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Nutrient demand of the carrot crop

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The existing literature for the recommendation of fertilizers and diagnosis of the nutritional status of the carrot crop is outdated because it contemplates productivities lower than those currently obtained. The objective of this research was to characterize the nutritional demand of the carrot crop by estimating the dry matter content of the roots, the coefficient of biological utilization of the nutrients and the harvest index of dry matter and of the mineral nutrients, in order to indicate fertilizers according to the desired productivity for winter and summer cultivations. We sampled 210 carrot plots located in the Alto Paranaíba region, Minas Gerais, Brazil, during 2012 and 2013. We determined the content of dry matter of the roots, the coefficient of biological utilization of the nutrients in the roots and leaves and the harvest index of dry matter and nutrients in the crop. Data were grouped in two groups of cultivations: Winter and summer. The harvest index of dry matter and of nutrients was bigger for the winter cultivars. Regardless of the growing season, the N, P, K, Mg and B were retained in greater amounts in the roots. Phosphorus had the highest harvest index, and the Cu, the lowest. The differences were insignificant in the nutritional demand of N, P, Ca, S, B, Cu and Zn between winter and summer cultivars for the average productivity obtained in each season. In the summer cultivars, the carrot accumulates greater amounts of Fe and lower of K, Mg and Mn when compared to winter. The modeling of the nutritional demand of the carrot crop can be carried out depending on the desired productivity and growing season.

Key words: Nutrients balance, *Daucus carota*, nutritional demand, nutrients recommendation.

INTRODUCTION

In the last years, there was an evolution in the cultivation of carrot due to the introduction of new techniques in the production system, and consequently, rapid evolution of productivity was achieved. Besides the introduction of new cultivars, phytosanitary and nutritional managements evolved to provide high productivity.

Fertilizer recommendations are made based on information available in tables published in state manuals; however, some drawbacks can be cited about this method of recommendation. The regional applicability, the non-constant updates in relation to new cultivars/hybrids that appear on the market and the scope of productivity generally lower than those obtained in technified crops represent the main negative points of this method of recommendation. In the state of Minas Gerais, Brazil, for example, the official recommendation

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was published in 1999 and includes productivity of up to 40 Mg ha^{-1} of roots (Ribeiro et al., 1999).

In this context, the use of nutritional balance models can be a strategic way of recommending fertilizers and correctives by taking into consideration numerous factors, in particular, the productivity (Haefele et al., 2003). The obtainment of information (attributes) necessary to calculate the nutrient demand is the critical point for the use of the nutritional balancing system in the carrot crop due to the lack of data in the literature.

The nutritional balance system comprises mathematical models which allow the estimation of the requirement of nutrients by the crop and the supply of nutrients by the soil, and thus, the recommendation comprises the difference between the demand of the crop and the soil supply (available nutrients in the soil plus the ones coming from the mineralization of crop residues).

Although efficient, the method of nutritional balance still cannot be used in carrot crop due to the lack of information of the nutritional demand of this species for high yields. To estimate the nutritional demand of the new cultivars you must know some attributes as dry matter content in the roots (DM), the coefficient of biological utilization (CBU) of nutrients in different organs of the plant and the harvest index (HI) of dry matter and nutrients. The CBU is the ratio of the accumulation of biomass and the accumulation of a particular nutrient (Fageria, 1998; Kurihara et al., 2013). The HI is the percentage of dry matter or nutrient, which is found in the harvested organ (tuberous root in the carrot crop) in relation to the whole plant biomass.

Thus, this study aimed to characterize the nutritional demand of the carrot crop by estimating the dry matter content of the roots, the coefficient of biological utilization of the nutrients and the harvest index of dry matter and of the mineral nutrients, in order to indicate fertilizers according to the desired productivity for winter and summer cultivations.

MATERIALS AND METHODS

To determine the attributes needed to estimate the nutritional demand of the carrot crop we generated a database with information of 210 commercial plots located in the region of Alto Paranaíba, Minas Gerais, Brazil. To achieve this, samples were taken during the growing seasons 2012 and 2013 and covered crops in the municipalities of Rio Paranaíba, São Gotardo and Campos Altos. In these places, the carrot fields were in the altitude of approximately 1100 m and in an environment with the prevailing Cwa climate, according to the Köppen-Geiger classification. This climate is characterized by a dry season and a well-defined rainy season that occurs between October and March. Regarding the type of soil, very clayey yellow, red and red-yellow latosols predominated. Fertilizers recommendations were made based on soil analysis. Irrigation and phytosanitary crop management followed the technical recommendations characteristic of the crop.

In the plots that were evaluated, we determined the root productivity, the dry matter content in the roots, the accumulation of dry matter of roots and leaves and the nutrient content in the plant. Samples of leaves and roots collected at harvest were dried in a greenhouse with forced air at 70ºC for 72 h. Then they were ground in a Willey mill equipped with sieve of 1.27 mm. The nutrients content was determined according to methods described by Malavolta et al. (1997).

The extraction of nutrients was obtained from the sum of the content of nutrients in the roots and leaves. This, in turn, was obtained by the product of the accumulation of the dry matter and nutrient concentration in each part of the plant (root or leaf). The CBU was calculated by dividing the accumulation of DM and accumulation of specific nutrients in each organ of the plant and expressed in kg kg^{-1} and kg g^{-1} for macro and micronutrients, respectively. We calculated the HI with the ratio between the accumulation of DM or nutrient in the commercial body (root) and the total accumulation of the crop, which was expressed in percentage. Data were grouped into two cultivation systems: Summer or winter.

