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NUTRIENT LEVELS IN A PRODUCTIVE CYCLE OF HYDROPONIC TOMATO CROP

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Abstract

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Analysis of nutrient solution (NS) recycling and non-recycling treatments in a hydroponic tomato crop was studied. The aims of the study were to measure nutrient concentration variations along the productive cycle in both treatments, to clarify the differences regarding fruit yield and to assess recycling system viability. Emitter and drained nutrient solution samples from both treatments were analyzed once per week, tomato samples were collected three times per week and they were measured and weighed.

The average nitrate concentration in the inlet of the recycling treatment was 11.60 meq/l. The concentration increased by 7.01% in the leachate solution. The average sulfate concentration was 8.07 meq/l in the recycling system supplied solution, and 146.47% higher in leachates. The calcium ion concentration in the recycling system inlet was 9.48 meq/l. The concentration increased by 21.26% in the drained solution. Three analyzed nutrients, i.e. phosphates, potassium and ammonium, presented a lower concentration in the drained solution than in the supplied solution. Average yield per plant was 7.17 kg/plant. Fruit yield was not increased by the recycling technique in the hydroponic crop. No significant differences were found regarding fruit yield, except for the commercialized smallest size tomatoes (57-67 mm diameter), whose production was 226% higher in the non-recycling area. Recycling treatment viability has to be measured in terms of water and fertilizer savings and minimization of polluting waste in drainage solutions.

Key words: concentrations, no recycling, recycling, tomato, yield

Introduction

Recirculation consists of gathering leachates, formed as a result of excessive water supplies, as well as adjusting the nutritional imbalance in the solution caused by the absorption processes of the plant. Once the imbalance is corrected, reintroducing to the crop to the resultant solution with a new one occurs, thereby establishing a closed system.

Experiments carried out under Mediterranean conditions on tomato plants grown in a closed system using an NS recommended by the Dutch greenhouse industry (Feltrin et al., 2012) showed the accumulation of ions less used by the crop as well as the accumulation of the main macronutrients in the recirculation solution, especially in the high evapotranspiration period. This accumulation requires a high frequency of NS renewal, which leads to the release of conspicuous quantities of minerals into the environment (Giuffrida and Leonardi, 2009).

Tomato is a plant that adapts better to warm environments. It needs temperatures over 15°C to grow, and is unfavorably affected by long exposures to temperatures under 10ºC. Better quality plants are obtained when night temperatures are 5.5°C lower than daily ones (Resh, 1997). The ideal temperature is 24-26°C during the daytime and 18-20°C at night. In the cold season, these temperatures are lower. In a cold climate, the absortion of phosphorus is lower, and the need of heating systems increases CO_2 emissions, with a high environmental impact that needs to be minimized (Page et al., 2011).

The main objective of the present study was to compare variations in the nutrients provided in the solution in two treatments, i.e. with and without recirculation. The drained

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solution was collected during the reproductive cycle and fruit production was assessed in these systems. We attempted to find alternatives in order to minimize the environmental impact caused by drainage by means of recycling these nutrient solutions.

Materials and Methods

The study was carried out in the facilities of the Caserío Pelegriñe located in San Sebastián (Gipuzkoa), Spain. Coordinates: latitude 43º18'24'' N, longitude 02º02'22'' W, altitude 104 m above sea level.

The test was carried out in a multi-tunnel greenhouse whose outer structure is made from methyl polymethacrylate slabs. The greenhouse surface is 3000 m^2 divided into ten plots, five on each side of a central corridor. Two 280 m^2 plots were selected: one for the non-recycling tomato crop and the other for the recycling nutrient solution system.

The chosen substrate was perlite, with a particle diameter of 1.5 mm, a density of 0.105-0.125 g/cm^3, and a total volume of 13.4 l/m^2. Perlite sacks contained 30 l and the sack density was 0.4 $sack/m^2$. The perlite sacks had an exit drainage hole on the base. Each sack had three emitters that were not placed on the stem to avoid infection the plant density was 1.6 $plant/m^2$, with four plants in each sack.

