Article

Nitrate/potassium interaction in the nutrient solution and potato yield in hydroponics

Saúl Parra Terraza[1§]
Werner Rubio Carrasco[2]
Sergio Hernández Verdugo[1]
Pedro Sánchez Peña[1]
Pablo Preciado Rangel[3]

[1]Autonomous University of Sinaloa-Faculty of Agronomy. Highway Culiacán-El dorado km 17.5, Culiacán, Sinaloa, México. (sergioh2002mx@yahoo.com.mx; spenap@hotmail.com). [2]Center for Research in Food and Development AC. Culiacán, Sinaloa, Mexico. (wrubio@ciad.mx). [3]Technological Institute of Torreón (ITT)-DEPI. Road Torreón-San Pedro km 7.5, Ejido Anna, Torreón, Coahuila, Mexico. (ppreciador@yahoo.com.mx).

[§]Corresponding author: saul.parra@uas.edu.mx.

Abstract

The interactions of nutrients in plants can be quantified by nutrient concentrations in plant organs, however, there are few studies that evaluate the interaction of more than one nutrient in the same experiment, and few reports of the N/K interaction in the nutritive solution in the yield and the mineral composition of potato (*Solanum tuberosum* L.). The objective of this research was to evaluate in greenhouse and hydroponics the interaction of three percentage ratios NO_3^-/anions (40/100, 60/100 and 80/100) and three of K^+/cations (15/100, 35/100 and 55/100) on the mineral composition of leaves, stems, tubers and potato yield cv. Agatha. The experimental design used was completely randomized with a factorial arrangement of treatments 32. The interaction NO_3^-/anions x K^+/cations was significant for the concentrations of P, K, Ca and Mg in leaves; K, Ca and Mg in stems; and Ca and Mg in tubers. The NO_3^-/anions and K^+/cations, and the interaction NO_3^-/anions x K^+/cations did not statistically affect the tuber diameter, the tuber dry matter, the number of tubers and the yield. These results indicate that potato production in a closed hydroponic system and coconut fiber substrate NO_3^-/anions and K^+/cations should not be greater than 60/100 and 15/100, respectively, since high ratios NO_3^-/anions (80/100) and K^+/ ations (55/100) reduce the yield of tubers 16.7% and 12.8%, each.

Keywords: *Solanum tuberosum* L., nitrate-anions relationship, potassium-cation ratio.

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Introduction

In Mexico, 64 646 ha of potatoes were planted in the 2016 agricultural year (42 027 ha of irrigation and 22 439 ha of rainfed), of which 13 635 ha of irrigation were planted in Sinaloa, with an average yield of 26.42 t ha^{-1}, consolidating itself as the first producer at the national level (SIAP, 2016). In Sinaloa, potato cultivation is carried out mainly in open fields, where the plants are exposed to physical, chemical and biological limitations of the soil and environmental conditions, which can affect yield.

In contrast, protected agriculture offers advantages over open-field production such as: certain independence of climate, the use of substrates as substitutes for soil, greater efficiency in the use of water and nutrients (Sánchez *et al*., 2014), among others, which allows obtaining higher yields. In Mexico, potato cultivation in the greenhouse is limited to obtaining seed-tuber, in which the progeny of pre-nuclear material (prebasic I), obtained in vitro, it is essential that it be multiplied in protected environment, in substrate and diagnosed free of pests and diseases (DOF, 2003).

In that sense, it is unknown if potato production in the greenhouse can be a viable alternative to produce for the national market. In potato cultivation, N is the most limiting nutrient of growth (Errebhi *et al*., 1998), while K is the most absorbed (Panagiotopoulos, 1995), inadequate amounts of N and K reduce the dry matter of the tuber, important characteristic in the quality of the potato (Alison *et al*., 2001) and an inadequate supply of N affects the number of tubers (O'Brien *et al*., 1998). The joint application of N and K is important to obtain high potato yields; Sifuentes *et al*. (2013) report that to produce 1 t ha^{-1} of potatoes a total extraction of 6.3 kg N ha^{-1} and 7 kg of K ha is required, while Berstch (2009), by gathering information worldwide, mentions averages of 6.2 and 8.7 kg of N and K ha^{-1}.