The demand for nutrients was calculated by dividing the content of nutrients in the tubers and the nutrient harvest index. The content of nutrients in the tubers was obtained from the ratio between the dry matter produced from tubers and the CBU of the nutrient for each cultivar, according to the equations:

$$DEM\ X = 100.\frac{EXP\ X}{HI\ X} \quad (1)$$

$$EXP\ X = \frac{10\ .\ Prod\ .\ DM}{CUB\ X_{root}} \quad (2)$$

Wherein: DEM X: demand of the nutrient X (kg ha^{-1}); HI X: harvest index of the nutrient X (%); EXP X: export of the nutrient X (kg ha^{-1}); Prod: desired productivity of roots (t ha^{-1}); DM: dry matter content in the roots (%); CBU X_{root}: coefficient of biological utilization of the nutrient X in the root (kg kg^{-1}).

The data were submitted to outliers` analysis, eliminating the values dissonant from the average. Descriptive statistics tools were employed to characterize the database and present the necessary attributes for modeling the nutrient demand of the carrot crop.

RESULTS AND DISCUSSION

The analysis of the chemical properties of the cultivation soil showed that they had corrected acidity (high pH) and adequate levels of macronutrients (adequate levels of P and K and less levels of Ca, Mg and S) (Table 1). In contrast, the soils showed imbalances as for the micronutrients, once, on average, the contents of Mn were considered low, the ones of B average, the ones of Fe good and the ones of Cu and Zn high, according to the classification proposed by the Ribeiro et al. (1999).

The soils presented average levels of organic carbon (2 dag kg^{-1}) and low remaining P (10.6 mg L^{-1}). The organic carbon content can be the result of the handling adopted in the properties in the region, where the carrot is within the crops rotation comprising other vegetable crops, such as garlic, onion and potatoes. Thus, these soils annually undergo intense turnings to condition the cultivation of these species and consequently, the mineralization of the organic matter of the soil is increased. In relation to the remaining P, the low value indicates that soils are much buffered for this nutrient, that is, addition of large amounts of this nutrient is required on soil to increase a small fraction of P available to the plant (Bedin et al.,

Table 1. Average and standard deviation of the main soil attributes in the layer 0 to 20 cm depth.

Attribute	Unit	Extractor/ method	Average	Standard deviation
pH	-	H_2O	6.3	0.3
Organic carbonic	dag kg^{-1}	$K_2Cr_2O_7$/ Walkley-Black	2.0	0.3
P - rem	mg L^{-3}	-	10.6	3.2
Phosphorus (P)	mg dm^{-3}	Mehlich-1	28.0	15.1
Potassium (K^+)	$mmol_c$ dm^{-3}	Mehlich-1	3.1	0.8
Calcium (Ca^{2+})	$mmol_c$ dm^{-3}	KCl	33.9	5.8
Magnesium (Mg^{2+})	$mmol_c$ dm^{-3}	KCl	10.7	3.0
Sulfur (SO_4^{2-})	mg dm^{-3}	$Ca(H_2PO_4)_2.H_2O$ in AcOH	7.5	4.5
CEC (T)	$mmol_c$ dm^{-3}	-	82.3	8.2
Base saturation (V)	%	-	58.0	7.0
Boron (B)	mg dm^{-3}	Hot water	0.52	0.21
Copper (Cu)	mg dm^{-3}	Mehlich-1	2.5	1.4
Iron (Fe)	mg dm^{-3}	Mehlich-1	38.0	12.2
Manganese (Mn)	mg dm^{-3}	Mehlich-1	3.2	2.3
Zinc (Zn)	mg dm^{-3}	Mehlich-1	6.8	3.0
Ca saturation	%	-	41.2	4.9
Mg saturation	%	-	13.0	3.4
K saturation	%	-	3.8	1.1

Table 2. Number of plots, cultivated area, total productivity of roots and cycle of carrot hybrids.

Cultivar	Number of plots		Area		Total productivity		Cycle	
	Nº	%	ha	%	Mg ha^{-1}	CV (%)	Day	CV (%)
Baltimore	18	8.6	67.5	10.1	83.4	25.2	123	8.7
Belgrado	10	4.8	20.3	3.0	83.4	13.0	118	7.1
Concerto	8	3.8	19.1	2.9	90.9	24.2	131	4.0
Maestro	27	12.9	118.6	17.8	82.1	18.1	127	6.3
Músico	13	6.2	40.3	6.1	86.4	19.5	130	4.4
Nancy	10	4.8	35.4	5.3	87.3	21.0	121	8.8
Nandrin	20	9.5	87.4	13.1	81.5	24.7	115	9.4
Soprano	16	7.6	85.4	12.8	87.0	18.8	129	6.7
Winter cultivars	155	73.8	495.3	74.4	81.6	24.3	125	7.9
Juliana	16	7.6	140.6	21.1	63.2	12.5	100	6.4
Poliana	7	3.3	20.4	3.1	56.5	16.4	101	9.3
Summer cultivars	55	26.2	170.6	25.6	60.9	14.3	105	8.1
General (winter and summer)	210	100.0	665.9	100.0	75.4	24.6	120	10.8

2003; Broggi et al., 2011).

There were more winter cultivars (8 major hybrids) than summer (2 major hybrids) (Table 2). This fact is related to climate requirements of the carrot, which are better contemplated in the winter season (mild temperatures, short days and less rainfall). The mild temperatures for the summer conditions in the region of the Alto Paranaíba and cultivars resistant to foliar diseases allow the cultivation of carrot during this time; however, with minor importance and productive potential than in winter cultivars.

