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# Nitrogen requirements for growth and early fruit development of drip-irrigated processing tomato (*Lycopersicon esculentum* Mill.) in Portugal

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**Abstract**

The effect of continuous application of small quantities of nitrogen (N) in irrigation water and N applied as starter on growth and development of processing tomato, from transplanting to beginning of fruit set, was studied in two experiments — a pot experiment and a field trial. The pot experiment was carried out with eight treatments, including two soil types and four levels of N application (13.2, 18.2, 28.2 and 48.2 mg/L of N). The field trial consisted of four N treatments, including a control with only 6.4 mg/L of N available naturally in the irrigation water, 15 kg/ha of N applied at pre-plant, 15 kg/ha of N applied at pre-plant plus 20 mg/L of N applied continuously during irrigation, and 15 kg $ha^{-1}$ N applied at pre-plant plus 40 mg/L of N applied continuously during irrigation. Plant growth was significantly affected by soil type and N level under controlled conditions, increasing linearly in luvisol (sandy loam) and regosol (sand) soil at an average rate of 0.52 and 0.64 g dry weight per mg N in the irrigation water, respectively. However, under field conditions in luvisol soil, additional N, whether added at pre-plant or continuously during irrigation, had no effect on any measure of aboveground plant growth, including leaf area, plant dry weight or early fruit production, but reduced root length density below ground. Overall, N in the irrigation water was sufficient for the young tomato plants between planting and fruit set, and adding more N at pre-plant or by fertigation only resulted in luxury N consumption.

***Key words:*** *Lycopersicon esculentum*, drip irrigation, luxury consumption, nitrogen fertilizer, root length density.

## Introduction

Many agricultural regions in the world have high amounts of N in the groundwater due to $NO_3$ leaching from fertilizers [1, 2]. This is especially a problem in Portugal where the levels can reach as high as 10-35 mg/L of $NO_3$-N [3, 4]. It is frequently pointed out that in order to reduce the input of fertilizer and improve groundwater quality, growers using groundwater for irrigation must consider the amount of N in the water when deciding how much fertilizer to apply to a crop [5, 6]. High amounts of N in the irrigation water can have a preponderant influence on plant growth and development, particularly since N transport to the root surface moves predominantly by mass flow [7, 8].

Many high cash-value crops grown in arid and semi-arid regions are irrigated by drip. In drip-irrigated systems, the root system is concentrated in a relatively small volume near the emitters. This effective volume is even more reduced during the period between transplanting and fruit set when root systems are still small [9]. Consequently, the volume of soil that contributes to plant N nutrition is extremely limited during establishment, and application of N fertilizer is therefore usually recommended prior to planting[10]. In processing tomato, usually 20% of the total N fertilizer applied over the season is added at pre-plant, which in most Mediterranean regions is a time when rain events are still relatively frequent. Little is known of how much of this starter fertilizer is actually used by the crop during early stages of development and how much is actually lost by leaching [11].

The objective of the present study was to determine the effect of N from irrigation water and N applied at pre-plant on early growth and development in processing tomato. We hypothesized that N levels in the groundwater typical of tomato growing regions in Portugal would be adequate to maximize growth from transplanting to fruit set without any additional N from N fertilizer.

## Material and Methods

***Experiment 1*:** Eighty tomato (*Lycopersicon esculentum* 'H9656') seedlings were transplanted at 40 days after emergence into individual 12-L plastic pots (21-cm high x 27-cm diameter) filled with 14 kg of luvisol sandy loam soil obtained from the Mitra Research Farm in Évora, Portugal, or 14 kg of regosol sandy soil obtained from Antonio Teixeira Research Station, Coruche, Portugal. Characteristics of the soils are shown in Table 1. Each pot was fertilized with 1.95 g of $P_2O_5$, 5.00 g of $K_2O$, 2.55 g of CaO and 0.16 g of MgO prior to transplanting and placed outdoors at the Mitra Research Farm immediately after transplanting.

