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Agronomic and Economic Feasibility of Tomato and Lettuce Intercropping in a Soilless System as a Function of the Electrical Conductivity of the Nutrient Solution

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***Abstract*. An intercrop is studied here as a new way of farming in soilless systems within a protected environment. To estimate the efficiency of intercropping in this cultivation system, an experiment was conducted to evaluate the effect of the electrical conductivity (EC) of the nutrient solution (2.0, 2.5, and 3.0 dS·m^{-1}) on lettuce and tomato plants and on the agronomic and economic feasibility of the intercrop compared with monoculture. The results indicated that a moderate increase in EC from 2.0 to 3.0 dS·m^{-1} did not exert any important effect on tomato plant production or quality but did cause a decrease in lettuce yield in both the first and second crops. Intercropping was only feasible for lettuce when the tomato and lettuce plants were transplanted on the same day. The highest tomato (G class) and lettuce yields were achieved at an EC of 2.5 dS·m^{-1}; this condition resulted in the highest intercrop profitability (0.53 €·m^{-2} more) when compared with tomato monoculture.**

Intercropping is a planting system where two or more species are farmed within the same area at the same time, coexisting for at least a portion of their production cycles (Caviglia et al., 2011; Cecílio Filho et al., 2010). This planting system has been extensively practiced worldwide with various crops under field conditions as a means to increase yield (Wang et al., 2014) and to facilitate the efficient use of natural resources and agricultural amendments, among other advantages (Cecílio Filho et al., 2013; Fuente et al., 2014).

However, few studies have been conducted with vegetables in protected environments. Cecílio Filho et al. (2011, 2013), Rezende et al. (2011), and Tringovska et al. (2015) tested the agronomic and economic feasibility of intercropping tomato and lettuce and intercropping cucumber and lettuce in protected cultivation.

In recent years in Brazil, soilless vegetable farming within a protected environment has become more popular as it avoids potential soil problems, such as salinization and pathogens and has other advantages over cultivation in soil, such as more efficient water and nutrient use by plants, which helps attain higher yields and better harvest quality (Martínez-Gutiérrez et al., 2012).

The EC of the nutrient solution is an important factor in soilless cultivation. High EC values compromise plant growth and development, resulting in low vegetable yield and quality (Caruso et al., 2011; Noshadi et al., 2013; Razzaghi et al., 2011). In addition, high EC hinders nutrient absorption, causing nutritional disorders in the plants because of the competition between salt ions and nutrients for the absorption sites of the plant roots (Gondim et al., 2010; Hafsi et al., 2007). Because a characteristic of intercropping is to combine species that have different resource demands, including nutrient demands, finding an adequate nutrient solution EC that minimizes the stress on the intercropped species is a challenge (Adams and Ho, 1989; Morales and Urrestarazu, 2013).

The objective of this study was to evaluate the effect of the EC of the nutrient solution on lettuce and tomato yields and on the agronomic and economic feasibility of the lettuce–tomato intercrop compared with each monoculture crop.

Materials and Methods

Growing conditions. The experiment was conducted in a plastic no heated greenhouse at the University of Almería (Universidad de Almería), Spain, located at 36°50′25″N and 2°28′05″W and at an elevation of 23 m. The region's climate is Mediterranean subtropical semiarid according to the agro-climatic classification by Papadakis (1980), with a mean annual temperature of 18.5 °C and annual rainfall of 250 mm.

During the experimental period, photosynthetically active radiation (*PAR*, mol·m^{-2}·d^{-1}) and total light intensity (L, lux) were measured at midday both outside and inside the greenhouse. Outside the greenhouse, mean values of 0.595 mol·m^{-2}·d^{-1} and 20,219 lx were observed for *PAR* and L, respectively. Inside the greenhouse, mean values of 0.194 mol·m^{-2}·d^{-1} and 9351 lx were obtained just above the tomato (monoculture and intercropped) and lettuce plants (monoculture) during the first crop. For the intercropped lettuce during the first crop, the observed values were 0.141 mol·m^{-2}·d^{-1} and 5648 lx. During the second crop, the *PAR* and L values above the tomato (monoculture and intercrop) and lettuce plants (monoculture) were 0.186 mol·m^{-2}·d^{-1} and 8188 lx. For the intercropped lettuce, the values were much lower at 0.105 mol·m^{-2}·d^{-1} and 3531 lx.