The winter cultivars showed productivities 34% higher than those obtained during the summer (81.6 Mg ha^{-1} against 60.9 Mg ha^{-1}), while concerning the cycle, winter cultivars presented cultivation periods 14% higher than summer (125 and 105 days of cycle, respectively). The highest temperatures recorded during the summer induce greater accumulation of DM in the shoot due to unfavorable climatic conditions for root growth (Hussain et al., 2008) and thus reduces the productivity of the roots due to the change in biomass partition. Furthermore, higher temperatures tend to reduce the cycle of the carrot

Table 3. Maximum, average and minimum content of dry matter of tuberous roots of carrot hybrids.

Cultivar	Content of dry matter in roots			
	Maximum (%)	Average (%)	Minimum (%)	CV(%)
Baltimore	11.1	9.7	8.0	9.5
Belgrado	10.9	8.6	6.3	17.9
Concerto	10.7	8.9	7.0	13.0
Maestro	11.5	9.2	4.5	14.1
Músico	12.1	8.8	6.7	18.5
Nancy	10.7	8.4	5.7	18.5
Nandrin	12.3	9.2	6.6	13.5
Soprano	11.1	9.0	7.0	13.7
Winter cultivar	12.3	9.1	4.5	14.4
Juliana	10.9	8.0	4.7	22.3
Poliana	10.0	8.1	6.0	18.6
Summer cultivar	11.5	9.0	4.7	18.5
General (Winter and Summer)	12.3	9.0	4.5	15.4

due to unfavorable environmental conditions for crop growth. According to Thiagaranjan et al. (2012), temperatures higher than 24°C significantly reduce the net photosynthesis of the carrot crop due to thermal stress caused to the species. Thus, the shortest time the plants remain in the field also contributes to the reduction of productivity in summer cultivars compared to winter.

The average yields obtained (75.4 Mg ha^{-1}) can be considered high in relation to the estimated national average in 2012 (28.9 Mg ha^{-1}) (FAO, 2014). In a study conducted by Cecílio Filho and Peixoto (2013) in 2004 in the municipality of São Gotardo in Alto Paranaíba – MG the average productivity obtained was 72 Mg ha^{-1}, similar to the average obtained in this work. In the international context, the yields achieved in Alto Paranaíba are above the world average (30.9 Mg ha^{-1} in 2013) (FAO, 2014) and similar to the ones obtained by Seljasen et al. (2012) in Norway (65.4 Mg ha^{-1}) and Tesfaendrias et al. (2010) in Holland (82.5 Mg ha^{-1}).

The contents of DM in carrot roots ranged from 4.5 to 12.3%, averaging 9.0% (Table 3). Similar average contents (9.9%) were obtained by Seljasen et al. (2012) in studies in Norway. The coefficients of variation (CV) obtained for the content of DM in the roots of the main hybrids of the carrot can be considered low. This parameter shows that the content of DM of the carrot roots does not tend to have large variations within the genetic material, even with the diversity of cultural handlings to which the sampled plots were submitted.

There was virtually no difference in the average levels of DM in winter (9.1%) and summer (9.0%) cultivars (Table 3). However, the main cultivars of carrots grown in summer (Juliana and Poliana) showed average levels of DM below the average for this time of cultivation. Among the main features that make genetic breeders and producers choose certain genetic material one can cite productivity. In the case of the Juliana and Poliana cultivars, the lower content of DM in the roots can provide higher yields, since for the same accumulation of DM in the roots there will be higher fresh mass of roots accumulation. Thus, it is possible that the fact that these cultivars present lower content of DM in the roots is related to the selection performed during the breeding processes of the species and, or, by selection of production traits by farmers. Regarding the winter cultivars, the average content of DM of the main cultivars revolved around the overall average for this time (Table 3).

The CBU showed high variability (CV) for cationic micronutrients (Cu, Fe, Mn and Zn) in both organs of the crop (roots and shoots) and, in some cultivars, the CBU of the root also presented great variability for Ca, Mg and S (Tables 4 and 5). Regarding the cationic micronutrients, part of this variation may be a consequence of the high variability of the contents of these elements in the plant tissue (data not shown). For other nutrients (macronutrients and B), the average CV of the leaf and root CBUs was close to 30%. The lower variability is interesting for the proposition of the model to estimate the demand for nutrients in line with productivity. This is because it allows a single model for the crop and not for the cultivar.

The averages of the CBUs in the root system of winter cultivars for N, P, K, S, Cu and Zn are greater than those of the summer (Table 4). In the shoot, winter cultivars showed the highest CBUs only for Ca, Fe and Zn (Table 5). The higher CBU indicates that these cultivars is more efficient in the use of the respective element, that is, there is greater accumulation of DM per unit absorbed from the nutrient.

Comparing the CBUs between the hybrids of each season it is observed that there is low variation in this

Table 4. Maximum, average, minimum values and coefficients of variation of the coefficient of biological utilizations of macro and micronutrients of carrot hybrids.

