Revista Brasileira de Ciência do Solo
ISSN: 0100-0683
revista@sbcs.org.br
Sociedade Brasileira de Ciência do Solo
Brasil

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Nutrient Recommendation Model for Carrot Crop – FERTICALC Carrot
Revista Brasileira de Ciência do Solo, vol. 39, núm. 6, 2015, pp. 1714-1722
Sociedade Brasileira de Ciência do Solo
Viçosa, Brasil

Nota

NUTRIENT RECOMMENDATION MODEL FOR CARROT CROP – FERTICALC CARROT

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ABSTRACT

The literature on fertilization for carrot growing usually recommends nutrient application rates for yield expectations lower than the yields currently obtained. Moreover, the recommendation only considers the results of soil chemical analysis and does not include effects such as crop residues or variations in yield levels. The aim of this study was to propose a fertilizer recommendation system for carrot cultivation (FERTICALC Carrot) which includes consideration of the nutrient supply by crop residues, variation in intended yield, soil chemical properties, and the growing season (winter or summer). To obtain the data necessary for modeling nutritional requirements, 210 carrot production stands were sampled in the region of Alto Paranaíba, State of Minas Gerais, Brazil. The dry matter content of the roots, the coefficient of biological utilization of nutrients in the roots, and the nutrient harvest index for summer and winter crops were determined for these samples. To model the nutrient supply by the soil, the literature was surveyed in regard to this theme. A modeling system was developed for recommendation of macronutrients and B. For cationic micronutrients, the system only reports crop nutrient export and extraction. The FERTICALC which was developed proved to be efficient for fertilizer recommendation for carrot cultivation. Advantages in relation to official fertilizer recommendation tables are continuous variation of nutrient application rates in accordance with soil properties and in accordance with data regarding the extraction efficiency of modern, higher yielding cultivars.

Keywords: nutrient balance, *Daucus carota* L., plant nutrition.

Received for publication on February 4, 2015 and approved on August 18, 2015.
DOI: 10.1590/01000683rbcs20150065

RESUMO: *MODELO DE RECOMENDAÇÃO DE NUTRIENTES PARA A CULTURA DA CENOURA – FERTICALC CENOURA*

A literatura existente para a fertilização da cultura da cenoura recomenda, de modo geral, doses de nutrientes para expectativas de produtividades inferiores às obtidas atualmente. Além do mais, a recomendação considera somente os resultados da análise química do solo e não contempla efeitos como dos resíduos culturais ou variações da produtividade. Objetivou-se, com este trabalho, propor um sistema de recomendação de nutrientes para a cultura da cenoura (FERTICALC Cenoura), que abranja o suprimento de nutrientes pelos resíduos culturais, a variação da produtividade almejada, os atributos químicos do solo e a época de cultivo (inverno ou verão). Para obter dados necessários à modelagem do requerimento nutricional, amostraram-se 210 talhões de cultivo de cenoura na região do Alto Paranaíba, MG. Com essas amostragens, determinaram-se o teor de matéria seca das raízes, o coeficiente de utilização biológica dos nutrientes nas raízes e o índice de colheita dos nutrientes para os cultivos de verão e inverno. Para modelar o suprimento de nutrientes pelo solo, realizou-se revisão na literatura buscando trabalhos relacionados ao tema. O modelo foi desenvolvido para recomendação de macronutrientes e B. Para os micronutrientes catiônicos, o sistema informa somente a exportação e extração da cultura. O FERTICALC desenvolvido pode auxiliar na recomendação de nutrientes para a cultura da cenoura. Como vantagens em relação às tabelas de recomendação oficiais citam-se a variação contínua das doses de nutrientes com a produtividade e com características do solo e de acordo com dados de eficiência de extração de cultivares modernas e de maior produtividade.

Palavras-chave: balanço de nutrientes, Daucus carota L., nutrição de plantas.

INTRODUCTION

Many recommendations of quantities of nutrients are made based on information available in tables published in state manuals; however, some inadequacies can be seen in regard to this method of recommendation. Specific regional applicability, the constant lack of updating in relation to new cultivars/hybrids that arise on the market, and the non-representative nature of yield levels that are generally less than those obtained from technologically advanced crops are the main negative points of this method of recommendation (Oliveira et al., 2007; Santos et al., 2008; Silva et al., 2009).

