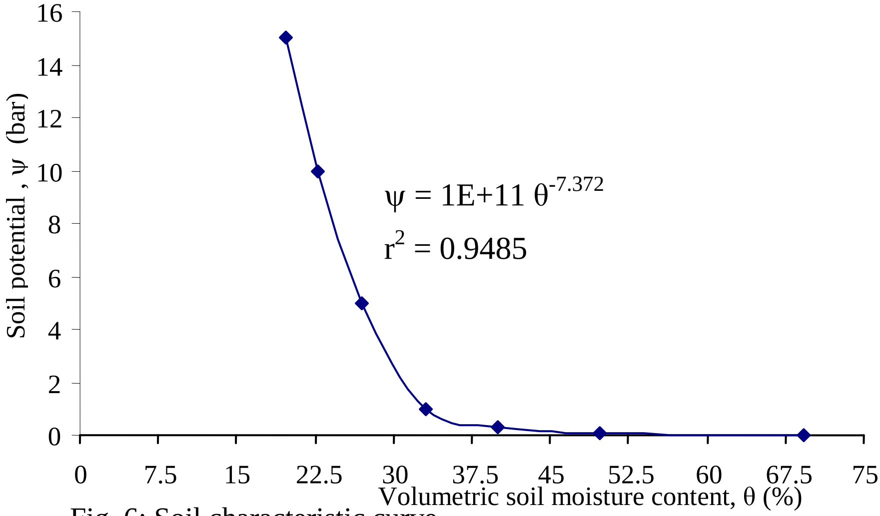

Fig. 6: Soil characteristic curve.

Field saturated hydraulic conductivity (K_s) was found using infiltometer as 18 mm/h as an average for one meter soil depth. As soil K_s was known as 18 mm/h, unsaturated hydraulic conductivity was calculated based on Eq. 34. The empirical coefficient (b) in Eq. 34 represented the slope of soil moisture characteristic curve (absolute value) was determined as 7.372 by linear regression as shown in Fig. (6). Unsaturated hydraulic conductivity was illustrated in Table 3. It was ranged from 1.8 to 1.62E-09 mm/h at saturated and permanent wilting points, respectively. It was evident that soil micro-pores were almost 70%. QDP was about 30%, which represented the percentage of pores of air movement. On the other hand, water-holding capacity was 20%. These results could indicate that soil had high water holding capacity and air exchange, which is favorable for plant growth.

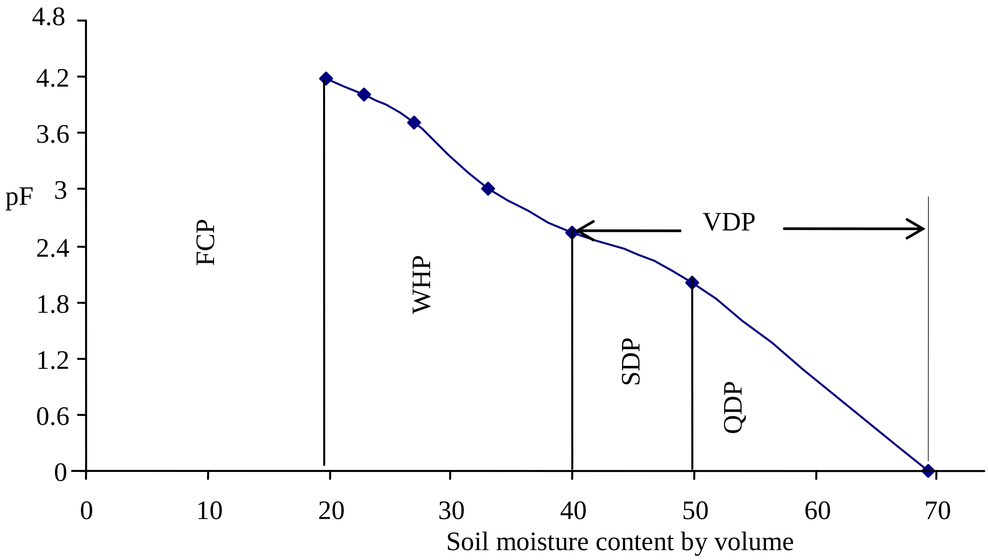

Fig. 7: Soil characteristic curve.