Conditions inside the greenhouse were regulated by a climate controller. The minimum temperatures to activate heating were 15°C/18°C night/day and the maximum temperatures to activate zenithal ventilation were 19°C/21°C night/day.

The tomato variety used in the study was Jack, hybrid F1, plants with few foliage, tomatoes type Beef (fleshy), very smooth and with a slightly green stem.

Plants were sown on 17/01/2012, and transplanted to the perlite sacks on 03/03/2012 (week 1); recirculation began on 03/04/2012 (week 6) and harvest was carried out between 19/05/2012 and 20/07/2012 (weeks 13-19).

Table 1 provides data on the irrigation water and nutrient solution composition used during the test period. The nutrient solution was pumped at a flow rate of 3 l/h for 6 minutes, for 464 plants. We started on-demand irrigation program one month after the tomatoes were planted on the perlite substrate.

The design was a simple random sampling, with two treatments, i.e. plots with recirculation and plots without recirculation. Each plot contained 116 bags of perlite, from which 12 sacks were chosen randomly (12 replicates) for yield testing. The sampling unit was the mean value of the four plants contained in each bag, 4-6 fruit clusters in each plant. Four sacks were randomly chosen in each plot to analyze the nutrients in the emitter and drainage solution. An emitter and a drained water sample from both treatments were analyzed once per week in the laboratory: four repetitions per treatment (four sacks with recirculation and four sacks without recirculation).

For the yield study, fruits were collected from 48 plants per treatment three times per week. Tomatoes were measured in five categories according to their diameter expressed in mm: >77, 67-77, 57-67, 47-57 and <47; tomatoes were also weighed.

The determination of nitrates, sulfates, calcium, magnesium and potassium was performed by ion chromatography with ionic suppression and conductivity detection (IC Professional 861, Metrohm, Switzerland).

Ammonium and phosphates were determined using an FIA auto-analyzer, with the stannous chloride method and diffusion through a membrane for ammonium (FIAStar 5000, Foss, Denmark).

Nutrient solution samples were analyzed once per week in the agronomic laboratory of Fraisoro (Zizurkil, Gipuzkoa).

A variance analysis, ANOVA with one factor, was carried out for total fruit yield and for fruit size-based production. The SAS statistical package version 8 (SAS, 1999) was used.

Results

The balance and concentration of the supplied solution were not the same as those found in the substrate, because the absorption concentrations were different from the supplied ones. Therefore, these were modified in the solution retained in the substrate. We readjusted the nutrient solution as a factor of the automatic control of fertilization allowed by the ir-

Table 1
Chemical composition of water and the nutrient solution used in the study

	Anions mM					Cations mM						
	NO_3^-	$H_2PO_4^-$	SO_4^{2-}	HCO_3^-	Cl^-	NH_4^+	K^+	Ca^{2+}	Mg^{2+}	Na^+	pH	CE mS/cm
Water	0	0	0.91	4	0.5	0	0	2.22	0.15	0.8		
Addition	13.75	1.5	2.7	0	0	1.25	8.75	2.03	1.85	0		
Final solution	13.75	1.5	3.61	0.5	0.5	1.25	8.75	4.25	2	0.8	6	2.0

rigation head in each treatment. The concentration of the different ions was chosen independently in both treatments.

Nitrate

Figure 1 shows the difference between the incoming solution and the drained one. The drained solution concentrations were increased by 30 to 50%. Fertilizer saving was about 43.64%. The nitrate concentration in the emitters in the non-recycling system had an average value of 13.14 ± 1.97 meq/l. In the recycling system emitter average concentration was 11.60 ± 1.02 meq/l. The nitrate content in the recycling system nutrient solution was 7.42% higher, while in the non-recycling system, the average concentration was 14.38% higher. The concentration variations in the drained solution were more noticeable in the non-recycling system, as can be observed in Figure 1.