A common practice of potato producers in Sinaloa is to apply excessive amounts of N and K, because chemical analyzes of soil and irrigation water are not usually used to know the contributions of these nutrients in the demand of the crop and the percentages of fertilization efficiency with N and K in the different soils of Sinaloa. Therefore, excess N and K can reduce yields, increase production costs and contaminate surface and groundwater with N (Vitosh and Jacobs, 1990). One way to reduce the negative impact on the environment of the excesses of N and other nutrients (P mainly) is to use closed hydroponic systems where the drained nutrient solution is collected for re-use in the crop, after measurement and adjustment, if necessary, pH and CE (Sánchez *et al*., 2014).

The N-K interaction generally occurs in agricultural ecosystems (Johnston and Milford, 2009), although most interactions are complex, since one nutrient when interacting with another can induce deficiencies, toxicities, modify the response in growth and alter the concentration of nutrients in plants. In the generality of the plant nutrition experiments carried out, the effect of a nutrient on growth was investigated, so that interaction studies carried out with more than one nutrient in the same experiment are limited (Fageria, 2001). In hydroponic crops one way to evaluate the effect of N, K and NxK interaction is by using relative ratios of ions in the nutrient solution, where a high concentration of NO_3^-, with respect to $H_2PO_4^-$ and SO_4^{2-} anions, and a low concentration of K^+, with respect to the Ca^{2+} and Mg^{2+}cations, indicates a high NO_3^-/K^+ ratio, better known as the N/K ratio.

In Mexico and Latin America there are no studies in potato, using NO_3^-/anions and K^+/cations in the nutritive solution, since to define these relationships it is necessary to consider the methodology proposed by Steiner (1984); however, this technique is not of usual knowledge or does not have a general acceptance, for this reason the objectives of this study were to determine the interaction of three percentage relations [NO_3^-/anions (NO_3^-, $H_2PO_4^-$ and SO_4^{2-})] and three percentage ratios [K^+/cations (K^+, Ca^{2+} and Mg^{2+})] in the nutritive solution in the mineral composition and yield of potato grown in a closed hydroponic system.

Materials and methods

The experiment was carried out in 2014 in a greenhouse, with lateral ventilation and anti-aphid meshes on the walls, located in Culiacan, Sinaloa, Mexico, at 24° 37’ 24.40” and 38 m altitude, the minimum and maximum average temperatures were 15.2 and 29.6 °C, respectively. A variety Agatha potato was used, cultivated in a hydroponic system of closed irrigation in a closed circuit, composed of 72 plastic containers with a capacity of 20 L each, connected each pair of containers with 1.25 cm diameter rubber hose. One of the containers contained 15 L of coconut fiber as a substrate and in the other 10 L of the corresponding nutrient solution (SN). In the containers containing the fiber, the tubers were placed at a depth of 10 cm, one per container. The separation between the rows was 1 m and between plants in each row was 0.30 m, with a planting density of 33 333.3 plants ha^{-1}.

The experimental design was randomized complete blocks with factorial arrangement of treatments 32 and four repetitions for a total of 36 experimental units, where each unit consisted of a potato plant. The factors and levels evaluated were: 1) three ratios (40/100, 60/100 and 80/100) percent NO_3^-/anions (NO_3^-, $H_2PO_4^-$, SO_4^{2-}); and 2) three ratios (15/100, 35/100 and 55/100) percents K^+/cations (K^+, Ca^{2+}, Mg^{2+}) (Table 1). When combining the three percentage ratios NO_3^-/anions with the three percentage ratios K^+/cations resulted in nine SN, which were designed from modifications of the universal solution of Steiner (1984), whose percentage relation between anions NO_3^-, $H_2PO_4^-$ and SO_4^2, is 60, 5 and 35 and between the cations K^+, Ca^{2+} and Mg^{2+} is 35, 45 and 20 and consisted of varying the concentration of NO_3^- in relation to $H_2PO_4^-$ and SO_4^{2-}, as well as the concentration of K^+ with respect to Ca^{2+} and Mg^{2+} (Table1).

Table 1. Percentage ratios between the ions of the nutritive solutions used.

