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ORIGINAL ARTICLES

The Relationship between Water Regimes and Maize Productivity under Drip Irrigation System: A Statistical Model

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ABSTRACT

Irrigation frequency is one of the most important factors in drip irrigation scheduling and production planning, where water resources are limited, that affects soil water regime, water and fertilization use efficiency and crop yield. Therefore, field experiments were conducted for 2 years in the summer season of 2011 and 2012 on sandy loam soil to investigate the effects of irrigation frequency under surface and subsurface drip irrigation systems on growth parameters, grain yield, N, P and K uptakes, and water use efficiency (WUE) of maize (*Zea mays* L.). The results indicated that the highest values of maize growth parameters were gained when irrigating plants with 100 % of the ETc (2500 m^3/fed.= high frequency) treatment by using subsurface drip irrigation system. On the contrary, the lowest values appeared by irrigating plants by 1900 m^3/fed. (70 % of ETc = low frequency) under surface drip irrigation system. There were no significant differences between the growth parameters values by using the two experimental irrigation systems, but the differences increased by using the different water quantities. The highest maize grain yield (2638 and 2575 kg/fed.) were gained by using control irrigation water quantity (2500 m^3/fed.) comparing with the other two water quantities under subsurface and surface drip irrigation system, respectively. The significant differences were appeared for N, P and K uptakes values by the effect of water quantities, and the interaction between water quantities and irrigation systems, but there were no significance under the individual effect of irrigation systems. The relationship between water quantities and maize grain yield using drip irrigation system under semi arid conditions is 1^{st} degree.

Key words: Maize-Surface and subsurface drip-WUE-Nutrient uptakes-Statistical model.

Introduction

Agriculture is the major user of freshwater (with a world's average of 71 % of the water use). Therefore, innovations are needed to increase the water use efficiency that is available. There are several possible approaches. Irrigation technologies and irrigation scheduling may be adapted for more effective and rational use of limited supplies of water.

Drip and sprinkler irrigation methods are preferable to less efficient traditional surface methods. All cultivated land in Egypt has an arid or semi-arid climate, and the water required for agricultural and horticultural crops is obtained mainly through irrigation systems which consume about 83 % of the country's available fresh water (Fahmy *et al.,* 2002). On the other hand, field application efficiency in most traditional irrigation methods is still very low, typically less than 50 % and often as low as 30 % (Molden *et al.,* 1998). Excessive application of water generally entails losses because of surface run-off from the field and because of deep percolation below the root zone within the field. Alternative water application methods such as the drip irrigation method allow for much more uniform distribution as well as more precise control of the amount of water applied and also decrease nutrient leaching (Phene *et al.*, 1994).

Frequency of water application is one of the most important factors in drip irrigation management because of its effects on soil water regime, root distribution around the emitter, the amount of water uptake by roots and the amount of water percolation under the root zone (Coelho and Or, 1999; Assouline, 2002; and Wang *et al.,* 2006). Due to these phenomena of irrigation frequency, water use efficiency (WUE) and crop yields may be different under different irrigation frequencies. Irrigation frequency that results in either excessive or inadequate applied water in each irrigations can have a negative impact on either drip irrigation efficiency or final grain yield. The lowest irrigation frequency may cause water stress between irrigations; especially in sandy soils because the duration of water application is much shorter than the time over which plants take up water.

Maize is an important cereal crop grown all over the world (Farhad *et al.,* 2009). Maize has been reported in the literature as having high irrigation requirements (Rhoads and Bennett, 1990 and Stone *et al.,* 2001). In arid and semi arid regions, the daily evapotranspiration rates of maize often exceed 10 mm/day) for significant time

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periods (Howell *et al.*, 1995). Maize yields are most sensitive to water stress, especially at flowering and pollination stages. Although, several experiments have shown positive responses in some crops to high-frequency drip irrigation, this is not the general case for maize in different soils and regions. Furthermore, seeming inconsistencies as to the frequency which might be optimum can also be found in the literature when the same quantity of water is applied under different irrigation frequencies. So, it is important to determine a proper drip irrigation frequency that promotes maize yield for specific localities, thereby avoiding water stress or leaching from the root zone. The objective of this study was to evaluate the effectiveness of drip irrigation frequency on maize yield and WUE to develop a best management drip irrigation system for high maize yield and WUE and to develop a statistical model considers the relationship between water frequencies and maize yield in a semi-arid region.