Plants in both soil types were irrigated with water containing 13.2, 18.2, 28.2 or 48.2 mg/L N, which included 8.2±1.8 mg/L of $NO_3$-N already in the water naturally plus 5, 10, 20 and 40 mg/L of N, respectively, mixed from $NH_4NO_3$. Water pH was 7.6-7.8 and never exceeded an electrical conductivity of 0.5 dS/m. Irrigation was scheduled based on daily evapotranspiration requirements of the crop and were applied by drip using one 1 L/h pressure-compensating emitter (Netafim, Tel Aviv, Israel) per pot. Each pot received approximately 15 L of irrigation and 4 L of rain over the

entire study. Total N applied per plant at each N level was 198, 273, 423 and 723 mg, respectively.

Plants were harvested at 40 days after transplanting. Shoots were cut off at the soil surface and separated into stems, leaves and immature fruit, and roots were washed from the soil. Each component was then oven-dried at 70ºC for 2-3 days and weighed.

**Table 1.** Physical and chemical characteristics of the soils used in Experiment 1.

| Characteristic | Soil type[1] | |
|---|---|---|
| | Luvisol | Regosol |
| Sand (%) | 72.6 | 92.6 |
| Silt (%) | 11.7 | 1.7 |
| Clay (%) | 15.7 | 5.7 |
| Bulk density (g/cm$^3$) | 1.48 | 1.51 |
| Organic matter (%) | 2.26 | 1.09 |
| pH ($H_2O$) | 6.84 | 6.08 |
| $NO_3^-$ (mg g$^{-1}$) | 66 | 20 |
| $P_2O_5$ (mg g$^{-1}$) | 250 | 144 |
| $K_2O$(mg g$^{-1}$) | 200 | 114 |
| $Ca^{2+}$ (meq/100g) | 7.47 | 2.00 |
| $Mg^{2+}$ (meq/100g) | 0.96 | 0.21 |

[1] Soils were collected from the top 40 cm of the soil profile.

***Experiment 2:*** A field trial was planted on 10 May 2005 in luvisol soil located at the Mitra Research Farm. 'H9656' tomato seedlings were transplanted at 40 days after emergence and spaced 0.2 m within rows x 1.5 m between rows. The experiment was comprised of four treatments: N0 – control (soil N + irrigation water N); NI (soil N + irrigation water N + 15 kg/ha N applied at pre-plant), NII (soil N + irrigation water N + 15 kg/ha N applied at pre-plant + 20 mg/L N applied continually to the irrigation water, NIII (soil N + irrigation water N + 15 kg/ha N applied at pre-plant + 40 mg/L N applied continually to the irrigation water). Since the irrigation water already contained 6.4±1.8 mg/L of $NO_3$-N, the total amount of N applied continually during irrigation in each treatment was 6.4 mg/L to N0 and NI, 26.4 mg/L to NII and 46.4 mg/L to NIII.

The experiment was arranged in a randomised block design with four replications per treatment. Each treatment plot was 5-m long and consisted of five rows of 25 plants each. Approximately 167 kg/ha of $K_2O$ from $K_2SO_4$, 5.3 kg/ha of MgO from $MgSO_4$, and pre-plant N treatments from $NH_4NO_3$ were applied in a 10-cm wide band directly in the row just prior to transplanting. Plants were irrigated by a single lateral of drip tape (Netafim, Tel Aviv, Israel) with 1 L/h pressure-compensating emitters spaced every 0.2 m, positioned near the middle of the row. Irrigation was applied daily and ranged from 0.73 to 3.63 mm/d. Each plant received approximately 19.7 L of irrigation and 16.1 L of rain during the study. Total N applied per plant at each N level was 126, 576, 970 and 1364 mg, respectively.