Treatments and experimental design. Two factors were evaluated: the planting system (tomato and lettuce monocultures and intercrop) and the EC of the nutrient solution (2.0, 2.5, and 3.0 dS·m^{-1}). The experiment was conducted with a randomized block design, with subdivided plots and three replicates. The planting system and EC variables corresponded to the plots and subplots, respectively. Each experimental unit was represented by one Pelemix GB1002410® coconut husk fiber bag (100 × 25 × 10 cm with a 25 L volume). Tomato plants, monoculture or intercropped, were placed at the center of the bag and spaced 0.33 m apart, totaling three plants per bag. The tomato rows were spaced 1.5 m apart. The lettuce was planted in two rows of three plants each, spaced 0.30 m between rows and 0.30 m between

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the plants in each row, totaling six plants per bag. In the intercropped experimental unit, three tomato plants were placed at the center, whereas six lettuce plants were placed laterally.

Experimental initiation and implementation. Tomato cv. Mayoral grafted onto cv. Emperor seedlings and lettuce cv. Romaine seedlings were transplanted into the coconut husk fiber bags with six and four leaves, respectively. The tomato plants were transplanted on 18 Oct. 2014, when the lettuce plants were also transplanted (first crop). After this lettuce was harvested, new lettuce seedlings were transplanted at the same positions where the lettuce plants had been removed from the coconut fiber bag on 12 Dec. 2014 (second lettuce crop). The tomato plants were supported with two stakes.

Two fertigation control points were established for each treatment, each comprising a drip control and a drain pan that served as points to measure and monitor the fertigation and the plant absorption response for each treatment. The nutrient solution volume, pH, EC, and nitrate (NO_3^-) and potassium (K^+) concentrations of the fertigation (both input and drainage) were measured daily. The volume, pH, and EC measurements were used to adjust and modify the fertigation program according to the treatments (Rodríguez et al., 2014; Urrestarazu, 2004, 2015).

Each new irrigation was performed when 10% of the easily available water was exhausted in the substrate, and the irrigation volume was sufficient to cause 15% to 25% drainage (Urrestarazu et al., 2008a). The duration of each irrigation was adjusted according to the input volume of each cultivation unit, where the volume of each irrigation was adjusted according to the need of each crop (lettuce and tomato monoculture or intercrop). Each cultivation bag was fertigated with three 3 $L \cdot h^{-1}$ emitters. The nutrient solutions corresponded to the three EC values shown in Table 1, according to Sonneveld and Straver (1994).

Tomatoes with uniform red color were harvested weekly from 17 Feb. 2015 to 5 May 2015. The first and second lettuce crops were harvested on 5 Dec. 2014 and 6 Feb. 2015.

Evaluated characteristics. The tomatoes were commercially classified according to their equatorial diameter (Reglamento 717/2001, 2001) as G (67–82 mm), M (57–67 mm), MM (47–57 mm), and MMM (40–47 mm). The yields ($kg \cdot m^{-2}$) for each class and the total yield were obtained. A subsample of three tomatoes was collected at each harvest and formed into a homogeneous mixture to measure pH and soluble solids (°Brix). Diameter (mm), stem length (cm), number of leaves per plant, and fresh weight (g/plant) were evaluated for the lettuce plants.

The total tomato yield, tomato yield per class, and lettuce yield values were used to calculate yield efficiency (YE) indices for the intercrop compared with the monocultures using the formula:

$$\mathrm{YE} = ((AB - A)/A) * 100 \tag{1}$$

where A represents tomato or lettuce in monoculture and AB represents the intercrop. A positive YE index indicates that the intercropped tomato plants are more productive than they are in monoculture; a negative YE index indicates the opposite.

Water absorption, NO_3^-, and K^+ were measured for both crops according to the procedure described by Morales and Urrestarazu (2013). Because the tomato is the main crop of the intercrop and the lettuce is a secondary crop that is added to the tomato crop, the use and absorption efficiency indices for water, nitrate, and potassium were evaluated for the tomato plants:

