FERTIGATION MANAGEMENT UNDER SUBSURFACE DRIP IRRIGATION SYSTEM FOR IMROVING TOMATO YIELDS AND AGRICULTURAL ENVIRONMENT

Journal

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ABSTRACT

Field experiments were carried out for two successive growing seasons (2005 and 2006), at the Experimental Farm of Faculty of Agriculture, Ain Shams University, which located in EL-Bustan Region, Beheira Governorate (which represents sandy soils conditions of Egypt), to clarify the role of fertigation technique management for tomatoes yields improvement.

Results revealed that the application of the total tomato plants-fertilizer requirements (100 kg-N per feddan) with bi-weekly fertigation interval and injecting fertilizers within the second-third of the total irrigation time may be an effective technical package of fertigation management under subsurface drip irrigated sandy soils for improving tomato yields and enhancement of the agricultural environment under drought ecosystem conditions.

Keywords: Fertigation regime, water regime, Injection time.

INTRODUCTION

Tomatoes are considered as one of the most commodity crops in Egypt at which about 464 491 feddan for all Seasons cultivated in 2004 with total yield of 7 640 818 Mgram per feddan (Ministry of Agriculture and Land Reclamation, Economic Affairs Sector, 2005).

Water is essential in the plant environment for a number of reasons. Water transports minerals through the soil to the roots where they are absorbed by the plant. Water is also the principal medium for the chemical and biochemical processes that support plant metabolism. Under pressure within plant cells, water provides physical support for plants. It also acts as a solvent for dissolved sugars and minerals transported throughout the plant. In addition, evaporation within intercellular spaces provides the cooling mechanism that allows plants to maintain the favorable temperatures necessary for metabolic processes. Water is transported throughout plants almost continuously. There is a constant movement of water from the soil to the roots, from the roots into the various parts of the plant, then into the leaves where it is released into the atmosphere as water vapor through the stomata (small openings in the leaf surfaces).

Localized irrigation is a highly efficient method of water application, which is also ideally suited for controlling the placement and supply rate of water-soluble fertilizers. Nutrients can be injected at various scheduling criteria based on system performance analysis, soil characteristics and grower preference (Elia *et al*, 2007 and Thompson *et al*, 2002). Although, chemigation was used to ensure stability of crop productivity, its use is being discontinued due to its potential hazardous to environment and humans. This may be attributed to the leakage of phasing out the appropriate management of the fertigation systems (El-Gindy *et al*, 2007, Chieng and Ghaemi, 2003 and Garbow *et al*, 2000). However, water and nutrients acquisition by plants, and the formation of a depleted zone in the immediate vicinity of the roots are the driving forces for solute movement towards the roots (Miccolis *et al*, 2007, Silberl et al, 2003 and Badr, 2002). Soil properties, crop characteristics and ambient conditions had a significant effect on the relative importance of chemigation management (Araki and Yamaguchi, 2007).

Several studies had been conducted on the crop response to fertigation management and its attributed impact on the environmental resources under different situations (Thompson *et al*, 2003). Solving agricultural- water uses problem in order to improve fertigation systems performance and enhancing the economical physical resources of the agricultural environment, may be involved judgment and subjective phase-out of the appropriate fertigation management criteria (Abdel-Aziz, 2008).

Therefore, the aim of this investigation was to clarify the effect of fertigation management criteria (amounts; intervals and injection time) under subsurface drip irrigation systems in sandy soils on the tomato yields.

MATERIALS AND METHODS

Experiments were conducted in two growing seasons (2005 and 2006) at the Experimental Farm of the Faculty of Agriculture, Ain Shams University, EL-Bustan Region, Beheira Governorate (which represents sandy soils conditions) under subsurface drip irrigation system. However, some characteristics of physiochemical of soils and irrigation water were tabulated in Tables (1; 2 and 3). Early summer tomatoes seedlings (cv castle rock) were transplanted (0.25 m plant-spacing in double sided cultivations of the bed) in the middle of January of 2005 and 2006 with about 13350 plants per feddan for the experimental purposes. Available soil NO_3^--N in the surface 0-30 cm was 4 mg/kg before tomato planting. Tomato seeds (open polenated CV was obtained from USA). Seedling trays contained a mixture of peat moss and vermiculite (1:1). The mixture was treated by fungicide (Benlate) used 1 g per liter. The trays were kept in the greenhouse. Before transplanting, the seedlings were hardened for 10 days by subjecting them to the open field. Tomato seedlings were transplanted to the main field in double rows (25 cm apart) on the middle of February (15th February) for both 2005 and 2006 seasons.

