A SIMPLIFIED MATHEMATICAL EQUATION TO STUDYTHE RELATIONSHIP BETWEEN WATER DRIVING FORCES AND WATER LOSSESAMOUNT IN IRRIGATION CANALS IN THE FIELD

Abstract

Two field experimentswereconducted at El-GemmeizaAgricultural Research Station, El-GharbiaGovernorate,Egypt,middleof Nile Delta (30° 43^{-} latitude and 31° 47^{-} longitude) on clay soil during two winter seasons (2019/2020 and 2020/2021).The cultivated wheat cultivar was Gemmeiza 11that planted in two seasonsandirrigated three times inaddition to planting irrigation.This investigation aimed to study the effect of water driving forces in irrigation canals in the case of using one or two irrigationcanals in the field and its impact on water losses amount by deriving a mathematical equation. The results across the two seasons showed that mean water driving forces (WDF) in the case of using one irrigation canal in field (0.26m^3/16.63minute) was greater than two irrigation canals (0.24m^3/36.13minute) and the water lossesamount (WLA)resulted from using one irrigation canal (17.78 m^3) was less than the two irrigation canals (36.25 m^3) by saving 18.47m^3 of irrigation water.Consequently, there is an inverse relationship between water driving forces in irrigation canals in the field and water losses.Grain yield in the case of using one irrigation canal in the field was 1.414 mg ha^{-1}, while in the two irrigation canals recorded1.365 mg $ha^{-1}$by increasing 49.17 kg ha^{-1}. Accordingly, a quantity of irrigation water can be saved during surface irrigation inorderto achieve water abundance can be used to irrigate new lands.Thequadratic model was the best statistical model to describe the relationship between Water Driving Force (WDF) and Water Movement Time (WMT) irrigation canal in field. Using the fitted quadratic model, it is clear that theCritical Water Movement Time (CWMT) which reflects the lowest WDF value was25.55 min. So by studying the relationship between water driving forces and water losses amountin the irrigation canals by calculating water driving forces rate can be controlled in water driving factors by the optimum irrigation canals planning to achieve water abundance is one of the goals Egypt's agricultural strategy 2030.

Key words: Equation, irrigation, canals, water, driving forces

INTRODUCTION

In arid and semi arid regions managing agriculture water for irrigation and yield productivity are essential ,in Egypt approximately 2.5 millonha^{-1}irrigated by surface irrigation systems, its from approximately 1.04 millonha^{-1}wheat, so used the optimum of irrigation canals in wheat planting may be achieve water abundance by reducing of water losses which can be used to cultivated new lands. As the world population grows, the need for food production has increased, and less water is allocated to the agriculture sector (Shaheed*et al.* 2017).Wheat has managed to increase its share of the winter cropped area ranged from 41 to 47%, and the cultivated area is limited to the narrow strip along the Nile Valley **(FAO, 2015).** Therefore, attempts have been made to expand the cultivated area in Egypt by reclaiming new lands using irrigation**.** The amount of wheat production in Egypt is about of 9 million ton in 2021 with an increase of 1.12% from the previous years **(FAO, 2022).**In a trial to increase wheat cultivation area to decrease dependency on wheat importing.Consequently, supply-oriented management strategies have been used to identify new potential water resources for agricultural purposes. However, climate change and continuous droughts in recent decades in arid regions have created challenges to the provision of a timely and [redacted] through precision agriculture systems **(Noorisamelehet al. 2020).**In recent years, water resources exposes to an increasing stress due to impacts ofclimate change, population increase and economic development. Water scarcity isrecognized as a main threat particularly in the Mediterranean area. Thus, water utilitiesshould become highly efficient throughout the entire water supply process, toguarantee sufficient quantities of good quality water. Since water is one of the mostvaluable natural resources, water losses in the Water Distribution System(WDS) represent an urgent problem that needs to be managed **(KanakoudisandMuhammetoglu, 2014).**Water conveyance and distribution process may be less benefit during irrigation canals due to the effect on water losses, so it is necessary to evaluate the performance of water conveyance and estimation water losses in irrigation canals in the field**(Barkhordariand Shahdany2022).**Water conveyance efficiency is affected byseveral factors such as seepage, soil type, canal length, canal width and physical damages of the canals **(Sen et al. 2018).**Also, the main factors that influence canal water losses arewater level, soilhydraulic properties, groundwater tablelocation and amount of sediment inside thecanal**(Yao et al. 2012).**Consequently,the reduction of seepage helps protectthe limited water resources, minimize production of water treatment products and energy consumption**(Ashton and Hope 2001).**The Egyptian country launched a program to lining water canals as part of a major project to reduce water losses in order to achieve water abundance within the national agricultural strategy 2030 to achieve this goal. Increasing water losses as a result to surface irrigation system reduces its efficiency. Therefore, the goal of the research is to reduce water losses by using irrigation canals with optimal planning of irrigation canals to increase the efficiency of water conveyance in irrigation canals in the field to achieve the least water losses amount.Thisresearch was carried out with the aim of studyingthe effect of water driving forces in irrigation canals in case of using one or two irrigation canal in the field and its impact on water losses amount by deriving a simple mathematical equation.