Absorption maximum values were reached during the fructification period (weeks 14-16).

Orthophosphates

It can be observed that the phosphate use pattern was very regular (Figure 2). The observed concentrations were slightly higher than in the non-recycling system, although this was not reflected in a higher fruit yield. The average phosphorus concentration in the recycling system emitters was 1.03 ± 0.38 meq/l and 1.50 ± 0.38 meq/l in the non-recycling system. A decrease in concentration of 51.04% and 35.66%, respectively, was observed in the drainage solution.

Both systems followed a similar pattern, with the maximum value approximately one week before the beginning of the harvest (week 12) and another at the end of May-beginning of June which coincided with a decrease in the outside temperature.

Recirculation provided 43.45% savings for this nutrient, which is an important benefit from the environmental point of view as phosphorus is the cause of lake and aquifer eutrophication.

Sulfates

The weekly sulfate average concentration is shown in Figure 3. The average sulfate value in the non-recycling system emitters was 8.07 ± 1.79 meq/l and 8.12 ± 0.90 meq/l in the recycling system. This anion concentration increased by 146.47% in the leachate solution in the recycling system and by 136.30% in the non-recycling system. Sulfate tended to concentrate in the substrate in a way that suggested the regulation of this fertilizer must be stricter.

It can be seen that drainage sulfate concentrations were higher than the supplied ones. This fact can be explained be-

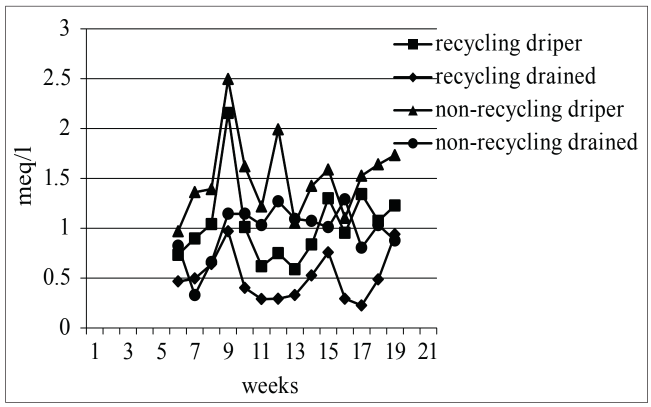

Fig. 2. Orthophosphate concentration variation in the hydroponic tomato crop

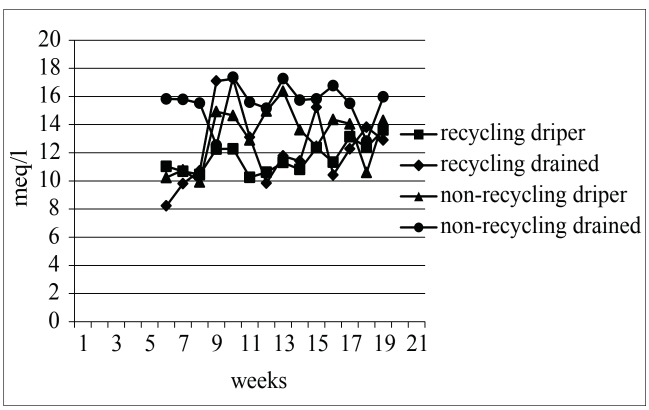

Fig. 1. Nitrate concentration variation in the hydroponic tomato crop

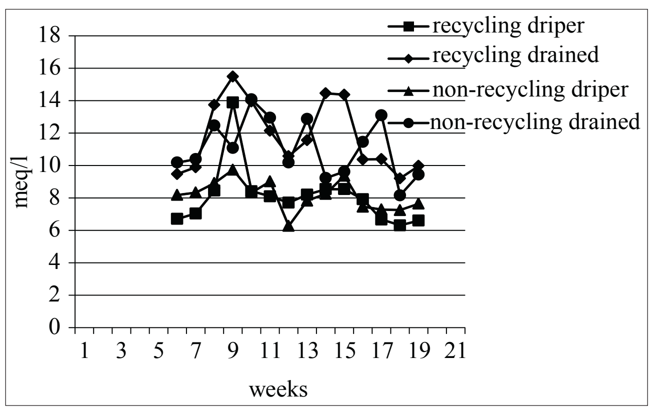

Fig. 3. Sulfate concentration variation in the hydroponic tomato crop

cause the absorption rate is lower than the rate applied and accumulates in substrate. Absorption varied, with much defined maximum and minimum values.

