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Article

NPK fertilization, biomass distribution and number of potatoes minitubers in the greenhouse

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Abstract

The objective of this research was to evaluate the response of the potato (*Solanum tuberosum*) to the fertilization of nitrogen (N), phosphorus (P) and potassium (K), in the accumulation of biomass, harvest index and number of tubers under conditions of hydroponics under greenhouse. The experimental design used was the San Cristóbal, with 12 treatments. The variables that were evaluated were: leaf biomass, stem, root, stolon and tuber, harvest index and number of tubers. The biomass distribution in all the treatments, with respect to the total biomass, varied from 9.88 to 13.1% in leaf; 1.83 to 4% stem, 1.9 to 4.9% root, 0.8 to 1.31% stolon and 77.6 to 83.6% in tuber. The fertilization treatment with 250N-80P-300K mg L^{-1} obtained the highest accumulation of total biomass per plant, 63.54 g; for leaves, 6.78 g, stem 2.36 g, stolon 0.5, root 1.2 g and tubers 52.56 g. While the treatment that presented the highest harvest index was T2 (200N-30P-250K) with 0.83, only different from the treatments T7 (100N; 130P; 350K) and T11 (150N; 180P; 300K) with 0.77 and 0.78, respectively. The harvest index was not related to the number of tubers per plant, since the treatments with the highest number of these were T8 (200N-130P-250K) with 18.6 tubers and T12 (150N-80P-400K) 18.2, with an index harvest of 0.82, while the T3 with the highest index (0.83) only produced 13.7 tubers per plant.

Keywords: biomass, hydroponics, potato.

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Introduction

The potato (*Solanum tuberosum* L.) demands large amounts of nutrients, which are important in the yield and quality of the tubers (Morales *et al*., 2013), mainly nitrogen (N), phosphorus (P) and potassium (K) throughout its cycle (White *et al*., 2007). Bertsch (2003) mentions that it absorbs 220, 20, 240, 60 and 20 kg ha^{-1} of N, P, K, Ca and Mg, respectively, for a production of 20 t ha^{-1}; however, Rocha and Quijano (2015) mention the use of a fertilization formula of 200 - 300 - 200 NPK, plus 30 kg of zinc sulfate and 25 kg of boron with yields greater than 40 t ha^{-1}, which that shows the high nutritional requirements that the crop presents.

In greenhouse it is grown on organic substrates (peat, coconut fiber, rice husk) mixed with inorganic substrates such as perlite or some other small diameter gravel; however, fertilization is done using physical mixtures of granulated fertilizers or soluble fertilizer formulas or hydroponic nutrient solutions (Flores *et al*., 2009).

Most of the nitrogen (N) absorbed by the plant occurs during the vegetative growth stage and before the tuber filling stage it consumes more than 50% with a daily demand of 7 kg ha^{-1} day^{-1}. In the case of phosphorus (P), the demand fluctuates between 0.4 to 0.9 kg ha^{-1} day^{-1}, in the middle of the cycle depending on the variety and climate. And in relation to potassium (K) the absorption is from 5 to 14 kg ha^{-1} day^{-1} (Horneck and Rosen, 2008).

The excess or deficiency of N has consequences on the yield of tubers (Westermann, 2005). N favors foliar development, increasing the photosynthesis surface, which leads to the production of starch, directly affects the translocation of starch from the leaves to the tubers, influences the yield, the height of the plant, the number of tubers per unit area, percentage of protein and dry matter (Ramírez *et al*., 2004). Excess nitrogen can lengthen the crop cycle, negatively affect yield and increase the risks of foliar diseases (Sierra *et al*., 2002).

Meanwhile, phosphorus influences growth, accelerates maturity, improves quality and yield; helps cell division and growth (Valverde *et al*., 1998). In potato plants with P deficiency, apical growth is retarded, giving rise to small and rigid plants and reduces the formation of starch in the tubers that manifests itself with necrotic spots distributed in the tuber (Pumisacho and Sherwood, 2002). On the other hand, it is generalized that potassium acts as an activator of essential enzymes in photosynthesis, respiration, starch and protein formation.

