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Effect of Fertigation Frequency from Subsurface Drip Irrigation on Tomato Yield Grown on Sandy Soil

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Abstract: Drip irrigation provides an efficient method of fertilizer delivery and allows precise timing and uniform distribution of applied nutrients. Fertilizer application through drip irrigation (fertigation) can reduce fertilizer usage and minimize groundwater pollution due to fertilizer leaching from excessive irrigation. Fertigation events can be scheduled as often as irrigation, up to several times per season. Optimum fertigation interval for drip-irrigated crops in general and for tomato in particular, is meager. A two-year field experiment was conducted on a sandy soil with subsurface drip-irrigated tomato to determine the effects of two N application rates and four-fertigation frequencies (intervals of 1, 3, 7, and 14 days) on tomato yield, N uptake and soil N status. Total tomato yield and yield components were responsive to N rate and to decreased fertigation frequency. The highest total fruit yields averaged (67.75, 65.13 and 63.29 - t/ha) with the frequencies of 1, 3 and 7 days respectively. Yields with the longest duration were significantly lower than these values (54.32 - t/ha). Wide differences in leaves N concentrations were observed in the early vegetative stage which mainly dependent on the rate of N supply. Although these differences gradually disappeared as season progressed, the differences in plant size remained until the end of the season. Similarly, N rate and fertigation frequency resulted in significantly differences in N uptake, N recovery and N use efficiency (NUE). Total N uptake was appreciable higher with increasing N rate and with more frequent than with less frequent fertigation. The averaged N recovery across fertigation frequencies was 60 and 54 % and NUE was 221 and 194 kg yield/kg N with 200 and 300 kg N/ha applied respectively. Analysis of soil samples following tomato harvest indicated considerable influence of fertigation frequency on NO_3^--N distribution in soil profile. The NO_3^--N in lower soil profiles (50-70 cm soil depth) with the high N rate treatments was marginally affected in daily, 3 days and weekly fertigation (15, 17 and 21 mg/kg soil), respectively. However, NO_3^--N in the corresponding soil depth was appreciable higher (80 mg/kg soil) in biweekly fertigation frequency, a fact which has important agronomic implications regarding the frequency of nitrate applications under drip irrigation.

Keywords: Drip irrigation, fertigation, frequency, nitrogen, tomato.

INTRODUCTION

Drip 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 frequencies (daily to monthly), depending on system design constraints, soil type and grower preference. Many studies have demonstrated drip-irrigated crop response to N (Hochmuth *et al.,* 1991; Thompson *et al.,* 2002). Drip irrigation and fertigation with N fertilizer sources offer what is probably the ultimate in flexibility for N fertilizer management. If properly managed, fertigation through drip irrigation lines can reduce overall fertilizer application rates and minimize adverse environmental impact of vegetable production.

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 (Silber1, *et al.,* 2003). Nutrient transport from the soil solution to the root surface takes place by two simultaneous processes: convection in the water flow (mass flow) and diffusion along the concentration gradient (Barber, 1995; Jungk, 1996). Soil properties, crop characteristics and growing conditions affect the relative importance of each mechanism, but the general situation is that the mobile NO_3^--N ion supply is taken up mainly through mass flow, while for less mobile elements such as P and K, diffusion is the governing mechanism

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(Claassen and Steingrobe, 1999; Mmolawa and Or, 2000; Nye and Tinker, 1977). The general wish to increase crop yields has led to frequent fertigation and, therefore, the time scale between successive fertigation events has diminished to hours, or even less.