Fig 1. Experimental area

MATERIALS AND METHODS

Tow field experimentswerecarried out at El-GemmeizaAgricultural Research Station, El-GharbiaGovernorate,Egypt, Middle of Nile Delta (30° 43^{-}latitude and 31° 47^{-} longitude) on clay soil during two winter seasons (2019/2020 and 2020/2021). Wheat cultivar,Gemmeiza 11 was planted on $16^{th}$and 18^{th}Novemberin two seasons, respectively and irrigated three times in addition to planting irrigation, where the experiment area was 2064m^2 (48m length × 43m width). The soil surface was leveled by laser.Wheat plants were harvested on $27^{th}$and 30^{th} April for two seasons respectively. The objective of the research is studying the effect of water driving forces within irrigation canals in the field and its impact on water losses by deriving a simplifiedmathematical equation.

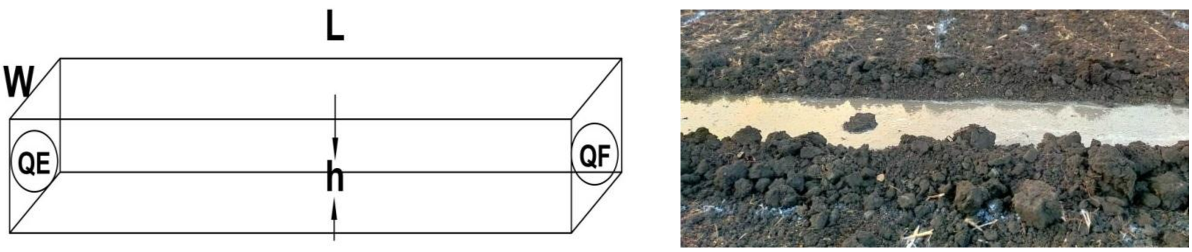


Fig 2. Description of the irrigation canal in the field

Water driving forces (WDF), m^3/min = $\frac{L \times W \times H \times G}{T}$

L: canal length, 48m

w: canal width, one m

H: water height in irrigation canal in field, 0.5m

T: water move time, minute

G: gravity 9.81m/second

Water losses amount (WLA), m^3 = QE – QF

QE: Water amount entering in canal irrigation in field, m^3

QF: Water amount flow out from canal irrigation in field, m^3 at water stability

The scientific basis of the equation

Water driving forces determine the direction and rate of water movement.As a result to water movement on soil surface and waterphysical properties (density and viscosity) change due to dissolved substances increasing in water as a result to water molecules rubbing with soil surface,according to **Reilly and Goodman(1985) and Reilly (1993)**theyindicatedthat water density is important because it is a part of the driving forces for water, moreover water density and viscosity affect the hydraulic transmitting properties(permeability and hydraulic conductivity).Therefore, there is relationship between water driving forces and water losses amount.

The equation importance and its applied domains

- The optimum irrigation canal planning in agricultural landsin the case of surface irrigationsystemto achieve the least water losses.
- By calculating water driving forces by using mathematical equation can be achieving water abundance by the reducing of water losses whichcan be used to irrigate new lands.
- Achieving one of the objectives of agricultural strategy 2030(water abundance) in Egypt.