The organic manure was added before transplanting at a rate of 30 m3/fed, mixed with calcium super phosphate (15.5% P_2O_5) at rate (30 kg P_2O_5/Fed.), plus potassium sulphate (100 kg P_2O_5/Fed.), plus potassium sulphate (100 kg/Fed.) and 75 kg/fed, agricultural sulpher with (50 kg/Fed.) Amonium sulphate. All N. fertilizer was supplied as ammonium nitrate (33.5% No_3). The other (P_2O_5) needed (32 kg P_2O_5/fed) was injected in phosphoric acid form and also K^+ needed was injected uniform of potassium sulphate at the rate of 100 kg/fed, during planting stages. Foliar fertilizer metalosite "multimicroelements" were applied two times during the early stages of growth. All plants were subsurface irrigated, disease and insect control program were performed according to recommendations of Ministry of Agriculture and Land Reclamation, Horticulture Institute (Vegetables), Agricultural Researches Center.

Table (1): Physical and hydro-physical properties of sandy soil at the experimental site.

Soil depth, cm	Particle Size Distribution, %				F.C., %	P. W.P., %	B.D., g/cm^3	Texture Class
	C. sand	F. sand	Silt	Clay				
0-30	52.8	41.4	4.1	1.7	9.4	4.3	1.68	**Sandy**
30-60	50.0	43.5	5.0	1.5	8.5	4.4	1.57	**Sandy**

Table (2): Chemical analysis of sandy soil at the experimental site.

Soil depth, cm	pH	EC, dS/m	Soluble Cations, meq/l				Soluble Anions, meq/l		
			Ca^{++}	Mg^{++}	Na^+	K^+	HCO^-_3	SO^{--}_4	CL^-
0-30	8.2	1.27	2.9	2.8	5.1	0.6	3.6	2	6.1
30-60	8.3	1.22	2.9	2.1	5.2	0.6	3.7	2.1	6.3

Table (3): Chemical analysis of irrigation water at the experimental site.

pH	EC, dS/m	Soluble Cations, meq/l				Soluble Anions, meq/l			SAR
		Ca^{++}	Mg^{++}	Na^+	K^+	HCO^-_3	SO^{--}_4	CL^-	
7.74	1.02	1.03	0.74	8.01	0.42	1.95	4.52	3.73	8.51

1- Experimental layouts and design:

Experimental layout and design of subsurface drip irrigation system with 16 mm nominal diameter PE laterals (buried at 10 cm below soil surface, with 1.5 m lateral spacing) 0.3m built-in emitter spacing, with 4 lph flow rate at 1.0 bar operating pressure. Moreover, Venturi type injector was used for fertigation treatments. Experimental design was based on split-split-plot arranged in a randomized complete block with three replicates. Uniform irrigation was applied through the drip tubing to encourage the seedlings and stand establishment.

2- Irrigation requirements:

i- based on traditional calculation methods

a- Irrigation water requirements had been applied according to the weather data of El-Bustan region, which had been collected from the Central Lab. of Agric. Climate, ARC and had been calculated according to FAO (1984). However, the crop water consumptive use was calculated according to Doorenbos and Pruitt (1977):

$$\mathbf{Et_c = Et_0 \times K_c}$$

Where, Et_c is the crop consumptive use (mm/day), Et_0 is the reference evapotranspiration (mm/day) and K_c is the crop coefficient (dimensionless) for tomato plant was used according to FAO (1984).

b- Applied irrigation water for tomato plant was calculated according to the following equation:

$$\mathbf{IR = [Et_C\ (1+LR) \times 4.2/E_a] \times I}$$

Where, IR is the applied irrigation requirement (m^3/fed. For each irrigation), LR is the leaching requirement (%, and equal $EC_i/2EC_d$), EC_i is the salinity of irrigation water (dS/m), EC_d is the salinity of drainage water (dS/m), E_a is the application efficiency (%) and I is the irrigation intervals (days).

ii- based on irrigation effectiveness criterion

The developed irrigation effectiveness criterion is based on the logicians of irrigation efficiency, may be better if it replaced by the developed irrigation effectiveness index (which had been developed by Arafa (2009) that represent a ratio of irrigation system performance and irrigated soils. The developed criterion may be expressed as follows:

$$E_i = \frac{S_i}{I_{pi}}$$

Where, S_i is the soil characteristics index and I_{pi} is the irrigation system performance analysis.

$$I_{pi} = \left[\frac{\Sigma (q_i - q_n)^2}{\bar{q} * n * p} \right] * \frac{t}{DU} * \frac{1}{w}$$