To overcome these problems, some nutrient recommendations are being made through the nutrient balance method (Haefele et al., 2003; Silva et al., 2009). This system of recommendation allows estimation of nutrient demand by the crop according to expected yield and the supply of nutrients by the soil (soil and crop residues). That way, fertilization recommendation through this method includes the difference between crop demand and supply from the soil.

In order to propose methods based on nutrient balance, crop information related to nutrient demand is necessary. This includes information on the dry matter content (*DMc*), the coefficient of biological utilization (*CBU*), the harvest index (*HI*), and recovery efficiency (*RE*) by the plant of the nutrients applied on the soil. The CBU may be defined as the amount of dry matter produced per unit of the nutrient accumulated in a determined plant organ (Fageria, 1998). The HI represents the fraction of the weight of DM of the roots (*w*DM_R) or nutrient present in the marketed part of the crop (tuberous root in the carrot crop) in relation to the entire dry matter of the plant (*w*DM_PL). The RE indicates the percentage of nutrient applied to the soil that the plant recovers (Fageria, 1998).

In addition to determining the nutritional requirements, it is necessary to know the supply of nutrients from the soil to be able to use the nutrient balance system. In contrast with models of nutrient demand that require specific information from the crop, such as the content of DM, CBU, HI, and RE, nutrient supply modeling can be obtained based on studies available in the literature. Noteworthy among them are studies performed to determine the recovery efficiency of the extractants used in soil analyses and studies carried out to analyze accumulation and the dynamic of mineralization and release of nutrients from crop residues (Gama-Rodrigues et al., 2007; Marcelo et al., 2012a,b). Thus, obtaining informations (data) necessary to calculate nutrient demand represents the critical point for using the nutrient balance model in the carrot crop, due to a lack of data in the literature.

The aim of this study was to obtain the data necessary for modeling the demand and nutrient requirements of the carrot crop and develop a model for recommendation of nutrients for the crop (FERTICALC Carrot) based on the principle of nutrient balance.

MATERIAL AND METHODS

Development of the FERTICALC Carrot Model

Modeling for recommendation of nutrients for the carrot crop (FERTICALC Carrot) was divided into two models, namely, nutritional requirement (*REQ*) and nutrient supply by the soil (*SUP*). To estimate the nutritional requirements, crop demand and recovery efficiency (*RE*) of the nutrient applied were taken into consideration. To calculate crop demand, for its part, the REQ model considered the yield intended from the roots (*yield*Root), the DM content in the roots (*DMc*_R), the CBU of the nutrients in the root system ($cbu\text{Nu}_i$_R), and the HI ($hi\text{Nu}_i$). The SUP model considered the supply of nutrients by the soil, by soil amendment (supplied by liming and gypsum application), and by residues from previous crops.

Model of Requirements – REQ

Obtaining data for Modeling of Nutrient Demand

To obtain the data necessary for estimating nutrient demand of the carrot crop, a database was generated with information on commercial stands located in the Alto Paranaiba region, MG. To generate the database, samples were taken in 2012 and 2013, which included crops located in the municipalities of Rio Paranaíba, São Gotardo, and Campos Altos, MG, Brazil. In these municipalities, carrot crops are grown at an altitude of approximately 1,100 m, with Cwa as the predominant climate, according to the Köppen-Geiger classification. This climate is characterized by a dry season and a well-defined rainy period that occurs from October to March. The main summer cultivars were Juliana and Poliana, and those of winter were Baltimore, Belgrado, Maestro, Músico, Nancy, Nandrim, and Soprano. In relation to soil type, there was a predominance of *Latossolos* (Oxisols; Soil Survey Staff, 2010) - *Latossolos Amarelos*, *Vermelhos* and *Vermelho-Amarelos*, with a very clayey texture (Embrapa, 2013).

A total of 210 carrot crop stands were sampled, in which the yields of roots and leaves were determined through harvest of four samples of 4 m of double rows. Samples of leaves and roots from harvest were dried in a forced air circulation laboratory oven at 70 °C for 72 h to obtain dry matter yield of roots and leaves. The dry matter content in the roots was calculated by the ratio between the dry and fresh matter of the roots. The summer cultivars exhibited dry matter content in the roots of 9.0 ± 0.2 % and those of winter, of 9.1 ± 0.1 %. The samples of roots and leaves were passed in a Willey mill with a 1.27 mm screen. Contents of N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn were determined according to methods described in Malavolta et al. (1997).