Very frequent or continuous fertigation of drip-irrigated vegetables has often been recommended in the technical or popular literature (Stark et al., 1983; Tyler and Lorenz, 1991; Burt *et al.,* 1995). However, very few studies have shown a benefit of frequent or continuous fertigation compared to less frequent fertigation. Bar-Yosef and Sagiv (1982) advocated continuous fertigation of surface drip-irrigated tomatoes with concentrations of 100 to 200 mg N/l in the applied irrigation water. However, this resulted in N applications in excess of 1000 kg N/ha, far greater than N uptake by the plants; consequently N use efficiency (NUE) was as low as 30 %. Stark *et al.,* (1983) determined that 75 mg N/l was the optimum concentration for continuous fertigation of tomatoes with surface drip irrigation. Bhella and Wilcox (1985) advocated continuous fertigation of surface drip-irrigated muskmelon with 150 mg N/l and 50 mg N/l during vegetative and reproductive stages, respectively. Cook and Sanders (1991) examined the effect of fertigation frequency (daily to monthly) on subsurface drip-irrigated tomato yields in two South Carolina soils. Daily or weekly fertigation significantly increased yield compared with monthly fertigation, but there was no advantage of daily over weekly fertigation on loamy sand. The same fertigation frequencies resulted in no differences in yield and quality on a loamy fine sand soil. Locascio and Smajstrla (1995) found that surface drip-irrigated tomato yields with daily fertigation were not increased compared with yields with weekly fertigation on a fine sand. Locascio *et al.,* (1997) found that there were no differences in yield or quality of surface drip-irrigated tomato fertigated either 6 or 12 times per season. Similarly, yields of surface drip-irrigated pepper were not affected by fertigation interval (11 or 22 d) on a loamy sand soil (Neary et al., 1995).

However, it is often assumed that high-frequency fertigation for crops irrigated with low-flow irrigation systems is preferable to less frequent fertigation, there is scant evidence in the literature to support this viewpoint. This is true even for drip-irrigated vegetable crops grown in sandy soils, where high-frequency fertigation might be most beneficial. Therefore, the objectives of the present study are to 1- determine the effects of N application rate and fertigation frequency on tomato yield and total N uptake, and 2- develop best guidelines for N application frequency and rate for drip-irrigated tomato grown on sandy soil.

MATERIALS AND METHODS

Tow field experiments were conducted using subsurface drip irrigation at Sarabium area, Ismaillia province, east Cairo during 2004 and 2005 winter growing seasons. The soil is sandy in texture (86.5, sand, 9.2, silt and 4.3 % clay) with pH 8.2, EC 0.85 dS/m, $CaCO_3$ 1.5 %, O.M 0.03 %, F.C 11.5 % and SP 25 %. Available soil N, P and K in the surface layer 0-30 cm were 12, 7 and 38 mg/kg respectively before tomato planting. The entire amounts of P (150 kg/ha) and K (250 kg/ha) were broadcast as single super phosphate and potassium sulphate respectively before planting and incorporated into the soil beds. All N fertilizer was supplied as ammonium nitrate, injected directly into the irrigation water using venture-type injector. Before tomato planting, drip irrigation 40-cm emitter spacing delivering 4 liter per hour was buried 10-cm deep in raised soil beds, 1.5 m apart and 50-cm wide at the top. Plot size was 15-m long by 4.5 m wide.

Twenty-eight old seedlings of tomato 'Castle rock' variety (open pollinated cv.) were transplanted to the main field in double rows (40 cm apart) on the early of September 2004 and 2005 (32,000 plant/ha). Uniform irrigation was applied through the drip tubing to encourage the seedlings and stand establishment. Irrigation amounts to all treatments was scheduled based on evaporation replenished (0.75 class "A" pan evaporation). Reference crop evapotranspiration (ET_0) was calculated on a daily basis by using Penman–Monteith's formula (Allen et al., 1998). Amounts of irrigation water used after stand establishment were 375 and 348 mm for 2004 and 2005 respectively. The experiments were randomized complete block designs consisting of combinations of two N rates (200 and 300 kg N/ha and four fertigation frequencies at (1, 3, 7, and 14 days) intervals. The experimental design included unfertilized control plots and was replicated four times. Injection of N fertilizer was commenced following one week of tomato transplanting and continued up to 120 days. Leaves (20-25) were collected biweekly from each plot beginning after one month of establishment, dried at 70 ^{o}C, ground and digested with H_2SO_4 in the presence of H_2O_2 for analysis of total N according to standard methods described by (Jackson, 1973).