Where, q_i is the actual discharge of the distributor devices, q_n is the nominal discharge of the distributor devices, $\bar{q}$ is the mean discharge rate of the distributor devices, n is a fraction of the clogging risks (based on data referred to Arafa, 2004), P is a fraction of pressure variation sensitivity, DU is the distribution uniformity, T is the operating time and w is the effective coverage width of the irrigated soils

Meanwhile, the soil-water transient flow index can be summarized as following:

$$S_i = \left[\frac{M.C_{after} - M.C_{before}}{[F.C - P.W.P] * \rho_s} \right] * \ln h_c * t * \text{coneversion}$$

Where, $M.C_{before}$ is the soil moisture content before irrigation in equivalent volumetric units, $M.C_{after}$ is the soil moisture content after irrigation in equivalent volumetric units, F.C. is the soil field, P.W.P. is the permanent wilting point, K is the soil hydraulic conductivity and ρ_s is the soil bulk density.

The first term in the equation considers the soil-sorptivity; meanwhile, the second term considers the cumulative infiltration of water due to the positive head pressure.

3- Experimental procedures:

Irrigation system performance had a significant impact on crop yield production and costs. However, fertilizers are wasted due to the deficiency of either irrigation system or chemical applicator, as well as improper management of the fertigation system. Hereby, the fertilizer distribution uniformity and activity behavior are depending on the engineering analysis of fertigation system. Therefore, an analysis of fertigation system management had been conducted under different operating conditions.

3-1- Fertigation management treatments:

i- fertigation application rate (fertigation regime): two fertigation regimes were investigated noted: 100 and 75% of the Nitrogen requirements of tomato plants at the studied area.

ii- fertigation intervals: two fertigation intervals had been investigated namely, weekly and bi-weekly.

iii- fertilizer Injecting time: two fertilizer injecting times had been investigated, according to El-Marsafy (1998), who stated that injecting fertilizer at third or half irrigation time is the most suitable time for improving fertilizer use efficiency under sandy soil conditions.

3-2- Data collection, measurements and analysis

At harvest time (with 4 picks harvested) fruit yields of tomato were taken for determining some response quality criteria and marketable and non-marketable yields, as well as fertilizer use efficiency.

RESULTS AND DISCUSSION

1- Tomatoes yield and yield components response to crop water requirements methods

Data presented in Table (4) revealed that the highest tomatoes yield (28.05 ton/fed) had been observed by calculating the water requirements based on the irrigation effectiveness criterion compared with traditional method (FAO 56), when applying the total required water of tomato plants and injecting fertilizers within the third irrigation time. This may be due to the uniformity of nutrients distribution and availability in the effective plant root zone.

Concerning the response of vegetative growth parameters to the tested parameter, results represent a same trend for all growth parameters such as: number of fruits per plant; mean fruit weight and plants fresh weight. The observed results had been developed except the data of the fresh weight of the weekly fertigated treatment with 100% water requirements and injecting fertilizers within the third irrigation time. This may be due to efficiency of subsurface drip irrigation for distributing water and nutrients acquisition by plants and the formation of a depleted zone in the immediate vicinity of the roots are the driving forces for solute movements towards the roots.

Table 4. Tomato yields response to fertigation management criteria under subsurface drip irrigation system in sandy soils.

Irrigation requirements calculation	Fertigation regime	Fertigation interval	Injecting time	Vegetative growth parameters			Total yield, ton/fed	% crop improvement	FUE, kg/kg-N
				Plant fresh weight, g	No. of fruits per plant	Mean fruit weight, g			
Calculation based on irrigation efficiency factor	100% of N_{CR}	Weekly	I_1	613.00	23.00	91.50	25.37	17.29	253.70
		Bi-weekly	I_2	640.00	28.54	93.46	26.18	21.04	261.80
		Weekly	I_1	665.00	26.80	94.25	21.63	0.000	216.30
		Bi-weekly	I_2	701.25	29.41	97.34	27.11	25.34	271.10
	75% of N_{CR}	Weekly	I_1	490.00	17.20	80.00	20.48	0.000	272.38
		Bi-weekly	I_2	498.00	18.25	82.15	21.03	02.69	279.70
		Weekly	I_1	545.00	16.75	83.50	25.00	22.07	332.50
		Bi-weekly	I_2	573.28	18.75	81.75	22.33	09.03	297.00
Calculation based on irrigation effectiveness factor	100% of N_{CR}	Weekly	I_1	665.00	25.00	90.40	27.50	18.84	275.00
		Bi-weekly	I_2	650.20	30.00	94.22	27.82	20.22	278.20
		Weekly	I_1	673.03	28.00	94.25	23.14	0.000	231.40
		Bi-weekly	I_2	714.14	33.14	99.13	28.05	21.22	280.50
	75% of N_{CR}	Weekly	I_1	500.00	17.35	81.20	21.44	0.000	285.15
		Bi-weekly	I_2	502.08	18.50	83.33	21.64	00.92	287.81
		Weekly	I_1	555.67	16.85	84.00	25.73	20.01	342.21
		Bi-weekly	I_2	600.17	18.50	85.00	27.29	27.29	363.00

NCR is the tomato crop-N fertilizer requirements under sandy soil conditions.