NO_3^- (%)	$H_2PO_4^-$ (%)	SO_4^{2-} (%)	K^+ (%)	Ca^{2+} (%)	Mg^{2+} (%)
40	7.5	52.5	15	58.85	26.15
60	5	35	15	58.85	26.15
80	2.5	17.5	15	58.85	26.15
40	7.5	52.5	35	45	20
60	5	35	35	45	20
80	2.5	17.5	35	45	20
40	7.5	52.5	55	31.15	13.85
60	5	35	55	31.15	13.85
80	2.5	17.5	55	31.15	13.85

The SN were prepared with irrigation water with an EC of 0.3 dS m^{-1} and pH of 7, classified C1S1 (low risk of salinization and sodification) (Ayers and Westcot, 1985), considering in the formulation of the SN the nutrients present in water. Fertilizers were used as sources of macronutrients: calcium nitrate, potassium nitrate, potassium sulfate, magnesium sulfate, monopotassium phosphate. The micronutrients were provided as chemical reagents (boric acid, zinc sulfate, manganese sulfate, copper sulfate and iron chelate).

At SN they were added micronutrient concentrations (mg L^{-1}) below: Fe 2.5 Mn 0.5, B 0.5, Zn 0.05 Cu 0.02 (Parra *et al*., 2010). The SN were adjusted to an osmotic potential of -0.072 MPa (Table 2), according to Steiner (1984). A daily irrigation was applied to the coconut fiber and the evapotranspirated water was replenished daily, by gauging it with irrigation water, without adjusting the pH of the SN, which were renewed every 15 d, using a reduction of 50% as a criterion of change of the initial EC of the SN. At 85 d after sowing, yield (kg ha^{-1}), number and diameter of tubers (diameters smaller than 12 mm were not counted), dry matter of tubers (MST) and nutritional concentration in leaves, stems were evaluated. and fruits.

Table 2. Chemical composition (mol_c m^{-3}) of the nutritive solutions used in the experiment.

NO_3^-	$H_2PO_4^-$	SO_4^{2-}	K^+	Ca^{2+}	Mg^{2+}
9.14	1.71	12	3.43	13.45	5.98
12.86	1.07	7.5	3.21	12.61	5.6
16.13	0.5	3.53	3.03	11.87	5.27
8.5	1.59	11.15	7.43	9.56	4.25
12	1	7	7	9	4
15.12	0.47	3.31	6.61	8.5	3.78
7.93	1.49	10.41	10.91	6.18	2.75
11.25	0.94	6.56	10.31	5.84	2.6
14.22	0.44	3.11	9.78	5.54	2.46

The MST was quantified considering the fresh and dry weights of the tuber, which were obtained by drying the fresh tubers at 100 °C for 48 h. The biomass was separated into its components: leaves, stems and tubers, which were dried at 70 °C until constant weight, ground and passed through a sieve of 0.5 mm in diameter. The N was determined by the semi-micro Kjeldahl procedure (Etchevers, 1987) modified to include nitrates. Phosphorus was quantified by the yellow vanadate molybdate method (Rodríguez and Rodríguez, 2002), calcium and magnesium by titration with EDTA (Chavira and Castellanos, 1987) and potassium by flamometry (Alcántar and Sandoval, 1999). The analysis of variance and correlation of the variables considered was carried out for the main factors and for their interaction, with the statistical package SAS, version 9.4 (SAS, 2013). For the comparison of means, the Tukey test ($\alpha \leq 0.05$) was used.

Results and discussion

Nutrimental analysis in leaves. The interaction between NO_3^-/anions and K^+/cations was significant for the concentrations of P, K, Ca and Mg and the NO_3^-/anions ratio affected ($p \leq 0.01$) the concentration of N (Table 3).

Table 3. Effect of the relation NO_3^-/anions and K^+/cations in the nutritive solution and the concentration of N, P, K, Ca and Mg in leaves of potato plants.