All aboveground biomass from within 1.2-m (4 plants) in each plot were collected at harvest and then dried, weighed, ground to 0.5 mm size. Samples of dry matter were digested and the concentration and uptake of N by plants were determined as described above. Soil samples were collected from each plot after harvest at the end of each growing season. The samples were taken from the horizontal and vertical directions of the

wetted area just after one hour of last fertigation events of each treatment at increments of 10-cm down to 70-cm depth. This was executed along with radial lines originating from at the water source at distances of 5-cm up to 30-cm. The samples from each depth increment were air-dried and ground to pass through 2-mm sieve. Analysis of 1 *M* KCl extractable NH_4^+-N and NO_3^--N was performed by the method described by Jackson, (1973).

Post harvest apparent N recovery was calculated as: $(N_t - No / N) \times 100$, where N_t equals the total aboveground crop N uptake under treatment, No equals N total uptake under control and N equals applied nitrogen. Apparent N use efficiency was calculated as: $(Y_t - Yo / K)$, where Y_t equals total yield under treatment, Yo equals total yield under control and N equal applied nitrogen. All equation variables are in units of kilogram per hectare. The average No and Yo was 23 kg N/ha and 4.56 ton/ha for the 2004 and 2005 growing season respectively.

RESULTS AND DISCUSSIONS

Tomato Yield and Yield Components:

During the two growing seasons, 2004 and 2005 total tomato yield and its components registered significant higher yield at the high N rate compare with low N rate (Table 1). Average total fruit yields across fertigation frequencies were 48.71 and 62.63 t/ha for (200 kg N/ha) and (300 kg N/ha) respectively. Overall yield and its components were generally more responsive to N application than to fertigation frequency within the range of this experiment. However, tomato is highly responsive to N, but application of excessive rates of N is rarely negatively affects quality (Huett and Dettmann, 1988).

Sainju *et al.,* (2001) also reported a positive response of surface drip-irrigated tomato yield and quality to increasing N rate, and found that marketable yields were maximized at N rates of 180 kg N/ha. There were statistically significant effects of fertigation frequency on yield and its components. Fertilizer N applied to the daily, 3 days and weekly fertigation treatments was always in advance of that applied to the biweekly fertigation treatments at the two N rates. Tomato yields were near the statewide variety average yield and the yield component most greatly affected was the number of fruits per plant, 23.2 versus 16.8 for the high N rate. With the high N rate treatments, the longest fertigation frequency (14 days) resulted in the greatest mean fruit weight (fruit diameter is a significant quality factor for fresh market tomato).

These results suggest that, for subsurface drip-irrigated tomato grown in sandy soil texture, fertigation frequency is a critical management variable affecting crop yields and their components. This could be an important consideration for growers who have system and management ability to fertigate continuously or at shorter duration. These results are in general agreement with results reported by several other authors. For example, Sousa, et al., (1999) found advantage of fertigation at 0.5 and 1-day intervals compared with 5-days intervals for surface drip-irrigated melon grown on a sandy soil. Cook and Sanders (1991) found that marketable yield and fruit size of subsurface drip-irrigated tomato were significantly higher with daily compared with biweekly or monthly fertigation on a loamy sand soil. Nwadukwe and Chude, (1994) reported that tomato yield was significantly different when N was fertigated at 5-days intervals compared with 9-days via a surface drip system. Patel and Rajput, (2005) found that daily, alternate day and weekly fertigation did not significantly affect yield of onion. The highest yield was recorded in daily fertigation followed by alternate day fertigation while the lowest in monthly fertigation. Application of 3.4 kg/ha urea in daily fertigation resulted in maximum yield of onion with least amount of NO_3^--N leaching.

Nitrogen Content:

Leaves N concentration was higher in the plants received the high N rate, but fertigation frequency did not significantly affect leaves N concentration except at longest period (Fig. 1). However, leaves N concentration in plants fertigated at biweekly intervals were significantly lower than those fertigated more frequently at the first sampling date. During the first 4 weeks, plants supplied with low N rate showed obvious visual symptoms of N deficiency (small plant size and light coloring).

