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Nutrient recycling in a hydroponic tomato crop

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ABSTRACT

A comparative 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. It was concluded that 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. Three analyzed nutrients, *i.e.* phosphate, potassium and ammonium, presented a lower concentration in the drained solution than in the supplied solution. Fruit yield was not increased by the recycling technique in the hydroponic crop. 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, nutrient recycling, *Solanum lycopercicum*, 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.

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, 11). 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.*, 10).

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 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.

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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, 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. 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. Conditions inside the greenhouse were regulated by a climate controller. The minimum temperatures to activate heating were 15°/18°C night/day and the maximum temperatures to activate zenithal ventilation were 19°/21°C night/day. The tomato variety used in the study was Jack, hybrid F_1, 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 min., for 464 plants. We started on-demand irrigation schedule one month after the tomatoes were planted on the perlite substrate. The design was a simple random sampling, with two treatments, *i.e.*

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

	Anion (mM)					Cation (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

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 cluters 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 estimation, 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, 12) was used.

RESULTS AND 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, 13). 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 Fig. 1.

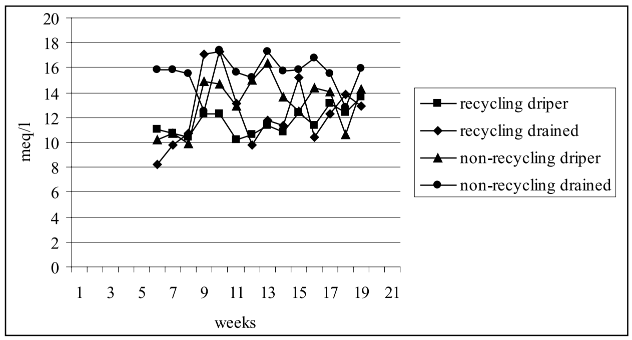

Fig. 1. Nitrate concentration variation in the hydroponic tomato crop.

Absorption maximum values were reached during the fructification period (weeks 14-16). The nitrogen concentrations found in this study coincide with those found by Marfà *et al*. (9), with a higher value in the leachate solution. On the contrary, Dhakal *et al*. (2) found a decrease in nitrogen concentrations in the drained solution in a tomato crop under tropical conditions. This fertilizer savings achieved similar values to those determined by Echer *et al.* (3) in a nutrient solution recycling system. The highest absorbed nitrogen values were found during fructification, which coincides with the results of Feltrin *et al.* (4).

In Fig. 2, it can be observed that the phosphate use pattern was very regular. 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)

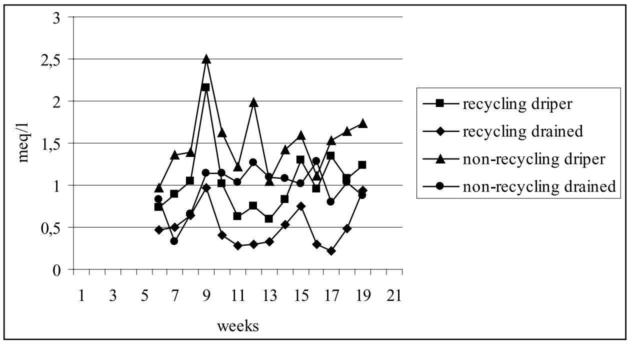

Fig. 2. Orthophosphate concentration variation in the hydroponic tomato crop.

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.

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*. (7) in a lettuce crop, but differ from those found by Marfà *et al*. (9) who used high phosphate concentrations in the emitters, and found excess phosphate in the leachate solution. The weekly sulfate average concentration is shown in Fig. 3. The average sulfate value in the non-recycling system emitters was 8.07 ± 1.79 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. Regarding sulfates, a higher concentration was found in the leachate solution than in the emitters, so an excess of this ion was being provided. According Vergote and Vermeulen (13), tomato plants should be cultivated under conditions where sulfates are the predominant salt.

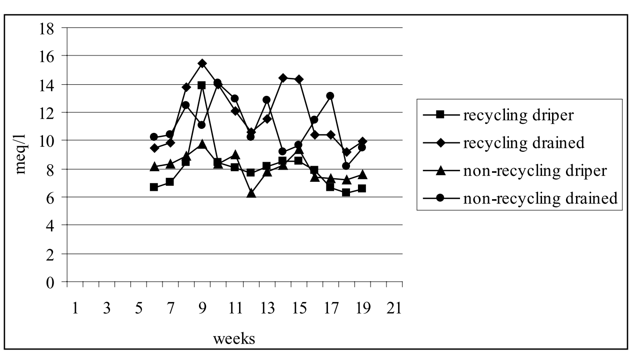

Fig. 3. Sulfate concentration variation in the hydroponic tomato crop.

Ammonium concentrations are shown in Fig. 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. Ammonium was optimally used during the productive process and very low concentrations were found in the drained solutions, these data coincide with the results of Kempkes and Stanghellini (8).

