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Tomato Fruit Yield and Nitrogen Use Efficiency as Affected by Drip Irrigation Method and Rate of Nitrogen in a Hot Dry Climate

1M.A. Badr, 1Shaymaa I. Shedeed and 2S.D. Abou Hussein

1Plant Nutrition Department, 2Vegetable Research Department, National Research Centre, Cairo, Egypt

ABSTRACT

Drip irrigation offers excellent method for crop production in arid and semi-arid regions where innovative and efficient of such irrigation technology can be used to improve water and nutrient management. The objective of this study was to determine the interactive effects between two irrigation methods namely, surface drip irrigation (SUR) and subsurface drip irrigation (SUB) and three N fertilizer rates (160, 220 and 280 kg ha\(^{-1}\)) on soil N distribution, crop N uptake, total biomass production, water use efficiency (WUE) and N use efficiency (NUE) of tomato grown on sandy soil. Tomato fruit yield appears to be mainly driven by soil moisture, nutrient distribution in the root zone and N application rate. Surface drip induces more water losses primarily in the upper soil layer, which exposed directly to the evaporation components. However, subsurface drip initially resulted in higher soil water content in the active part of root zone and maintained favorable growth conditions for tomato growth. For both drip irrigation methods, ammonium dominated close to the drip line at all times with low concentrations near the edges of the wetted zone. In contrast to ammonium, a uniform distribution of nitrate was found around the drip line after each fertigation with more even distribution under subsurface drip system. The average total fruit yield was significantly higher in subsurface drip (52.23 t ha\(^{-1}\)) over surface drip (45.74 t ha\(^{-1}\)), which accounted for 14.2% yield increase. Moreover, increasing N supply consistently increased tomato yields and N uptake benefits where N rate of 280 kg ha\(^{-1}\) result in higher fruit and shoot biomass. Nitrogen use efficiency for subsurface drip was significantly higher (240 kg yield kg\(^{-1}\) N) than for the conventional surface drip (209 kg yield kg\(^{-1}\) N) but reduced significantly under both drip irrigation methods with increasing N rate because of differences in total N inputs. Water use efficiency was also higher under subsurface drip and maximum value was obtained with the highest N rate. These results suggested that subsurface drip provides effective way to supply water and nutrients directly in the root zone and contribute immensely towards improving crop yield as well as water and nitrogen use efficiency.

Key words: tomato, drip irrigation, soil moisture, nitrogen distribution, nitrogen uptake, nitrogen use efficiency, water use efficiency.

Introduction

Tomato is the most important vegetable commodity in Egypt in terms of planted area and crop value. Egypt's tomato output has grown strongly over the past 15 years, from 5.03 million ton in 1995 to a record 8.55 million ton presenting a crop value of 3.16 billion dollars (FAO, 2010). In the same period, the tomato farming area actually increased, from 149,342 ha to 216,385 ha, with yields averaging around 34 tons per hectare. Drip irrigation is common cultural practices for vegetable crops particularly on low water retention soils, these techniques can reduce evaporation and thereby increase crop water use efficiency (Simonne et al., 2007). Moreover, use of drip irrigation also facilitates frequent fertilizer application via injection in the irrigation system, which allows growers to improve the simultaneity between nutrient application and crop nutrient uptake. On sandy soils, most of the N fertilizer is applied via injection in the drip lines during the crop growing season but excessively high N fertilizer and irrigation rates greatly increase the risk of nitrate leaching (Olson et al., 2005).