After nitrogen, potassium is the mineral nutrient required in greater quantity by potato plants, it is very mobile within it and is absorbed from the soil as a K+ cation (Becerra and Ñustez 2007). The deficiency symptoms appear first in the older leaves, the plants become small due to the shortening of the internodes, the stems and branches are weak, the roots have poor development, the stolons are short and small tubers are produced.

Hydroponics is an alternative for the production of potato seed with advantages over traditional cultivation, since a smaller cultivation area is used, due to the higher density per unit of surface that can be managed (Chuquillanqui *et al*., 2010). It has been shown that it is possible to increase the number of tubers produced by the hydroponic production technique (Rolot and Seutin, 1999). And a requirement for this is to achieve a balance between the proportions of nutrients within the nutrient solution, electrical conductivity (EC) and pH as necessary for potato production (Chang *et al*., 2011).

The yield in a crop is the final result of the biomass accumulation and distribution processes and is given by the ability of the genotype to accumulate biomass in the organs of economic interest, so the proportional increase in the biomass destined for these organs guarantees increased yield.

The accumulation and distribution of biomass in plants are genotypic characteristics easily affected by the environment and its interaction (Rajwade *et al*., 2000). Thus, the proportion of biomass assigned to leaves, stems and tubers at each moment of development depends on the growth kinetics and the distribution rate, which are governed by the leaf area, climate and nutrient availability (Heemst, 1986).

The potato (*Solanum tuberosum*) accumulates a greater amount of dry matter in the aerial organs and the roots during the initial half of the biological cycle and subsequently decreases part of it due to the loss of leaves and translocation of photosynthates towards the tubers (Aguilar *et al*., 2001), so that at a certain point there is a competitive relationship between the canopy and the tubers (Susnoschi and Shimshi, 1985). It is mentioned that the growth of the tubers is determined by the rates of accumulation and distribution of biomass in the different organs of the plant (Khurana and Pandita, 1994) and in favorable environments, more than 90% of the photosynthates produced in the leaves are translocated to tubers (Wolf *et al*., 1990).

The harvest index (IC) determines the relationship in distribution of biomass in the complete plant and the organs of anthropocentric importance, such as tubers, for which it is considered as an index of physiological efficiency (Mora *et al*., 2005) and in potato, can vary between 57 and 91% when the tubers have matured and the foliage is in senescence (Rajwade *et al*., 2000), this range represents the differences due to the production environment, the genotype or the interaction between both factors (Jefferies and Mackerron, 1993), in early potato genotypes the IC is higher than in late ones; in both, it is affected by environmental factors (Sierra, 2002).

Under greenhouse conditions, several factors that affect yield such as genotype, sowing date, density, agronomic management, water availability, control of pests, diseases and crop nutrition can be affected, this being the most important factor in the development and yield of the potato crop. The objective of this research was to evaluate the response of the potato (*Solanum tuberosum*) to the fertilization of nitrogen (N), phosphorus (P) and potassium (K) in the accumulation of biomass, harvest index and yield under hydroponic under greenhouse conditions.

Materials and methods

The experiment was carried out in greenhouses of the National Institute of Forestry, Agricultural and Livestock Research (INIFAP), Metepec experimental site, located at km 4.5 Toluca-Zitácuaro highway, Zinacantepec, State of Mexico at 19° 17’ 21’’ north latitude and 99° 42’ 49’’ west longitude at 2 640 masl. The average temperature inside the greenhouse was 15.5 °C with maximums of 36 and minimums of -0.9. The potato variety used in this research was Nevada, recently released by INIFAP, with high yield, quality for the industry and tolerance to internal staining of the tuber caused by the purple tip syndrome of the potato and tolerant to blight and purple tip.

1.8 L volume pots with horticultural grade perlite of 1 to 4 mm in diameter were used. Virus-free minitubers of 10 to 15 mm in diameter were used, with a single sprout, the tubers were treated with a rooting agent (Miyaraiz) at 5 ml L^{-1} and Miyafungi TH (*Trichoderma harsianum*), 1 g L^{-1} per immersion for 5 minutes.