Ammonium

Ammonium concentrations are shown in Figure 4. The emitter average ammonium concentrations in the recycling system were 0.74 ± 0.31 meq/l. There were higher concentrations in the non-recycling system, 0.83 ± 0.32 meq/l. Ammonium use was greater in the recycling system where its concentration dropped by 93.19% compared to the provided concentration. The concentration dropped by an average of 80.8% in the non-recycling system.

Leachate concentrations were very low compared to the provided ones, but they did not disappear. The absorption curves for the recycling and non-recycling systems were very different.

Potassium

The potassium concentrations found in the study are shown in Figure 5. The emitter average concentration was 6.49 ± 0.67 meq/l in the recycling system and 9.56 ± 1.28 meq/l in the non-recycling system. The average concentration in the drained solution was 5.23% lower in the recycling system and 34.71% lower in the non-recycling system. The concentration of potassium in the non-recycling system was much higher.

Absorption was highly variable with much defined maximum and minimum values in both treatments. These peaks were observed before the harvest, for one week at the end of May-beginning of June when temperature decreased, and in the last weeks of cultivation. A 45.77% savings was achieved with this element in the recycling system compared to the non-recycling system.

Calcium

The variations in the calcium concentrations in both systems are shown in Figure 6. The emitter average concentration in the recycling system was 9.48 ± 0.73 meq/l and 13.38 ± 2.02 meq/l in the non-recycling system. In the drained solution, the concentration increased by 21.26% and 24.48%, respectively. An accumulation of this ion was seen in the drained solution.

Both contributions and absorption presented their maximum values in the weeks immediately before the harvest.

The leachate solution concentrations presented higher values in the recycling treatment compared to the supplied ones. This did not happen in the non-recycling system. The absorption curves of both systems followed similar dynamics.

Magnesium

The weekly variations in the magnesium concentration are shown in Figure 7. The average magnesium concentra-