Nitrogen fertilizer may be injected in the drip irrigation systems using a number of different N compounds including urea, ammonium, or nitrate forms (Boman and Obreza, 2002). Regardless of the applied compound, under conditions that prevail in arid and semi-arid regions most of the soil N is rapidly converted into nitrate, which is more susceptible to leaching. Actual N distribution in the soil depends on N source and application rates, crop removal capacity, and water displacement below the active root zone. As the nitrate tends to accumulate towards the boundary of the wetted volume (Li, et al., 2004; Hanson et al., 2006) the use of irrigation strategies that limit the wetted volume in the root zone may improve water and nitrogen fertilizer use efficiency (Thind et al., 2008), as well as reducing nitrate leaching. The installation of drip irrigation tube below
the soil surface potentially reduces water losses due to soil evaporation thereby increasing water use efficiency (Ayars et al., 1999). The increase of irrigation water use efficiency should inherently minimize nitrate leaching for vegetable crops. The application of fertilizer through drip irrigation system should further reduce nitrate leaching by maintaining nutrients in the root system (Hebbar et al., 2004; Zotarelli et al., 2008).

Subsurface drip irrigation is an adaptation of drip irrigation, where the irrigation drip tube is installed below the soil surface to reduce water losses due to soil evaporation thereby increasing water use efficiency (Ayars et al., 1999; Patel and Rajput, 2007). A comprehensive review of published information on subsurface drip irrigation is given by Camp, (1998) to determine the state of the art on the subject. Subsurface drip systems are used to provide water to plant roots while maintaining a relatively dry soil surface, which ensures that the applied water becomes available to a substantial fraction of the plant root system. Drip irrigation using buried emitters has the potential to save irrigation water by reducing soil surface wetting and thus reducing evaporation components (Patel and Rajput, 2007; Kong et al., 2012).

As critical as irrigation management, both the timing and amount of N applied to the crop must be managed to fulfill crop N demands with fertilizer applications, so that any risk of N leaching is minimized. A better understanding of the interactions of irrigation method, soil type, crop root distribution, and uptake patterns and rates of water and nutrients provides improved means for proper and efficient drip irrigation water management practices (Hopmans and Bristow, 2002). A properly designed drip fertigation systems delivers water and nutrients at a rate, duration and frequency, so as to maximize crop water and nutrient uptake, while minimizing leaching of nutrients and chemicals from the root zone of agricultural fields (Gardenas et al., 2005). Nitrate leaching potential depends on soil properties, crops and crop rotation, irrigation methods, management practices and climatic parameters (Ajdary et al., 2007). This necessitates the development of appropriate water and fertilizer application strategies to maximize their application efficiency and minimize fertilizer losses through leaching. However, information is lacking about the interactive effects of water and nitrogen on crop performance for drip irrigated tomato production in arid climate. The objective of the present study was therefore, to determine how different drip irrigation methods and nitrogen rates affected the soil water and N distribution, crop yield, N and water use efficiency of tomato grown on sandy soil.

Materials and Methods

2.1. Location and soil of experimental site:

The field experiment was conducted at the Main Research Station, National Research Center located at Nubaria district west of Nile Delta of Egypt during the early summer (March-June) growing season of 2011. The research field is situated in an arid climate region (latitude of 30°30’N and longitude of 30°20’E), in a sandy soil (Entisol-Typic Torripsamments). During the growing season, climate of the experimental site was dry as usual with ineffective rainfall amounts of 4.2 mm, between planting and harvest. The mean monthly evapotranspiration ranged from 4.8 to 8.2 mm in the respective cropping season. The climate parameters recorded from March to June during the growth season of tomato are summarized in (Table 1). The soil of the experimental site was deep, well-drained sandy profile composing of 85.5% sand, 11.7% silt and 2.8% clay, with an alkaline pH of 8.2, EC of 0.85 dS m⁻¹, CaCO₃ 1.5%. Average available N, P and K from surface soil layer down to 60 cm depth at 20 cm intervals was 7, 4 and 38 mg kg⁻¹ soil, respectively before the initiation of the experiment. The average soil water content at field capacity from surface soil layer down to 80 cm depth at 20 cm intervals was 0.18 (v/v) and the permanent wilting point for the corresponding depths was 0.08 (v/v), respectively.