Table (3): Pore size distribution (%) and its unsaturated hydraulic conductivity, K.

Parameter	VDP		SDP	WHP	CCP	FCP
(μ) Pore diameter	> 8.62		28.8 – 8.62	8.62 – 0.19	28.8 – 0.19	< 0.19
(%) Pore distribution	29.3		9.8	20.2	30	19.8
K (mm/h)	> 7.1E-04		0.035 – 7.1E-04	7.1E-04 – 1.62E	0.035 – 1.62E-0	< 1.62E-09

				- 0 9	9	

Water application under border irrigation

Border system that supplied water in the beginning of growing season was treated to apply water in dry treatment as a control treatment. Water infiltrated depth was determined from water advance, recession, and infiltration functions ($r^2 = 0.965$). Empirical power form equations were obtained by regression for the measured advance data in border strip with blocked-end yielding $t_\ell = 0.1242\ \ell^{1.42}$ by applying 7.5 m^2/h inlet discharge per unit width and 44 min water cutoff as shown in Table (4). While the horizontal water recession time was described as $t_r = 0.214\ \ell^{1.127}$. The total time T that included advance, storage, and depletion phases was 54 minute. The total advance time t_L was recorded as 38 min. The total recession time t_R was found to be 75 min. Data of advance and recession times as well as infiltrated water depths in four stages were illustrated in Table (4).

Table (4): Border infiltrated depths in four stages using water advance and recession.

Length m	Advance time (min)	Recession time (min)	Infiltrated water depth (mm) at the end stage of			
			advance	storage	depletion	recession
0.0	0.0	54	74.5	80.2	88.9	88.9
4.5	1.2	57	73.3	79.1	87.9	90.4
9.0	3.0	61	71.5	77.4	86.4	92.1
13.5	4.7	66	69.7	75.8	84.9	94.7
18.0	6.5	73	67.8	74.0	83.3	98.7
22.5	9.0	77	65.1	71.5	81.1	99.8
27.0	12.0	83	61.6	68.4	78.4	102.0
31.5	16.0	90	56.6	63.9	74.5	104.1
36.0	19.6	99	51.8	59.7	70.9	107.9
40.5	25.5	106	42.6	51.9	64.5	108.6
45.0	30.0	112	34.1	45.1	59.2	109.6
49.5	33.8	120	24.7	38.5	54.3	112.4
54.0	38.0	129	0.0	29.5	48.3	115.5
Cutoff at 44 min		Average	53.3	62.7	74.1	102.0

Soil water intake was slightly infiltrated in storage and depletion stages due to minimal of storage and depletion times. On the contrary, soil water intake was largely infiltrated due to maximal advance and recession times. Average infiltrated water depth along border was 102 mm (428 m^3/feddan) by applying 7.5 m^2/h inlet discharge per unit width. Maximum infiltrated depth

was 115.5 mm occurred on down stream end. Minimum infiltrated depth was recorded as 88.9 mm occurred at the upstream end. Seasonally irrigation water was averaged 2100 m^3/feddan as determined based on 5 irrigations by border including water applied in first irrigation.

Water application by furrow irrigation

New technical of furrow irrigation system was developed to supply water into grape farm using pipelines by reducing the wetted surface area in order to save water. The system applied water into furrow width as 0.7 m nearby the plant roots. Partially soil wetted area under furrow was determined as 615×58 mm and 659×120 mm under wet and dry treatments, respectively. Wetted furrow width and depth were dependent on irrigation time in which increased by increasing irrigation time.