Water use efficiency (WUE, L/kg tomato) was calculated using the formula:

$$\mathrm{WUE} = \text{applied water}/\text{total yield} \tag{2}$$

NO_3^- use efficiency (NUE, g NO_3^-/kg tomato) was calculated using the formula:

$$\mathrm{NUE} = \text{applied } NO_3^- / \text{total yield} \tag{3}$$

K^+ use efficiency (KUE, g K^+/kg tomato) was calculated using the formula:

$$\mathrm{KUE} = \text{applied } K^+ / \text{total yield} \tag{4}$$

Water absorption efficiency (WAE, L/kg tomato) was calculated using the formula:

$$\mathrm{WAE} = \text{absorbed water}/\text{total yield} \tag{5}$$

NO_3^- absorption efficiency (NAE, mol NO_3^-/kg tomato) was calculated using the formula:

$$\mathrm{NAE} = \text{absorbed } NO_3^- / \text{total yield} \tag{6}$$

K^+ absorption efficiency (KAE, mol K^+/kg tomato) was calculated using the formula:

$$\mathrm{KAE} = \text{absorbed } K^+ / \text{total yield} \tag{7}$$

The economic characteristics of the tomato and lettuce crops were calculated for the monocultures and intercrops to evaluate the economic feasibility of the intercrop as a function of the nutrient solution. Thus, the net revenue (NR) that corresponded to the estimated monetary value of the tomato, lettuce, or intercropped production was first calculated, considering the price of the tomatoes in each commercial class (G = 0.63 $€ \cdot kg^{-1}$, M = 0.48 $€ \cdot kg^{-1}$, MM = 0.28 $€ \cdot kg^{-1}$, and MMM = 0.20 $€ \cdot kg^{-1}$). A mean price of 0.30 $€ \cdot kg^{-1}$ was used for lettuce. The prices were obtained from Frutas y Hortalizas de Almería (2015). To calculate the operational cost, the nutrient solution that was used was considered as the only difference among the planting systems. The nutrient solution cost was calculated according to the amount of solution used by the plants and the price of the nutrient solution. The profit of the enterprise ($€ \cdot m^{-2}$) was calculated as the difference between the NR and the nutrient solution cost.

Statistical analysis. The data were subjected to analysis of variance (ANOVA) using the F test at 5% probability, and the treatment means were compared using Tukey's test at 5% probability.

Results

The pH and EC values (Table 2) remained within the desired limits (Urrestarazu et al., 2008b). It was necessary to provide a greater amount of water to maintain the desired pH and EC conditions for the lettuce monoculture, and thus, there was a correspondingly greater drainage percentage.

The yields of each tomato class responded differently to the evaluated factors. The G class was affected by the planting system and EC, and the highest yields were obtained in the intercrop with lower EC (2 $dS \cdot m^{-1}$). The yields of the M and MMM classes remained unaffected by the evaluated factors, whereas the yield of the MM class was only affected by the planting system; higher yields were obtained with the tomato plants in monoculture. The total yield remained unaffected by the evaluated factors, and the mean yield was 11.36 $kg \cdot m^{-2}$ (Table 3). The YE of the intercropped tomato plants for the two largest tomato classes was positive compared with tomato monoculture, regardless of the EC of the nutrient solution. A positive YE was also observed for the MMM class, but only at an EC of 2.5 $dS \cdot m^{-1}$. Under other conditions, the YE values were negative, which means that the tomato plants produced less when intercropped. For the two largest size classes and

Table 1. Nutrient solutions used in the tomato and lettuce monocultures and intercrop.

		Macronutrients (mM)						Micronutrients (µM)					
EC ($dS \cdot m^{-1}$)	pH	NO_3^-	$H_2PO_4^-$	SO_4^{2-}	K^+	Ca^{2+}	Mg^{2+}	Fe	Mn	Cu	Zn	B	Mo
2.00	5.80	10.25	1.50	1.75	4.75	5.00	1.51	15	10	0.75	5	30	0.5
2.50	5.80	12.81	1.88	2.19	5.95	6.25	1.89	15	10	0.75	5	30	0.5
3.00	5.80	15.37	2.26	2.63	7.14	7.50	2.27	15	10	0.75	5	30	0.5

EC = electrical conductivity.

Table 2. The pH, electrical conductivity (EC), and amount of leached nutrient solution (LNS) relative to that applied according to planting system (intercrop or monoculture) and EC (2.0, 2.5, or 3.0 $dS \cdot m^{-1}$).

	pH			EC			LNS (%)		
	2.0	2.5	3.0	2.0	2.5	3.0	2.0	2.5	3.0
Lettuce	6.97	6.33	6.08	2.60	3.08	3.39	51.75	50.24	55.12
Intercrop	7.02	6.85	6.47	2.41	3.41	4.01	30.40	30.21	31.75
Tomato	7.06	6.98	6.58	2.65	3.21	3.97	30.32	35.83	35.39

in total yield, the greatest YE values were observed at an EC of 2.5 dS·m^{-1} (Table 3).