I_1 is the injecting fertilizer in the range of (water: fertilizer: water): 0.25:0.50:0.25

I_2 is the injecting fertilizer in the range of (water: fertilizer: water): 0.33:0.33:0.33

2- Effect of fertigation regime and intervals on tomatoes yield

Regarding the calculation of tomato crop-water requirements based on the irrigation efficiency, which described in FAO 56, data presented in Table (4) indicated that the highest tomatoes yield increment percentage was about 29.68 percent, which had been obtained with applying the complete fertigation rate with bi-weekly fertigation interval and injecting fertilizers within the third of irrigation time. On the other hand, the lowest yield increment was 2.69% which had been obtained with the applying 0.75% of the crop fertilizer requirement rate with a weekly fertigation interval and injecting fertilizers within the third of irrigation time. Concerning, the calculation of tomato crop-water requirements based on the irrigation effectiveness criterion, data analysis indicated that the highest tomatoes yield increment ratio was about 33.25% which had been obtained with applying bi-weekly fertigation interval at 100% of the fertilizer requirements and injecting fertilizers within the third of irrigation time. Meanwhile, the lowest yield increment ratio was 4.69% which had been obtained with the applying 0.75% of the crop fertilizer requirement rate with a weekly fertigation interval and injecting fertilizers within the half of the total irrigation time.

Generally, data analysis revealed that, under el-Bustan region conditions the application of the total tomatoes crop fertilizer requirements (100 kg-N per feddan) had higher values of either vegetative growth parameters or economical yield compared with the application of the reduction coefficient of about 25% of the total fertilizer requirement.

With regard to the effect of the applied fertigation intervals on the tomatoes yield, data revealed that the bi-weekly fertigation treatment is the more acceptable than a weekly fertigation interval. However, the investigated vegetative growth parameters and attributed tomatoes yield were higher at bi-weekly tomato-fertigated compared with the weekly fertigated one. For instance, the highest tomatoes yields were about 27.11 and 28.05 Mgram (ton) per feddan at a bi-weekly fertigated tomato, with calculating the crop water requirements based on FAO 56 and the irrigation effectiveness criterion, respectively. This may be due to the nutrients deficiency is prevented by increasing their concentrations in the irrigation water to levels that ensure optimal uptake by plants. Thus, the nutrient concentrations in the rhizosphere may be high or even excessive immediately after irrigation and may fall to deficit levels as time proceeds.

3- Tomatoes crop response to fertilizer injection time

Data processing and analysis revealed that the application of fertilizers in the second- third of the total irrigation time is most suitable for improving tomato yields under sandy soil conditions of El-Bustan region, as shown in Table (4). However, the investigated vegetative growth parameters and attributed tomatoes yield were higher at injecting fertilizer within the second-third part of the irrigation time for tomato-fertigated compared with the injecting fertilizer within the half irrigation time. This may be due to increasing the injecting fertilizer time within successive irrigation events lead to maintain constant, optimal water content in the root zone and may reduce the variations in nutrient concentration, thereby increasing their availability to plants and reducing their leaching beneath the effective root zone.

4- Fertilizers use efficiency as regard to fertigation management

With this point of view of FUE, data revealed that there was significantly influences of FUE with low applied amounts of N fertilizers compared with that at high amount ones. With respect to the other management parameters (fertigation interval), data analysis indicated that there was a heterogeneity response trend, as presented in Table (4).