Table (1):Some soil charactersof the experimental site.

Soil depth, cm		0-10	10-30	Soil depth, cm		0-10	10-30
Particle size distribution,%	Coarse sand	6.19	5.70	Settling, %		31.06	31.41
	Fine sand	18.75	18.76	Pore size distribution,%	> 9µ	21.88	22.42
	Silt	30.96	29.93		9 – 0.2µ	11.89	12.19
	Clay	44.10	45.61		<0.2 µ	14.16	12.19
Texture class		Clay	Clay				
Bulk density (Db, g cm^{-3})		1.34	1.36	Hydraulic conductivity (Kh,cm hr^{-1})		0.48	0.44
Total porosity (E, %)		49.43	48.68	Soil pH, 1:2.5 (suspension)		7.75	7.79
Void ratio (e)		0.98	0.95	Soil EC, dSm^{-1} (soil paste extract)		2.37	2.54

Settling percentage of the soil aggregates wasdetermined in soil aggregates of 2 – 5 mm size, as themethod described by *Williams and Cooke (1961) and Hartge (1969).*

Pore size distribution wascalculated according to *De Leenher and De*

Boodt (1965).

Amount of water applied: the discharge through an orifice was determined from the following equation as described by *Israelson and Hansen (1962).*

$$Q = CA(2Gy)^{1/2}$$

Where: Q = Discharge rate, $m^3 sce^{-1}$, C = discharge coefficient ranges from 0.6 to 0.8, A= area of orifice opening (m^2), G= accelerating of gravity ($9.8 msec^{-1}$),Y= the head causing free flow where Y is the upstream head measured from the center of orifice opening.

Soil bulk density (Db, gcm^{-3}) was determined using the core methods **(Vomocil, 1986).** Total porosity (E,%) and void ratio (e) were calculated using the following equations:-

$$E, \% = \left(1 - \frac{Db}{Dr}\right) \times 100$$

and $e = \frac{Dr}{Db} - 1$

Where: Db = the bulk density, gcm^{-3}

Dr = the real density, 2.65 gcm^{-3}

Hydraulic conductivity ($cmhr^{-1}$) was determined using undisturbed soil cores using a constant water head according to **Richards (1954)**. Soil pH in soil water suspension (1: 2.5) and soil electrical conductivity (EC, dSm^{-1}) in soil paste extract were measured

Climatic Condition The meteorological data including: maximum temperatures (T- max)°C, minimum temperatures (T- min)°C,: relative humidity(RH): %, wind speed (WS)m/s and rainfall (RF)m.mduring the two years of study were recorded and their monthly mean values are presented in Table (2).

Table (2). Meteorological data in 2019/2020 and 2020/2021 growing season

Month	T-ma x		T-min		T-mea n		RH		WS		RF	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
November	**21.02**	**24.64**	**8.25**	**10.78**	**14.64**	**17.71**	**65.32**	**63.38**	**7.49**	**8.16**	**0.11**	**0.36**
December	**18.85**	**22.57**	**6.17**	**6.93**	**12.51**	**14.75**	**61.55**	**60.63**	**6.48**	**6.38**	**0.08**	**0.02**
January	**17.63**	**21.52**	**5.32**	**2.03**	**11.48**	**11.78**	**69.18**	**59.04**	**5.61**	**5.62**	**0.55**	**0.07**
February	**20.11**	**21.78**	**6.11**	**5.14**	**13.11**	**13.46**	**66.43**	**61.52**	**5.93**	**5.68**	**0.67**	**0.72**
March	**24.42**	**23.27**	**6.83**	**6.90**	**15.63**	**15.09**	**59.88**	**62.38**	**6.36**	**6.32**	**2.39**	**3.36**
April	**26.88**	**29.43**	**8.63**	**6.68**	**17.76**	**18.06**	**57.24**	**50.20**	**7.13**	**6.29**	**2.86**	**0.13**
May	**32.57**	**36.84**	**10.55**	**7.84**	**21.56**	**22.34**	**50.77**	**36.64**	**8.17**	**6.89**	**0.0067**	**0.00**

* Source:WaterRequirementandFieldirrigationRes.,Dept

- Abbreviations: T-max: Maximum temperatures, T-mim: Minimum temperatures, RH: Relative humidity, WS: Wind Speed, RF: Rainfall

<u>Response curve analysis</u>

Description of the relationship between Water Driving Force (WDF) and Water Movement Time (WMT) involved fitting three types of models over the data collected under the four irrigations during the two wheat growing seasons, according to **Neter*et al.*, (1990).** Considering the canal length is constant**,** the tested models were linear, quadratic and logarithmic model.