With respect to tomato quality, the pH and soluble solids content of the fruits remained unaffected by the EC and planting system (monoculture or intercropped). The observed mean pH and soluble solid values were 3.9 (3.85–3.92) and 4.3 °Brix (4.2–4.4 °Brix), respectively.

For the first crop of lettuce, stem diameter and length were only affected by the planting system; lower stem diameters and higher lengths were obtained in the intercrop (Table 4). The number of leaves per plant was only affected by the planting system, and it was lower in the intercrop, with two to four leaves or fewer per plant, compared with the monoculture (Table 4). The fresh weight of the lettuce was affected by the interaction between the factors. In monoculture, the weights obtained at 2 and 2.5 dS·m^{-1} did not differ from each other and were higher than that with the higher-EC nutrient solution. In the intercrop, the fresh weights of the plants did not differ at different EC values and exhibited a mean value of 215 g/plant. The presence of tomato plants compromised lettuce growth, and the fresh weight in monoculture was higher regardless of the EC of the nutrient solution, which led to negative YE indices because of the poorer performance of the intercrop (Table 4).

In the second lettuce crop, only the planting system significantly affected all of the evaluated lettuce characteristics, as the lettuce was greatly compromised by the presence of the tomato plants (Table 4). Second-crop lettuce plants intercropped with tomato plants did not attain commercial size and quality (Table 4), excluding the hypothesis that a second lettuce crop may be intercropped with tomato plants. Thus, all of the other results presented below refer to the first crop season, when the lettuce was transplanted on the same day as the tomato plants.

Lettuce potassium absorption was not affected by EC. However, the K absorption increased in the tomato in monoculture and in the intercrop with higher EC. By contrast, the EC affected the nitrate absorption of the monocultures, which was higher when the EC of the nutrient solution was 2.5 dS·m^{-1}. Nitrate absorption in the intercropped plants was unaffected by EC, but there was a trend toward higher absorption at an EC of 2.5 dS·m^{-1}. Water absorption was lower at higher EC values only for lettuce in monoculture (Table 5). Except for lettuce K emissions that they not differ among EC, greater emissions of NO_3^- and K^+ to the environment were observed with increasing EC in both the intercrop and tomato monoculture (Table 6).

K^+ absorption efficiency was unaffected by EC in tomato plants in monoculture or when intercropped with lettuce. However, in both planting systems, the nitrate absorption efficiency was higher when the EC of the nutrient solution was 2.5 dS·m^{-1}, but that did not differ of the efficiency obtained at the highest EC for intercropping. The water absorption efficiency differed from the nutrient efficiencies and was highest at the lowest EC (Table 7).

The NO_3^- and K^+ use efficiencies increased with increasing EC in the tomato plants, both in monoculture and when intercropped with lettuce, whereas the water use efficiency decreased with increasing EC, similar to the results observed for water, NO_3^-, and K^+ absorption. By contrast, differences between planting systems were only observed at ECs of 2.5 and 3.0 dS·m^{-1} and were always higher in the intercrop (Table 8), which corroborates the higher profitability of the intercrops (Table 9).

Table 3. Total tomato yield, tomato yield per class (kg·m^{-2}), and yield efficiency (YE) as a function of planting system (monoculture or intercrop) and electrical conductivity (EC) (2.0, 2.5, or 3.0 dS·m^{-1}).

		EC		
	Planting system	2.0	2.5	3.0
G (67–82 mm)	Monoculture	0.82 Ab	0.47 Bb	0.59 Bb
	Intercrop	1.15 Aa	0.92 Ba	0.85 Ba
YE (%)		40.2 B	95.7 A	44.1 B
M (57–67 mm)	Monoculture	6.40 Aa	6.72 Aa	6.70 Aa
	Intercrop	6.59 Aa	7.71 Aa	7.10 Aa
YE (%)		3.00 C	14.7 A	6.00 B
MM (47–57 mm)	Monoculture	3.22 Aa	3.49 Aa	3.39 Aa
	Intercrop	2.69 Ab	2.69 Ab	2.35 Ab
YE (%)		–16.5 A	–22.9 B	–30.7 C
MMM (40–47 mm)	Monoculture	0.76 Aa	0.92 Aa	0.55 Aa
	Intercrop	0.54 Aa	0.65 Aa	0.87 Aa
YE (%)		–28.9 B	–29.4 B	58.2 A
Total	Monoculture	11.20 Aa	11.60 Aa	11.23 Aa
	Intercrop	10.97 Aa	11.97 Aa	11.17 Aa
YE (%)		–2.1 C	3.2 A	–0 B

For each characteristic, different uppercase and lowercase letters in the same row and column, respectively, indicate significant differences according to Tukey's test at $P \leq 0.05$.