Root distribution was determined by collecting soil cores at 40 days after transplanting in three randomly selected replicates per treatment. Cores (7-cm diameter) were collected perpendicular to three plants per plot at a distance of 0.4 m from the plant row. Each core was 0.4-m deep and separated into 0.1-m increments. Roots were washed from the cores using a hydro-pneumatic elutriation root separation system [12] and total root length was measured using a Comair root length scanner (Hawker De Havilland Victoria Ltd., Port Melbourne, Victoria, Australia). Root length density (cm roots per cm$^3$ soil) was calculated by dividing total root length by volume of the cores (385 cm$^3$).

Four representative plants were harvested at 43 days after transplanting from each plot at fruit set, separated into leaf and stem components, oven-dried at 70ºC for 2-3 days and weighed. The leaf area of each plant was also determined prior to drying using a leaf area meter (model MK2, Delta-T Devices, Cambridge, UK); leaf area index was calculated by dividing total leaf area by the area of soil occupied by each plant. Leaf N and leaf petiole $NO_3$-N was also measured at harvest following procedures outlined by Hochmuth [13]. Briefly, approximately 50 of the most recently matured leaves were randomly collected from each plot and divided into petioles and leaf blades. The petioles were cut and immediately stored in sealed plastic bags and transported on ice in an insulated cooler from the field to the laboratory. Four to five drops of extracted sap were then placed directly on the sensor pad of a Cardy nitrate meter (Horiba, Kyota, Japan) for analysis. The blades were oven-dried at 70ºC for 24 h, ground, and analyzed for total N using a combustion analyser [14].

***Statistical analysis*:** Data were analyzed by analysis of variance using SPSS software (Chicago, Illinois, USA) and means were separated at the 5% level using Fisher's least significant difference (LSD) test.

## Results

***Experiment 1*:** Each treatment displayed at least one visual symptom of N deficiency, such as dwarfed growth, a thin, upright habit, rigid stems and petioles, thick, pale-green leaves, purple tint on the leaf veins and petioles, and, in the most extreme cases, yellowing and sencescence of the older leaves. Symptoms were especially prominent in plants fertilized with ≤ 273 mg of N.

Leaf, stem, root, and total plant dry weight were significantly affected by N level ($P < 0.01$), increasing linearly with the total amount of N applied (Fig. 1). Leaf and total dry weight were also significantly affected by soil type ($P < 0.001$), where plants grown on luvisol produced more biomass than those grown on regosol (Table 2). No component of dry weight, however, was affected by N level * soil type interactions, including fruit dry weight, which was similar at each N level and soil type and averaged 0.43-0.72 g/plant (or 1.5-2.5 fruit/plant).

Plants grown at high N generally allocated relatively less biomass to roots ($P < 0.01$) and relatively more biomass to stems ($P < 0.01$) than those grown at low N levels (Fig. 2). Plants also allocated relatively less biomass to roots ($P < 0.01$) and relatively more biomass to stems ($P < 0.001$) when grown on luvisol than on regosol (Table 2). Like dry weight, biomass allocation was not affected by N level * soil type interactions.

**Table 2.** Effect of soil type on dry weight and biomass allocation in pot-grown processing tomatoes (Experiment 1).

| Soil type | Dry weight (g) | | Root:shoot dry weight ratio | Stem:leaf dry weight ratio |
|---|---|---|---|---|
| | Leaf | Total | | |
| Luvisol | 14.5 a[1] | 28.3 a | 0.26 b | 0.48 a |
| Regosol | 12.4 b | 24.3 b | 0.33 a | 0.43 b |

[1] Different letters within columns indicate a significant difference at the 5% level.