Factor	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
Percentage ratio of NO_3^-/anions					
40/100	4.3 c	0.34 a	5.8 a	4.8 a	1.4 a
60/100	5.4 b	0.27 ab	5.6 a	3.2 c	1.3 a
80/100	6 a	0.2 b	5.4 a	4 b	1.5 a
Percentage ratio of K^+/cations					
15/100	5.3 a	0.29 a	5.8 a	5.2 a	1.8 a
35/100	4.1 a	0.25 a	5.9 a	4 b	1.4 b
55/100	5.3 a	0.26 a	5.1 a	2.9 c	1 c
Mean	5.23	0.27	5.59	4.02	1.42
Standard deviation	1.01	0.15	1.02	1.63	0.54
NO^{3-}/anions x K^+/cations	ns	**	**	**	**

Averages with equal letters in each column and for each factor are statistically equal (Tukey, 0.05).

The percentages of P obtained with the three K^+/cations ratios were different for the 40 and 60/100 NO^{3-}/anions ratios. In the 40/100 NO^{3-}/anions ratio the highest concentration of P (0.47%) was obtained with 55/100 K^+/cations and when increasing the ratio to 60/100 NO^{3-}/anions the concentration of P (0.11%) was reduced significantly (Table 4), possibly due to the lower proportion of P (5%) in the 60/100 NO^{3-}/anions ratio, compared to 40/100 NO^{3-}/anions (7.5% of P) (Table 1). Dechassa *et al*. (2003) mention that low concentrations of P limit the transport of this element to the roots, reducing absorption. The results of Soratto *et al*. (2015) in potato (*Solanum tuberosum* L.) coincide with what was found in this study, because they also reported higher concentration of P in the leaves with increases in P in the SN.

With the combination 80/100 NO_3^-/anions and 15/100 K^+/cations the highest concentration of K (6.5%) was obtained and when increasing to 35 and 55/100 K^+/cations the concentration was reduced 18.5 and 32.3% when obtaining 5.3 and 4.4% of K, which can be attributed to the higher percentage of Ca (58.85%) in the combination 80/100 NO_3^-/anions and 15/100 K^+/cations, since Ca stimulated the absorption of K by stabilizing the pH of the solution (Marschner, 1995). This result partially coincides with that reported by Kavvadias *et al*. (2012), who obtained lower concentration of K (3.7%) in potato leaves with applications of 450 kg of K_2O ha^{-1}, compared to 112 and 225 kg of K_2O ha^{-1} (5.6 and 4% of K in leaves, respectively).

Regarding Ca, with the combination of 40 NO_3^-/anions and 15/100 K^+/cations, the highest concentration of Ca (6.3%) and the lowest (0.6% Ca) was obtained with 60/100 NO_3^-/anions and 55/100 K^+/cations (Table 4). With the combination 60/100 NO_3^-/anions and 15/100 K^+/cations the highest concentration of Mg (2.3%) and the lowest (0.6%) was obtained with 60/100 NO_3^-/anions and 55/100 K^+/cations (Table 4).

Table 4. Effect of the interaction NO_3^-/anions x K^+/cations in the nutrient solution in the concentration of P, K, Ca and Mg in potato leaves.

Factor	P (%)	K (%)	Ca (%)	Mg (%)
NO_3^-/anions x K^+/cations				
40/100 x 15/100	0.35 abc	5 ab	6.3 a	1.8 ab
60/100 x 15/100	0.28 abc	5.9 ab	4.3 b	2.2 a
80/100 x 15/100	0.26 abc	6.5 a	4.9 ab	1.5 bc
40/100 x 35/100	0.2 bc	6.5 a	4 b	1.1 c
60/100 x 35/100	0.42 ab	5.9 ab	4.7 ab	1.5 bc
80/100 x 35/100	0.14 c	5.3 ab	3.1 b	1.6 bc
40/100 x 55/100	0.47 a	6 ab	4.2 b	1.3 bc
60/100 x 55/100	0.11 c	5 ab	0.6 c	0.3 d
80/100 x 55/100	0.21 abc	4.4 b	4 b	1.4 bc

Averages with equal letters in each column are statistically equal (Tukey, 0.05).