Table 1: Average of maximum (Tmax) and minimum (Tmin) air temperature, relative humidity, rainfall and reference evapotranspiration (ET0) during the growing season.

<table>
<thead>
<tr>
<th>Month</th>
<th>Tmax (°C)</th>
<th>Tmin (°C)</th>
<th>Relative humidity (%)</th>
<th>Rainfall (mm)</th>
<th>ET0 (mm)</th>
<th>Wind speed (km h⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>March</td>
<td>18.3</td>
<td>10.4</td>
<td>47</td>
<td>2.8</td>
<td>4.8</td>
<td>8.2</td>
</tr>
<tr>
<td>Ariel</td>
<td>27.6</td>
<td>13.2</td>
<td>43</td>
<td>1.0</td>
<td>6.1</td>
<td>8.5</td>
</tr>
<tr>
<td>May</td>
<td>30.7</td>
<td>16.1</td>
<td>42</td>
<td>0.4</td>
<td>7.2</td>
<td>8.2</td>
</tr>
<tr>
<td>June</td>
<td>33.8</td>
<td>19.2</td>
<td>43</td>
<td>0.0</td>
<td>8.2</td>
<td>8.2</td>
</tr>
</tbody>
</table>

2.2. Experimental design and treatments:

The experiment was laid in a complete factorial design consisting of combination of two drip irrigation methods and three nitrogen rates. The irrigation methods included surface drip irrigation (SUR) and subsurface drip irrigation (SUB) as main factor and three nitrogen levels included 160 (N160), 220 (N220) and 280 (N280) as the sub main factor. The experimental design included unfertilized control plots and was replicated three times in 4.5 m wide × 15.0 m long plots of each treatment. Before tomato transplanting, drip tubing (twin-wall GR, 15 mm inner diameter, 40 cm dripper spacing delivering 2.5 liter h⁻¹ at operating pressure 100 kPa) were either
placed on soil surface or buried at 15 cm soil depth at 1.5 meter apart under different N-rate in each row at the center of the soil beds. Subsurface drip system was placed at the shallowest soil depth possibly, consistent with lower capillary forces prevalent in sandy soil. Twenty-five day old seedlings of tomato (*Lycopersicon esculentum* Mill) cultivar ‘Castel Rock’ were transplanted to the main field (32 000 plants per hectare) in early March 2010. The plants were arranged into double rows, 40 cm apart and 25 cm intervals along the row, in north south oriented soil beds pre-furrowed to receive 40 t ha⁻¹ of organic manure and provided with one drip line for each treatment. The total amount of N at variable levels was applied as ammonium nitrate, which was injected directly into the main line of drip system in water-soluble form using venturi-tube injector. Nitrogen fertilizer was applied at weekly intervals in 12 equal doses of N starting one week after transplanting and stopped 30 days prior to the end of the crop period. All treatments received the same amount of phosphorus, 150 kg P ha⁻¹ (phosphoric acid) and 250 kg K ha⁻¹ (potassium sulphate) for the season, which were injected weekly with water through drip system, from the first week after transplanting until the last week of April.

2.3. Estimation of crop water requirement:

Reference crop evapotranspiration (ETo) was calculated from weather station of the Central Laboratory of Agricultural Climate for Nubaria province on a daily basis by using Penman-Monteith’s semi-empirical formula (Allen *et al.*, 1998). The actual evapotranspiration was estimated by multiplying reference evapotranspiration with crop coefficient values (ETc = ETo × Kc) for different months based on crop growth stages. Tomato is about 145 days duration crop and it may be divide into four stages, namely initial, 30 days; developmental, 40 days; middle, 45 days; and tuber maturity, 30 days. The crop coefficient during the crop season was 0.45, 0.75, 1.15 and 0.80 at initial, developmental, middle and maturity stages, respectively (Allen *et al.*, 1998). The ETo value during the irrigation differential period was 695 mm and the total actual amount of irrigation water applied during the growing season was 472 mm for both drip irrigation methods. Irrigation frequency was running daily and began in the early March and ended 30 June, 15 days before last harvest.