Table 4. Characteristics of lettuce plants in the first and second crops as a function of planting system (monoculture or intercrop) and electrical conductivity (EC) (2.0, 2.5, or 3.0 dS·m^{-1}).

		EC		
		2.0	2.5	3.0
	Planting system	First lettuce crop		
Fresh weight (g/plant)	Monoculture	384 Aa	396 Aa	348 Ba
	Intercrop	217 Ab	227 Ab	200 Bb
YE (%)		–43.5 A	–42.7 A	–42.5 A
Number of leaves	Monoculture	33 Aa	31 Aa	34 Aa
	Intercrop	29 Ab	29 Ab	30 Ab
Stem length (cm)	Monoculture	16.9 Aa	17.1 Aa	16.4 Aa
	Intercrop	22.9 Ab	25.2 Ab	24.7 Ab
Stem diameter (mm)	Monoculture	27.3 Aa	27.5 Aa	24.1 Aa
	Intercrop	16.5 Ab	19.4 Ab	19.5 Ab
		Second lettuce crop		
Fresh weight (g·m^{-2})	Monoculture	172 Aa	152 Aa	169 Aa
	Intercrop	22 Ab	18 Ab	18 Ab
YE (%)		–87.2 A	–88.2 A	–89.3 A
Number of leaves per plant	Monoculture	25 Aa	21 Aa	22 Aa
	Intercrop	14 Ab	13 Ab	12 Ab
Stem length (cm)	Monoculture	3.8 Aa	3.2 Aa	4.1 Aa
	Intercrop	4.1 Aa	4.4 Aa	4.7 Aa
Stem diameter (mm)	Monoculture	19.2 Aa	16.8 Aa	20.8 Aa
	Intercrop	3.8 Ab	3.7 Ab	3.1 Ab

For each characteristic, different uppercase and lowercase letters in the same row and column, respectively, indicate significant differences according to Tukey's test at $P \leq 0.05$.

Table 5. Absorption of NO_3^-, K^+, and water by the plants as a function of planting system (intercrop or monoculture) and electrical conductivity (2.0, 2.5, or 3.0 dS·m^{-1}) during the first crop cycle.

	(L·m^{-2}) mol·m^{-2}								
	Water			NO_3^-			K^+		
	2.0	2.5	3.0	2.0	2.5	3.0	2.0	2.5	3.0
Lettuce	19 A	20 A	15 B	0.11 B	0.18 A	0.11 B	0.62 A	0.69 A	0.62 A
Intercrop	895 A	930 A	815 B	8.08 B	10.62 A	9.46 A	12.29 B	12.79 A	13.61 A
Tomato	898 A	799 B	762 C	7.79 C	9.71 A	8.93 B	12.17 B	12.73 A	13.17 A

For each characteristic, different letters indicate significant differences among the electrical conductivities in each planting system according to Tukey's test at $P \leq 0.05$.

Discussion

Lettuce growth was compromised in both crop seasons when intercropped with tomato

Table 6. Emission of NO_3^- and K^+ to the environment as a function of planting system (intercrop or monoculture) and electrical conductivity (2.0, 2.5, or 3.0 $dS \cdot m^{-1}$) during the first crop cycle.

	$g \cdot m^{-2}$					
	NO_3^-			K^+		
	2.0	2.5	3.0	2.0	2.5	3.0
Lettuce	37 AB	35 B	41 A	23 A	22 A	21 A
Intercrop	252 C	327 B	440 A	164 C	263 B	326 A
Tomato	250 C	382 B	464 A	168 C	263 B	335 A

For each characteristic, different letters indicate significant differences among the electrical conductivities in each planting system according to Tukey's test at $P \leq 0.05$.