The CBU was calculated for the winter and summer crops by the ratio between the accumulation of dry matter weight (*w*DM) and the concentration of the given nutrient ($c\text{Nu}_i$). The separation of winter and summer cultivars was due to the differences in their capacity for conversion of nutrients into dry matter (Aquino et al., 2015). The CBU obtained for N, P, K, Ca, Mg, and S for the root system were 78.7, 325.3, 27.4, 293.8, 649.2, and 1,676.8 kg kg^{-1} in the winter crop; and 65.2, 275.9, 25.5, 414.2, 815.6, and 1,447.6 kg kg^{-1} in the summer crop. In relation to micronutrients, the CBU obtained for B, Cu, Fe, Mn, and Zn for the root system were 26.9, 278.4, 8.2, 125.8, and 114.8 g kg^{-1} in the winter crop; and 28.0, 466.1, 5.5, 230.7, and 103.8 g kg^{-1} in the summer crop.

The HI was calculated by the ratio between the accumulation of nutrients in the marketed part (root) and the total accumulation of the crop, which was expressed in percentage. The HI estimated for N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn was 63.3, 84.4, 69.0, 31.6, 59.5, 45.9, 66.7, 21.8, 42.1, 30.6 and 50.5 % in the winter crop; and 58.2, 78.7, 64.3, 19.2, 54.2, 42.8, 58.3, 17.7, 25.2, 28.8 and 39.6 % in the summer crop.

The RE of the applied nutrient was calculated only for the macronutrients. The definition of RE was carried out by simulation, seeking values that would draw near the nutrient management practices (nutrient application rate) adopted by carrot producers in the stands sampled. The RE values posited were those that in the recommendation model returned to the nutrient application rates that producers practice to achieve the mean yields in the winter and summer crops.

Determining the RE of the nutrient applied is complex and involves numerous factors, requiring studies to understand the effects of climate (temperature, rainfall, and solar radiation), the soil properties (pH, texture, organic matter content, Al^{3+} toxicity, fertility class, and porosity), and the crop (morphology of the root system and physiology) on this variable (Fageria, 1998). Thus, due to the complexity of estimating the RE, values obtained by iterative simulation were adopted in the first version of FERTICALC Carrot. However, studies in this line of research are necessary for refining the recommendations of nutrients for the carrot crop by this model.

The information of CBU, HI, and RE was placed in two groups: summer crop and winter crop. Of the 210 stands sampled, 155 (74 %) were classified in the winter subgroup, and the rest (55 stands – 26 %) in the summer subgroup. The data obtained were analyzed for outliers to eliminate the values divergent from the mean values.

Modeling of nutritional requirements

To estimate nutritional requirements, the model took into consideration crop demand (calculated according to the intended yield (*yield*Root), the DM content in the root (*DMc*_R), and the growing period), and the recovery efficiency of the nutrient applied (*re*Nu_Apl) (Table 1). The nutritional demand (*dem*Nu_i) was calculated by the ratio between the export and the harvest index of each nutrient. Export of the nutrient (*exp*Nu_i), for its part, was calculated by the product of the intended yield, the dry matter content in the roots (*DMc*_R), and the inversion of the CBU of each nutrient in the root system (*cbu*Nu_i_R). The nutrient requirement (*req*Nu_i) was calculated by the ratio between the DEM and the recovery efficiency of the nutrient applied. Thus, the *exp*Nu_i, the *dem*Nu_i, and the *req*Nu_i were estimated according to the following equations:

$$expNu_i = (10 \times yieldRoot \times DMc\_R) / cbuNu_i\_R$$

$$demNu_i = (100 \times expNu_i) / hiNu_i$$

$$reqNu_i = demNu_i / reNu_i\_Apl$$

in which, *exp*Nu_i: export of the nutrient (kg ha^{-1} or g ha^{-1} for macro and micronutrients, respectively); *yield*Root: intended yield of carrot roots (Mg ha^{-1}); *DMc*_R: dry matter content in the carrot roots (9.1 ± 0.1 % for winter cultivars and 9.0 ± 0.2 % for summer cultivars); *cbu*Nu_i_R: coefficient of biological utilization of the nutrient in the root (kg kg^{-1} and g kg^{-1} for macro- and micronutrients, respectively); *dem*Nu_i: nutrient demand (kg ha^{-1} or g ha^{-1} for macro- and micronutrients, respectively); *hi*Nu_i: harvest index of the nutrient (%); *req*Nu_i: nutrient requirement (kg ha^{-1} or g ha^{-1} for macro- and micronutrients, respectively); and *re*Nu_Apl: recovery efficiency of the nutrient applied (mg dm^{-3}/mg dm^{-3}) (Table 1).