2.4. Soil water and soil N measurements:

The volumetric water content on the wetted soil volume of the bed was monitored every 4 hours at interval between 14 and 30 DAT by time domain reflectometry (TDR) probes (PICO-BT). The TDR probes were installed vertically under the dripper to measure the soil moisture in the profile at 10, 40 and 60 cm depth and 5 cm from the irrigation drip line across both drip irrigation treatments receiving N-rate of 280 kg ha⁻¹. To determine spatial distribution of ammonium and nitrate in the wetted area for each drip irrigation system, soil samples were collected taken from below the drippers at depths of 10 cm down to 70 cm along with a radial line originating at the point-source at distances of 5 cm up to 35 cm using tube auger from the wetted area. The samples were collected from each plot at end of first fertigation, end of next irrigation, end of second fertigation and end of last fertigation. Treatments sampled included the highest rate of N for both surface and subsurface drip irrigation system. Composite samples were placed on ice and refrigerated until further analysis. The samples from each depth increment were air-dried and ground to pass through 2-mm sieve. Analysis of 2 M KCl extractable ammonium and nitrate were performed by steam distillation (Keeney and Nelson, 1982).

2.5. Plant N uptake and yield:

Maximum biomass production included vegetative and reproductive plant parts was evaluated by harvesting three representative plants per treatment replicate at 90 DAT and was also used for nitrogen uptake analysis. Shoot and fruit tissues were dried at 70 °C in a forced air oven for subsequent dry weight analysis. Dried plant samples were then ground to pass through a 0.5 mm screen and total N was determined by the micro-Kjeldahl method (Bremner and Mulvaney, 1982). Seasonal N uptake was derived from the whole plant sample data and N uptake was calculated as the product of crop dry weight and the N concentrations in the plant tissues. Plant nitrogen uptake was calculated by multiplying weights of stems plus leaves and fruit tissue by the corresponding N concentrations. Tomato fruits were collected periodically and at last pick of fruits all aboveground biomass in each plot were collected from 50 randomly selected plants in each plot in all the replications and weighed to determined total yield of shoots and fruits and data were presented as ton per hectare.

2.6. Water and nitrogen use efficiency:

Water use efficiency (WUE) was calculated from the total fruit yield (kg ha⁻¹) divided by seasonal crop water applied for each irrigation treatment during the growing season and expressed as kg yield⁻¹ mm⁻¹. Nitrogen use efficiency (NUE) was calculated using the following equation:
NUE = \frac{(Y_t - Y_o)}{N}

where \( Y_t \) equals total yield under treatment, \( Y_o \) equals total yield under control and \( N \) equals applied nitrogen. All equation variables are in units of kilogram per hectare. The average crop \( N \) uptake from the unfertilized field plots (\( N_o \)) and total yield from the same plots (\( Y_o \)) were 8 kg N ha\(^{-1}\) and 0.750 t ha\(^{-1}\), respectively for the growing season.

2.7. Statistical analysis:

Experimental data were subjected to the analysis of variance (ANOVA) appropriate to the experimental design to evaluate the effects of treatments on crop \( N \) uptake, total yield, dry biomass production and water and \( N \) use efficiency by the plants. CoStat (Version 6.303, CoHort, USA, 1998-2004) was used to conduct the analysis of variance. Least significant differences (LSD) were used for means separation at 5% probability level.