Table 7. Absorption efficiency of water, NO_3^-, and K^+ by the fresh weight fruit (FW) of tomato plants as a function of planting system (intercrop or monoculture) and electrical conductivity (2.0, 2.5, or 3.0 $dS \cdot m^{-1}$) during the crop cycle.

	Absorbed water ($L \cdot kg^{-1}$ FW)			Absorbed NO_3^- (mol NO_3^-/kg FW)			Absorbed K^+ (mol K^+/kg FW)		
	2.0	2.5	3.0	2.0	2.5	3.0	2.0	2.5	3.0
Intercrop	13 Aa^z	13 Aa	11 Ba	109 Ba	138 Aa	129 Aa	153 Aa	159 Aa	185 Aa
Tomato	14 Aa	12 Ba	10 Ca	112 Ba	128 Aa	119 Ba	154 Aa	157 Aa	165 Aa

^{z}Different uppercase and lowercase letters indicate significant differences ($P \leq 0.05$) in the row and column, respectively.

Table 8. Use efficiencies of water, NO_3^-, and K^+ by the fresh weight fruit (FW) of tomato plants as a function of planting system (intercrop or monoculture) and electrical conductivity (2.0, 2.5, or 3.0 $dS \cdot m^{-1}$) during the crop cycle.

	Water use efficiency ($L \cdot kg^{-1}$ FW)			NO_3^- use efficiency (g NO_3^-/kg FW)			K^+ use efficiency (g K^+/kg FW)		
	2.0	2.5	3.0	2.0	2.5	3.0	2.0	2.5	3.0
Intercrop	20 Aa	19 Aa	18 Ba	10 Ca	13 Ba	15 Aa	8 Ca	10 Ba	12 Aa
Tomato	20 Aa	18 Bb	16 Cb	9 Ca	12 Bb	14 Ab	8 Ca	9 Bb	11 Ab

For each characteristic, different uppercase and lowercase letters in the same row and column, respectively, indicate significant differences according to Tukey's test at $P \leq 0.05$.

Table 9. Net revenue, cost of the nutrient solution (NS), and profit obtained in monoculture or in the intercrop of tomato (T) and lettuce (L) as a function of the electrical conductivity of the nutrient solution (2.0, 2.5, or 3.0 $dS \cdot m^{-1}$).

	Net revenue (€$\cdot m^{-2}$)^z			NS cost (€$\cdot m^{-2}$)			Profit (€$\cdot m^{-2}$)		
	2.0	2.5	3.0	2.0	2.5	3.0	2.0	2.5	3.0
T monoculture	4.64	4.68	4.65	0.70	0.94	1.27	3.94	3.74	3.38
L monoculture	0.11	0.12	0.10	0.06	0.09	0.12	0.05	0.03	–0.02
T intercrop	4.74	5.17	4.77	0.70	0.95	1.28	4.04	4.22	3.49
L intercrop	0.07	0.07	0.06	0.018	0.021	0.025	0.05	0.05	0.03
Intercrop (both)	4.81	5.24	4.83	0.718	0.971	1.305	4.09	4.27	3.52

^{z}Mean price based on what farmers receive in agricultural cooperatives within the same cultivation period for each crop. Source: Frutas y Hortalizas de Almería (2015).

(Table 4) because of lower light availability, as half of the available *PAR* was lost because of the shade of the tomato plants.

In the first crop, the lettuce attained commercial size and quality, when the lettuce and tomato plants were transplanted on the same day, because of less shading caused by tomato plants. In this planting time, because of low competition between the species, space and time were highly complementary between the intercropped species (Cecílio Filho et al., 2008). By contrast, in the second crop, the lettuce plants did not develop and did not reach commercial standards (Table 4). However, transplanting the lettuce together with the tomato plants for a second time was not agronomically feasible. According to the results obtained for the lettuce (Table 4) in the second crop season, the lettuce plants intercropped with the tomato plants exhibited a weight equivalent to ≈10% of that obtained in the monoculture during the second cycle or in the intercropped crop in the first cycle. Low light intensity greatly compromised photosynthesis, directly affecting weight accumulation. Small, etiolated plants with elongated and thin leaf blades were observed, as also reported (Ghanbari et al., 2010; Gong et al., 2015; Sinoquet and Caldwell, 1995).