Wet treatment

Table (5) shows water advance and recession times in wet furrow treatments. Empirical power form equations were obtained by regression to the measured advance data for furrow yielding $t_\ell = 0.181\ \ell^{1.4}$ by applying 2.1 m^3/h inlet discharge. While the horizontal water recession time was described as $t_r = 0.47\ \ell^{1.2}$ by applying 2.1 m^3/h and 55 min water cutoff. The total time T that included advance, storage, and depletion phases was 57 minute. The total advance time t_L was recorded as 50 min. The total recession time t_R was 37 min. It was evident that soil water intake slightly infiltrated ascendingly in recession, storage and depletion stages due to its minimal times. Reversibly, soil water intake was largely infiltrated due to maximal advance time. Average infiltrated water depth along furrow was 58 mm by applying 2.1 m^3/h inlet discharge. Amount of water applied was 57.64 m^3/feddan per irrigation. Maximum infiltrated depth was 59.7 mm occurred on upstream end. Minimum infiltrated depth was recorded as 51.1 mm occurred at the downstream end. The total amount of water irrigation was seasonally averaged as 1062 m^3/feddan based on 11 irrigations for wet treatment plus first irrigation (428 m^3/feddan) using border irrigation.

Table (5): Furrow infiltrated depths in four stages in wet treatment.

Length m	Advance time (min)	Recession time (min)	Infiltrated water depth (mm) at the end stage of			
			advance	storage	depletion	recession
0.0	0.0	57	55.2	58.5	59.7	59.7
4.5	1.8	60	54.0	57.3	58.6	60.5
9.0	3.8	62	52.7	56.0	57.3	60.5
13.5	5.8	65	51.3	54.7	56.0	61.1
18.0	8.0	67	49.7	53.2	54.5	61.0
22.5	10.8	69	47.7	51.3	52.7	60.5
27.0	14.0	72	45.3	49.0	50.4	60.4

31.5	**18.3**	**75**	**42.0**	**45.9**	**47.4**	**59.6**
36.0	**23.5**	**78**	**37.7**	**41.8**	**43.4**	**58.1**
40.5	**31.0**	**82**	**30.9**	**35.5**	**37.3**	**55.9**
45.0	**38.5**	**86**	**22.9**	**28.4**	**30.4**	**53.5**
49.5	**44.3**	**90**	**15.0**	**21.9**	**24.3**	**52.3**
54.0	**50.0**	**94**	**0.0**	**13.9**	**17.0**	**51.1**
Cutoff at 55 min		**Average**	**38.8**	**43.6**	**45.3**	**58.0**

Dry treatment

Table (6) shows water advance and recession infiltrated depths in Dry furrow treatment. Empirical power found for water advance for Dry furrow with blocked-end yielding $t_\ell = 0.62\ \ell^{1.28}$ by applying 2.1 m^3/h inlet discharge. While the horizontal water recession time was described as $t_r = 0.343\ \ell^{1.22}$. The total time T that included advance, storage, and depletion phases was 124 minute. The total advance time t_L was recorded as 102 min. The total recession time t_R was found to be 42 min.

It noticed that soil water intake slightly infiltrated ascendingly in storage and depletion stages due to its minimal times. On the contrary, soil water intake largely infiltrated due to maximal advance and recession times. Average infiltrated water depth along furrow was 120 mm by applying 2.1 m^3/h inflow rate for Dry furrow. Amount of water applied was 132.8 m^3/feddan per irrigation. Maximum infiltrated depth was 134.9 mm occurred on upstream end. Minimum infiltrated depth recorded as 99.2 mm occurred at the downstream end. The amount of irrigation water was seasonally averaged as 1092 m^3/feddan as determined based on 5 irrigations by Dry furrow plus water amount in first irrigation.

Table (6): Furrow infiltrated depths in four stages using water advance and recession in dry treatment.