Results and Discussion

3.1. Soil moisture content:

During initial crop stage, when plant canopy was still young and soil surface area exposed to direct evaporation, soil moisture content was monitored across the wetted soil volume at interval between 15 and 30 DAT under both drip irrigation methods received N-rate of 280 kg ha\(^{-1}\). Soil moisture content was related to the position of drip line where soil surface layer 0-10 cm appeared moist with surface drip while the soil surface remained relatively dry with subsurface drip (Fig. 1). After each irrigation event, moisture content at soil surface increased to about 0.35 cm cm\(^{-1}\) soil with surface drip in comparison to 15 cm cm\(^{-1}\) soil in subsurface drip. However, water delivered on top soil in surface drip exposed directly to evaporation components, which resulted in very pronounced soil moisture fluctuations at soil surface. These soil moisture contents under surface drip reached to soil field capacity or more and as a result the excess soil moisture was moved to deeper soil layers, which may indicates vertical displacement and leaching fraction.

By comparison, subsurface drip resulted in a relatively small increase in soil moisture content at soil surface; the upward capillary movement of water was not sufficient to reach top soil and consequently in minimal vertical displacement and leaching fraction. Although subsurface drip was buried at 15 cm soil depth but a great deal amount of soil water remained at the root zone for plants utilization and was not lost due to deep percolation. As a result, fluctuations in soil moisture content at surface soil layer 0-10 cm were minimal as most of the applied water was retained under soil surface for plant needs. Further, the buried drip line in subsurface treatment produced relatively constant soil moisture values over time in the root zone 10-40 cm depth, where the fluctuation in soil moisture content were considerably lower and irrigation water distributed more evenly across soil profile according to the soil moisture capacity. As a result, subsurface drip showed little variation in soil moisture at 40-60 cm soil depth, indicating that the volume of water applied did not exceed soil field capacity, consequently reducing water movement and thus facilitating more efficient water and nutrient for plant use. Therefore, subsurface drip seems to be more suited to effectively address the limitation of low water storage capacity of sandy soils and could preserve more water efficiently for plant uptake.

![Fig. 1: Soil moisture content at different depths between 15 and 30 DAT of tomato for (A), surface and (B), subsurface drip irrigation.](image-url)
Similar indication of water distribution in the soil profile was noted by Zotarelli et al. (2009) who found that irrigation systems can sustain high yields while reducing irrigation application as well as reducing nitrate leaching in coarse texture soils. Philip (1991) and Meshkat et al. (2000) reported that moving of water through the soil to the surface becomes limiting as the soil surface dries, which resulted in smaller soil evaporation loss there by repressing the upward movement of water. This finding holds, both in terms of amount of available water and distribution uniformity by placing the drip line sufficiently below the soil surface, which ensures that applied water becomes available to the most active part of crop root zone and also cuts of evaporation losses due to restricted upward capillary flow (Patel and Rajpat, 2008). Therefore, placing the drip line within the crop root level below the soil surface replenishes water effectively, which have positive effects on water savings and thus increase the irrigation efficiency.

3.2. Soil ammonium distribution:

Ammonium concentrations with surface drip were existed mostly in the upper soil layer and restricted to a small wetted soil volume around the drip line (Fig. 2). This was the case at all the times, as the fertilizer is highly adsorbed by the soil particles, preventing its movement further down the soil profile. Some slight preferential lateral movement was occurred, likely because of soil adsorption and subsequent occasional soil particles saturation and/or root uptake. At the end of fertigation period, ammonium concentration did not show any marked accumulation in the soil profile as a result of relatively quick nitrification and slow transport due to adsorption. Similar distribution patterns were observed for other experiments (Li et al., 2003; Hanson et al., 2006).

Fig. 2: Soil ammonium concentration (mg kg⁻¹) under N rate of 280 kg ha⁻¹ for selected times during growth season, (A): end of first fertigation (7 DAT), (B): beginning of second fertigation (14 DAT), (C): end of third fertigation (21 DAT) and (D): end of fertigation period (90 DAT). The heavy peripheral lines present the position of the wetting fronts.