(1): The linear model is defined by the equation;

$$WDF = a + b\,(WMT)$$

(2): The quadratic model is defined by equation;

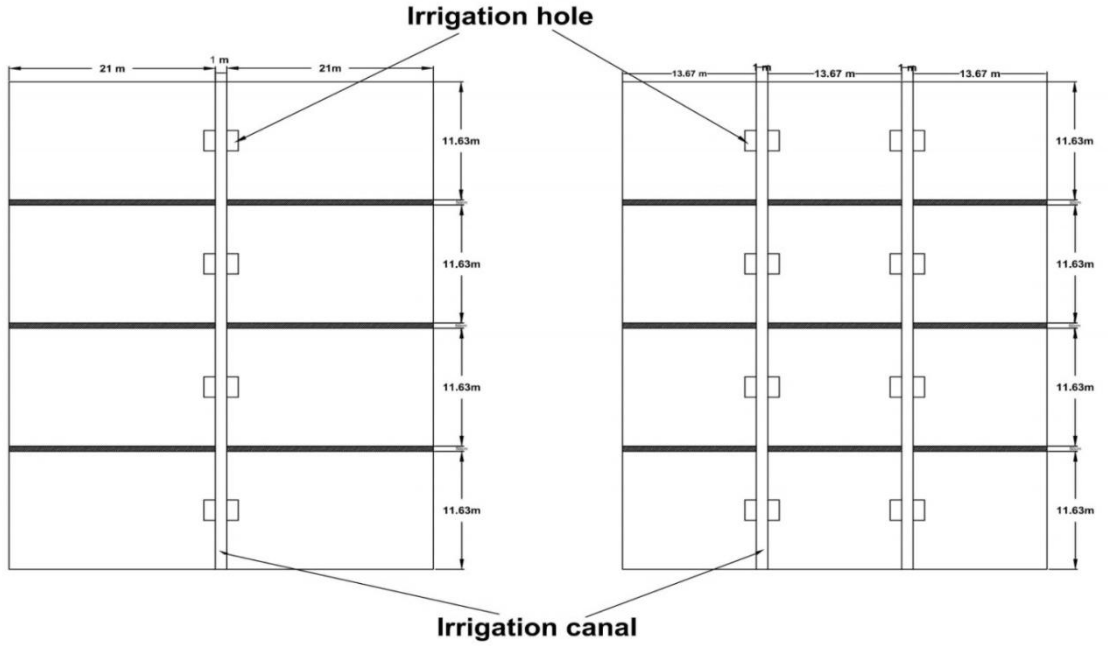
$$WDF = a + b\,(\mathbf{WMT}) + c\,(WMT)^2$$

(3): The logarithmic model is defined by equation;

$$WDF = a + b\ln\,(WMT)$$

Where, (a) represents as intercept, b and c are coefficients of the regression equation. Coefficient of determination (R^2), standard error of estimate (SE) and significance of the model were used as the basis forcomparing the above-mentioned response models. The model that had the highest (R^2) value and the lowest estimate (SE) was the best model for describing the relationship between Water Driving Force (WDF) and Water Movement Time (WMT). By taking the first derivative of the optimum quadratic equation with respect to WMT and equating that to zero, itgetsthe Critical Water Movement Time (CWMT) which reflect the lowest WDF. In other words, Water Driving Force (WDF)should not significantly after this critical time period.

Experiments design



One irrigation canal   Two irrigation canal

Fig 3. Irrigation Canal

RESULTS AND DISSCUTION

The results in Tables(3 and 4) showed that water losses amount were 17.26 and 18.29 m^3 in the two seasons, respectively at the rate of water driving forces 0.25m^3 in 16.50 minute in the first season and 0.27 m^3 in 16.75minute in the second season by using one irrigation canal. These resultsmaybeattributed to the effect of several factors of water driving forces such as canal length, canal width and change in water density and viscosityby the controlling in the conveyance of water by increasing water driving forces can be reducing of water losses in the irrigation canals in the field. These resultsareinagreement with those obtained by Yao *et al.*(2012) and Sen*et al.*(2018).