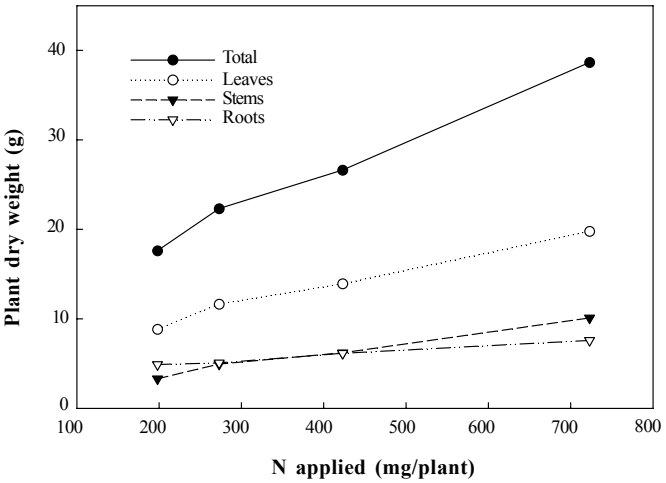


***Figure 1.*** Effect of various amounts of N in irrigation water and soil on leaf, stem, root, and total dry weight of tomato plants grown in pots under controlled conditions (Experiment 1).

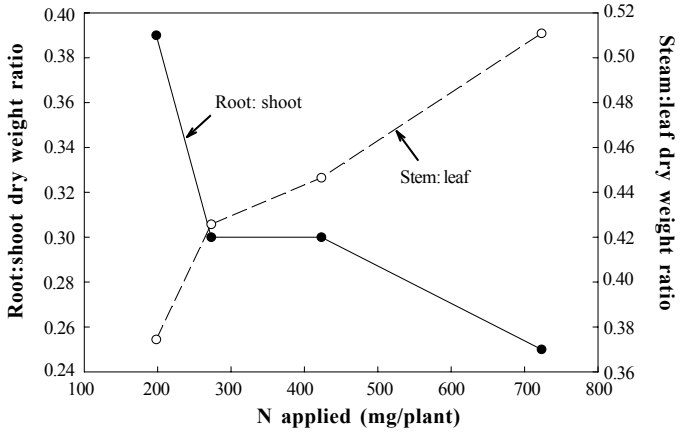


***Figure 2.*** Effect of various amounts of N in irrigation water and soil on dry weight distribution of tomato plants grown in pots under controlled conditions (Experiment 1).

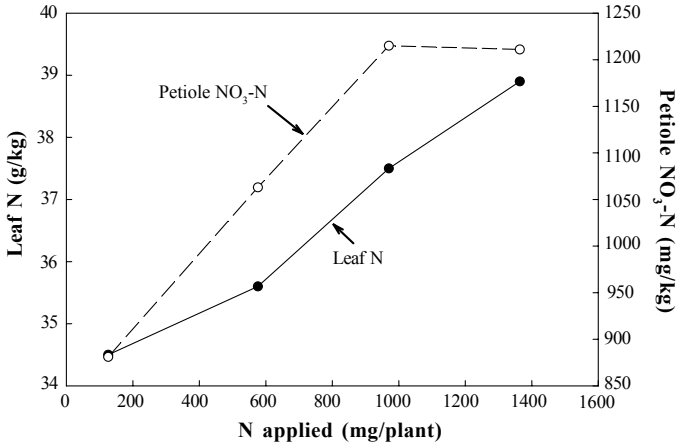


***Figure 3.*** Total leaf N and leaf petiole $NO_3$-N in tomato plants grown with 126 (N0), 576 (NI), 969 (NII) or 1362 (NIII) mg N $plant^{-1}$ (Experiment 2).