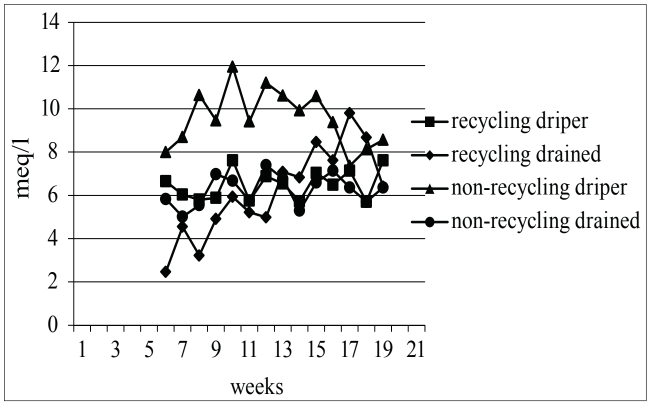

Fig. 5. Potassium concentration variation in the hydroponic tomato crop

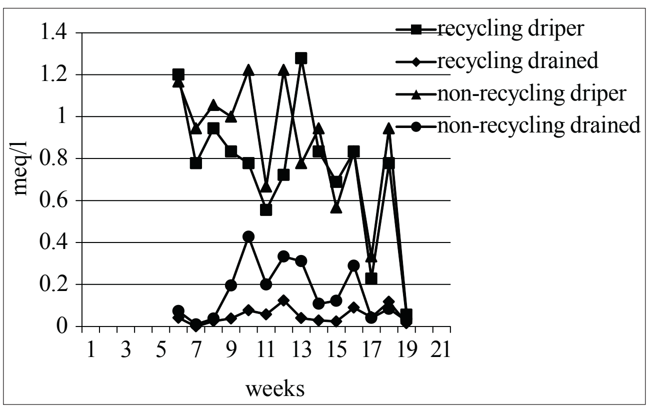

Fig. 4. Ammonium concentration variation in the hydroponic tomato crop

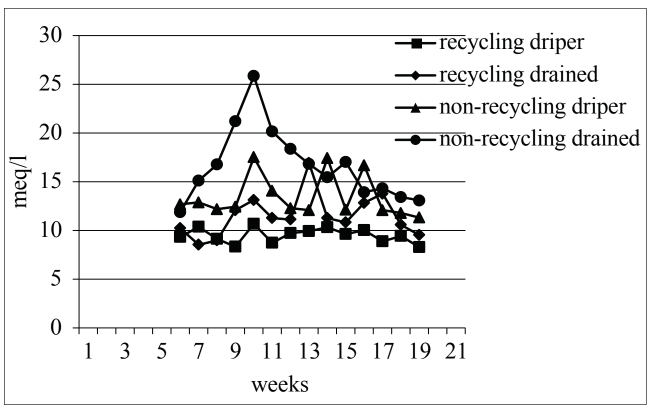

Fig. 6. Calcium concentration variation in the hydroponic tomato crop

tion in the recycling system was 4.45 ± 0.42 meq/l. The average concentration in the non-recycling system was 4.89 ± 0.38 meq/l. This ion was present at a higher concentration in the drained solution. The magnesium concentration increased by 19.98% in the recycling system and by 8.26% in the non-recycling system. Magnesium absorption was similar in both treatments. Higher levels were observed in the drained nutrient solutions than in the supplied solutions, which indicate that the magnesium transport rate was greater than its absorption rate. Magnesium absorption evolution was similar in both systems and a maximum was seen one week before the start of the harvest, as occurred with the majority of the elements discussed above.

The weekly average yield per plant is shown in Figure 8. It is represented by tomato weight, collected during the harvest in both treatments. Weekly average yield per plant ranged between 205.6 g/plant and 1124.8 g/plant. An average production of 7.08 kg/plant was obtained in the recycling system compared to 7.26 kg/plant in the non-recycling system. These differences were not significant. Fruit yield followed a similar pattern in both treatments. The decrease detected in week 14 in the non-recycling treatment was likely due to a temperature decrease that affected these plants. Harvest started on 19/05 (week 13) and finished on 20/07 in 2012. The increase detected at week 21 was caused by the recollection of all the plants in order to uproot them and start a new crop in the greenhouse.

Table 2 provides the results of fruit yield in the tested plants and the ANOVA carried out with these data and sized-based fruit production for both treatments with 12 repetitions per treatment. There were no significant differences regarding total fruit yield in both treatments. An analysis of size-based production showed that there were no significant differences for tomatoes with diameter >77 mm, nor in the tomatoes between 67 and 77 mm in diameter. There were differences in the tomatoes with a diameter of 57-67 mm, where there was 226.1% higher production in the non-recycling system compared to the recycling system. This is the minimum commercialized diameter. Regarding smaller sizes, which are not marketable, differences between one cultivation method and the other were not significant.

