Doi: https://doi.org/10.17584/rcch.2023v17i3.16508

Macronutrient absorption curves of carrot in the high tropics

Curvas de absorción de macronutrientes en zanahoria en el trópico alto

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Carrot Cordoba F1 hybrid.

Photo: P.A. Serrano-Cely

ABSTRACT

Carrot cultivation in Colombia reached 9,000 ha in 2020. The production chain of this crop faces various problems, among which marketing and nutrition stand out, the latter a decisive factor for performance. Some studies claim that with the use of hybrids in combination with irrigation and balanced fertilization, yields greater than 70 t ha^{-1} can be obtained. The commercial competitiveness of crops is related to the timely, adequate and efficient application of nutrients; element absorption curves are tools that offer effective information on how much the crop assimilates during its phenological cycle, allowing us to know the minimum required amount of elements for the specific area. A carrot crop was established to determine the foliar absorption curves of macronutrients (N, P, K, Mg and Ca). The yield obtained was 39.6 t ha^{-1}, with 552,500 plants/ha. K was the element with the highest absorption 147 days after sowing with 29.36 kg ha^{-1} for the leaves and 27.74 kg ha^{-1} in the root and a total of 57.1 kg ha^{-1}. The order of the other elements was N, Ca, P and Mg. This information is useful for managing carrot nutrition in order to make fertilizer management efficient and improve yield.

Keywords: nutritional status; plant requirements; root vegetables; *Daucus carota* L.

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RESUMEN

El cultivo de zanahoria en Colombia alcanzó 9.000 ha para el año 2020 y la cadena de producción de este cultivo afronta diversos problemas, entre los que se destacan la comercialización y la nutrición, este último un factor decisivo para el rendimiento. Algunos estudios aseguran que con el uso de híbridos en combinación con riego y fertilización balanceada se pueden obtener rendimientos mayores a 70 t ha^{-1}. La competitividad comercial de los cultivos está relacionada con la oportuna, adecuada y eficiente aplicación de los nutrientes; las curvas de absorción de elementos son herramientas que ofrecen información eficaz sobre cuanto asimila el cultivo durante su ciclo fenológico, permiten conocer la cantidad mínima requerida de los elementos para la zona específica. Se estableció un cultivo de zanahoria para determinar las curvas de absorción foliar de macronutrientes (N, P, K, Mg y Ca). El rendimiento obtenido fue 39,6 t ha^{-1}, con 552.500 plantas/ha. El K fue el elemento de mayor absorción a los 147 días después de siembra con 29,36 kg ha^{-1} para hojas y 27,74 kg ha^{-1} en la raíz y un total de 57,1 kg ha^{-1}. El orden de los demás elementos fue N, Ca, P y Mg. Esta información es útil para el manejo de la nutrición en zanahoria a fin de hacer eficiente el manejo de fertilizantes y mejora en el rendimiento.

Palabras clave: estado nutrición; necesidades de la planta; hortalizas de raíz; *Daucus carota* L.

Received: 06-09-2023 Accepted: 17-09-2023 Published: 12-12-2023

INTRODUCTION

Globally, carrot production in 2021 reached an average of 41,500,000 t on 1,096,000 ha, with a yield of 36 t ha^{-1}. Countries such as China, Uzbekistan and the United States are the main producers, while the United States stands out among the leading importers (FAO, 2022). In Colombia, about 9,000 ha were cultivated in 2020; the main producing departments were Boyaca and Cundinamarca with yields of 28 t ha^{-1}, followed by Antioquia with yields close to 41 t ha^{-1} (Agronet, 2022). Carrot is used in various culinary preparations. It has high nutritional value due to the high content of carotenoids, precursors of vitamin A (Kopsell and Kopsell, 2006; Geoffriau and Simon, 2020).

Colombia faces various problems in the carrot production chain, among which marketing and nutrition stand out, the latter adverse to performance (Agbede, 2021). Generally, carrot cultivation is the rotation option in potato crop cycles, as it takes advantage of the remnants from the previous crops without comprehensive management. Abundance of remnants from the previous crop indicates that this was carried out in an unbalanced manner, contaminating the agroecosystem; if adequate nutritional management is not provided, high yields cannot be expected.