Subsurface drip caused a uniform and more extended ammonium distribution throughout the wetted soil volume compared to surface drip where the capillary forces, through carrying ammonium to larger soil volume around the root system, controlled spatial distribution patterns. As for surface drip, the highest ammonium concentrations occurred near the dripper but since the drip line is buried 15 cm under soil surface, thereby carrying ammonia to deeper soil depth. Concentrations of ammonium were relatively higher in the root zone with subsurface drip placement compared to surface drip, which was reflected in the relatively higher amounts
of ammonium being retained in the wetted zone. This result is likely because of most wetted soil volume occurred under soil surface which prevents ammonium volatilization from surface soil layer.

3.3. Soil nitrate distribution:

The distribution of nitrate was considerable, with surface drip treatment nitrate was found near the drip line immediately after first fertigation due to injection of the fertilizer, but little nitrate remained near the drip line at the beginning of second fertigation, because of root uptake and dispersion during downward transport (Fig. 3). However, by the start of the third fertigation, nitrate concentrations increased near the drip line as a result of nitrate injection and nitrification of ammonium during the growing season. Nitrate moved to deeper layer with the advance of the experiment and at the last fertigation event, the nitrate peak was found at the edge of the wetting front. At this time, most of the nitrate distributed near the periphery of the wetted region due to subsequent irrigation cycles.

For subsurface drip, fertigation of nitrate resulted in a different distribution patterns from that observed for surface drip. However, nitrate distributed more uniformly throughout the wetted zone as compared to surface drip; the nitrate concentrations above and below the drip line were almost equal due to capillary upward movement during fertigation. In both drip irrigation methods, the predominance of downward water movement led the displacement of the fertilizer solution occurring preferentially underneath the dripper in vertical direction with a gradual increase in the lateral direction. This trend was similar for all the sampling points at different distances from the dripper with a gradual increase in the laterals of the wetted zone. The phenomenon that nitrate accumulated at the boundary of the wetted volume was also found for the continuous application of nutrients during an irrigation in a previous studies (Santos et al., 1997; Mailhol et al., 2001; Hanson et al., 2006).

**Fig. 3:** Soil nitrate concentration (mg kg⁻¹) under N rate of 280 kg ha⁻¹ for selected times during growth season, (A): end of first fertigation (7 DAT), (B): beginning of second fertigation (14 DAT), (C): end of third fertigation (21 DAT) and (D): end of fertigation period (90 DAT). The heavy peripheral lines present the position of the wetting fronts.

Nitrate is very mobile in the soil and has a tendency to move away from the dripper to the periphery of the wetting front (Li, et al., 2003; Ajdary et al., 2007). However, the distribution of nitrate in the soil profile was perfect under subsurface drip. The design of the drip irrigation system coupled with best management can, therefore, optimize both water and fertilizer use by a crop. Zotarelli et al., (2009), reported that surface drip
treatment applied a certain volume of irrigation water according to the soil moisture and plant requirement, which reduced water percolation and consequently maintained fertilizer in the root zone, which was reflected in the relatively higher amounts of ammonium and nitrate being retained in the root zone.

3.4. Tomato yield and N uptake:

The use of different drip irrigation methods and N rates showed significant interactions on tomato biomass production and N uptake therefore, both factors were analyzed together. Subsurface drip irrigation registered higher total tomato yield (52.23 t ha\(^{-1}\)) over drip irrigation system (45.74 t ha\(^{-1}\)), which accounted for 14.2% yield increase (Table 2). Further, the difference in the dry matter production due to different treatments can be referring to the vegetative growth of shoots. The better performance under subsurface drip was attributed to maintenance of favorable soil water and nutrient status in the root zone, which create an adequate environment in soil plant system and helped for proper growth conditions.

**Table 2:** Tomato yield, biomass production, N uptake, water use efficiency (WUE) and N use efficiency (NUE) as affected by drip irrigation methods and rates of nitrogen.