Materials and Methods

This study was conducted during the 2011 and 2012 summer seasons at the Research and Production Station of the National Research Centre, in El-Nubaria, El-Beheira Governorate, Egypt. The farm is intersected by 30°25'55.6" N and 30°19'10.5"E. The weather is hot and dry from May to October where temperatures can reach up to 40 °C. Soil of the experimental site was sandy loam, and has no salinity and drainage problem. Some physical and chemical properties of soil were noted in Table (1). Irrigation systems (subsurface drip at 0.2 m depth and surface drip) were assigned in the main plots, and irrigation water frequencies were distributed in the sub-plots. The drip irrigation system was divided into three sectors, and each sector had one valve, one flow meter, and one pressure gauge to control the operating pressure and measure the irrigation quantity. The three experimental irrigation frequencies were namely 2500 m^3/fed. (100% of ETc, control= high frequency), 2050 m^3/fed./season (80% of ETc = medium frequency), and 1900 m^3/fed. (70% of ETc = low frequency), with same quantity of water for all irrigation times, while number of irrigations were varied in the three cases. The amount of irrigation water was applied according to the daily reference evapotranspiration (ET_o) computed from daily climatic data, which were obtained from the Central Laboratory of Agricultural Climate (CLAC) for Nubaria location using the Modified Penman-Monteith equation (Allen *et al.*, 1998). Thereafter, the calculated ET_o values with the crop coefficient (Kc) that depended on plant growth stage were used to calculate the amount of water requirements for maize (m^3/fed.) with the following equation:

$$\mathbf{ETc = ETo * kc} \qquad (1)$$

The crop coefficient, which depends on the growth stage of the plant, is the ratio of the crop evapotranspiration to the reference evapotranspiration and represents an integration of the effects of selected primary characteristics that distinguish it from the reference crop grass (Achtnich 1980). As recommended by Allen *et al.* (1996) and Neale *et al.* (1996), the FAO Kc was adjusted according to local climatic conditions, including minimum relative humidity, wind speed and maximum plant height. The adjusted Kc values in the months of the cropping season varied between 0.35 and 1.30 were calculated in those periods in which plants were not under water stress. The drip irrigation efficiency was assumed to be 0.9, and the root extension coefficient according to Moon and Gulik (1996).
Irrigation water use efficiency WUE was calculated with Equ. (2) (Kanber *et al.,* 1993).

$$\mathbf{WUE = (Yield,\ kg/fed.\ /Total\ applied\ irrigation,\ m^3/fed.)} \qquad (2)$$

Maize crop was sown in 75 cm apart furrows by using a seed rate of 30 kg ha^{-1}. The regular tillage and agricultural operations of growing maize of the location were followed. All other agronomic practices were kept normal and uniform for all the treatments. Fertilizers used were based on the recommendations of the regional extension service. Where, 120 kg N/fed., 30 kg P_2O_5/fed. and 24 kg K_2O/fed. were added. Representative plant samples were collected after 90 days from sowing and their growth criteria were recorded for plant height (cm), number of leaves per plant, dry weight of leaves, stem, root and whole plant. After harvest the following data were recorded grain yield, NPK uptakes, and water use efficiency (WUE). Finally the statistical relationship was calculated to develop a mathematical relationship between water quantities and the productivity of maize crop under semi arid conditions in Egypt.

Split-split design with four replicates was used in each season. All data analyses in this study were done using the CoStat program. The least significant difference (LSD) test to assess the significant difference between the mean values were calculated and probability levels lower than 0.05 were categorized as significant as described by Gomez and Gomez (1984).

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Results and Discussion

Growth Parameters:

Data presented in Table (2) show the effect of irrigation systems (subsurface and surface drip), irrigation water quantities, and the interaction between them on the growth parameters of maize plants. It is clear that, significant differences in all studied maize growth parameters were observed under the effect of studied irrigation systems, water quantities treatments and the interaction between them, except for plant height and dry weight of root under the individual effect of the studied irrigation systems (subsurface and surface drip). There was another exception, where number of leaves per plant didn't affected significantly with any studied factors. Data indicated that the highest values of maize growth parameters were gained by irrigating plants with 100 % of the ETc (2500 m^3/fed.) by using subsurface drip irrigation system. On the contrary, the lowest values were appeared by irrigating plants by 1900 m^3/fed. (70 % of ETc) under surface drip irrigation system. Leaves, stem and whole plant weight values increased significantly by using subsurface drip irrigation, this may be due to decreasing water loss by evaporation. In addition to this method of irrigation cause an increase of water stored in root zone. Except number of leaves/plant, all growth parameters increased significantly by increasing water quantity. The decrease percentages of leaves, stem, roots and whole plant weight by using 80 and 70% of ETc were 8.8 and 44.3%, 24.4 and 48.3%, 6.9 and 32.7% and 16.8 and 46.3% under subsurface irrigation system, while surface irrigation system decreased these parameters by 12.5 and 35.8%, 11.6 and 37.7%, 9.4 and 33.7% and 12.1 and 36.7% compared to 100% of ETc treatment, respectively. The decline in irrigation rate means increasing the period between irrigations, these conditions put the plant under drought stress thus, all growth parameters were negatively affected.

Table 1: Some physical and chemical properties of the experimental soil.

Characteristics	Value
pH (1 : 2.5 soil : water ratio)	8.20
EC (Soil paste extraction) dSm^{-1}	1.32
Soluble cations (m.e./100g soil):	
Calcium	0.48
Magnesium	0.12
Potassium	0.69
Sodium	0.06
Soluble anions (m.e./100g soil):	
Bicarbonate	0.22
Chloride	0.77
Sulphate	0.36
Available nutrients (ppm):	
Nitrogen	29.7
Phosphorus	7.90
Potassium	116.63
Physical properties (%):	
Organic matter	0.47
Calcium carbonate	24.9
Sand	68.91
Silt	16.57
Clay	14.52
Textural class	Sandy loam
Soil Taxonomy	*Entisol-Typic Torripsamments*

Table 2: Effect of irrigation systems and water regimes on growth parameters of maize plants.
As an average of the two growing seasons

Irrigation systems	Water regime, m^3/fed./season	Plant height (cm)	Number of leaves/plant	Dry weight (g/plant)			
				leaves	stem	roots	whole plant
Subsurface drip	2500 (control)	155.00	11.33	19.31	20.43	10.11	39.74
	2050	154.67	10.33	17.61	15.44	9.41	33.05
	1900	129.33	9.33	10.76	10.57	6.80	21.33
Mean		146.33	10.33	15.89	15.48	8.77	31.37
Surface drip	2500 (control)	146.00	10.00	15.41	12.87	10.13	28.27
	2050	135.33	9.67	13.48	11.38	9.18	24.86
	1900	124.00	8.67	9.89	8.02	6.72	17.9
Mean		135.11	9.44	12.92	10.76	8.68	23.68
Mean values of water regimes	2500 (control)	150.50	10.67	17.36	16.45	10.12	34.01
	2050	145.00	10.00	15.55	13.41	9.29	28.96
	1900	126.67	9.00	10.32	9.29	6.76	19.62
L.S.D. at 5% level	Irrigation systems (I)	N.S.	N.S.	2.36	1.12	N.S.	3.48
	Water regimes (W)	18.58	N.S.	1.72	2.24	1.79	3.31
	I x W	26.28	N.S.	2.44	3.17	0.78	4.68

Decreasing irrigation water has a harmful effect on maize growth parameters. In this concern, Kramer and Boyer (1995) reported that the growth of plants is controlled by rates of cell division and enlargement and by the supply of organic and inorganic compounds required for the synthesis of new protoplasm and cell walls. Cell enlargement is particularly dependent on at least a minimum degree of cell turgor and stem and leaf elongations are quickly checked or stopped by water deficits. Many investigators among them; El-Noemani *et al.* (1990), Batanouny *et al.* (1991), Davies and Zhan (1991), Mahrous (1991), E1-Sheikh (1994) and Ahmed and Mekki (2005) reported that growth criteria of maize plants were reduced when plants were subjected to drought. The physiological mechanisms involved in cellular and whole plant responses to water stress, therefore, generate considerable interest and are frequently reviewed (Davies and Zhan, 1991; and Smith and Griffiths, 1993). Drought stress in plants occurs when evaporative demand exceeds water uptake. Water deficit budgets lead to numerous physiological alterations, both in the long term as well as the short term. Long-term drought responses include altered root to shoot ratio (Blum and Arkin, 1984) and reduced leaf area (Batanouny *et al.*, 1991). Short-term responses include altered stomatal function (Stewart *et al.*, 1995) and osmotic adjustment (Turner *et al.*, 1986). According to Kramer and Boyer (1995) plants respond to drought either by delaying dehydration where the plant maintains a relatively high plant water potential or by tolerating dehydration where the plant continues to function but at lower plant water potentials. Drought has different effects on maize plants depending on the development of growth stage at which it occurs. Previous reports showed that stress during tasseling and silking was most harmful and stress during grain filling was more drastic than that during the vegetative growth stage (Grant *et al.*, 1989). Changes in morphological characters are the ultimate determinants of stress effects on plants (Farooq *et al*., 2009 and Jaleel *et al*., 2009).