Although the differences in plant color later disappeared, the differences in plant size remained until the end of both seasons. For high N rate, N concentration in the leaves decreased with time through the growing season as in general reported by (Stark, *et al.,* 1983). With both N rates, leaves N concentrations were below published critical levels (Rhoads, *et al.,* 1995; Locascio, *et al.,* 1997) for significant portion of the seasons. This time probably represents a period of adjustment during which the plant top and root system are modifying their relative growth rates to compensate low soil N. Thus, a higher rate of N applied preplant or at planting may have been beneficial during these periods.

Table 1: Yield and yield components of tomato plants as influenced by N application rate and fertigation frequency. (Mean of 2 seasons).

N rate kg/ha	Fertigation frequency	Tomato yield (t/ha)		Number of fruits per plant	Mean fruit weight (g)	Fruit yield kg / plant
		Fruits	Shoots			
200	Daily	52.54	3.45	20.4	85.8	1.75
3-days	50.76	3.38	19.5	83.6	1.63	
Weekly	49.18	3.29	19.2	82.3	1.58	
Biweekly	42.37	2.8	17.6	79	1.39	
300	Daily	67.75	4.11	23.2	97.9	2.27
3-days	65.13	3.95	22.5	94.7	2.13	
Weekly	63.29	3.87	21.6	93.5	2.02	
Biweekly	54.35	3.3	16.8	104.8	1.76	
LSD (P = 0.05)		4.76	0.38	1.8	6.4	0.15

Table 2: Nitrogen uptake, N recovery and NUE by tomato plants as influenced by N application rate and fertigation frequency. (Mean of 2 seasons).

N rateKg/ha	Fertigation frequency	N uptake - kg/ha			N recovery%	NUE
		Leaves	Fruits	Total		
200	Daily	56	103	159	68	240
3-days	51	99	150	64	231	
weekly	45	93	138	58	223	
Biweekly	34	85	119	48	189	
300	Daily	68	147	215	64	211
3-days	62	135	197	58	202	
weekly	56	127	183	53	196	
Biweekly	43	103	146	41	166	
LSD (P = 0.05)		7	16	24	-	14

Low leaves N concentration during the early part of the growing season might depress any potential benefits of increased fertigation frequency. The lack of any such benefit suggests that fertigation frequency was a critical management variable under the conditions of nutrient stress. The leaves N concentration for low N rate remained constant after week 8, indicating steady state stability had developed between N supplying power of the root system and N demand by the shoots. Creation and maintenance of constant relationship between shoot and root development has been reported under many conditions (Badr, 2002). Thus, though plants are smaller and essentially yield less, their N status, as reflected in leaves N concentration, is not distinctive from that of larger plants. The fertigation frequency affected the leaves N levels at weeks 4 and 8 for high N rate, but little difference was observed after 10 weeks. The decrease in concentration with time does not appear to be due to diminished supply because N application rates were maintained throughout the whole season, and significant quantities remained available in the root zone until the end of the experiment.

Crop response to fertigation frequency is likely a function of soil texture and irrigation management. Crops grown in coarse-textured soils, or crops grown during summer growing seasons, when higher amounts of water are applied, may benefit most from frequent, as opposed to infrequent fertigation. Positive crop response to frequent fertigation is most often seen in very coarse textured soils (Cook and Sanders, 1991), and a lack of crop response to frequent fertigation is more common when soils are finer than loamy sand (Locascio *et al.,* 1997). The influence of soil texture is very likely that soil clay content will largely determine cation-exchange capacity and hence nutrient-holding capacity, and rates of water and nutrient leaching are usually higher in coarse-textured than in fine-textured soils. Cook and Sanders (1991) observed that NO_3^--N concentrations within subsurface drip-irrigated vegetable beds were higher throughout a tomato-growing season in loamy fine sand compared with loamy sand, when both received equal amounts of N by fertigation.