Length m	**Advance time (min)**	**Recession time (min)**	**Infiltrated water depth (mm) at the end stage of**			
			advance	**storage**	**depletion**	**recession**
0.0	**0.0**	**124**	**122.3**	**133.8**	**134.9**	**134.9**
4.5	**5.0**	**126**	**119.3**	**131.0**	**132.6**	**133.7**
9.0	**9.0**	**129**	**116.8**	**128.8**	**129.2**	**132.0**
13.5	**15.0**	**132**	**112.9**	**125.3**	**125.1**	**129.8**
18.0	**22.0**	**136**	**108.3**	**121.1**	**120.6**	**127.7**
22.5	**30.0**	**140**	**102.7**	**116.1**	**115.4**	**125.2**
27.0	**39.0**	**144**	**96.0**	**110.3**	**109.7**	**122.4**
31.5	**48.0**	**148**	**88.9**	**104.1**	**103.5**	**119.3**
36.0	**62.0**	**152**	**76.5**	**93.7**	**96.5**	**115.9**
40.5	**71.0**	**155**	**67.3**	**86.4**	**88.7**	**111.5**

45.0	82.0	160	54.0	76.5	79.9	108.1
49.5	93.0	163	36.2	65.1	69.7	102.9
54.0	102.0	166	0.0	54.0	57.4	97.3
Cutoff at 122 min		Average	84.7	103.6	104.9	120.0

Irrigation evaluation and grape yield

Coefficient of variation was determined for furrow and border treatments and illustrated in Table (7). The coefficient of variation was 6.2, 10.2% for Wet and Dry treatments of furrow systems, respectively. It was 8.5% by applying water under border system.

Schedule parameter α was determined using statistical model based on Eq. 20 as shown in Table (7). The schedule parameter (α) was -1.9 under furrow treatments. It was -1.3 in border irrigation. The irrigated area was received only surplus of water along the furrow length. For that reason, the irrigated area did not had any water deficit and water was deeply percolated as 11.9 and 18.9 % for Wet and Dry treatments in furrow irrigation, respectively. It was 11.1% in border irrigation due to irrigating when ASW was below 50% (initial soil moisture was 22.6% by weight). Wet furrow irrigation treatment achieved 86.2% application efficiency and 100% storage efficiency. Grape fruit yield was achieved highly value as 12.9 ton/feddan by applying wet furrow treatment, leading to higher water use efficiency (WUE), 12.1 kg/m^3, than under border irrigation...

Table (7): Irrigation system evaluation.

Parameters	Furrow irrigation		Border irrigation
	Wet T	Dry T	Dry T
Average infiltrated depth ($\bar{Z}$), mm	58	120	100
Irrigation schedule depth (d), mm	51.1	97.3	88.9
Average width of flow (w), m	0.615	0.659	2.5
Coefficient of variation (CV), %	6.2	10.2	8.5
Uniformity coefficient (UC), %	95.1	91.9	93.2
Distribution uniformity (DU), %	92.1	87.0	89.2
Schedule parameter (α)	-1.9	-1.9	-1.3
Deep seepage percentage (P_{DS}), %	11.9	18.9	11.1
Water deficit percentage (P_D), %	0.0	0.0	5.5
Application efficiency (E_a), %	88.1	81.1	88.9
Storage efficiency (E_s), %	100	100	94.5
Water applied, m^3/feddan	1062	1092	2100
Yield ton/feddan	12.9	10.8	9.3
Water use efficiency (WUE), kg/m^3	12.1	9.9	4.4

SUMMARY AND CONCLUSION

The main goal of the work was to study the effect of using furrow irrigation system compared with border method on infiltration and storage of water into agricultural fields. For that purpose, a field study was conducted at Shibin El-Kom in grape farm from 25 February to 5 July 2008 season. The field is a clay loam soil with 1.28 gm/cm^3 average bulk density for one meter soil depth and 1.8 mm/h saturated hydraulic conductivity and irrigated using partially wetted furrow irrigation with blocked-end 54 m long and 0.8 m shape wide with 0.1% slope compared with wholly border with 2 m width. Two different irrigation scheduling techniques with 2.1 m^3/h inflow rate (Dry and Wet treatments) were applied based on supplying water in the field when soil water content was in between 23 to 24% by weight (DRY T) and 26.4 to 27.2% by weight (Wet T). Border irrigation system had only dry treatment consisted of two replicates with 7.5 m^2/h inflow rates per unit width. The results showed that:

- **Average infiltrated water depth along the furrow was 58 and 120 mm by applying Wet and Dry treatments, respectively. The seasonal amount of water in furrow irrigation was 1062 and 1092 m^3/feddan using Wet and Dry treatments, respectively, comparing with 2100 m^3/feddan under border irrigation.**
- **Coefficient of variation (CV) was recorded as 6.2% and 10.2% wet and dry treatment under furrow comparing with 8.5% applying border irrigation;**
- **Schedule parameter was -1.9 and -1.3 under furrow treatments, and border treatment, respectively.**
- **Irrigated area did not have any water deficit under furrow treatments comparing with 5.5% deficit percentage under border irrigation.**
- **Water was deeply percolated as 11.9 and 18.9% for wet and dry treatments in furrow irrigation, respectively. It was 11.1% in border irrigation,**
- **Application efficiency was valued 88.1% for wet furrow treatment.**
- **Grape yield was achieved highly value as 12.9 ton/feddan applying wet furrow with highly water use (WUE) as 12.1 kg/m^3.**

The results could conclude that the short irrigation interval using furrow irrigation with little amount of water (wet treatment) was better than far interval with large amount of water per irrigation (dry treatment). Wet treatment achieved 12.1 kg/m^3 WUE with 11.9% deep seepage percentage compared with 9.9 kg/m^3 WUE with 18.9% deep seepage under dry treatment. Grape yield was highly decreased due to increasing irrigation interval and insignificantly affected by increasing amount of water per irrigation. In generally, furrow irrigation practices were better than that in border irrigation in grape production. Resulting a 1.1% deep seepage and a 5.5% deficit under border irrigation, therefore, border practices achieved 9.3 ton/feddan grape yield, 4.4 kg/m^3 WUE, 94.5% storage efficiency that were less than those occurred under furrow irrigation.

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تسرب وتخزين الماء في الأراضي تحت نظام الري السطحى

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الملخص العربي

ترجع أهمية دراسة تسرب وتخزين المياه في منطقة جذور النباتات أثناء الرى إلى مدى الاستفادة العظمى من كمية مياه الرى المعطاة فى الرية الواحدة والتى تتوقف على نوع التربة ومعدل الترشيح ، وأيضا يتأثر تخزين وحركة المياه بالتربة بطريقة توزيع مياه الرى فى الأراضى وبنوع نظام الرى المتبع ، لذا فإن هذا البحث يهدف إلى دراسة تسرب وتخزين المياه بالتربة فى منطقة جذور النباتات تحت نظام الرى بالخطوط مقارنة مع الرى بالشرائح ودراسة تأثير بعض من عوامل التربة ونظام الرى على توزيع المياه واختراقها بمنطقة جذور النبات بغرض تحديد ميعاد الرى وكمية المياه اللازمة لتلبية احتياج النبات فى الفترة بين الريات.

أجرى البحث بكلية الزراعة– جامعة المنوفية على نباتات العنب المثمرة والنامية فى أرض طينية طمييه ف موسم النمو خلال الفترة من ٢٥ فبراير حتى ١١ يوليو ٢٠٠٨ وأجريت التجربة فى تصميم قطع كاملة العشوائية وقد تم رى العنب فى بداية الموسم باستخدام النظام التقليدى لجميع المعاملات. ابتداء من الرية الثانية حيث تم الرى باتباع نظام الرى بالخطوط لمعاملتين هما الرى عندما يستنفذ تقريباً ٥٠٪ من الماء الميسر كمعاملة جافة والرى عندما يستنفذ حوالى ٣٥٪ من الماء الميسر كمعاملة رطبة ، بالمقارنة مع الرى التقليدى بالشرائح للعنب كمعاملة جافة.