The reductions in the concentrations of Ca and Mg in leaves obtained with the relation 55/100 K^+/cations are attributed to the antagonism of K over Ca (Kavvadias *et al*., 2012) and Mg (Fageria, 2001), because higher proportion of K in the nutrient solution (SN), lower concentrations of Ca and Mg in the leaves. With the 80/100 NO_3^-/anions in the SN, the highest concentration of N (6%) was obtained, while the lowest (4.3% of N) with 40 NO_3^-/anions (Table 3). Geary *et al*. (2015) reported concentrations of 3.1 to 6.5% of N in potato leaves growing Russets Burbanks when using 20 to 320 mg N L^{-1} of solution in a closed hydroponic system, concentrations of N similar to those obtained in the present work. The averages of the nutrient concentrations in leaves had the order K> N> Ca> Mg> P and the concentrations of Ca and K varied more than the concentrations of N, Mg and P, based on their standard deviations (Table 3).

Kavvadias *et al*. (2012) reported averages of N> K> Ca> Mg> P in leaves of cultivated potato Spunta, cultivated in soil, values very similar to those obtained in the present work, in addition these authors indicate that K and N had greater variation with respect to Ca, Mg and P. The N on the leaf was positive and significantly correlated with the NO_3^-/anions ratio ($r= 0.73^{**}$) and negatively with the concentration of P on the leaf (-0.38^{*}). This positive correlation indicates that increasing the concentration of NO_3^- in the SN increased the concentration of N in the leaf, which coincides with Kavvadias *et al*. (2012) and with Geary *et al*. (2015), while the negative correlation found in the P concentration in leaves is explained because the concentration of P was reduced with the increases of NO_3^- in the SN. The ratio K^+/cations in the SN had a negative and significant correlation with the concentrations of Ca in the leaves (-0.58^{**}) and Mg (-0.65^{**}), since increases in the ratio K^+/cations in the SN reduced the concentrations of Ca and Mg in the leaves.

Nutrimental analysis in aerial stems. The concentrations of K, Ca and Mg were affected ($p\leq 0.01$) by the interaction NO_3^-/anions x K^+/cations (Table 5). The highest values of K (8.4 and 9%) were obtained with the combinations 60/100 and 80/100 NO_3^-/anions with 55/100 K^+/cations and the lowest concentration of K (4.7%) with 60/100 NO_3^-/anions and 15/100 K^+/cations (Table 6), which may be due to the fact that these bodies accumulate K to cover the K demand of the leaves and tubers, since the potato crop absorbs more K than of N and P (Panagiotopoulos, 1995). Regarding Ca, the highest concentration (2.7%) was obtained with the ratio 15/100 K^+/cations combined with 40/100, and the lowest concentration (0.5% Ca) with the mixture 60/100 NO_3^-/anions and 55/100 K^+/cations (Table 6).

Table 5. Effect of the relation NO_3^-/anions and K^+/cations in the nutritive solution and the concentration of N, P, K, Ca and Mg in aerial stems of potato plants.

Factor	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
Percentage ratio of NO_3^-/anions					
40/100	2.3 b	0.39 a	5.9 a	2.2 a	1.3 a
60/100	3.3 a	0.26 b	7 a	1.7 a	1.1 a
80/100	3.7 a	0.25 b	7.2 a	2 a	1.5 a
Percentage ratio of K^+/cations					
15/100	3.7 a	0.3 ab	5.8 b	2.5 a	1.5 a
35/100	2.6 b	0.38 a	6.3 b	1.9 b	1.5 a
55/100	3 b	0.22 b	7.9 a	1.6 b	0.9 b
Mean and	3.1	0.3	6.7	1.9	1.3
Standard deviation	1.02	0.14	1.91	0.75	0.49
NO_3^-/anions x K^+/cations	ns	ns	**	**	**

Averages with equal letters in each column and for each factor are statistically equal (Tukey, 0.05).

Table 6. Effect of the interaction NO_3^-/anions x K^+/cations in the nutrient solution in the concentration of K, Ca and Mg in aerial stems of potatoes.