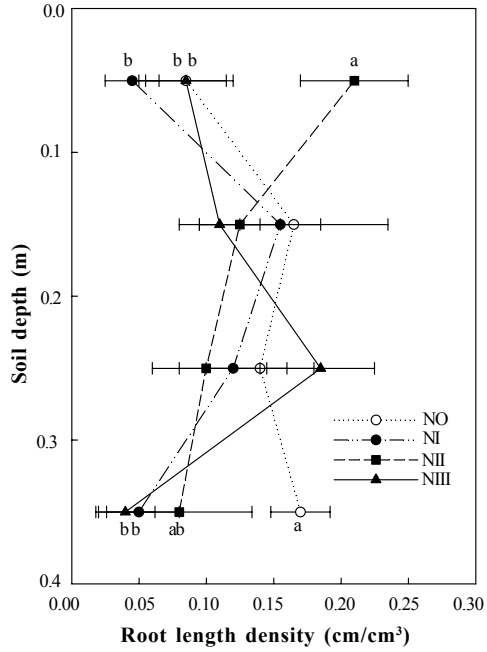


***Figure 4.*** Root length density at 10-cm depth increments in tomato plants grown with 126 (N0), 576 (NI), 969 (NII), or 1362 (NIII) mg N $plant^{-1}$ (Experiment 2). Each symbol represents the mean of three replicates and error bars represent SE of the mean. Analysis of variance indicated that N treatment had a significant effect ($P < 0.05$) at 0-10 and 30-40 cm depths but not at 10-20 and 20-30 cm depths. Means were separated by LSD at the 5% level.

***Experiment 2:*** Nitrogen deficiency was not evident in any treatment in the field study. Leaf, stem and fruit dry weight was similar among N treatments and averaged 46.5, 29.0 and 1.9 g/plant, respectively. Leaf area index was also similar among the treatments, ranging from 1.9 to 2.3, despite the fact that leaf N ($P < 0.01$) and petiole $NO_3$-N ($P < 0.10$) increased with the total amount of N applied (Fig. 3).

Root length density at 40 days after planting differed among N treatments and was significantly affected by the interaction between N level and soil depth (Fig. 4). Densities ranged 0.05-0.23 $cm/cm^3$ at 0-0.4 m but generally increased with depth in low N plants (i.e. 126 mg N per plant). Root length densities were more variable among the other treatments, but additional N (i.e. 576-1364 mg N per plant) consistently resulted in lower root length density at 0.3-0.4 m depth (Fig. 4).

## Discussion

Plant growth was unaffected by N treatment under field conditions, indicating that N in the irrigation water was sufficient for the young tomato plants between planting and fruit set. As mentioned above, the irrigation water contained 6.4 mg/L $NO_3$-N. Apparently, adding more N at pre-plant or by fertigation only resulted in luxury N consumption. However, this additional N may be beneficial later on, such as during fruit production, when demands for N are much higher [15, 16].

Leaf N ranged from 34.5 to 38.9 g/kg in the field study, while leaf petiole $NO_3$-N ranged from 880 to 1200 mg/kg. These values were comparable to drip-irrigated tomatoes at the same stage of development produced in California, USA [17, 18], and higher, even when no fertilizer was added, than those produced under greenhouse and field conditions in Florida, USA [19].

Under more controlled conditions (i.e. Expt. 1), residual N from soil and organic matter was high and similar to the field trial (i.e. Expt. 2), but N limited plant growth, especially in the lighter regosol soil. This suggests that soil volume plays a considerable role in plant response to N application. Roots undoubtedly explored more soil volume in the field than in pots. Soil N may have also migrated into the root zone from the area beyond that wetted by the drip emitters. Nitrate-N, in particular, moves readily to the roots by mass flow as water is absorbed by the plants during transpiration [8]. Precipitation could also increase N mass flow and diffusion and perhaps encourage root growth outside the drip zone [20].

In conclusion, plant biomass was affected by N application and soil type in pots, increasing linearly in both sandy loam and sandy soil as more N was added during irrigation. Dry-mass partitioning was also affected in pots, where the root:shoot ratio decreased and stem:leaf ratio increased as N was applied. Others observed similar results in young tomato plants [21,22]. Under field conditions, however, neither leaf, stem nor fruit growth was affected by N application beyond the amount already naturally available in the irrigation water. Future experiments will be established to find out if precipitation or the volume of the soil explored by roots was responsible for the lack of response up to fruit set . More work is also underway to determine how N in the irrigation water affects N requirements after fruit set.

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