- بلغت كمية المياه المعطاة للعنب خلال موسم النمو هو ١٠٦٢ ، ١٠٩٢ م^{٣}/فدان لكل من المعاملة الرطبة والجافة تحت نظام الرى بالخطوط مقارنة بكمية ٢١٠٠ م^{٣}/فدان تحت نظام الرى بالشرائح ، على التوالى.
- بلغ متوسط عمق تسرب المياه لطول خط الرى ٥٨ مم بعرض ابتلال للخط ٠.٦١٥ م للمعاملة الرطبة ، ١٢٠ مم بعرض إبتلال ٠.٦٥٩ م للمعاملة الجافة ، فى حين كان ١٠٠ مم بعرض ابتلال ٢.٥ م للشرائح.

- كان عمق ماء جدولة الرى هو ٥١.١ ، ٩٧.٣ مم للمعاملة الرطبة والجافة للخطوط ، ٨٨.٩ مم للشرائح وعدد الريات المعطاة هى ١١ ، ٥ ، ٤ ريات بالإضافة إلى الرية الأولى ، على التوالى.
- بلغ معامل الاختلاف لتوزيع مياه الرى على طول خط الزراعة ٦.٢ ، ١٠.٢٪ فى الرى بالخطوط لكل من امعاملة الرطبة والجافة ، على التوالى ، بينما حقق ٨.٥٪ لمعاملة الرى بالشرائح.
- كان نسبة التسرب العميق للمياه تحت المعاملة الرطبة ١١.٩٪ مقابل ١٨.٩٪ تحت المعاملة الجافة للرى بالخطوط دون مع كفاءة تخزين ١٠٠٪ ، حيث كانت النسبة ١١.١٪ بكفاءة تخزين ٩٤.٥٪ للرى بالشرائح.
- حققت معاملة الرى بالخطوط قيماً عظمى فى إنتاجية العنب بمقدار ١٢.٩ طن/فدان بكفاءة استخدام ١٢.١ كجم/م^{٣} للمعاملة الرطبة ، ١٠.٨ طن/فدان بكفاءة استخدام ٩.٩ كجم/م^{٣} للمعاملة الجافة بينما بلغت انتاجية العنب ٩.٣ طن/فدان بكفاءة استخدام ٤.٤ كجم/م^{٣} للرى بالشرائح فى موسم ٢٠٠٨.

ومن نتائج البحث يمكن استنتاج أن الرى السطحى بالخطوط على فترات متقاربة (رى بعد استنفاذ ٣٥٪ ماء ميسر) مع كميات مياه أقل فى الرية الواحدة (معاملة رطبة) أفضل من فترات الرى المتباعدة (رى بعد استنفاذ ٥٠٪ ماء ميسر) مع كميات مياه أكبر للرية الواحدة (معاملة جافة) حيث بلغت كفاءة استخدام المياه ١٢.١ كجم/م^{٣} للمعاملة الرطبة مقابل ٩.٩كجم/م^{٣} تحت المعاملة الجافة . ويبلغ عمق متوسط الماء المترشح ٥٨ مم تحت المعاملة الرطبة مقابل ١٢٠ مم تحت المعاملة الجافة مما أدى إلى زيادة نسبة التسرب العميق للمياه تحت المعاملة الجافة بنسبة ١٨.٩٪ مقابل ١١.٩٪ تحت المعاملة الرطبة. أى أن محصول العنب يتأثر أكثر بنقص المياه الناتج عن طول الفترة بين الريات ولايتأثر كثيراً بزيادة كمية المياه فى الرى ، وبالمقارنة مع نظام الرى بالشرائح حيث كانت عدد الريات ٥ ريات خلال الموسم بلغت نسبة تسرب المياه العميق أسفل جذور النباتات ١١.١٪ ونسبة عجز المياه بمنطقة الجذور ٥.٥٪ مما أدى إلى نقص محصول العنب مقارنة بالرى السطحى فى الخطوط حيث بلغ ٩.٣ طن/فدان تحت ظروف منطقة الدراسة وانخفضت كفاءة استخدام المياه إلى ٤.٤ كجم/م^{٣} وكفاءة تخزين المياه إلى ٩٤.٥٪.