Irrigation was done with the use of 8 L h^{-1} drippers with a four outputs distributor. Four irrigations were scheduled the first two weeks, followed by five the next four weeks and seven the last six, the expenditure was 33 ml per pot in each irrigation for a maximum expenditure of 231 ml per pot. The N P K levels were four, distributed according to the San Cristobal design (Martínez, 1996), 12 treatments, four repetitions and 16 plants for each repetition.

The concentrations in mg L^{-1} were 100, 150, 200 and 250 of nitrogen; 30, 80, 130 and 180 for phosphorus and 250, 300, 350 and 400 for potassium. The 12 resulting treatments present the following NPK combinations: T1 (100-30-250); T2 (200-30-250); T3 (100-130-250); T4 (200-130-250); T5 (100-30-350); T6 (200-30-350); T7 (100-130-350); T8 (200-130-350); T9 (150-80-300); T10 (250-80-300); T11 (150-180-300) and T12 (150-80-400). For this, the 12 nutritional solutions were made supplemented with 45 mg L^{-1} of Mg, 200 mg L^{-1} Ca, 3 mg L^{-1} Fe-EDTA, 0.5 mg L^{-1} Zn, 0.5 mg L^{-1} Cu, 0.5 mg L^{-1} B. The pH was adjusted to 6 and the conductivity ranged from 2 to 2.6 ds m^{-1}.

The variables evaluated were biomass of leaf, stem, root, stolon and tuber, harvest index and total number of mini tubers, taking this last variable as yield. For biomass, three samples were taken from each treatment and repetition. Each of the parts was placed in paper bags. These organs were dried in an oven with forced air circulation at 70 °C until constant weight. An Anova was performed, in addition to a Tukey test at 95% confidence, using the SAS V9 program.

Results and discussion

The biomass distribution in percentage followed the following behavior with values for leaves from 9.88 to 13.1%, stem from 1.83 to 4%, root 1.9 to 4.9%, stolon from 0.8 to 1.31% and tuber from 77.6 to 83% with respect to the total biomass of the plant, which agrees with that mentioned by Alva *et al*. (2002), who mention that the percentage of biomass in tuber is from 76 to 85%, in stem from 3 to 11% and in leaf from 9 to 13% under field conditions.

In Figure 1, the average biomass distribution of the twelve NPK treatments is observed in the Nevada variety under greenhouse and hydroponic conditions, where it is appreciated that the tuber biomass exceeds that of the other parts of the plant in percentage, tuber 82.0, while for leaf it is 11.1, stem 2.95, root, 2.95 and stolons 1.02. However, between treatments there were significant statistical differences in biomass in all the organs under study (Table 1).

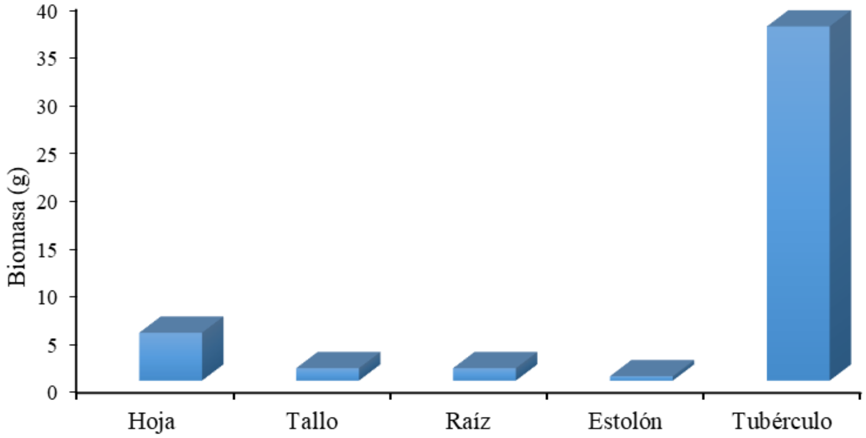

Figure 1. Average distribution of dry biomass of leaf, stem, root, stolon and tuber in the Nevada variety and NPK in hydroponics and greenhouse.