Cultivar	Parameter	Coefficient of biological utilization										
		N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
		kg kg^{-1}						g kg^{-1}				
Baltimore	Maximum	131.1	605.2	39.8	1492.5	1342.2	3656.6	42.9	1945.6	23.1	169.5	241.5
	Average	86.3	357.3	28.2	336.0	801.1	1661.6	27.4	351.7	8.4	98.4	73.0
	Minimum	59.2	209.1	18.5	140.1	548.5	771.3	20.6	57.6	3.7	50.0	20.8
	CV (%)	23.5	35.1	21.1	91.6	28.6	48.9	22.4	127.7	65.1	38.6	95.2
Belgrado	Maximum	111.1	513.2	39.7	258.0	1041.7	1585.5	34.5	385.3	8.9	344.8	185.2
	Average	84.5	272.4	27.9	195.6	519.0	1213.9	22.3	142.1	4.5	131.3	59.7
	Minimum	65.8	160.0	20.9	151.0	345.1	623.0	14.6	56.8	2.6	67.5	21.7
	CV (%)	18.4	46.4	20.7	16.6	39.2	29.0	26.6	90.8	56.1	64.7	95.0
Concerto	Maximum	106.0	719.4	50.1	819.7	650.7	4200.0	39.3	635.7	19.3	250.0	186.4
	Average	87.6	422.3	29.7	312.2	547.4	2014.9	29.3	281.5	10.6	114.2	77.3
	Minimum	64.0	232.6	19.4	174.2	377.8	1098.7	22.6	87.6	3.8	72.9	31.7
	CV (%)	15.4	38.3	36.0	67.1	18.9	57.9	19.9	65.3	52.5	52.8	69.0
Maestro	Maximum	103.8	629.0	33.7	295.9	815.0	4023.1	50.0	1907.2	27.1	203.1	697.1
	Average	70.4	361.8	27.2	239.7	564.6	1427.9	29.3	371.5	11.8	136.5	169.4
	Minimum	48.6	191.3	20.6	167.3	401.1	550.0	21.4	45.7	4.2	83.4	23.4
	CV (%)	18.9	31.2	17.1	15.7	21.8	62.1	23.0	118.9	49.1	22.5	95.3
Músico	Maximum	88.7	505.8	37.6	295.9	820.1	5928.4	40.2	1192.0	13.5	158.8	286.1
	Average	71.7	294.4	29.3	228.7	552.3	1765.0	28.0	312.0	9.6	114.9	114.8
	Minimum	53.3	195.5	20.4	140.7	372.9	518.9	18.3	66.6	5.5	67.8	18.6
	CV (%)	17.4	29.3	19.5	18.2	22.5	82.8	22.5	97.2	31.1	21.7	64.5
Nancy	Maximum	244.4	489.1	37.7	337.4	797.3	3782.3	37.5	328.5	13.2	190.1	313.6
	Average	96.0	308.2	26.8	261.3	565.8	1776.3	25.7	136.9	6.3	111.5	98.1
	Minimum	71.1	171.4	19.0	189.1	419.5	747.9	19.8	57.4	1.9	64.2	27.1
	CV (%)	54.7	37.2	23.9	21.8	21.6	51.8	25.0	65.2	60.8	30.9	102.1
Nandrin	Maximum	97.4	782.4	39.4	378.9	1015.4	2643.5	44.9	1366.9	20.6	232.4	1353.1
	Average	78.5	408.4	27.8	265.6	692.6	1686.2	28.3	423.6	10.7	141.1	275.1
	Minimum	56.4	184.0	15.6	162.7	398.5	731.1	16.8	118.8	4.1	70.4	26.4
	CV (%)	17.2	43.7	23.1	22.1	24.7	38.4	31.6	88.6	42.1	33.1	116.7
Soprano	Maximum	104.7	488.8	56.5	308.7	3276.7	2878.6	46.2	422.3	23.7	136.2	1353.1
	Average	75.9	259.7	29.8	253.0	836.5	1602.3	25.3	168.8	8.0	96.5	199.2
	Minimum	55.9	153.7	17.4	185.0	417.9	781.4	16.1	51.0	2.8	63.8	13.7
	CV (%)	18.0	31.8	28.7	16.5	79.8	44.3	34.5	60.5	67.6	25.7	141.9
Winter cultivars	Maximum	244.4	782.4	56.5	1538.5	3276.7	8510.1	50.0	1945.6	27.1	536.3	1353.1
	Average	78.7	325.3	27.4	293.8	649.2	1676.8	26.9	278.4	8.2	125.8	114.8
	Minimum	46.7	93.5	15.6	140.1	345.1	517.3	14.6	37.6	1.8	47.4	11.9
	CV (%)	26.2	40.4	23.6	79.2	43.5	62.1	26.9	112.2	62.1	49.3	138.9
Juliana	Maximum	97.5	399.3	58.7	402.7	1020.4	2445.1	41.5	1376.0	22.1	416.7	1353.1
	Average	74.7	273.8	31.2	256.5	645.3	1580.9	29.5	296.9	6.7	138.0	252.9
	Minimum	49.5	186.1	18.0	191.4	461.4	833.3	18.3	73.1	2.7	40.5	21.1
	CV (%)	17.0	27.4	43.2	22.4	24.9	32.3	30.3	114.6	98.8	69.9	121.1
Poliana	Maximum	96.6	281.1	31.3	1075.3	1492.5	2873.7	45.1	2384.0	7.9	454.5	1353.1
	Average	66.2	217.6	22.5	361.6	844.8	1818.0	21.0	950.5	4.4	218.3	262.8

Table 4. Contd.

	Minimum	48.1	161.7	14.8	178.8	517.4	900.9	12.2	169.7	2.9	106.8	30.2
	CV (%)	24.1	23.1	24.8	88.2	40.6	40.4	44.5	90.9	42.8	61.6	116.1
Summer cultivars	Maximum	97.5	661.9	58.7	1369.9	2244.8	6041.5	41.5	2384.0	22.1	555.6	960.0
	Average	65.2	275.9	25.5	414.2	815.6	1447.6	28.0	466.1	5.5	230.7	103.8
	Minimum	41.2	161.7	14.8	161.8	441.5	775.2	15.8	73.1	1.8	40.5	21.1
	CV (%)	24.7	39.2	36.2	85.0	39.0	57.6	21.7	85.4	83.3	61.5	138.7
General (Summer and winter)	Maximum	244.4	782.4	58.7	1538.5	3276.7	8510.1	50.0	2384.0	27.1	555.6	1353.1
	Average	75.0	312.4	26.9	326.2	693.9	1616.2	27.2	327.8	7.5	154.6	111.7
	Minimum	41.2	93.5	14.8	140.1	345.1	517.3	14.6	37.6	1.8	40.5	11.9
	CV (%)	27.2	40.9	27.4	84.6	43.5	61.8	25.7	106.2	68.7	66.5	139.4

Table 5. Maximum, average and minimum values and coefficients of variation of macro and micronutrients coefficients of biological utilization from shoot of carrot hybrids.