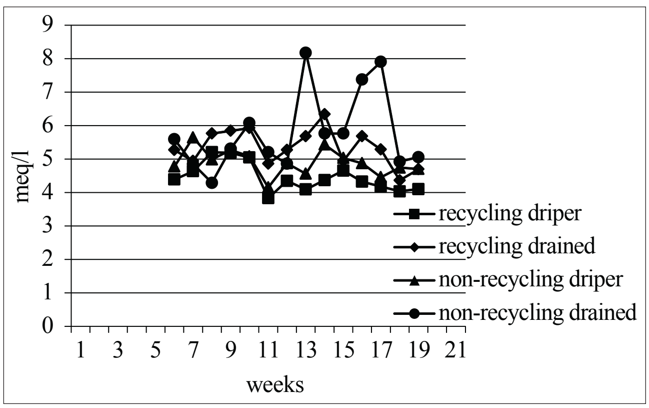

Fig. 7. Magnesium concentration variation in the hydroponic tomato crop

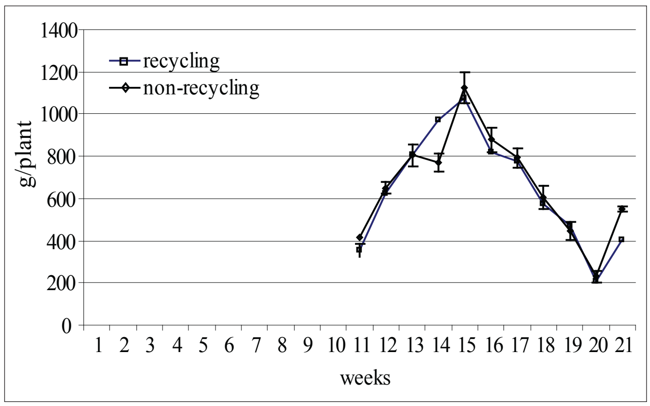

Fig. 8. Average fruit yield per plant (g/plant) in both plots during the productive cycle

Table 2
Production of 48 tested plants (kg) and variance analysis of total tomato production and production according to tomato size, ns 95%, ** 99%, * 99.5%**

	Recycling	Non-recycling	SS	df	P	
Diameter > 77 mm	281.09	250.79	885.2858	23	0.1895	ns
Diameter 67-77 mm	45.89	50.11	47.0902	23	0.4694	ns
Diameter 57-67 mm	10.86	35.39	169.8726	23	0.0001	***
Diameter < 57 mm	1.29	8.25	20.3985	23	0.0069	**
Disorder	0.56	0.58				
Total production	339.69	345.12	19916.6251	23	0.7810	ns

Discussion

The balance and concentrations in the supplied solution were not the same as those found in the substrate because the absorbed concentrations were different to the supplied ones, as they were oxidized or reduced in the solution retained in the substrate (Vergote and Vermeulen, 2012). The nitrogen concentrations found in this study coincide with those found by Marfà et al. (2000), with a higher value in the leachate solution. On the contrary, Dhakal et al. (2005) found a decrease in nitrogen concentrations in the drained solution in a tomato crop under tropical conditions. A low concentration does not have an influence on fruit yield, although its influence is greater in terms of the amount of plant biomass (Giuffrida and Leonardi, 2009; Caetano et al., 2013).

This fertilizer savings achieved similar values to those determined by Echer et al. (2012) in a nutrient solution recycling system. The highest absorbed nitrogen values were found during fructification, which coincides with the results of Feltrin et al. (2012). This fact is important from an economic point of view because it is the most influential one regarding final fertilizer expenses, and from an environmental point of view because nitrogen causes subterranean water pollution.

The average phosphate concentration in the emitter solution was 1.25 meq/l, which indicates better use of this ion. These results coincide with those of Kano et al. (2012) in a lettuce crop, but differ from those found by Marfà et al. (2000) who used high phosphate concentrations in the emitters, and found excess phosphate in the leachate solution. Phosphorus needs are lower than the supplied levels leading to inefficient use of this fertilizer. To provide smaller amounts, its use was optimized and greater concentration decreases were found in the drained solution.

Regarding sulfates, a higher concentration was found in the leachate solution than in the emitters, so an excess of this ion was being provided. These results coincide with the results of Lorenzo et al. (2000) in a cucumber crop. According Vergote and Vermeulen (2012), tomato plants should be cultivated under conditions where sulfates are the predominant salt. This provokes sulfur accumulation in their organs, but hardly any variation is observed in fruit yield.