Table 1. Accumulation of leaf biomass (g dry matter per plant), stem, root, stolon and tuber in potato with twelve NPK treatments.

Treatments	Leaf	Stem	Root	Stolon	Tuber
T1(100N-30P-250K)	4.7 bcd	0.8 fe	1.2 ba	0.5ba	36.5 cd
T2(200N-30P-250K)	5.1 bc	1 fecd	1.1 b	0.6 ba	40.8 bc
T3(100N-130P-250K)	5.3 bc	0.9 fed	1.4 ba	0.4 bac	39.1 bcd
T4(200N-130P-250K)	4.2 cd	0.7 f	1.1 b	0.4 bac	25.9 e
T5(100N-30P-350K)	3.8 d	0.8 fe	1.2 ba	0.3 c	31.2 ecd
T6(200N-30P-350K)	5.8 ab	1.7 ba	1.3 ba	0.6 a	48.3 ba
T7(100N-130P-350K)	4.2 cd	1.4 becd	1.7 a	0.4 bc	26.7 e
T8(200N-130P-250K)	4.8 bcd	1.5 bcd	1.5 ba	0.5 bac	40.3 bcd
T9(150N-80P-300K)	5 bcd	1.4 becd	1.3 ba	0.4 bac	34.5 ecd
T10(250N-80P-300K)	6.7 a	2.3 a	1.2 ba	0.5 bac	52.5 a
T11(150N-180P-300K)	5.2 bc	1.6 bc	1.5 ba	0.4 bac	31 ed
T12(150N-80P-400K)	5.2 bc	1.5 bcd	1.5 ba	0.6 a	37.1 cd
DMS	1.27	0.63	0.5	0.21	8.56

Treatments with the same letter do not differ statistically according to Tukey's test $p < 0.05$.

The leaf biomass represented between 9.88 and 13.1%, with respect to the biomass of the complete plant, being the treatments T10 (250N-80P-300K) and T6 (200N-30P-350K) the ones that presented the highest values, 6.7 and 5.8 g, respectively (Table1); however, in percentage it is not the highest, for these treatments with 10.5 and 10% respectively, which may be due to the higher dry weight of the tuber reached in these, while the lowest dry weight of the leaf was for the T7 treatments (100N- 130P-350K), T4 (200N-130P-250K) and T5 (100N-30P-350K), with 4.2 g for the first two and 3.8 g for the last, which represented percentages of 12.21, 13 and 10.19%, while the stem biomass, represented between 1.8 and 4% of the total biomass and the best treatment for this variable in accumulation of dry matter was T 10 with 2.3 g, followed by T6 1.7 g, with percentages of 3.6 and 2.95 and those of lower accumulation of dry mass in stem were treatments T1 (100N-30P-250K) and T5 (100N-30P-350K) with 0.8 g that represented 1.83 and 2.14%, respectively (Table 1).

Regarding leaf, similar results found in their study Alva *et al*. (2002), where the dry weight of leaves represented from 9 to 13%, not so for the stem where it mentions that it ranges from 3 to 11%. In particular, the best treatments in both leaf and stem biomass were those with high doses of nitrogen (200 and 250 mg L^{-1}), unlike the treatments that contained the minimum dose of N, which was 100 mg L^{-1}, due to because they did not obtain a good foliage development and therefore a smaller light catchment area. In potatoes, the linear phase of tuber growth can be prolonged until the leaf area index decreases to almost 1, while the root grows rapidly only until after the middle of the biological cycle and then decreases 80 days after the emergence, which coincides with the loss of biomass in the foliage (Aguilar *et al*., 2001). This is important to consider, since the sampling was done at the end of the cycle and there could be loss of leaves due to senescence.

The leaf biomass results agree with that mentioned by Zebarth and Ros (2007), who point out that an adequate supply of nitrogen is required to improve the capacity of the canopy to intercept light, due to the critical participation of nitrogen in vegetative development and biomass accumulation. On the other hand, Coraspe *et al*. (2008), mention that the accumulation of N in the tubers increased with the doses of N varying from 252.31 to 355.82 mg $plant^{-1}$, while in the aerial part the variation was lower, from 103.92 to 172.11 mg $plant^{-1}$.