Table (3): Water losses amount of one irrigation canal in the first season

planting irrigation		first irrigation		second irrigation		third irrigation	
QE = 34.16m^3	Water movement time(23 minute)	QE = 29.37m^3	Water movement time (17 minute)	QE = 26.83m^3	Water movement time (14 minute)	QE = 24.29m^3	Water movement time (12 minute)
QF = 26.27m^3		QF = 24.19m^3		QF = 23.82m^3		QF = 23.11m^3	

Total QE = 114.65m^3

Total QF = 97.39m^3

Water losses amount, Total(QE – QF) = 17.26m^3

$$\text{Water driving forces} = \frac{L \times W \times h \times g}{T}$$

$$WDF_{T23} = \frac{48 \times 1 \times 0.5 \times 9.81}{23 \times 60} = 0.17 m^3/min$$

$$WDF_{T17} = \frac{48 \times 1 \times 0.5 \times 9.81}{17 \times 60} = 0.23 m^3/min$$

$$WDF_{T14} = \frac{48 \times 1 \times 0.5 \times 9.81}{14 \times 60} = 0.28 m^3/min$$

$$WDF_{T12} = \frac{48 \times 1 \times 0.5 \times 9.81}{12 \times 60} = 0.33 m^3/min$$

Mean $WDF_{16.50}$ = 0.25m^3/min

Table (4): Water losses amount of one irrigation canal in the second season

planting irrigation		first irrigation		second irrigation		third irrigation	
QE = $34.72m^3$	Water movement time (25 minute)	QE = $29.84m^3$	Water movement time (19 minute)	QE = $27.18m^3$	Water movement time (13 minute)	QE = $24.68m^3$	Water movement time (10 minute)
QF = $27.37m^3$		QF = $24.47m^3$		QF = $23.56m^3$		QF = $22.73m^3$	

Total QE = $116.42m^3$

Total QF = $98.13m^3$

Water losses amount, Total (QE − QF) = $18.29m^3$

Water driving forces = $\frac{L \times W \times h \times g}{T}$

$WDF_{T25} = \frac{48\times 1 \times 0.5 \times 9.81}{25 \times 60} = 0.16m^3/min$

$WDF_{T19} = \frac{48\times 1 \times 0.5 \times 9.81}{19 \times 60} = 0.21m^3/min$

$WDF_{T13} = \frac{48\times 1 \times 0.5 \times 9.81}{13 \times 60} = 0.30m^3/min$

$WDF_{T10} = \frac{48\times 1 \times 0.5 \times 9.81}{10 \times 60} = 0.39m^3/min$

Mean $WDF_{16.75}$ = $0.27m^3/min$

The results in Tables(5 and 6)obtained that water movement in irrigation canal were affected by water driving forces $0.24m^3/34.75$ minute in the first season and $0.23m^3/37.50$ minute in the second season led to water losses amount 35.11 and37.39m^3in the two seasons, respectively by using two irrigation canal in the field.These results may beattributedto the effect of water driving forces on water movement in irrigation canal, consequently water losses amount were affectedby the relationship between water driving forces and water movement time by increasing water driving forces, water movement timedecreased in the irrigation canals.

These results are in parallel line with those reported by **(Ashton and Hope 2001) and Sen*et al*. (2018).**

Table (5): Water losses amount oftwo irrigation canal in the first season

planting irrigation		first irrigation		second irrigation		third irrigation	
QE = $70.13m^3$	Water movement time (49 minute)	QE = $59.64m^3$	Water movement time (36 minute)	QE = $55.38m^3$	Water movement time (29 minute)	QE = $51.86m^3$	Water movement time (25 minute)
QF = $54.72m^3$		QF = $51.19m^3$		QF = $48.43m^3$		QF = $47.56m^3$	