<table>
<thead>
<tr>
<th>Main effect</th>
<th>Biomass (kg ha(^{-1}))</th>
<th>N uptake kg ha(^{-1})</th>
<th>WUE kg ha(^{-1}) mm(^{-1})</th>
<th>NUE (kg kg(^{-1}) N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fruit Shoot DW Total DW</td>
<td>Fruit Shoot Total</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Drip system</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>SUR</td>
<td>45.74 1.41 3.93 94 38 132</td>
<td>97 209</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SUB</td>
<td>52.23 1.62 4.49 104 42 147</td>
<td>111 240</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>N-rate kg ha(^{-1})</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N(_{160})</td>
<td>41.77 1.25 3.54 83 32 115</td>
<td>88 256</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N(_{220})</td>
<td>49.56 1.53 4.25 100 40 140</td>
<td>105 222</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N(_{280})</td>
<td>55.63 1.77 4.83 114 48 163</td>
<td>118 196</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SUR</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>N(_{160})</td>
<td>38.76 1.15 3.28 78 30 109</td>
<td>82 238</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N(_{220})</td>
<td>45.85 1.41 3.93 94 38 132</td>
<td>97 205</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N(_{280})</td>
<td>52.62 1.68 4.57 109 46 155</td>
<td>112 185</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SUB</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N(_{160})</td>
<td>44.78 1.35 3.79 88 34 122</td>
<td>95 275</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N(_{220})</td>
<td>53.26 1.64 4.57 106 42 148</td>
<td>113 239</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N(_{280})</td>
<td>58.64 1.87 5.10 119 49 170</td>
<td>124 207</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>LSD (5%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigation (I)</td>
<td>2.21 0.04 0.18 4.50 1.76 6.12</td>
<td>4.70 13.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen (N)</td>
<td>3.09 0.09 0.26 6.23 2.51 8.78</td>
<td>6.57 15.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I × N</td>
<td>4.37 0.13 0.37 8.81 3.55 12.42</td>
<td>9.29 21.27</td>
<td></td>
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</tr>
</tbody>
</table>

LSD (5%): least significant difference at probability level 5%.

Overall shoot (leaves and stem) dry weight ranged between 1.41 and 1.62 t ha\(^{-1}\) over the irrigation methods, with major variations of shoot dry weight between N rates. The average fruit harvest indices (HI = fruit dry weight/total above ground dry weight at harvest) was 0.64 for both drip irrigation methods. Overall HI across N-rates was the same as observed in both drip irrigation methods and related to favorable growth conditions enhanced initial canopy development, greater water use and fruit dry biomass. Across N rates, the use of subsurface drip statistically increased shoot dry weight and accumulated about 15% increase compared to the use of surface drip treatment. There were major differences between applied N-rates where the increase of N from 160 to 220 kg ha\(^{-1}\) resulted in an increase of 19% of fruit yield and from 220 to 280 kg ha\(^{-1}\) the increase in fruit dry weight was only 13%. The corresponding increase in shoot dry weight with applied N rates was 22% and 16%, respectively. As a result, tomato plant N nutrition was drastically enhanced by subsurface drip and N content in fruits and shoots were significant greater. The leaf N concentration found in plants received 280 kg N ha\(^{-1}\) was in the range of optimum leaf N concentration reported by Hochmuth (1994) and Hartz et al., (1998). The higher shoot and fruit dry weights in subsurface showed 12% higher N uptake than in surface drip, which may be related to the higher N concentration in the root zone of measured by soil sampling. Although N concentrations in shoots and fruits were relatively lower at most crop growth periods, subsurface drip resulted in higher daily and total N uptake compared to surface drip (data not shown). The observed decrease in plant N concentration was expected as related to more favorable growth conditions resulting in an increase of biomass production thus resulting in nutrient dilution in dry matter.
A detailed performance of plant above ground N uptake and daily N uptake during the growing season showed significant effect for drip irrigation method and N rate (Fig. 4). Difference among irrigation treatments was began at the end of initial stage and most pronounced during the reproductive stage. Total plant N uptake was appreciably higher under subsurface drip at most growth stages compared to surface drip. During the first 30 DAT, the plant vegetative growth showed higher daily N uptake capacity for both drip irrigation methods. Overall maximum N uptake rates peaked for surface drip around 42 DAT with a rate of 2.07 kg ha$^{-1}$ of N day$^{-1}$, while for subsurface drip, N uptake rate peaked around the same period with a rate of 2.21 kg ha$^{-1}$ of N day$^{-1}$, respectively. Maximum daily N uptake occurred between 42 and 56 DAT and the peaks were 1.86, 2.29 and 2.57 kg ha$^{-1}$ day$^{-1}$ for N rates of 160, 220, and 280 kg ha$^{-1}$, respectively. Lower N supply appeared to reduce crop N uptake, as reflected by low leaf N content and in turn, N limitations hamper full canopy development and crop yield (Scholberg et al., 2000). However, adequate N supply through subsurface drip showed a clear advantage over surface drip in reducing water and nutrient losses in the root zone and sustains the vegetative biomass production and N uptake.