Factor	K (%)	Ca (%)	Mg (%)
NO_3^-/anions x K^+/cations			
40/100 x 15/100	5.8 abc	2.7 a	1.4 a
60/100 x 15/100	4.7 c	2.3 ab	1.7 a
80/100 x 15/100	7.2 abc	2.4 a	1.4 a
40/100 x 35/100	5.6 abc	1.8 ab	1.3 a
60/100 x 35/100	8.0 abc	2.4 a	1.4 a
80/100 x 35/100	5.3 bc	1.4 bc	1.7 a
40/100 x 55/100	6.3 abc	2 ab	1.2 a
60/100 x 55/100	8.4 ab	0.5 c	0.3 b
80/100 x 55/100	9 a	2.2 ab	1.2 a

Averages with equal letters in each column are statistically equal (Tukey, 0.05).

The concentration of Mg in stems had a pattern similar to that of Ca, since the highest concentration (1.7% Mg) was obtained with the ratio 15/100 K^+/cations and the lowest (0.3%) with the ratio 55/100 K^+/cations (Table 6). The reductions in Ca and Mg concentrations obtained with the combination 55/100 K^+/cations and 60/100 NO_3^-/anions are a reflection of the antagonism of K over Ca and Mg (Fageria, 2001; Kleiber *et al*. 2012); therefore, the ratio K^+/cations in the nutrient solution had a negative and significant correlation with the concentrations of Ca in stems (-0.5**) and Mg (-0.51**).

In contrast, the ratio K^+/cations had a positive and significant correlation (0.46**) with the concentration of K in the stems, since when increasing this ratio, the concentrations of this element in the stems were increased. The concentrations of N and P in the stems were affected ($p \leq 0.05$) by the NO_3^-/anions and K^+/cations in the SN, the highest concentrations of N (3.7%) and P (0.39%) were obtained. with the ratio 80/100 NO_3^-/anions and with 40/100 NO_3^-/anions, respectively (Table 5), attributed to the highest concentrations of N and P in these SN (Table 2). Due to the lack of research carried out worldwide on the nutritional analysis of potato stems, it was not possible to compare the results obtained in the present study with other scientific studies, since only the leaves and tubers are analyzed in all the studies consulted.

Nutrimental analysis in tubers. The interaction NO_3^-/anions x K^+/cations was significant ($p \leq$ 0.01) for the concentrations of Ca and Mg, while the percentage relationship NO_3^-/anions affected the concentration of N and the percentage ratio K^+/cations was different for the K concentration (Table 7).

Table 7. Effect of the relation NO_3^-/anions and K^+/cations in the nutritive solution and the concentration of N, P, K, Ca and Mg in potato tubers.

Factor	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
	Percentage ratio of NO_3^-/anions				
40/100	2.9 b	0.43 a	1.8 a	0.4 b	0.3 b
60/100	3.8 a	0.42 a	1.8 a	1 a	0.7 a
80/100	3.6 a	0.44 a	1.8 a	0.4 b	0.3 b
	Percentage ratio of K^+/cations				
15/100	3.6 a	0.44 a	2.1 a	1.2 a	0.7 a
35/100	3.2 a	0.38 a	1.7 b	0.3 b	0.3 b
55/100	3.5 a	0.46 a	1.6 b	0.4 b	0.2 b
NO_3^-/anions x K^+/cations	ns	ns	ns	**	**

Averages with equal letters in each column and for each factor are statistically equal (Tukey, 0.05).

The highest value of Ca (2.3%) was obtained with the combination 60/100 NO_3^-/anions and 15/100 K^+/cations and the lowest (0.4 and 0.3% Ca) with 55 and 35/100 K^+/cations. The highest Mg concentration (1.7%) was obtained with 60/100 NO_3^-/anions and 15/100 K^+/cations and the lowest ones, which were statistically equal to each other (0.3 and 0.2% Mg) with 35 and 55/100 K^+/cations (Table 8).

Table 8. Effect of the interaction NO_3^-/anions x K^+/cations in the nutrient solution in the concentration of Ca and Mg in potato tubers.

Factor	Ca (%)	Mg (%)
NO_3^-/anions x K^+/cations		
40/100 x 15/100	0.6 b	0.3 b
60/100 x 15/100	2.3 a	1.7 a
80/100 x 15/100	0.7 b	0.3 b
40/100 x 35/100	0.3 b	0.3 b
60/100 x 35/100	0.3 b	0.2 b
80/100 x 35/100	0.3 b	0.3 b
40/100 x 55/100	0.4 b	0.2 b
60/100 x 55/100	0.4 b	0.2 b
80/100 x 55/100	0.3 b	0.2 b

Averages with equal letters in each column are statistically equal (Tukey, 0.05).