5- Environmental impact of fertigation management criteria

Evaluation of nutrient elements distribution patterns in general and N element in particularly, within the vertical and horizontal coordinates along either the emission points or soil profile depths from the emission points, could be an effective indicator of the relative effects of fertigation system efficiency.

i- residual Nitrogen distribution pattern within soil profile

Data analysis, which presented in Table (5), revealed that there was a positive proportional trend between the fertigation rate and the N concentration in the soil profile in either vertical or horizontal coordinates from the emission points of view. However, nitrate distribution under different factors showed a leached zone in the immediate vicinity of the subsurface drip laterals; however, much higher concentration had been observed near the boundary of the wetted areas. On the other hand, data analysis indicated that there was a negative proportional relationship between the residual N concentration in the effective root zone and fertigation frequency. This may be due to that plants roots were apparently very active in removing nitrates as evidenced by the low residual concentrations. Moreover, with higher water distribution patterns uniformity and quantity equity due to good irrigation management, an optimal soil-water content and availability in the effective root zone may reduce the variations of nutrient concentrations, thereby, their availability to plants and reducing their leaching beneath in the effective root zone.

ii- Residual Nitrogen concentration in tomato fruits

Data analysis, which presented in Table (5), revealed that there was a positive proportional trend between the fertigation rate and the residual N concentration in the tomato fruits. On the other hand, data indicated that a negative trend had been observed due to the fertigation intervals (weekly and bi-weekly), how ever the highest N residual concentration percentage was 1.87% which had been observed when applied the irrigation water requirement based on the irrigation efficiency factor and weekly-fertigation intervals and application of 100% of the tomato fertilizer requirements, mean while, the lowest percentage was 1.17%, when applied the irrigation water requirement based on the irrigation effectiveness criterion and application of 75% of the tomato fertilizer requirements with a bi-weekly intervals

Table 5. Residual N concentration in either soil or tomato fruits under different treatments.

Irrigation requirements calculation	Fertigation regime	Fertigation interval	Injecting time	Vertical distance from the emission point, cm			Horizontal distance from the emission point, cm			N concentration in Tomato fruits, %
				0-20	20-40	40-60	0-25	25-50	50-75	
Calculation based on irrigation efficiency factor	100% of N_{CR}	Weekly	I_1	0.37	0.42	0.23	0.31	0.24	0.13	1.87
		Bi-weekly	I_2	0.28	0.37	0.21	0.26	0.22	0.12	1.57
		Weekly	I_1	0.24	0.35	0.8	0.36	0.27	0.15	1.63
		Bi-weekly	I_2	0.23	0.29	0.77	0.23	0.18	0.09	1.47
	75% of N_{CR}	Weekly	I_1	0.25	0.27	0.13	0.2	0.16	0.09	1.67
		Bi-weekly	I_2	0.22	0.26	0.13	0.11	0.085	0.05	1.63
		Weekly	I_1	0.18	0.25	0.48	0.22	0.18	0.095	1.53
		Bi-weekly	I_2	0.17	0.26	0.51	0.077	0.059	0.032	1.34
Calculation based on irrigation effectiveness factor	100% of N_{CR}	Weekly	I_1	0.38	0.41	0.23	0.33	0.24	0.12	1.74
		Bi-weekly	I_2	0.25	0.34	0.18	0.24	0.21	0.12	1.62
		Weekly	I_1	0.22	0.31	0.77	0.3	0.21	0.1	1.52
		Bi-weekly	I_2	0.21	0.27	0.77	0.17	0.13	0.08	1.35
	75% of N_{CR}	Weekly	I_1	0.24	0.25	0.11	0.19	0.115	0.07	1.58
		Bi-weekly	I_2	0.18	0.22	0.13	0.1	0.07	0.045	1.23
		Weekly	I_1	0.16	0.23	0.39	0.2	0.17	0.09	1.28
		Bi-weekly	I_2	0.13	0.17	0.29	0.07	0.04	0.031	1.17

NCR is the tomato crop-N fertilizer requirements under sandy soil conditions,
I_1 is the injecting fertilizer in the range of (water: fertilizer: water): 0.25:0.50:0.25
I_2 is the injecting fertilizer in the range of (water: fertilizer: water): 0.33:0.33:0.33

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إدارة الري التسميدي تحت نظام الري بالتنقيط تحت السطحي لتحسين انتاجية الطماطم والبيئة الزراعية

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تم اجراء التجارب الحقلية بالمزرعة الصحراوية للتجارب والبحوث التابعة لكلية الزراعة – جامعة عين شمس بمنطقة البستان – محافظة البحيرة (والتي تمثل ظروف الأراضي الرملية بالزراعة المصرية) وذلك للوصول الى أفضل حزمة تكنولوجية لادارة تقانة الري التسميدي لزيادة انتاجية محصول الطماطم وتحسين البيئة الزراعية.

وقد أوضحت النتائج أن اضافة الاحتياجات السمادية النيتروجينية (١٠٠ كج / فدان) وذلك بفترات اضافة كل ١٥ يوم من خلال الحقن في الثلث الثاني من زمن الري تعتبر أفضل المعايير لادارة الري التسميدي لمحصول الطماطم تحت ظروف الأراضي الرملية.