Knowing the ecophysiology is imperative for searching adaptation strategies in vegetable and fruit plants exposed to changing environments (Sánchez-Reinoso *et al*., 2019). Climate change transforms the water supply and increases the different phytosanitary measures needed (Bodeker *et al*., 2022). Traditional management of vegetables such as carrots become less functional due to prolonged periods of high precipitation or drought and variation in maximum and minimum temperatures (Godwin *et al*., 2023). In addition, soil fertility is affected. Competitive crop performance is related to the timely, adequate and efficient application of nutrients; the inadequate use of fertilizers causes economic losses and damage to the environment (Suárez and Torres, 2014; Hoyos *et al.*, 2015).

Some studies show that the use of hybrids in combination with irrigation and balanced fertilization achieves yields close to 70 t ha^{-1} (Smoleń and Sady, 2009; Sosa *et al*., 2013; Reid and Gillespie, 2017; Reid *et al.*, 2018); research by Reid and English (2000) simulates the productive potential of the species at 100 t ha^{-1}. Westerveld *et al*. (2006a) point out that the accumulation of N in foliage has priority over the root until 53 days after sowing (DAS); they also add that the total N content in the roots decrease during the cycle, while in the leaves it decreased around 80 and 100 DAS; the greatest absorption occurred between 50 and 60 DAS and the total N absorbed by the plant at the end of the cycle was 380 kg ha^{-1}. Hochmuth *et al*. (2021) evaluated the application of eight nitrogen fertilization rates (56, 112, 168, 224, 280, 336, 392 and 448 kg ha^{-1}); a regression analysis showed that the optimal dose was 206 kg ha^{-1} N, reaching a commercial yield of 71.3 t ha^{-1}. For Montazar *et al*. (2021) the total N accumulated at harvest ranged between 205.4 kg ha^{-1} (almost 52% in roots) and 350.5 kg ha^{-1} (almost 64% in roots), although none of the rates of N application evaluated showed a significant relationship with performance.

The element absorption curves are a tool that offer information on the assimilation by the crop during its phenological cycle, allowing to know the minimum required amount of elements for the specific area, improving and increasing the yield through correct decisions in the amount and time of nutrient application, in turn helping to reduce electrochemical imbalances in the soil and therefore in the agroecosystem (Pedraza and Henao, 2008; Chica-Toro and Garzón-González, 2018; González *et al*., 2018). Therefore, the objective of this study was to determine the absorption of macronutrients N, P, K, Mg and Ca, in the carrot crop. This information is useful for nutrition management to make fertilizer management efficient and increase crop yield.

MATERIALS AND METHODS

The study was carried out in the municipality of Soraca, Colombia, in the center of the department of Boyaca, located in Quebrada Vieja at 5.492492N and 73.302448 W. From the information generated by a mobile agroclimatic station Vantage Pro2 Plus (Davis Instruments, Hayward, CA), precipitation, evapotranspiration and temperature were monitored during the crop cycle. In addition, the climatic information was compared with that generated from the UPTC hydro-climatology station (Tunja), as well as with historical values.

Three soil samples were extracted at a depth of 0-20 cm for physical and chemical characterization (Tab. 1) and volume rings described by Cooper *et al*. (2017).

To correct exchangeable acidity before sowing, dolomite was applied at a dose of 150 kg ha^{-1}. The fertilization plan was established with the results reported in the chemical analysis of the soil and according to the following extractions for carrot in kg ha^{-1}: N 210, P_2O_5 150, K_2O 250, CaO 140, MgO 30, S 25, B 2 and Zn 3. Chemical fertilizer applications for sowing and replanting were distributed laterally to the soil (Tab. 2).

The Cordoba F1 hybrid was distributed by a mechanic al roller seeder in 6 rows at a distance of 15 cm at a depth of 1 cm. The final configuration was 6 rows with 5 cm between each, on a 2 m pressed bed. Prior to soil preparation, *Streptomyces* was incorporatedfor the control of nematodes (2 kg ha^{-1}); in addition, integrated management of pests and diseases was guaranteed during the cycle.