Cultivar	Parameter	Coefficient of biological utilization										
		N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
		kg kg^{-1}						kg g^{-1}				
Baltimore	Maximum	56.3	1077.8	41.1	67.6	666.7	654.5	22.3	97.3	3.8	37.7	31.4
	Average	47.0	658.5	19.1	44.8	302.4	414.3	18.9	34.6	1.9	18.6	19.4
	Minimum	35.3	318.3	13.4	30.3	198.3	260.9	16.1	7.2	0.7	7.0	11.6
	CV (%)	13.2	33.3	33.6	20.4	36.0	28.9	9.4	100.5	50.8	49.6	31.4
Belgrado	Maximum	67.6	1052.6	57.7	56.3	625.0	1021.6	25.6	33.6	3.8	54.3	42.2
	Average	50.5	518.4	22.1	40.4	363.2	538.0	19.2	10.8	1.2	21.2	21.5
	Minimum	37.8	356.1	14.7	28.8	267.9	314.8	13.2	4.9	0.4	5.5	13.9
	CV (%)	15.5	38.6	57.8	21.2	30.4	40.7	23.6	82.5	83.2	71.8	45.8
Concerto	Maximum	57.0	952.4	43.2	43.6	416.7	679.3	23.4	38.3	2.5	60.2	39.6
	Average	52.9	779.4	20.7	34.1	342.2	532.4	17.2	17.2	1.7	21.7	21.3
	Minimum	45.0	506.4	13.5	22.8	264.6	416.7	14.3	7.4	0.7	5.0	13.0
	CV (%)	8.6	17.7	47.6	18.8	16.4	23.4	15.9	64.0	38.8	96.9	39.4
Maestro	Maximum	61.6	1457.8	48.5	59.0	546.0	1566.0	26.4	106.9	5.7	75.2	87.4
	Average	47.1	666.1	24.9	38.7	329.6	544.0	19.0	21.9	2.6	18.4	35.8
	Minimum	36.8	399.0	12.3	30.8	218.2	278.5	13.9	4.2	1.0	5.2	14.8
	CV (%)	12.8	33.8	39.9	18.7	25.6	57.7	16.7	113.6	50.7	83.0	52.4
Músico	Maximum	63.7	1438.8	42.3	41.6	459.6	1274.2	23.3	38.2	3.3	51.8	82.8
	Average	51.2	796.3	25.6	32.7	355.7	721.5	18.6	17.7	2.0	18.6	47.5
	Minimum	42.5	549.9	16.9	26.6	258.9	478.9	14.5	6.7	1.0	5.1	13.5
	CV (%)	11.4	32.1	31.6	13.9	15.6	45.7	14.1	62.5	41.3	77.9	51.6
Nancy	Maximum	60.7	1188.2	50.5	54.3	361.2	521.0	22.5	23.3	3.8	29.9	58.4
	Average	48.1	664.8	24.7	42.9	301.9	357.5	17.2	14.3	2.5	17.9	29.3
	Minimum	37.7	354.9	14.3	34.8	223.0	248.1	11.8	5.0	1.4	10.4	10.6
	CV (%)	15.8	33.5	46.4	15.3	14.8	26.0	17.4	53.6	38.2	36.1	53.4
Nandrin	Maximum	52.0	909.0	44.1	73.3	434.4	645.4	24.8	81.1	3.9	25.1	51.6
	Average	42.4	618.9	21.4	49.7	332.7	402.9	19.1	23.2	2.6	15.2	31.1
	Minimum	29.8	368.3	12.2	34.5	258.9	260.8	14.5	3.6	1.4	8.8	11.6
	CV (%)	13.3	24.3	34.3	20.9	14.4	26.2	15.6	103.2	26.9	31.7	34.3
Soprano	Maximum	59.6	1041.7	32.8	49.2	400.0	1240.9	23.9	42.0	4.0	79.4	56.4

Table 5. Contd.