The lettuce plants in the second crop were transplanted 7 d after harvesting the lettuce plants from the first transplant, i.e., 55 d after the start of the experiment (when the tomato plants were transplanted). Thus, in contrast to the first lettuce transplant, in the second crop, the lettuce plants grew under strong shade from the tomato plants, which were large at the time of the second transplant. Even in the first crop, the lettuce plants already showed compromised growth as the plants developed ≈42% less weight than the monoculture plants produced (Table 4). During the second crop, the intense shade from the tomato plants that was experienced from the onset of lettuce development was decisive in the failure of the second transplant. During the second lettuce transplant, the day was shorter (9 h 36 min) than that of the first crop (10 h 26 min). Inside the greenhouse, means values of 0.141 $mol \cdot m^{-2} \cdot d^{-1}$ and 5648 lx were obtained for the intercropped lettuce in the first crop; however, during the second crop, the *PAR* and light intensity values were 0.105 $mol \cdot m^{-2} \cdot d^{-1}$ and 3531 lx, respectively. Cecílio Filho et al. (2011) observed that transplanting lettuce up to 10 d after tomato produced plants with good commercial size and characteristics. However, later transplants led to significantly reduced lettuce weight; when lettuce was transplanted 30 d after the tomato plants, the lettuce plants were etiolated and had no market value. Similar results were observed by Rezende et al. (2011), who evaluated the effect of the transplant time of lettuce intercropped with cucumber. The authors observed that the intercrop was only feasible when the lettuce was transplanted on the same day as the cucumber as late lettuce transplanting caused a strong decrease in accumulated weight and commercial characteristics.

The entire discussion below applies to the results of the first lettuce crop only as lettuce production was unsuccessful in the second transplant.

The losses of NO_3^- and K^+ to the environment were higher with increasing EC because of the higher nutrient concentration. This result may also be partially explained by the absence of an increase in nutrient absorption by lettuce and tomato plants, both in monoculture and in the intercrop, showing that there was no excess intake of nitrate or potassium by either species (Table 6). The amounts of potassium and nitrate lost to the environment were within the ranges cited by Morales and Urrestarazu (2013), Rodríguez et al. (2014), and Urrestarazu et al. (2015).

The use and absorption efficiencies of water and nutrients (NO_3^- and K^+) are indicative of the behavior of plants when subjected to stress, as reflected in the yield (Tables 7 and 8). Similar results were found by Hafsi et al. (2007). Tomato plants in monoculture under higher salt stress absorbed less water (Table 5), which was directly reflected in reduced absorption and use efficiencies (Tables 7 and 8) because of the decrease in water potential (Adams and Ho, 1989; Qadar, 1988). By contrast, increased EC led to an increase in the absorption efficiencies of water and the nutrients (Tables 7 and 8), similar to that found in tomato crops by Morales and Urrestarazu (2013), which likely contributed to the absence of any yield loss for tomato plants with increasing EC (Table 4). Regardless of the EC of the nutrient solution, the absorption and use efficiencies of water, NO_3^-, and K^+ for the intercropped tomato plants did not differ from those obtained in the monocultures (Table 4), demonstrating that the tomato plants were unaffected by the presence of lettuce, as found by Cecílio Filho et al.

(2008) in tomato and lettuce intercropping as function of the transplanting time of lettuce.

For lettuce, the planting system affected lettuce yield, as lettuce plants cultivated in monoculture were always more productive than intercropped lettuce, regardless of the EC (Table 4). Cecílio Filho et al. (2011, 2013) evaluated lettuce in monoculture and when intercropped with tomato with respect to the lettuce transplant time and observed that lettuce intercropped with tomato experiences yield loss compared with the monoculture but achieves commercial quality when transplanted within 10 d of tomato transplanting.

Increases in EC caused yield loss in lettuce (Table 4). The recommended EC for a lettuce crop is between 1.5 and 2.0 $dS{\cdot}m^{-1}$ (Sonneveld and Straver, 1994), and lettuce exhibits poor tolerance to increased salinity without undergoing losses (Pascale and Barbieri, 1995). In addition to yield loss, increases in EC can cause nutritional disorders because of interactions between specific elements (Eraslan et al., 2007; Yamaguchi and Blumwald, 2005). Tip-burn was observed in lettuce at solution EC values of 2.5 and 3.0 $dS{\cdot}m^{-1}$. At 2.5 $dS{\cdot}m^{-1}$, the signs of tip-burn appeared occasionally and did not compromise the commercial quality of the vegetable. By contrast, the symptom was largely present at 3.0 $dS{\cdot}m^{-1}$, which affected the quality and commercial value of the lettuce.