The foliar analyses were carried out when the crop presented 50 % emergence and at 62, 98, 125 and 147 DAS. The sample was obtained randomly until 150

Table 1. Physicochemical characterization of the soil.

pH	OM	Exc. Ac.	Al^{+3}	Ca	K	Mg	Na	BS	ECEC
	%	cmol kg^{-1}							
4.65	4.35	3	2.6	2.1	0.6	0.63	0.03	3.36	6.36
P	S	Cu	Fe	Mn	Zn	B	A	L	Ar
mg kg^{-1}							%		
233.56	127	5.11	218	17.72	1.34	0.6	28	30	42
SE	AD	Pt	Macro	Meso	Micro	SHC	FC	PWP	
g cm^{-3}		%				cm h^{-1}	%	%	
1.14	2.41	52.53	11.62	15.31	25.58	0.137	36.06	22.56	

pH – 1:1 ratio; organic matter (OM) – Walkley-Black; extractable acidity (Exc. Ac.) - titration; exchangeable aluminum (Al^{+3}) – 1N KCl; Ca-K-Mg-Na – extract NH_4 and atomic absorption; base saturation (BS) – sum of bases; effective cation exchange capacity (ECEC) – extract NH_4; available phosphor (P): Bray II, colorimetry; sulfur (S): monocalcium phosphate; Cu-Fe-Mn-Zn: DTPA extract – atomic absorption; boron (B): hot water; texture – Bouyoucos: sand (% A), clay (% Ar) and silt (% L); saturation extract (SE); apparent density (AD); ring of known volume; porosity (Pt), macropores (Marco), mesopores (Meso), micropores (Micro); saturated hydraulic conductivity (SHC) – laboratory constant head permeameter; field capacity (FC) and permanent wilting point (PWP) – pressure cookers.

g of fresh tissue from the third mature leaf from the outside to the inside of the crown was completed. At the time of harvest, root samples were taken to determine the elemental contents. Likewise, complete plants were taken to determine the distribution of dry matter.

The elemental contents (N, P, K, Ca and Mg) were determined from the decomposition of the plant tissue through acid digestion. For the minerals P, K, Ca and Mg, nitric acid (HNO_3) and perchloric acid ($HClO_4$) were used in a 2:1 ratio; for the determination of N, sulfuric acid (H_2SO_4) was used. The extracts were subsequently prepared for quantification according to the following methodologies: nitrogen-Kjeldahl, phosphorus-colorimetric phosphomolybdic potassium, calcium and magnesium -atomic absorption flame. From the concentration of the elements in leaves and their weight, the foliar absorption curve was calculated. Yield was determined from planting density (plants/ha) and production.

The data obtained from the response variables in the sampling units were subjected to Box-plot analysis and analysis of homogeneity of variance through the R software version 4.0.1.

RESULTS AND DISCUSSION

Climatic conditions during the experiment period (February to June) showed an increase in precipitation (150%) in relation to the historical monthly averages of the hydro-climatic station (33.7, 58.1, 66.8, 73.2 and 53 mm, respectively). The maximum temperature was in the month of January (18°C), however, it decreased for April, May and June (15°C); the average minimum temperature was constant except for January (6 °C) (Fig. 1).

The distribution of soil pores before the tillage process showed 25.58 % micropores, 15.31% mesopores and 11.62% macropores. The movement of water in the soil occurs when the largest pores are hydrologically active and interconnected with each other, contributing to the dynamics of usable water (Mazurana *et al*., 2017; Hlaváčiková *et al*., 2019). The microporosity was high (>20%) which can be

Table 2. Fertilization ($kg \cdot ha^{-1}$) applied to the carrot crop.