3.5. Water and N use efficiency:

Water use efficiency was significantly affected by drip irrigation method and N-rates (Table 2). At the same quantity of water, WUE values for subsurface drip were always higher than those for surface drip and increased with increasing N application rate. The increase in WUE was conditioned by N rate and continued to the level of N at which the fruit production was highest in all the treatments. Since the source of water is at a certain depth when subsurface drip is used, the soil surface usually remains drier than for the surface drip treatment. This leads to the reduction of evaporation from the soil surface and consequently to an increase in transpiration and overall water use efficiency (Romero et al., 2004). Higher WUE for subsurface drip might be owing to more water available to each plant primarily due to the ability of applying water and nutrients to the most active part of the root zone and less soil surface area is available for direct evaporation (Enciso et al., 2005; Lamm and Camp, 2007).

Nitrogen use efficiency was significantly higher with the use of subsurface drip, which was related to relatively higher N concentrations in the root zone, thus enhancing N uptake efficiency (Table 2). The NUE
increased with decrease in rate of N applied in both drip irrigation methods to the extent at which maximum fruit yield was obtained. Linear NUE values decreased with increasing N rates may be related to limitation in uptake and sink capacities resulting in a saturation response (law of the diminishing returns). Although higher N rates increased tissue N concentrations, overall NUE values decreased with higher N rates. However, NUE was influenced greatly by the N amount, the most efficient treatments being those which received less amount of N indicating that NUE was inversely proportional to the amount of N applied. Similar trend was observed by Aujla et al., 2007 and Cabello et al., 2009, who found that plants grown under limiting nitrogen supply extracted more N from the soil in order to sustain crop N demand. This higher utilization may be attributed to extraction of more nitrogen under N-stress conditions in order to sustain crop N demand.

4. Conclusions:

Tomato plants received to different combinations of drip irrigation method (surface or subsurface) and N rates in an arid region. Subsurface drip preserved more water efficiently for plant use and showed superior water and nutrients utilization as related to reduced displacement of both water and nitrogen below the root zone. Ammonium remained concentrated near the water source at all times, an area where root density is greatest and most of the plant root uptake takes place while nitrate moved readily with the irrigation water away from source. Across N rates, subsurface drip resulted in significant higher tomato yield (52.23 t ha\(^{-1}\)) over drip irrigation (45.74 t ha\(^{-1}\)) and gave higher NUE (240 kg yield gk\(^{-1}\) N) and considerable WUE (111 kg ha\(^{-1}\) mm\(^{-1}\)), respectively. Total plant N uptake was affected by irrigation and N rate and total above-ground plant N (shoot and fruit) accumulation followed the same pattern of plant biomass accumulation. Better performance under subsurface drip might be owing to more water available to each plant due to less soil surface area was available for direct evaporation where most wetting volume occurred around the center of the root zone. These results indicate that subsurface drip can sustain profitable yield due to better water and nitrogen distribution in the soil, which was conducive for good growth and tomato yield.

References


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