Yield and irrigation water use efficiency (WUE):

The results of maize grain yield are presented in Fig. (1). It is clear from the figure that, the highest values were obtained under subsurface drip irrigation system for the three quantities of irrigation water (100%, 80% and 70% of ETc) comparing with those gained using surface drip irrigation system, and there were significant differences between maize grain yield values (2638 and 2575 kg/fed.) which were gained using control irrigation water quantity (2500 m^3/fed.) comparing with the other two water quantities under subsurface and surface drip irrigation system, respectively. So water stress affects maize grain yield, especially under surface drip irrigation system.

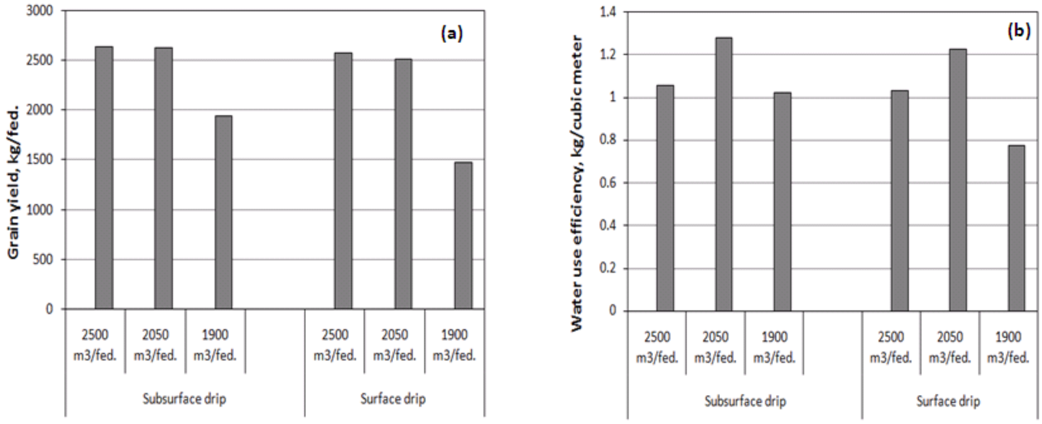

Fig. 1: Effect of the interaction between irrigation system and water regimes on (a) maize grain yield, kg/fed., and (b) water use efficiency, kg/m3.

The moderate water quantity (80% of ETc or 2050 m^3/fed.) resulted no significant grain yield value comparing with that obtained using the control water quantity. So, 20% (about 450 m^3/fed.) of used water quantity could be saved. Rasheed *et al.* (2010) concluded that I_2 (80% of water requirement) was considered to be best as it produced high maize grain yield, and about 20% of irrigation water could be saved when only 80% of calculated water requirement of maize plants was applied. Calculations of irrigation water use efficiency (WUE) under the experimental conditions emphasized that the moderate water quantity (2050 m^3/fed.) is suitable for indicating the economical maize grain yield, where the highest WUE values (1.28 and 1.22 kg/m^3) were detected using 80% of ETc water regime under subsurface and surface drip irrigation system, respectively. These results are in confirmation with those of Quaranta *et al*. (1998). Simpson (1981) reported that the variations in yield and its components due to drought stress at different growth stages could be ascribed to the impairment of many metabolic and physiological processes in plants. In this regard, Song *et al.* (1998) showed that water stress led to slower pollen and filament development, decreased filament fertility and resulted in a

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reduction in grain number and weight per ear. Similar results were recorded by Grant *et al.* (1989), Batanouny *et al.* (1991), El-Sheikh (1994) and Ahmed and Mekki (2005).