Total QE = $237.01m^3$

Total QF = $201.90m^3$

Water losses amount, Total (QE – QF) = $35.11m^3$

Water driving forces = $\frac{L \times W \times h \times g}{T}$

$WDF_{T49} = \frac{(48 \times 1 \times 0.5 \times 9.81)\ X\ 2}{49 \times 60} = 0.16m^3/min$

$WDF_{T36} = \frac{(48 \times 1 \times 0.5 \times 9.81) X\ 2}{36 \times 60} = 0.22m^3/min$

$WDF_{T29} = \frac{(48 \times 1 \times 0.5 \times 9.81) X\ 2}{29 \times 60} = 0.27m^3/min$

$WDF_{T25} = \frac{(48 \times 1 \times 0.5 \times 9.81) X\ 2}{25 \times 60} = 0.31m^3/min$

Mean $WDF_{34.75} = 0.24m^3/min$

Table (6): Water losses amount of two irrigation canal in the second season

planting irrigation		first irrigation		second irrigation		third irrigation	
QE = $71.92m^3$	Water movement time (54 minute)	QE = $61.86m^3$	Water movement time (40 minute)	QE = $56.18m^3$	Water movement time (29 minute)	QE = $49.74m^3$	Water movement time (27 minute)
QF = $56.46m^3$		QF = $50.37m^3$		QF = $48.92m^3$		QF = $46.56m^3$	

Total QE = $239.70m^3$

Total QF = $202.31m^3$

Water losses amount, Total (QE − QF) = $37.39m^3$

Water driving forces = $\frac{L \times W \times h \times g}{T}$

WDF_{T54} = $\frac{(48\times 1 \times 0.5 \times 9.81)X\ 2}{54 \times 60}$ = $0.15m^3/min$

WDF_{T40} = $\frac{(48\times 1 \times 0.5 \times 9.81)X\ 2}{40 \times 60}$ = $0.20m^3/min$

WDF_{T29} = $\frac{(48\times 1 \times 0.5 \times 9.81)X\ 2}{29 \times 60}$ = $0.27m^3/min$

WDF_{T27} = $\frac{(48\times 1 \times 0.5 \times 9.81)X\ 2}{27 \times 60}$ = $0.29m^3/min$

Mean $WDF_{37.50}$ = $0.23m^3/min$

Across the two seasons, the results in Table (7)referredthatmean water driving forces (WDF) in the case of using one irrigation canal in field ($0.26m^3$/16.63minute) was greater than its corresponding value under two irrigation canals ($0.24m^3$/36.13minute) while water losses amount (WLA) from one irrigation canal (17.78 m^3) was less than its value under the two irrigation canals (36.25 m^3) by saving $18.47m^3$ of water. Consequently, there is an inverse relationship between water driving forces in irrigation canals in the field and water losses amount.On the other hand, grain yield in the case of using one irrigation canal in field was 1.414mg ha^{-1}, while the productivity in the two irrigation canals was 1.365 mg $ha^{-1}$by increasing 49.17 kg ha^{-1}, whichmay be increasethe total production of wheat cultivated area in Egypt by surface irrigation.

Table (7): Mean water driving forces, water losses amount, water saving and grain yieldacross the two seasons.

Season	In the case of one	In the case of two irrigation	Grain yield	Saving

	irrigation canal		canal				water
	Water driving forces	Water losses amount	Water driving forces	Water losses amount	one irrigation canal	two irrigation canal	
First	0.25 m^3/16.50 min	17.26 m^3	0.24 m^3/34.75 min	35.11 m^3	1.363 mg ha^{-1}	1.310 mg ha^{-1}	18.47 m^3
Second	0.27 m^3/16.75 min	18.29 m^3	0.23 m^3/37.50 min	37.39 m^3	1.465 mg ha^{-1}	1.420 mg ha^{-1}	
Mean	0.26 m^3/16.63 min	17.78 m^3	0.24 m^3/36.13 min	36.25 m^3	1.414 mg ha^{-1}	1.365 mg ha^{-1}	

Linear, quadratic and Logarithmic models were fitted to describethe relationship between Water Driving Force (WDF) and Water Movement Time (WMT) under the four irrigations during the two wheat growing seasons. Three statistical bases were considered to compare the three models i.e. coefficient of determination (R^2), standard error of estimate (SE) and the significance of the model. The significant model which had the highest R^2 and lowest SE was the best model fitted to the yield data.