	Average	47.7	626.1	20.3	36.6	260.6	656.5	17.7	14.8	2.1	28.0	21.4
	Minimum	39.8	290.1	15.3	26.2	202.1	369.1	11.2	4.7	0.7	5.7	8.2
	CV (%)	11.8	33.9	29.6	17.4	21.3	34.5	22.0	82.3	45.7	80.7	67.1
Winter cultivars	Maximum	71.9	1457.8	66.0	73.3	625.0	1566.0	26.4	106.9	5.7	68.0	89.1
	Average	47.0	623.0	24.3	40.4	321.3	481.8	18.6	19.9	2.0	20.5	28.2
	Minimum	29.8	290.1	12.2	22.8	198.3	200.3	11.2	3.6	0.3	5.0	8.2
	CV (%)	15.9	33.3	42.1	22.4	23.4	46.5	17.2	101.2	53.6	63.3	59.3
Juliana	Maximum	73.5	1315.8	51.8	51.3	735.3	1101.6	35.4	29.1	3.5	149.3	43.2
	Average	43.1	414.5	29.1	39.5	483.5	555.7	19.5	11.4	1.2	34.0	21.7
	Minimum	34.0	257.1	18.5	26.4	300.0	262.8	14.6	5.6	0.5	7.2	12.6
	CV (%)	21.1	62.5	36.3	17.3	24.0	44.3	27.9	66.6	72.2	113.3	45.0
Poliana	Maximum	64.9	1098.9	33.3	48.1	588.2	835.3	29.0	13.4	3.2	119.0	38.2
	Average	52.1	566.9	26.5	34.8	450.2	668.8	20.5	9.4	1.7	43.5	24.7
	Minimum	42.7	272.0	22.1	21.2	367.8	434.8	15.9	6.9	1.1	10.4	15.7
	CV (%)	15.4	56.9	14.3	26.2	17.9	27.6	22.1	23.4	60.7	91.8	34.4
Summer cultivars	Maximum	73.5	1315.8	55.9	69.2	735.3	1101.6	35.4	526.3	3.5	149.3	44.9
	Average	50.6	686.0	26.4	36.9	511.3	537.1	21.5	75.0	1.0	53.3	25.0
	Minimum	34.0	257.1	16.6	21.2	255.2	262.8	12.9	5.2	0.2	7.1	12.6
	CV (%)	20.8	53.4	32.5	30.8	22.9	34.7	24.8	203.3	72.9	67.1	39.9
General (Summer and Winter)	Maximum	73.5	1457.8	66.0	73.3	735.3	1566.0	35.4	526.3	5.7	149.3	89.1
	Average	47.8	649.7	24.7	39.3	376.9	497.6	19.5	35.1	1.7	30.3	27.1
	Minimum	29.8	257.1	12.2	21.2	198.3	200.3	11.2	3.6	0.2	5.0	8.2
	CV (%)	17.9	41.0	39.8	25.1	33.8	42.5	21.1	241.2	64.0	87.5	56.2

attribute, except for the CBU of Cu in the root system of the Poliana cultivar (summer cultivation). For this cultivar, the CBU for the Cu was high (950.5 kg g^{-1}) when compared with the overall average of the summer cultivars and the Juliana cultivar, indicating that this is the most efficient in the use of this nutrient.

The winter cultivars showed export tax of dry matter 16% higher than summer cultivars (74% against 64%), that is, higher HI (Table 6). As a result of this greater HI of DM, winter cultivars had higher HI of nutrients to all the quantified elements when compared to the summer cultivars.

As for the nutrients accumulated preferably in the root (HI > 50%) N, P, K, Mg and B stood out in both growing seasons. Similar results were obtained by Cecílio Filho and Peixoto (2013), who, by analyzing only the macronutrients, concluded that N, P, K, Mg and S accumulate preferentially in the roots. However, according to the results shown in Table 6, S is accumulated preferentially in the leaves (HI = 45%). Phosphorus is the nutrient that has the highest HI (83%), while Cu is the nutrient with the smallest exported fraction (21%). Cecílio Filho and Peixoto (2013) also concluded that P is the macronutrient with the highest HI (86.1%).

The demand for nutrients can be calculated by the ratio between export and harvest index for each element. The export in turn can be calculated as the product of productivity, content of dry matter of root and inverse of CBU of the nutrient for the root system. Based on this model, to obtain 80 Mg ha^{-1} of roots of winter cultivars, extractions vary from 114 to 163 kg ha^{-1} of N, 23 to 32 kg ha^{-1} of P, 338 to 411 kg ha^{-1} of K, 77 to 106 kg ha^{-1} of Ca, 17 to 20 kg ha^{-1} of Mg, 7 to 11 kg ha^{-1} of S, 383 to 483 g ha^{-1} of B, 44 to 280 g ha^{-1} of Cu, 1446 to 4259 g ha^{-1} of Fe, 180 to 244 g ha^{-1} of Mn and 62 to 246 g ha^{-1} of Zn. For summer cultivars, the extractions of nutrients to obtain 60 Mg ha^{-1} of roots vary from 129 to 147 kg ha^{-1} of N, 25 to 31 kg ha^{-1} of P, 253 to 361 kg ha^{-} of K, 68 to 98 kg ha^{-1} of Ca, 12 to 14 kg ha^{-1} of Mg, 8 to 9 kg ha^{-1} of S, 299 to 459 g ha^{-1} of B, 65 to 244 g ha^{-1} of Cu, 2728 to 3896 g ha^{-1} of Fe, 81 to 123 g ha^{-1} of Mn and 52 to 131 g ha^{-1} of Zn. For variations in nutrient extraction we considered the differences in CBUs, content of DM and HI of the nutrients of each cultivar.

By comparing the nutritional demands of winter and summer cultivars with yields of 80 and 60 Mg ha^{-1} of roots (averages of both growing seasons), respectively, it was observed that there are virtually no differences in the extractions of N, P, Ca, S, B, Cu and Zn. In contrast, the summer cultivars tend to present higher demand for Fe

Table 6. Harvest indexes of dry matter, macronutrients and micronutrients of carrot hybrids.