Ammonium was optimally used during the productive process and very low concentrations were found in the drained solutions, although this level was not zero, as shown by Zahedifar et al. (2012). These data coincide with the results of Kempkes and Stanghellini (2003).

Potassium requirements are very low in a tomato crop, although the higher contribution of potassium in the non-recycling system irrigation solution provoked greater absorption by the plant. The concentrations found coincide with the results obtained by Giuffrida and Leonardi (2009). According to Caetano et al. (2013), potassium is used above the necessary levels for fruit crops. This consumption can only be explained by the better quality of the obtained fruit. The potassium concentration in the non-recycling solution was extremely high, and there was a large amount of potassium in the drained solution. The recycling system presented a better balance between the provided amount and the amount recovered in the drained solution.

Calcium accumulated and increased in the drained solution. Its concentration was greater than that in the emitters. Calcium accumulation was also shown in two previous studies (Marfà and Blanch, 2000; Kempkes and Stanghellini, 2003). Nevertheless, Dhakal et al. (2005) found decreased calcium in a tomato crop leachate in a tropical climate. Calcium needs are low in this crop and calcium accumulation was observed. An excessive level of sulfate can provoke calcium precipitation, so the recycling solution must be corrected to avoid this.

Regarding magnesium, its concentration was higher in the leachate solution than in the emitters. Magnesium accumulation has also been shown in cut flower crops (Marfà and Blanch, 2000) and tomato crops (Graham et al., 2011).

The outgoing nutrient solution increased its salinity progressively, and it was more defined way in the non-recycling system due to a higher contribution of nutrients. According to Papadopoulus et al. (1999), the generous administration of low-cost fertilizers in the water supply is very common in greenhouse crops, which may be why higher nutrient values were found in the non-recycling system. Adjusted maintenance of the nutrient solution is not easy because it is influenced by several factors, including the substrate, climate conditions, nutrient interactions, etc. (Caetano et al., 2013).

The total fruit yield was not significantly different between the two treatments, which coincides with the results obtained by others authors (Marfà et al., 2000; Riga and Anza, 2004; Dhakal et al., 2005; Graham et al. 2011) in a tomato crop. Zekki et al. (1996) did not find significant differences in either fruit yield or in the mineral composition of cultivated leaves with or without recirculation in a rock-wool and turf substrate, even with a 40% reduction in the nutrient supply (Giuffrida and Leonardi, 2009). The decrease in production detected after the production maximum peak also coincides with the behavior found by other authors (Page et al., 2012). Resh (1997) showed that recirculation is viable for vegetable crops and cut flowers where the plant density is low, such as tomato, cucumber and rose bush, but is not recommended for lettuce where the plant density is higher, due to the difficulty of controlling pathogens mainly.

Tomato size-based production was 10% lower in the plot without recirculation for the larger diameter tomatoes, which can be correlated to the higher conductivity in this plot. According to Zahedifar et al. (2012), fruit size decreases as a consequence of salinity, i.e. a conductivity of 4 mS/cm decreases fruit yield by 10% while a conductivity of 8 mS/cm decreases fruit yield by 50% compared to the normal yield. Production per plant was very similar to that found for the Jack variety by Riga and Anza (2004).

Conclusions

A good balance in nutrient supply in the emitters is necessary to avoid nutrient excess in leachates. This contributes to saving money on fertilizers and the consequent minimization of the environmental impact due to waste elimination. Four of the seven tested nutrients presented an increase in their concentration in the leachate solution with respect to the supplied solution (nitrate, sulfate, calcium and magnesium); these nutrients are known to cause environmental eutrophication.

No significant differences in the use pattern were observed during the weeks before fructification. Total production differences in both treatments were not significant. They were significant for smaller size commercialized tomatoes, i.e. production was higher in the non-recycling system. This simple nutrient recycling system can be considered as a practical alternative to the conventional cropping practice using open fertilization.

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