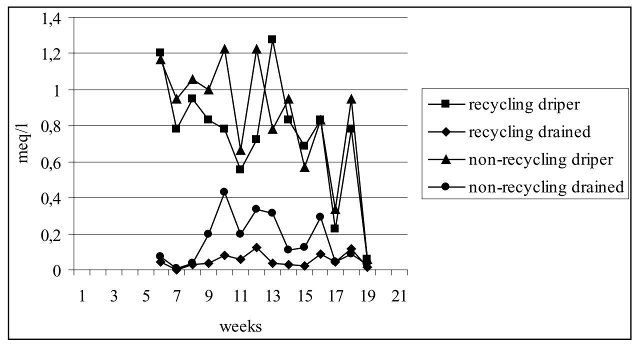

Fig. 4. Ammonium concentration variation in the hydroponic tomato crop.

The potassium concentrations found in the study are shown in Fig. 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 very defined maximum and minimum values in both treatments. These peaks were observed before the

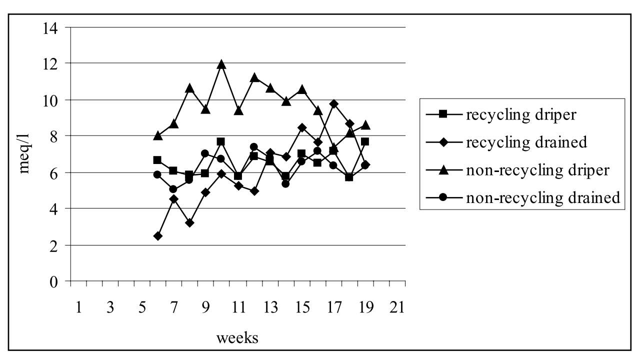

Fig. 5. Potassium concentration variation in the hydroponic tomato crop.

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. The concentrations found coincide with the results obtained by Giuffrida and Leonardi (5). According to Caetano *et al*. (1), 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 variations in the calcium concentrations in both systems are shown in Fig. 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. Calcium accumulated and increased in the drained solution. Its concentration was greater than that in the emitters. Calcium accumulation was also shown in previous studies (Kempkes and Stanghellini, 8). Nevertheless, Dhakal *et al*. (2) found decreased calcium in a tomato crop leachate in a tropical climate. Calcium needs are low in this crop and calcium accumulation was observed.

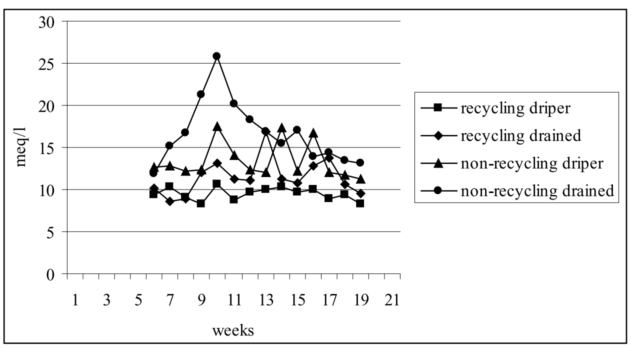

Fig. 6. Calcium concentration variation in the hydroponic tomato crop.

The weekly variations in the magnesium concentration are shown in Fig. 7. The average magnesium concentration 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. 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. 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 *et al.*, 9) and tomato crops (Graham *et al.*, 6).

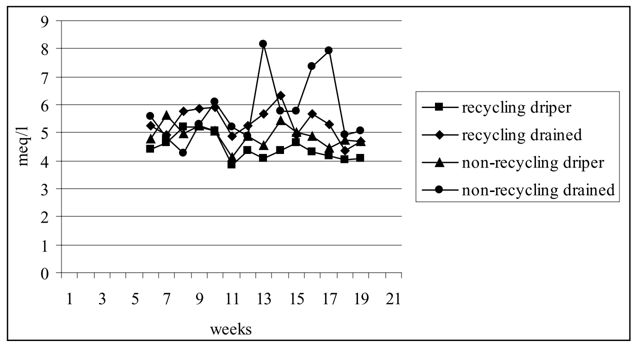

Fig. 7. Magnesium concentration variation in the hydroponic tomato crop.

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. 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 >67 mm. There were differences in the tomatoes with a diameter of 57-67

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%.

Fruit	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

mm, where there was 226,1% higher production in the non-recycling system compared to the recycling system. Regarding smaller sizes, differences between one cultivation method and the other were not significant. The total fruit yield was not significantly different between the two treatments, which coincides with the results obtained by others authors (Marfà *et al.*, 9; Dhakal *et al.*, 2; Graham *et al.*, 6) in a tomato crop. The decrease in production detected after the production maximum peak also coincides with the behavior found by other authors (Page *et al.*, 10).

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