The root biomass represented from 1.9 to 4.9% with respect to the total weight of the plant; the highest root biomass treatments were T7 (100 N; 130 P; 350 K), T11 (150 N; 180 P; 300 K) and T12 (150 N; 80 P; 400 K) with 1.7, 1.5 and 1.5 g respectively and the lowest were T4 (200 N; 130 P; 250 K) and T2 (200 N; 30 P; 250 K) with 1.1 g, the only treatments statistically different from each other were T7 and T2, the rest of the treatments being the same, even with these two contrasting treatments, in general no differences were found between the different levels of phosphorus used of 30, 80, 130 and 180 mg L^{-1} (Table 1), so it is considered that a good amount of root was obtained with all the levels of phosphorus used; however, it can be stated that as phosphorus doses are increased, its use decreases; this agrees with what Camozzi (2015) mentioned.

The stolon biomass represented between 0.79 to 1.31% of the total biomass of the plant; the treatments with the highest values were T6 (200 N; 30 P; 350 K), T12 (150 N; 80 P; 400 K) and T2 (100 N; 30 P; 350 K) with 0.6 g, while the T5 was lower (100 N; 30 P; 350 K) with 0.3 g, in this variable in relation to phosphorus levels it had no greater effect, since the treatments with greater weight had doses of 30 and 80 mg L^{-1} respectively, T5 (100 N; 30 P; 350 K) that showed low values had the same amount of P as T6 (200 N; 30 P; 350 K) and T7 (100 N; 130 P; 350 K, this last with 130 mg L^{-1} of phosphorus, so it is can mention that it did not affect the stolon biomass.

In relation to tuber biomass, it is important to mention that the treatments with the highest values in tuber dry weight were treatments T10 (250N-80P-300K) and T6 (200 N; 30 P; 350 K) with 52.5 and 48.3 g, respectively, with concentrations of 300 and 350 mg L^{-1} of potassium as shown in

Figure 2 and those with the lowest tuber biomass, were treatments T7 and T4, the first with 350 mg L^{-1} of potassium and with only 100 mg L^{-1} of nitrogen, the above indicates the importance of using high concentrations of potassium, and that the lack of nitrogen affects tuber yield.

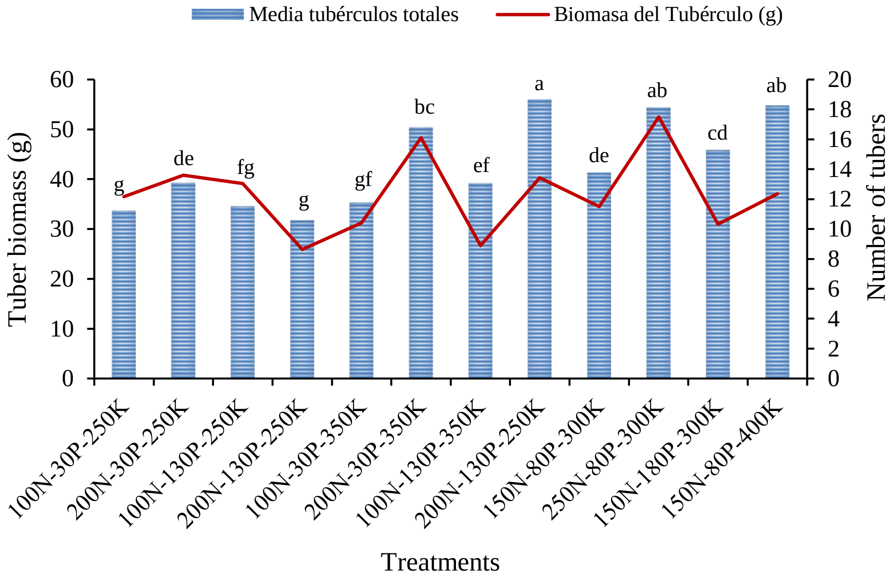

Figure 2. Comparison of total number of tubers and tuber biomass (g) produced in the greenhouse of the Nevada variety for the NPK experiment in hydroponics. Treatments with the same letter are not significantly different, Tukey $p < 0.05$.