Application	N	P_2O_5	K_2O	CaO	MgO	S	B	Zn	Date
Sowing	75.6	54.6	45.6	52.2	18.6	8.7	1.8	2.7	20/12/22
Replanting	50.4	36.4	30.4	34.8	12.4	5.8	-	-	16/02/23
Total	126	91	76	87	31	14.6	1.8	2.7	-

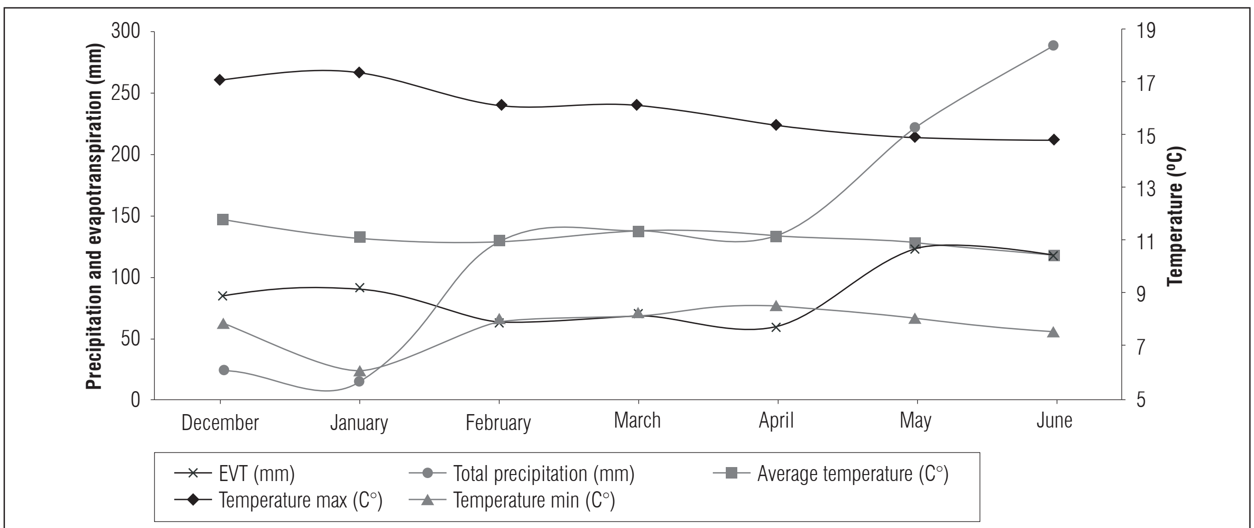

Figure 1. Precipitation, evapotranspiration and temperature during the growing cycle.

a trigger for compaction, one of the main causes of soil degradation, reducing its volume and increasing the apparent density (Moraes *et al.*, 2018; Fidalski and Tormena, 2022).

The yield presented an average of 39.6 t ha^{-1} and 552,500 plants/ha. The production of dry matter at harvest was 547.70 kg ha^{-1} of the leaves and 1,403.35 kg ha^{-1} of the root (Fig. 2). Hochmuth *et al*. (2021) report yields of up to 71.3 t ha^{-1} with a planting density of 992,827 plants/ha for 'Choctaw', 849,331 plants/ha for 'Maverick', 1,648,279 plants/ha for 'Triton' and 2,496,123 plants/ha for 'Uppercut 25'. The total yield of fresh roots reported by Montazar *et al*. (2021) varied from a minimum of 83.9 t ha^{-1} carrots for processing harvested at 128 DAS, to a maximum of 132.7 t ha^{-1} harvested 193 DAS and a minimum planting density of 1,260,000 plants/ha to a maximum of 3,200,000 plants/ha; these trials were carried out in productive areas of the United States with a high level of technology in machinery, improved materials, irrigation and nutrition.

Similar yield results are reported by Agbede (2021) with 22 and 43 t ha^{-1}, where reduced tillage was highlighted, increasing yield between 2.3 and 2.6 t ha^{-1} compared to conventional tillage in two seasons. Reid *et al*. (2018) reported between 270,000 to 930,000 carrot plants/ha and an average of 520,000 plants/ha (coefficient of variation of 22%) in response to different nitrogen fertilizers. Reid and Gillespie (2017) assure that minimizing water deficit is decisive to achieve high yields of quality carrot; they mention that total biomass and root yield decreased linearly as the maximum potential water deficit of the soil (D Ømax) increased; they found no significant relationship between the concentration of soluble solids in the root and D Ømax.