Macronutrient uptake:

Data illustrated in Fig. (2) show that there were no significance between the values of N, P and K concentrations under the effect of the two studied factors. Rasheed *et al.* (2010) showed that P and K concentration in maize grain increased as the amount of water increased without a significant difference. On the contrary, the significant differences were appeared for N, P and K uptakes values by the effect of water quantities, and the interaction between water quantities and irrigation systems, but there were no significance under the individual effect of irrigation systems. Generally, N, P and K uptakes (mg/plant) values were enhanced by rising irrigation water quantity. This increment was perhaps attributed to the effect of water as a solvent liquid on both fertilizers and native soil nutrients. There is one exception, where nitrogen uptake decreased by application of 2500 m^3/fed. (100% ETc) under surface drip irrigation, this may be confirms that nitrogen fertilizer was leached easily with addition of high irrigation rate under surface drip irrigation system. While, using 80% of ETc treatment protect nitrogen from leaching by time. Nitrogen, P and K uptake values support the result of grain yield. The highest values of N, P and K uptakes were recorded by using the control water quantity under subsurface drip irrigation system. But the lowest values were obtained by using the lowest water quantity under surface drip irrigation system. For that water stress affect N, P and K uptakes. In this concern Gahoonia *et al.* (1994) reported that reducing the soil water content decreased P uptake because it diminished the movement of P to roots by reducing the thickness of water films.

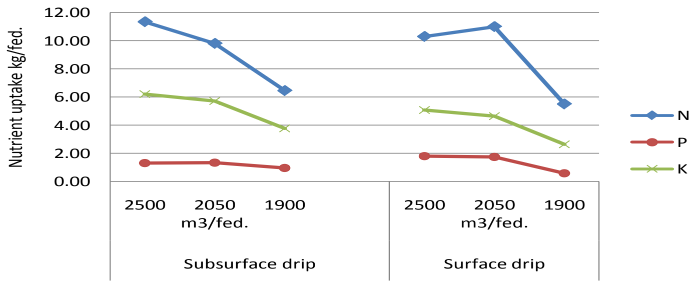

Fig. 2: Effect of irrigation system and water regimes on N, P, and K percent and uptake of maize plants.

So, it is important to express the relationship between water quantities and maize grain yield using drip irrigation system under semi arid conditions (Fig., 3 and Eq., 3). It can be observed that the relationship is 1st degree, with very good regression (0.99) and correlation coefficient (0.95), it is as following:

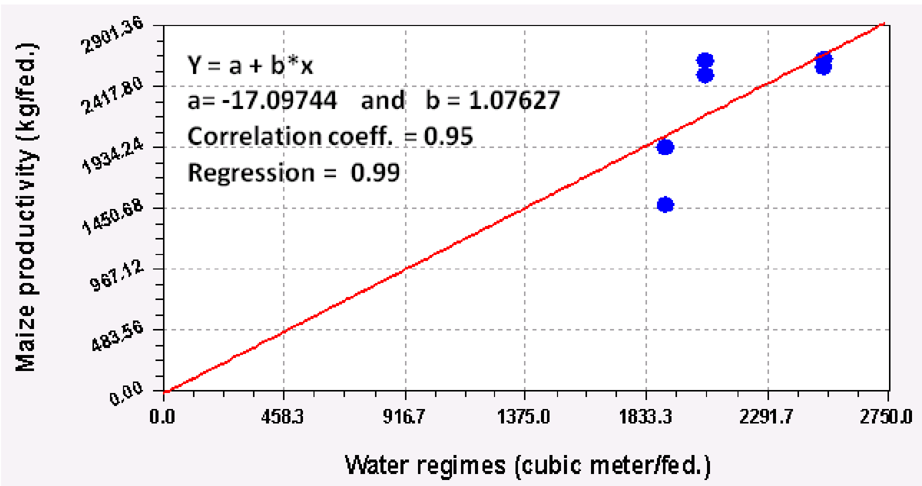

Fig. 3: The relationship (Statistical model) between the irrigation water quantities and maize productivity.

Y = a + b*X (3)
where
Y = maize grain yield (kg/fed.)
X = irrigation water quantity (m^3/fed.)
a = -17.097, and b = 1.07627
This statistical model could be used to predict maize grain yield under similar conditions of this study.

Conclusion:

It can be concluded that, subsurface drip irrigation was considered to be best irrigation system particularly in newly reclaimed soil. Addition of 80% of ETc treatment gave highest WUE, nitrogen uptake (under surface system) and high grain yield without significant difference compared to 100% of ETc. So, it's wise to irrigate maize with 80% of ETc as recommended for attaining maximized yield and WUE especially in arid and semi-arid regions.

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