The results in Table (8)and Figure (4) indicated clearly that the highest value of the coefficient of determination (R^2) was in favor of the significant quadratic model in addition to its lower SE confirmed that the quadratic model is the best model compared to others. Accordingly, the Critical Water Movement Time (CWMT) which reflects the lowest WDF value was calculated as follows:

$$\text{Critical Water Movement Time (CWMT)} = \frac{-\mathbf{b}}{\mathbf{2}c} = \frac{-(-0.04672)}{2(0.000914)} = 25.55 \text{ min.}$$

This means that Water Driving Force (WDF) did not decreased significantly after 25.55 minutes. On the other hand, the Water Driving Force (WDF) at the moment it enters the irrigation canal (WMT = zero) would equals 0.7596 m^3/min.

Table (8): Linear, quadratic and logarithmic models describing the relationship between Water Driving Force (WDF) and Water Movement Time (WMT) under the four irrigations during the two wheat growing seasons.

Regression models	Regression equation	R^2 %	SE	Sig.
Linear	WDF = -0.0145 + 0.4995 WMT	93.5	0.022	000
Quadratic	WDF = 0.7596 - 0.0467 WMT + 0.0009 WMT^2	99.6	0.006	000
Logarithmic	WDF = 0.94 - 0.247 In (WMT)	98.2	0.012	000

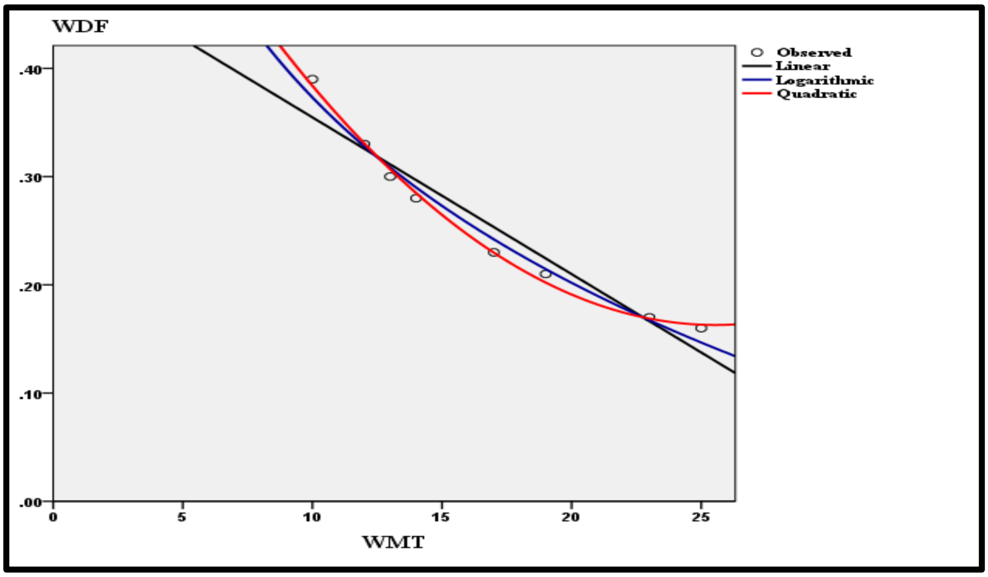


Fig 4. Graphical Presentation of Linear, quadratic and logarithmic models for describing the relationship between Water Driving Force (WDF) and Water Movement Time (WMT)

The results in figure (4) obtained that, the relationship between water driving forces and water movement time is by increasing water driving forces, water movement time reduced, consequently water losses amount reduced in the irrigation canals in the field.

CONCLUSION

The present research showed thatthere is an inverse relationship between water driving forces in irrigation canals in the field and water losses amount.Whenwater driving forces increased, water losses amount reduced.The potential areas for future research are the optimum irrigation canals planning in agriculture lands in the case of surface irrigation system to achieve the least water losses and by calculating water driving forces by using mathematical equation can be achieving water abundance by the reducing of water losses in irrigation canals in the field which can be used to irrigate new lands

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