In relation to potassium, he agrees with Coraspe (2008); Moshileh and Errebi (2004) who mention that the application of increasing doses of potassium in the potato crop increased the amount of biomass produced by the plants, requiring high concentrations of this for its optimal growth, production and quality of the tuber, because, as is known, potassium activates enzymes necessary for the production of starch and proteins that help increase the weight of grains and fruits (Rozo and Ñustez, 2011).

In potato, Aguilar and Carrillo (2006), mention that before tuberization the photoassimilates are used mainly to develop leaves, stems and roots, and the force of the demand of the leaves is greater than that of another organ; with the onset of tuberization this trend changes and as the tubers grow, their demand for assimilates increases. Likewise, it can be observed that the best treatments in tuber dry weight contained levels of 200 and 250 mg L^{-1} of nitrogen, consistent with that mentioned by Sharifi *et al*. (2005) who located, in addition, that the absorption of the majority of N by the plant occurred 76 days after emergence; thereafter, the translocation of N from the canopy to the tubers occurs in response to tuber growth.

On the other hand, the treatments with the highest leaf and stem biomass were those that had the highest tuber biomass, contrary to what was mentioned by Hancock *et al*. (2014), who point out that a lower accumulation of biomass in leaves and stems, ensures a greater proportion towards tubers, this statement is applied in a balanced nutrition, since it is known that applications in excess of nitrogen lengthen the crop cycle and potato yields decrease (Rocha and Quijano, 2015).

The highest accumulation of biomass in the complete plant was obtained in treatment T10 (250 N; 80 P; 300 K) with 63.5 g and T6 (200 N; 30 P; 350 K) with 57.9 g and the treatments with the lowest total biomass were T5 (100 N; 30 P; 350 K) with 37.6 g and T7 (100 N; 130 P; 350 K) with 34.5 g. (Table 2); the relationship between N and K has been known for a long time regarding the production of biomass in potatoes, high concentrations of nitrogen favor the development of the canopy, lengthen the cultivation cycle and inhibit tuberization, while high concentrations of potassium favor it; however, it can be observed that at concentrations of 200 to 250 N, higher total and tuber biomass was obtained, which agrees with Coraspe *et al*. (2008) who mention that biomass production is directly related to the nitrogen dose in the nutrient solution.

Table 2. Total biomass accumulation and harvest index in potato with twelve NPK treatments in hydroponics and greenhouse.

Treatments	Biomass (g)	
	Total	Harvest index
T1(100N-30P-250K)	44 cebd	0.82 ba
T2(200N-30P-250K)	48.8 b	0.83 a
T3(100N-130P-250K)	47.3 b	0.82 ba
T4(200N-130P-250K)	32.5 e	0.79 bc
T5(100N-30P-350K)	37.6 ced	0.82 ba
T6(200N-30P-350K)	57.9 a	0.82 ba
T7(100N-130P-350K)	34.5 ed	0.77 c
T8(200N-130P-250K)	48.8 b	0.82 ba
T9(150N-80P-300K)	42.8 cbd	0.8 bac
T10(250N-80P-300K)	63.5 a	0.82 ba
T11(150N-180P-300K)	39.9 cebd	0.77 c
T12(150N-80P-400K)	46.1 cb	0.8 bac
DMS	9.5	0.0356

Treatments with the same letter do not differ statistically. Tukey $p < 0.05$.

On the other hand, the accumulation of total biomass is determined mainly by the dry weight of the tuber and not by the biomass of the other organs of the potato plant.