The N absorption rate was 13.38 kg ha^{-1} at 147 DAS in the leaves of the plant and 8.21 kg ha^{-1} in the root (Fig. 3). An increase in absorption in the leaves was observed at 98 and 125 DAS, the stage where root thickening begins due to the activity of the secondary cambium. Its development depends on the contribution of assimilates and growth regulators from the leaves (Vega *et al*., 2012). Montazar *et al*. (2021) report total N content of 350.5 kg ha^{-1} for fresh carrots harvested at 193 DAS, and 227.3 and 123.2 kg ha^{-1} for roots and leaves, respectively; in addition, they indicate that approximately 50% of the total N was absorbed during a period of 50 days (between 80 to 130 DAS). This period seems to be the most critical for N absorption; N availability in the effective zone of roots is essential during this period (Westerveld *et al*., 2007). N was the element with the second highest absorption at the end of the cycle, unlike in other vegetables such as bulb onions and tomatoes (Quesada-Roldán and Bertsch-Hernández, 2013; Geisseler *et al*., 2022).

For Reid *et al.* (2018) N contents ranged between 131 and 468 kg ha^{-1}, with an average of 237 kg ha^{-1} harvest at 156 DAS and 321 kg ha^{-1} at 203 DAS. For

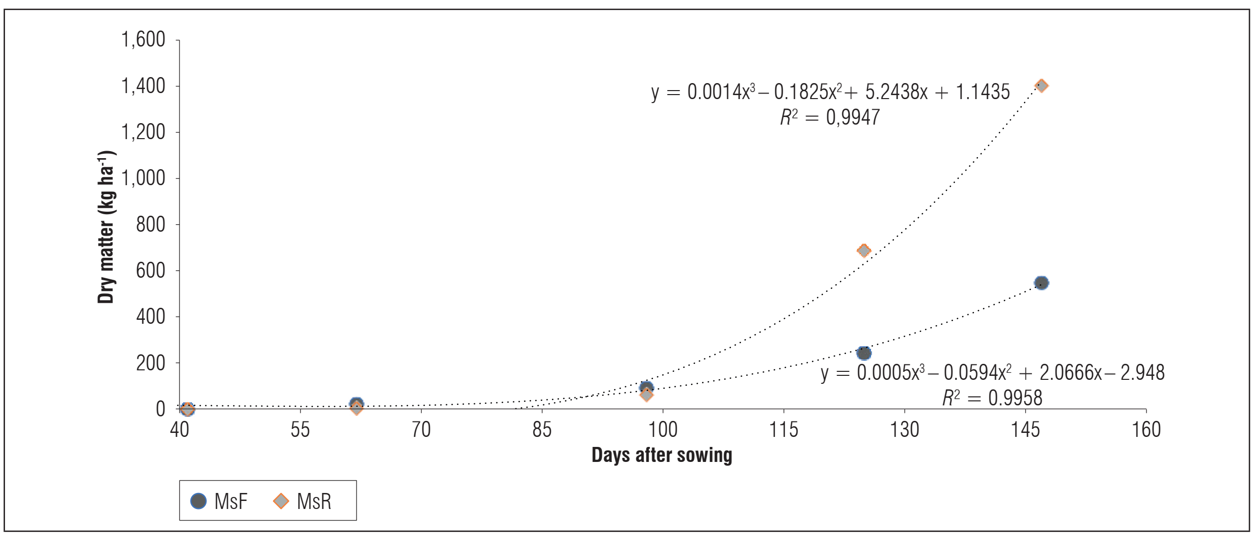

Figure 2. Distribution of dry matter in carrots. MsF, aerial; MsR, root.