Cultivar	Parameter	Harvest index (%)											
		DM	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
Baltimore	Maximum	81.6	71.4	93.9	82.9	48.9	66.2	62.7	78.3	44.9	52.6	49.7	74.1
	Average	73.2	59.6	82.8	64.6	31.8	50.6	41.4	66.5	22.1	41.1	32.3	52.7
	Minimum	63.8	40.8	67.6	45.9	9.2	39.7	19.3	57.4	6.8	20.9	15.4	18.0
	CV (%)	7.0	14.3	8.1	18.2	28.9	13.7	35.7	8.9	51.9	21.4	32.2	29.5
Belgrado	Maximum	77.6	62.2	92.5	90.5	38.4	71.1	68.2	78.8	41.2	51.8	58.6	66.7
	Average	67.7	56.0	79.1	59.4	30.6	60.0	48.5	64.0	17.3	35.6	25.5	46.8
	Minimum	62.9	49.6	60.8	44.9	25.6	52.0	30.7	54.3	4.3	7.8	11.6	18.7
	CV (%)	6.5	7.7	12.0	20.9	12.9	8.5	24.6	10.2	58.4	35.2	52.6	30.3
Concerto	Maximum	88.5	82.6	92.6	91.1	58.7	86.4	51.9	85.4	61.6	58.3	75.4	82.0
	Average	78.6	69.4	87.7	70.6	35.4	69.8	39.0	68.6	21.1	43.2	42.9	53.2
	Minimum	61.8	51.4	80.1	55.5	4.3	54.3	28.1	58.3	6.9	30.4	13.8	25.9
	CV (%)	9.3	12.1	4.1	16.3	40.9	12.9	25.2	11.9	81.9	23.9	66.4	36.2
Maestro	Maximum	84.5	80.0	94.4	89.1	48.5	80.8	77.6	81.7	47.2	62.1	52.7	88.1
	Average	75.3	67.7	84.7	72.2	34.1	63.9	54.8	66.4	19.2	43.0	25.6	47.5
	Minimum	64.4	59.1	74.9	51.8	25.2	51.2	35.0	52.6	2.5	25.4	9.1	17.5
	CV (%)	7.8	7.7	7.0	12.6	19.8	13.0	21.7	11.5	61.1	21.6	45.0	40.1
Músico	Maximum	81.4	75.2	94.0	85.0	37.2	73.9	73.1	75.0	46.0	48.4	57.8	64.7
	Average	74.4	67.2	88.5	71.1	29.1	64.7	59.6	65.6	20.0	35.1	34.1	49.7
	Minimum	68.4	61.6	84.9	62.3	22.6	58.5	41.8	58.0	7.3	21.3	9.9	35.9
	CV (%)	4.4	6.3	3.1	10.6	14.1	7.3	17.2	8.2	59.0	21.4	74.9	22.6
Nancy	Maximum	81.2	70.8	92.5	86.2	39.7	69.4	62.5	78.2	45.9	71.6	49.5	67.6
	Average	75.0	61.6	85.9	69.5	33.6	61.5	36.3	66.2	25.6	55.5	33.5	52.3
	Minimum	66.2	38.2	79.9	52.1	26.7	57.2	20.7	50.0	18.8	46.3	18.4	24.1
	CV (%)	6.4	14.8	4.7	18.2	13.5	6.2	35.7	12.3	36.9	13.9	31.4	30.4
Nandrin	Maximum	78.3	67.5	88.6	89.6	46.0	71.3	58.2	80.6	60.4	56.4	37.4	68.8
	Average	71.1	57.5	79.0	64.3	31.9	54.6	38.2	63.1	39.9	38.6	22.0	35.0
	Minimum	64.2	49.3	55.7	44.3	25.8	44.3	19.5	48.2	1.9	19.7	11.2	7.5
	CV (%)	5.8	9.2	10.2	14.9	16.6	13.7	27.9	13.3	102.8	26.5	35.0	56.4
Soprano	Maximum	81.6	72.9	91.1	83.3	35.9	62.5	75.0	79.4	61.9	61.6	57.8	75.7
	Average	74.8	65.4	87.4	66.5	31.5	51.2	55.0	67.9	20.9	45.9	36.7	58.5
	Minimum	66.7	47.2	80.8	37.1	24.5	22.7	30.3	45.8	3.3	30.0	15.5	33.9
	CV (%)	6.2	10.3	3.7	16.0	9.5	20.1	22.1	12.7	62.4	21.8	41.7	22.5
Winter cultivars	Maximum	88.5	82.6	94.5	94.9	58.7	86.4	77.6	89.5	61.9	71.6	75.4	88.1
	Average	73.9	63.3	84.4	69.0	31.6	59.5	45.9	66.7	21.8	42.1	30.6	50.5
	Minimum	61.8	38.2	55.7	37.1	4.3	22.7	10.1	45.8	1.9	7.8	9.1	7.5
	CV (%)	7.5	12.4	8.2	16.6	28.1	16.2	32.8	12.1	62.8	28.5	46.5	37.6
Juliana	Maximum	73.3	77.2	93.9	78.7	31.6	64.3	60.1	76.9	39.8	56.5	61.9	69.8
	Average	63.2	50.0	70.6	60.7	21.3	56.5	37.1	54.5	11.6	26.3	28.3	36.4
	Minimum	49.0	38.2	55.1	33.2	14.2	43.4	20.0	40.8	2.1	6.6	6.4	2.0
	CV (%)	9.1	20.6	15.8	22.7	22.9	11.8	34.3	20.3	94.8	48.4	57.0	58.8
Poliana	Maximum	66.3	72.2	91.0	67.9	17.6	48.3	48.7	65.5	3.7	45.6	33.5	52.5
	Average	55.6	49.8	72.7	60.0	13.7	41.5	35.6	50.3	2.1	28.2	18.6	34.4
	Minimum	43.4	37.2	50.7	46.4	3.6	33.9	24.2	29.7	0.7	16.0	7.3	15.3
	CV (%)	15.4	25.9	19.3	12.4	32.1	12.6	26.4	24.6	60.4	41.7	48.1	39.6

Table 6. Contd.