In the harvest index variable there were significant differences between treatments (Table 2), this value fluctuated from 0.77 to 0.83; however, nine of the twelve treatments were statistically equal, it can also be observed that a high harvest index does not guarantee greater efficiency of the crop, since it depends on the total biomass, which indicates the distribution of biomass in the different organs, such as is observed in the T2 treatment (200 N; 30 P; 250 K) with the highest IC of 0.83, but not with the highest tuber dry weight of 48.8 g, compared to T10 with tuber biomass of 52.5 g and IC of 0.82 statistically equal to T2, while the treatments with a lower harvest index were T4 (200 N; 130 P; 250 K), T7 (100 N; 130 P; 350K) and T11 (150N-180P-300K) with values of 0.79 for the first and 0.77 for the last two.

In general, these IC results exceed those obtained by Aguilar and Carrillo (2006), who in their research obtained harvest rates of 69 and 62% in different irrigation systems. The relationship that exists between the total dry weight of the plant and the tuber is very important because if it has good foliage, the production of photoassimilates increases, which when exported to the organs of economic interest contribute to increasing the IC. The higher the index, the more efficient the plant is to accumulate dry matter in the organ of interest.

Regarding the number of total tubers (Figure 2), a significant difference is observed between treatments, possibly due to the different combinations of NPK used. The treatments with the highest production of minitubers per plant were T8 (200N-130P-250K) with 18.6 tubers, T12 (150N-80P-400K) 18.2, T10 (250N-80P-300K) 18.1 and T6 (200N-30P-350K) with 16.8, it was observed that N influenced the number of tubers in three of the four solutions, of which its concentration was equal to or greater than 200 mg L^{-1}; likewise, the treatment with the highest number of minitubers was the one with 130 mg L^{-1} phosphorus (T8), while the T12 with the lowest nitrogen concentration and high potassium concentration with 400 mg L^{-1} was statistically equal to the latter.

These results agree with what was reported by Alva *et al*. (2002); Giorgetta *et al*. (1993), who mention that N is very important for potato yield and that P is important in stolon generation and yield. N is one of the main factors that affects potato yields and it is considered that the key to increasing the size of the tubers, without sacrificing their quality, lies in the adequate application of nitrogen fertilization (Ramírez *et al*., 2004).

However, when observing the tuber biomass, only the treatments T10 (250 N; 80 P; 300 K) followed by T6 (200 N; 30 P; 350 K), presented high biomass values with 52.5 and 48.3 g, while treatments T12 and T8 presented a lower biomass of 37.1 and 40.3 g, respectively, and a higher number of tubers (Figure 2); the above highlights the importance of potassium and nitrogen, in T8 (200N-130P-250K), lacking potassium, but the nitrogen concentration favored tuberization, contrary to T12 (150N-80P-400K) with high concentration of potassium and under nitrogen, this indicates the importance of the availability of potassium in the solution from the first day of the cultivation cycle, due to the fact that tie a large number of minitubercules, although the majority of smaller diameter and weight, which was possibly due to the lack of nitrogen in the solution as this element that not only favors the formation of leaves, but is also a structural part of chlorophyll a and b which are responsible for carbon fixation and consequently the production of photosynthates.

Results similar to those of this research were obtained by Alva *et al*. (2002), where the dry weight of the tuber represented from 76 to 87% of the total weight of the plant. The aforementioned results indicate the relationship between nitrogen and potassium, which is decisive in the accumulation of dry weight of tuber. Ramírez *et al*. (2004) mention that the number of tubers per plant and the average mass per tuber increased due to nitrogen fertilization, oscillating between 1.6 and 6.18 t ha^{-1}, proportionally with the increase in the dose of nitrogen fertilizer until application 100 and 150 kg ha^{-1} of N.

Conclusions

High concentrations of nitrogen and potassium in the nutrient solution favor a higher yield in number and biomass of minitubers, so that concentrations greater than 200 mg L^{-1} of nitrogen and 300 mg L^{-1} of potassium in the nutrient solution showed better production of tubers and biomass in the potato crop in hydroponics and greenhouse.

The total biomass is determined mainly by the biomass of the tuber and the higher biomass of the aerial part (stem and leaves) favors a higher biomass and number of minitubercules. High concentrations of potassium applied from the beginning of the crop cycle favor the attachment of minitubers during the tuberization process.

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