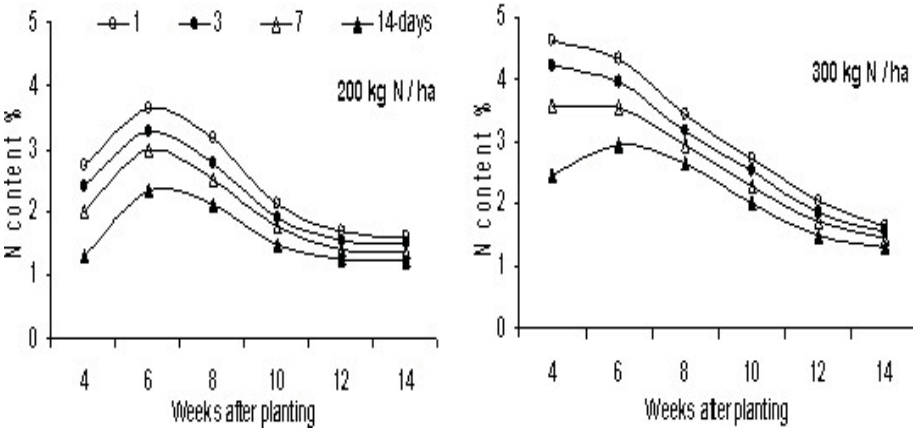

Fig 1: Leaves N concentration in tomato plants as influenced by N application rates and fertigation frequency. (Mean of 2 seasons).

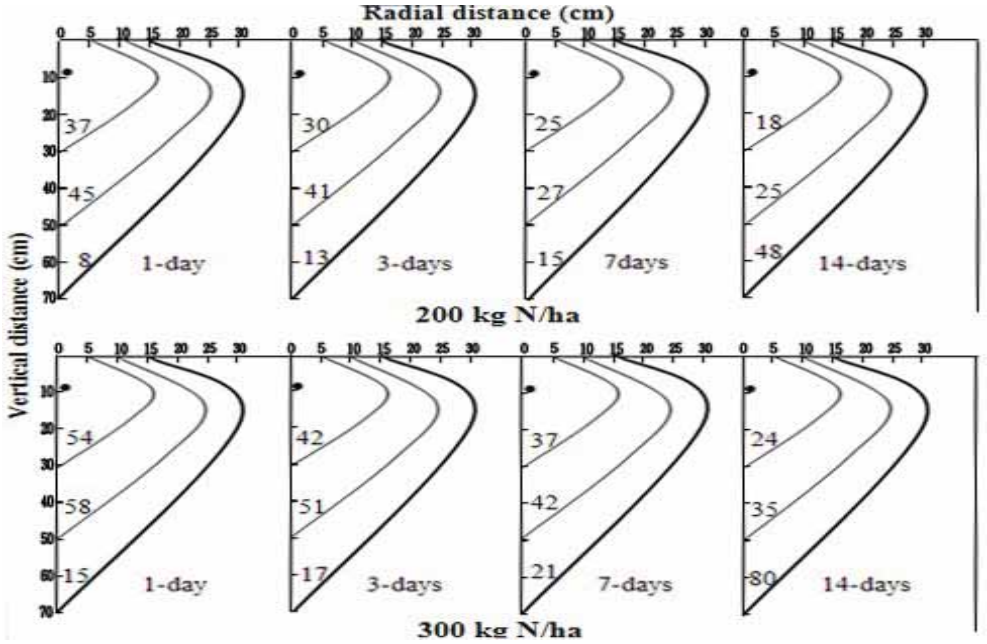

Fig. 2: Post harvest residual soil NO3--N concentrations as influenced by N application rate and fertigation frequency. Lines indicate contour of concentrations. The heavy peripheral lines are the position of the wetting fronts. (Mean of 2 seasons).

Nitrogen Uptake:

Results of N uptake by shoots and fruits confirm the trend observed in tomato yields (Table 2). Nitrogen uptake in leaves and fruits was directly related to N applied and fertigation frequency. With both N rates, frequent fertigation at shorter duration (daily, 3 days and weekly) intended to stimulate the pattern of tomato N uptake. With 200 kg N/ha applied, there were no significant differences among fertigation frequencies. N uptake in the fruits was significantly higher with daily than with biweekly fertigation.