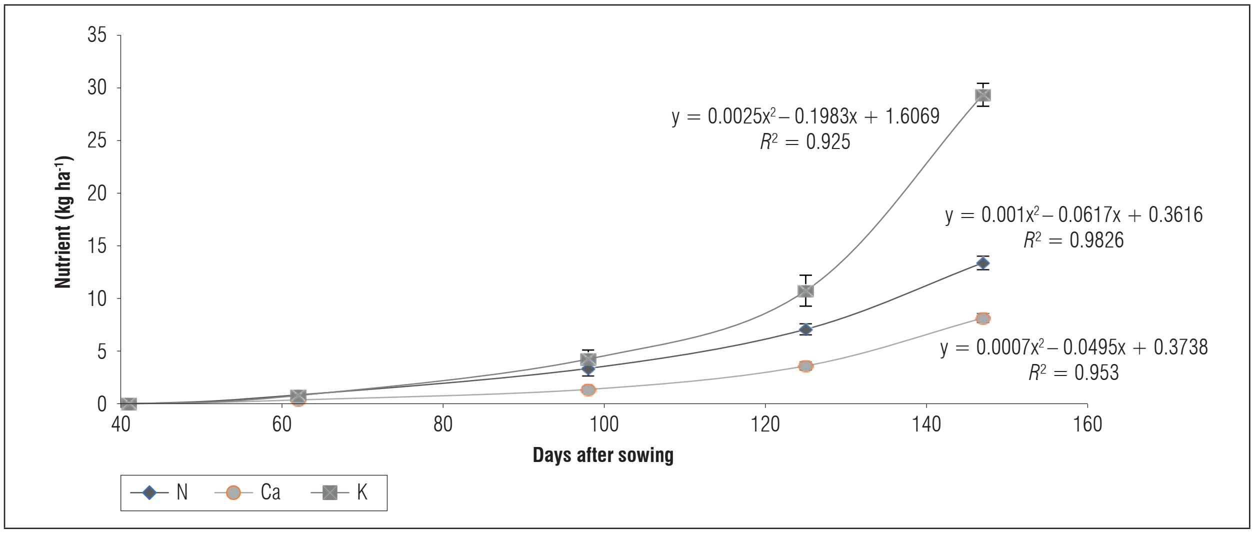

Figure 3. Absorption curve of N, Ca and K for carrot.

Westerveld *et al*. (2006b), total N absorption was 380 kg ha^{-1} for processing carrot ('Fontana'), with an average biomass of 13 t ha^{-1}

K was the element with the highest absorption at 147 DAS with 29.36 kg ha^{-1} for the leaves and 27.74 kg ha^{-1} for the root, with a total of 57.1 kg ha^{-1} at harvest time (Fig. 3). K absorption increased between 98 and 124 DAS for the leaves. In mint plants, the element with the highest concentration was K, followed in order by N, Ca, P, Mg (Pedraza and Henao, 2008). In melon, Mendoza-Cortéz *et al*. (2014) found that the sequence of greatest accumulation of macronutrients in the evaluated cultivars was K>Ca>N>Mg>S>P ('V. Olimpic express') and K>N>Ca>Mg>S >P ('V. Iracema'). In similar studies, K is reported as the nutrient with the highest accumulation in various parts of the plant (Delgado-Ospina *et al*., 2012; Barahona-Amores *et al*., 2019) (Fig. 3).

The Ca absorption rate was 8.12 kg ha^{-1} for the leaves at 147 DAS and 4.77 kg ha^{-1} for the root for a total of 12.89 kg ha^{-1}. The Ca absorption curve of the leaves during the crop cycle showed an increase during 125 to 147 DAS, when the root is in the thickening process (60% of the root diameter). Vega *et al*. (2012) report that the accumulation of dry matter and absorption of nutrients such as N, P and K, for 5 hybrids showed four differentiable phases: the first of slow growth, the second of exponential growth, the third of growth deceleration and finally, the fourth of stability. Avitia-García *et al*. (2014) report that in strawberry plants Ca is the element with the highest absorption with 250.9 kg ha^{-1}, followed by K with 237.6 kg ha^{-1}.

The absorption curves of P and Mg in the leaves during the crop cycle (Fig. 4) at 147 DAS reached 1.19 and 0.83 kg ha^{-1} respectively, and 2.72 and 1.16 kg ha^{-1} for the root, respectively. Sosa *et al*. (2013) out that the accumulation of nutrients in carrots accelerates mainly at 65-130 DAS, where almost 70% of the total amounts of N, P and K are absorbed; the low mobility of P and K in the soil make its application necessary at the time of sowing and not throughout the cycle, even for sources of high solubility such as those applied in fertigation. Similarly, Menezes *et al*. (2013) under Brazilian conditions, report for bulb onion that the aerial part absorbs P between 0.47 and 0.80 kg ha^{-1} at 48 DAS, between 1.88 and 3.67 at 68 DAS and between 7.45 and 9.05 kg ha^{-1} at 108 DAS. Other results on absorption curves in rice showed that the reproductive stages are those with the highest P absorption (tillering, mature grain filling) (Barahona-Amores *et al*., 2019). In general, P in the soil is retained when it is adsorbed by clays, which implies low availability and applications at the time of sowing favor availability in the reproductive stage, the time of greatest demand, since it has great mobility within the plant (Fig. 4).