Summer cultivars	Maximum	78.5	80.2	93.9	83.2	43.8	69.1	72.2	76.9	71.4	61.0	61.9	69.8
	Average	64.5	58.2	78.7	64.3	19.2	54.2	42.8	58.3	17.7	25.2	28.8	39.6
	Minimum	43.4	37.2	50.7	33.2	3.6	27.1	18.5	29.7	0.7	6.6	6.4	2.0
	CV (%)	10.8	22.8	15.9	17.1	48.1	15.8	29.4	18.6	124.1	53.2	43.2	39.9
General (Summer and winter)	Maximum	88.5	82.6	94.5	94.9	58.7	86.4	77.6	89.5	71.4	71.6	75.4	88.1
	Average	71.3	61.9	82.9	67.8	28.2	58.0	44.9	64.4	20.7	37.4	30.1	47.3
	Minimum	43.4	37.2	50.7	33.2	3.6	22.7	10.1	29.7	0.7	6.6	6.4	2.0
	CV (%)	10.2	16.0	11.0	17.0	37.4	16.6	32.0	15.0	79.8	39.0	45.8	39.7

and lower demand for K, Mg and Mn.

Summer cultivars produced fewer roots to the same accumulated quantity of the nutrients N, P, Ca, S, B, Cu and Zn, as compared to winter cultivars. This indicates that winter cultivars have higher agronomic efficiency of use of these nutrients. The higher agronomic efficiency of winter cultivars may be related to the biomass partitioning (HI of DM), because for the same amount of produced roots, summer cultivar generates greater accumulation of DM in the shoot, and consequently, greater accumulation of nutrients in this organ.

According to the estimated accumulations we verified the following nutrients extractions order for the winter and summer cultivars, respectively: K > N > Ca > P > Mg > S > Fe > B > Mn > Zn > Cu and K > N > Ca > P > Mg > S > Fe > B > Zn > Mn > Cu. The decreasing order of nutrient accumulation of winter and summer cultivars is identical for macronutrients; however, there is change in the order of accumulation of Mn and Zn. The accumulation of macronutrients in "Forto" carrots – verified by Cecílio Filho and Peixoto (2013) - was similar to that seen in this work, except that the S accumulation is greater than that of Mg.

Different cultivars of winter and summer promote low effect on the nutritional demand of the carrot crop in each growing season, except for the nutrients K, Mg and Mn, as discussed above. Thus, the nutritional demand of the carrot crop can be estimated as a function of the desired productivity and the growing season.

Conclusions

The harvest index of dry matter and nutrients is greater for winter cultivars. The differences are insignificant in the nutritional demand of N, P, Ca, S, B, Cu and Zn between winter and summer cultivars for the average yields obtained in each season. The summer cultivars accumulate larger amounts of Fe and lower amounts of K, Mg and Mn when compared to the winter cultivars. The modeling of the nutritional demand of the carrot crop can be performed depending on the desired productivity and growing season.

Conflict of Interest

The authors have not declared any conflict of interest.

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REFERENCES

Bedin I, Furtini Neto AE, Resende AV, Faquin V, Tokura AM, Santos JZL (2003). Phosphate fertilizers and soybean yield in soils with different phosphate buffer capacities. Rev. Bras. Ci. Solo. 27(4):639-646.

Broggi F, Oliveira AC, Freire FJ, Freire MBGS, Nascimento CWA (2011). Phosphate capacity factor in mineralogically different soils in Pernambuco and the influence of pH on the maximum capacity of adsorption. Ciênc. Agrotec. 35(1):77-83.

Cecílio Filho AB, Peixoto FC (2013). Accumulation and exportation of nutrients by carrot 'Forto'. R. Caatinga. 26(1): 64-70.

Fageria NF (1998). Optimizing nutrient use efficiency in crop production. Rev. Bras. Eng. Agric. Ambient. 2:6-16.

FAO (2014). Agriculture sector: Production Crops. Available at: http://www.fao.org (accessed August 2014).

Haefele SM, Wopereis MCS, Ndiaye MK, Barro SE, Ouldisselmou M (2003). Internal nutrient efficiencies, fertilizer recovery rates and indigenous nutrient supply of irrigated lowland rice in Sahelian West Africa. Field. Crop. Res. 80(1):19-32.

Hussain SI, Hadley P, Pearson S (2008). A validated mechanistic model of carrot (*Daucus carota* L.) growth. Sci. Hortic. 117(1):26-31.

Kurihara CH, Alvarez Venegas VH, Neves JCL, Novais RF (2013). Accumulation of dry matter and nutrients in soybean, as a variable of the productive potential. Rev. Ceres. 60(5):690-698.

Malavolta E, Vitti GC, Oliveira SA (1997). Avaliação do estado nutricional das plantas: Princípios e aplicações. 2nd ed. Associação Brasileira para Pesquisa da Potassa e do Fosfato, Piracicaba, São Paulo. P. 319.

Ribeiro AC, Guimarães PTG, Alvares VVH (1999). Recomendações para o uso de corretivos e fertilizantes em Minas Gerais - 5ª aproximação. UFV, Viçosa, Minas Gerais. P. 349.

Seljasen R, Lea P, Torp T, Riley H, Berentsen E, Thomsen M, Bengtsson GB (2012). Effects of genotype, soil type, year and fertilization on sensory and morphological attributes of carrots (*Daucus carota* L.). J. Sci. Food. Agric. 92(8):1786-1799.

Tesfaendrias MT, McDonald MR, Warland J (2010). Consistency of long-term marketable yield of carrot and onion cultivars in muck (organic) soil in relation to seasonal weather. Can. J. Plant Sci. 90(5):755-765.

Thiagaranjan A, Lada R, Adams A (2012). Ecophysiological characteristics of two carrot cultivars in response to agroecological factors and nitrogen application. Photosynthetica. 50(2):282-290.