The lower concentrations of Ca and Mg obtained by the combinations NO_3^-/anions with 55/100 K^+/cations are attributed mainly to the antagonism of K with Ca and Mg (Kleiber *et al*., 2012) due to the high proportion of K^+ (55%) in the SN with respect to Ca^{2+} (31.15%) and Mg^{2+} (13.85%), which generates greater availability of K and lower Ca and Mg in the SN (Table 1), therefore the K^+/cations ratio in the SN had a significant and negative correlation with the concentrations of Ca (-0.53^{**}) and Mg (-044^{**}) in the tubers. The ratios 60 and 80/100 NO_3^-/anions statistically increased the concentration of N in the tuber, with respect to 40/100 NO_3^-/anions (Table 7), which coincides with Özturk *et al*. (2010), who mention that increasing applications of N increased the concentration of N in the tubers and differs from Kavvadias *et al*. (2012) and Biemond and Vos (1992) who reported that increasing applications of N did not increase the concentration of this nutrient in the tuber. The ratio 15/100 K^+/cations in the SN increased ($p\leq 0.05$) the concentration of K in the tuber, with respect to 35 and 55/100 K^+/cations, possibly because the concentrations of K in these two relationships were excessive, which contributed to generate a nutritional imbalance, which manifested itself with lower concentrations of K, Ca and Mg in the tubers (Table 7).

Performance and its components. The analysis of variance showed no significant effects of the NO_3^-/anions and K^+/cations, nor the interaction NO_3^-/anions x K^+/cations in the yield, the dry matter of the tuber, the diameter and the number of tubers. However, the factors NO_3^-/anions and K^+/cations affected ($p\leq 0.05$) the harvest index (IC) (Table 9). The 60 and 80/100 NO_3^-/anions in the SN significantly reduced the IC compared to the ratio 40/100 NO_3^-/anions, attributed to a delay in the formation of the tuber and a decrease in its growth (Allison *et al*., 2001), caused by high nitrogen fertilization (Vos, 1997), which reduced the translocation of C to the leaves and tubers and increased the flow of this element to the young leaves, instead of the tubers (Mohamed *et al*., 2017).

Table 9. Effect of the relation NO_3^-/anions and K^+/cations in the nutritive solution on tuber diameter (DT), tuber dry matter (MST), number of tubers (NT), harvest index (IC) and the yield of potatoes.

Factor	DT (mm)	MST (%)	NT	IC	Yield (t ha^{-1})
Relation NO_3^-/anions					
40/100	42 a	16 a	17 a	0.44 a	31.43 a
60/100	39 a	15 a	22 a	0.3 b	37.15 a
80/100	47 a	17 a	16 a	0.34 b	30.95 a
Relation K^+/cations					
15/100	40 a	14 a	23 a	0.3 b	35.27 a
35/100	48 a	17 a	16 a	0.4 a	33.01 a
55/100	41 a	17 a	16 a	0.38 a	30.74 a
NO_3^-/anions x K^+/cations	ns	ns	ns	ns	ns

Averages with equal letters in each column are statistically equal (Tukey, 0.05).

With the 35 and 55/100 K^+/cations ratios, the highest IC (0.40 and 0.38) were obtained, while the lowest IC (0.3) was obtained with 15/100 K^+/cations, which implies that the plants developed with 35 and 55/100 K^+/cations in the SN allocated a higher proportion of assimilated to the tuber, which coincides with Singh and Lal (2012). The dry matter of the tuber (MST) is important for the destination of production, because a high content of MST favors the industrialization of potatoes (Pritchard and Scanlon, 1997). With the relation NO_3^-/anions, an average of 16% of MST was obtained and with the relation K^+/cations 14% of MST; these values are low, considering the quality criteria proposed by Cacace *et al*. (1994), so that the most appropriate use of these tubers is for fresh consumption and not for dehydration or frying.