In contrast to the lettuce, increases in the EC of the nutrient solution did not affect the total yield of the tomato plants (Tables 3 and 4) because the tomato and lettuce plants differ in their nutrient demand and tolerance of higher nutrient solution salinity (Maas and Hoffman, 1977; Sonneveld and Voogt, 2009). EC between 2.0 and 3.0 in the nutrient solution is moderate for tomato plant (Urrestarazu, 2004), but high level for lettuce plant (Gondim et al., 2010). Lettuce and tomato plants grown in monoculture in nutrient solution with higher EC values absorbed less water and nitrate (Table 5), which negatively affected lettuce growth (thereby resulting in smaller plants) but did not affect the yield of the tomato plants (Tables 3 and 4) that is a species more tolerant to high EC (Maas and Hoffman, 1977; Sonneveld and Straver, 1994; Sonneveld and Voogt, 2009). However, the intercrop did not show similar results to the monoculture crops as higher absorption of NO_3^- and K^+ was observed at 2.5 $dS{\cdot}m^{-1}$, whereas water absorption did not change as a function of EC (Table 5). Intercropping is a complex planting system that in no way resembles the single-crop system, and its success lies in obtaining combinations that optimize differences in the cultivation medium (Chapman and Reiss, 1992); such combinations were observed in the present study.

The planting system did not affect the yield of the tomato plants (Table 3). The rapid growth of the tomato plants compared with the lettuce plants and the distribution of their photosynthetic canopy above the space occupied by the lettuce prevented the tomato plants from experiencing any decrease in *PAR* availability when intercropped, and their yield was accordingly unaffected (Table 3). Cecílio Filho et al. (2011, 2013) and Tringovska et al. (2015) observed that tomato plants were unaffected by lettuce plants and exhibited similar production in monoculture or when intercropped. The quality of the tomato plants also remained unaffected. The absence of any effect of lettuce on tomato fruit quality was also observed by Cecílio Filho et al. (2011, 2013). When there is a considerable increase in the salinity of the nutrient solution, in addition to potential yield losses, fruit quality parameters can also be negatively affected (Cuartero and Fernández-Muñoz, 1998; Noshadi et al., 2013). However, in this experiment, the increased nutrient solution EC had no significant effect on 2the fruit quality parameters. The total difference of only 1 $dS{\cdot}m^{-1}$ among the evaluated ECs was most likely insignificant to the tomato plants. Maas and Hoffman (1977) reported that tomato plants are more tolerant of the salinity of the nutrient solution when compared with other vegetables. The rootstock also contributes to salt tolerance (Lazof and Bernstein, 1999; Lee and Oda, 2003).

The intercropped tomato and lettuce exhibited higher profitability compared with the monoculture, regardless of the EC of the nutrient solution (Table 9). The greatest profit was observed at an EC of 2.5 $dS{\cdot}m^{-1}$; it was ≈25% higher than that obtained at EC values of 2 or 3 $dS{\cdot}m^{-1}$ (Table 9). This higher value was due to the greater productivity obtained from the higher yield of G-class tomatoes, which have a higher market value (Table 3) and the economic contribution of the lettuce, despite the loss in size and value for intercropped lettuce relative to the monoculture (Table 4). In addition, intercropping permitted increased absorption and use efficiencies for both nutrients, especially when the EC of the nutrient solution was 2.5 $dS{\cdot}m^{-1}$ (Tables 7 and 8), and it allowed optimization of the nutrient solution cost (Table 9). These results corroborate those observed in other studies that evaluated the agronomic and economic feasibility of tomato and lettuce intercropping (Cecílio Filho et al., 2008, 2011).

Conclusions

Thus, we conclude that a moderate increase in EC from 2.0 to 3.0 $dS{\cdot}m^{-1}$ does not exert an important effect on the yield of the grafted tomato or on fruit quality parameters but does cause a decrease in the lettuce yield for both the first and second crops. Intercropping is feasible when lettuce is transplanted on the same day as the tomato plants. A second tomato and lettuce intercrop is not feasible because of the strong light interception by the tomato plants and the low light availability for the lettuce. At an EC value of 2.5 $dS{\cdot}m^{-1}$, the greatest tomato and lettuce yields were achieved and the highest economic return was observed, thus indicating the economic feasibility of intercropping.

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