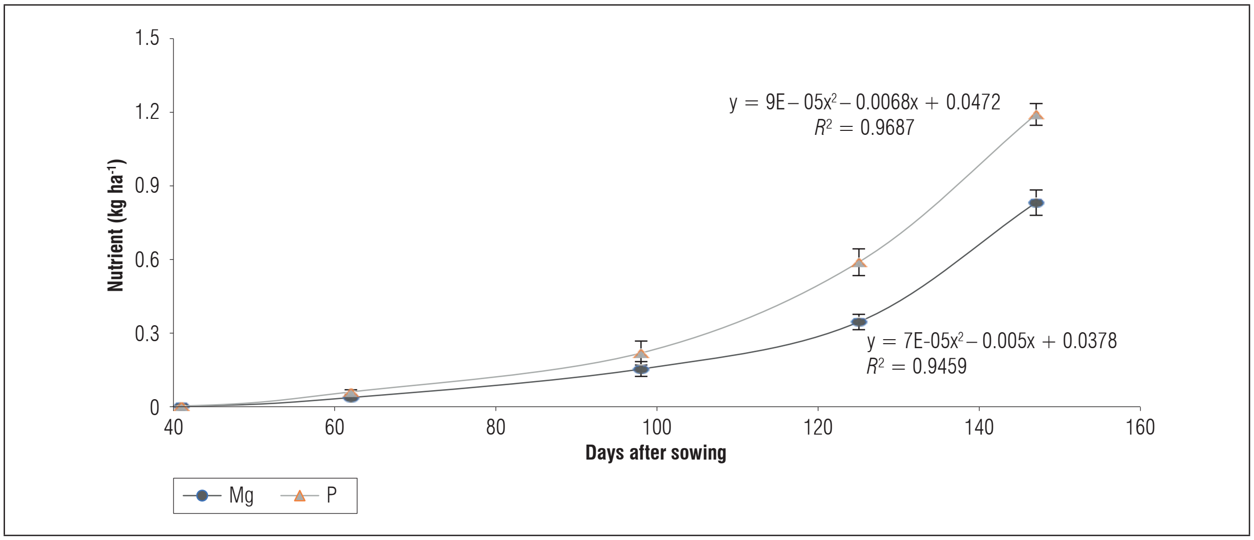

Figure 4. Absorption curves of P and Mg in carrot.

CONCLUSIONS

K was the element with the highest absorption, 29.36 kg ha^{-1} for the leaves, 27.74 kg ha^{-1} for the roots and a total of 57.1 kg ha^{-1} at 147 days after sowing, approaching harvest. N was 13.38 kg ha^{-1} for leaves and 8.21 kg ha^{-1} for roots. Ca presented a total of 12.89 kg ha^{-1} . For P and Mg the contents were 1.19 and 0.83 kg ha^{-1} for leaves and 2.72 and 1.16 kg ha^{-1} for roots, respectively. The yield was 39.6 t ha^{-1} with 552,500 plants/ha.

According to our results and the bibliographic references, the best yields are when nitrogen fertilization does not exceed 220 kg ha^{-1}. High application of P and K at the time of sowing is the best time for root development due to low mobility in the soil.

ACKNOWLEDGEMENTS

This article is part of the research project: "Development of an adaptation strategy that leads to reducing the vulnerability of agricultural systems to climate change in some municipalities in the central zone of the department of Boyacá" identified with BPIN code: 2018000100046, financed by the General Royalties System and executed by the School of Agricultural Sciences of the Universidad Pedagógica y Tecnológica de Colombia.

Conflict of interests: The manuscript was prepared and reviewed with the participation of the authors, who declare that there exists no conflict of interest that puts at risk the validity of the presented results.

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