Kavvadias *et al*. (2012) reported 9 and 16.8% of MST, while Badillo *et al*. (2004) obtained 25.9 and 26.9% of MST and Özturk *et al*. (2010) reported 20 to 20.6% of MST. The variations in MST are related to the genetic materials used, prevailing environmental conditions, fertilization used and agronomic management. Allison *et al*. (1998) and Sharma and Arora (1987) mention that the number of tubers was not affected by nitrogenous or potassium fertilization, which coincides with the present study. With the 60/100 NO_3^-/anions ratio, the highest yield of fresh tuber (37.15 t ha^{-1}) was obtained, statistically ($p \leq 0.05$) similar to those obtained with the 40 and 80/100 NO_3^-/anions ratios (31.43 and 30.95 t ha^{-1}, respectively).

Regarding the ratio K^+/cations the highest yield (35.27 t ha^{-1}) was obtained with 15/100 K^+/cations, equal value ($p \leq 0.05$) to those obtained with 35/100 K^+/cations (33.01 t ha^{-1}) and with 55/100 K^+/cations (30.74 t ha^{-1}) (Table 9). Kang *et al*. (2014) reported that increasing applications of K did not increase performance, which coincides with the present study; they mention that the absorption of K by the plants increased with the increases of K, which suggests that the potato crop absorbs more K than required when the availability of K is high.

It is generally considered that the potato crop responds to potassium fertilization, which is why high amounts of this element are applied (Kavvadias *et al*., 2012). The data of this study indicate that, for the conditions in which this work was developed, the ratio of 15/100 K^+/cations is the most adequate, so that higher ratios of K^+/cations are not necessary. The maximum yield (40.36 t ha^{-1}) was obtained with the combination 60/100 NO_3^-/anions and 15/100 K^+/cations, not significant value with respect to the other combinations, while the lowest (27.79 t ha^{-1}) was obtained with the combination 80/100 NO_3^-/anions and 55/100 K^+/cations (Figure 1).

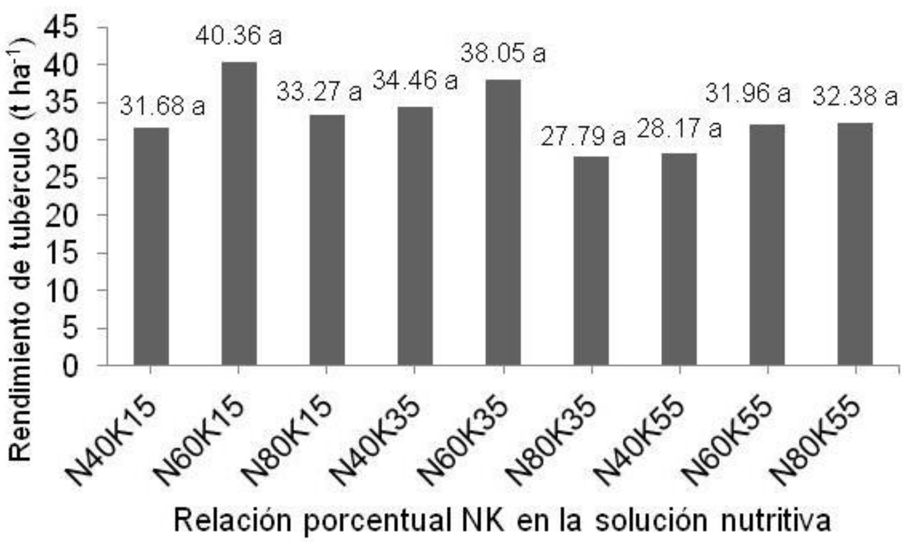

Figure 1. Effect of NK percentage ratios in the nutrient solution on tuber yield.

Conclusions

The NO_3^-/anions and K^+/cations and the interaction NO_3^-/anions x K^+/cations did not affect the yield, the dry matter of the tuber, the diameter and the number of tubers. The interaction NO_3^-/anions x K^+/cations reduced the concentrations of Ca and Mg in leaves, stems and tubers by antagonism of K with these elements. To reduce fertilization costs in potato production, in a closed hydroponic system and coconut fiber as substrate the NO_3^-/anions and K^+/cations should be 40/100 and 15/100, respectively.

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