With 300 kg N/ha applied, nitrogen uptake in leaves and total N uptake were significantly higher with daily fertigation than with weekly and biweekly fertigation. Other differences were not significantly different. In the high N treatment, nitrogen removal in the fruits with daily fertigation was as high as 147 kg N/ha, and total aboveground N uptake was as high as 215 kg N/ha. Apparent N use efficiency was significantly affected by both N rate and fertigation frequency (Table 2). NUE was significantly higher at the low N compared with

the high N rate. With both N rate treatments, NUE was significantly higher with daily compared with bi-weekly fertigation. When averaged across fertigation frequencies, NUE was 221 and 194 kg yield/kg N with 200 and 300 kg N/ha applied respectively. Stark et al. (1983) practiced continuous fertigation of surface drip-irrigated tomato on sandy soils; however, they reported NUE of 60 % even with 600 kg N/ha applied. Cook and Sanders (1991) reported that when equal amounts of N were applied via fertigation, soil NO3$^-$-N concentrations were higher throughout a growing season in a loamy fine sand compared with a loamy sand soil. Thompson, et al., (2003) also reported that NUE was significantly affected by N rate, but not by fertigation frequency. NUE was 90 % with 250 kg N/ha applied and 81% with 350 kg N/ha applied to broccoli plants in sandy loam soil.

Residual Soil N:

Very few studies have evaluated the effects of fertigation frequency on residual soil NO3$^-$-N; such evaluation can indicate the relative effects of fertigation treatments on N losses from cropping systems. In the present study, post harvest residual soil NO_3^--N appeared to be higher at the high N rate and was significantly affected by fertigation frequency (Fig. 2). Analysis of soil samples indicated considerable influence of fertigation frequency on NO_3^--N distribution in soil profile. Nitrate distribution for the different fertigation frequency showed a leached zone in the immediate vicinity of the drip line with concentrations much higher near the boundary of the wetted area. Residual soil NO_3^--N concentration with high N rate in lower soil profiles (50-70 cm soil depth) was marginally affected in daily, 3 days and weekly fertigation (15, 17 and 21 mg N/kg soil), respectively.

However, NO_3^--N concentration at the corresponding depth was more in biweekly fertigation frequency (80 mg N kg/soil). Nitrate was dispersed more uniformly in the upper part of the soil profile for daily application while nitrate distribution showed a zone of leached soil in the immediate vicinity of the drip line for the longer period with a zone of nitrate beyond the leached soil due to the relatively long irrigation time after fertigation. However, more nitrate leaching occurred for more longer frequent compared to the other less frequent durations. Below the surface layer, the roots were apparently very active in removing NO_3^--N as evidenced by the low residual concentrations at the greater depths. The concentrations of NH_4^+-N were very low (less than 4 mg/kg soil) and are not presented in details.

In general, agricultural practice, nutrients deficiency is prevented by increasing their concentrations in the irrigation water to levels that ensure optimal uptake by plants. Thus, as the period between successive irrigation events becomes longer, the nutrient concentrations in the root zone may be high or even excessive immediately after irrigation and may fall to deficit levels as time proceeds. Reducing the time interval between successive irrigations in order to maintain constant, optimal water content in the root zone may reduce the variations in nutrient concentration, thereby increasing their availability to plants and reducing their leaching beneath the root zone.

Finally, Nitrogen was applied by fertigation at daily, 3 days, weekly, or biweekly intervals from subsurface drip irrigation to grow tomato plants at two N application rates on sandy soil. Tomato yield was significantly affected by N rate and fertigation frequency. Fertigation frequency resulted in significant variations in residual soil NO_3^--N and NUE. It can be concluded that, provided growers manage irrigation properly, and use appropriate amounts of N; high-frequency fertigation is an important management variable for subsurface drip-irrigated tomato grown on sandy soil textures. Since leaching is possible with drip irrigation, nutrients applied in any irrigation must not be subjected to excessive irrigation either during that application or in subsequent irrigations. It is reasonable to assume, however, that more frequent fertigation may be needed for tomato grown on very coarse-textured soils, or for other crops that receive much higher amounts of irrigation water such as summer-grown crops.

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