Supply Model - SUP

The SUP model of FERTICALC Carrot was developed only for the macronutrients. To estimate the nutrient supply (*sup*Nu_i), the model took into consideration the supply coming from soil amendment (supplied through liming and gypsum application), from the soil, and from crop residues.

Table 1. Recovery efficiency of macronutrients applied (*re*Nu_Apl) on the carrot crop during the winter and summer crop in Alto Paranaíba

Nutrient	*re*Nu_Apl(1)	
	Winter	Summer
	mg dm^{-3}/mg dm^{-3}	
N	0.80	0.75
P	0.078	0.069
K	0.65	0.55
Ca	0.60	0.60
Mg	0.60	0.60
S	0.50	0.50

(1) Values obtained by simulation based on the relationship between nutrient extraction and supply from the soil, crop residues, and fertilizers for mean yield of each crop season, winter or summer.

Supply of nutrients by soil amendment

The supply of Ca and Mg through liming was estimated by the following equations:

$$supCa\_Liming = QC \times tCaO\_Lime \times f$$

$$supMg\_Liming = QC \times tMgO\_Lime \times f$$

in which, *sup*Ca_Liming: supply of Ca through liming (kg ha^{-1}); *sup*Mg_Liming: supply of Mg through liming (kg ha^{-1}); QC: amount of limestone applied (Mg ha^{-1}); *t*CaO_Lime: CaO content in the soil amendment (%); *t*MgO: MgO content in the soil amendment (%); and *f*: conversion factor of mass of oxides (CaO or MgO, Mg ha^{-1}) to mass of element (Ca or Mg, kg ha^{-1}). To determine the supply of Ca and Mg through liming, use *f* equal to 7.15 and 6.03, respectively.

The supply of Ca and S through gypsum application was estimated by the following equations:

$$supCa\_Gypsum\ application = QG \times tCa\_gypsum \times 10$$

$$supS\_Gypsum\ application = QG \times tS\_gypsum \times 10$$

in which, *sup*Ca_Gypsum application: supply of Ca through gypsum application (kg ha^{-1}); *sup*S_Gypsum: supply of S through gypsum application (kg ha^{-1}); QG: amount of gypsum applied (Mg ha^{-1}); *t*Ca_gypsum: Ca content in the gypsum applied (%); and *t*S_gypsum: S content in the gypsum applied (%).

Supply of nutrients by the soil

To estimate the supply of nutrients by the soil, the results of soil chemical analysis, the recovery efficiency of the nutrients by the extractants used in the analyses, and the effective depth of the root system of the carrot crop was taken into consideration, according to the following equation:

$$supNu_i = (X_{analysis} \times DEP) / (reNu_i\_Ext \times 10)$$

in which: sup X_{soil}: supply of nutrient X by the soil (kg ha^{-1}); $X_{analysis}$: content of nutrient X in the chemical analysis (mg dm^{-3}); DEP: effective depth of the root system (m); and *re*Nu_i_Ext: recovery efficiency of the nutrient by the extractant (mg dm^{-3}/mg dm^{-3}) (Table 2).

To estimate the N supply from the soil, the kinetic equation of mineralization of organic matter of Brazilian soils was used as described by Carvalho et al. (2006), developed according to the model proposed by Stanford and Smith (1972).

$$supN\_Soil = (0.5 \times DEP \times dSoil \times tOM\_Soil \times 1.48)e^{0.006t}$$

in which: *sup*N_Soil: supply of N by the soil (kg ha^{-1}); DEP: effective depth of roots (m); *d*Soil: soil density (Mg m^{-3}); *t*OM_Soil: organic matter content in the soil (dag kg^{-1}); and t: crop cycle (d).

Supply by crop residues

Supply of nutrients by crop residues (*sup*Nu_i_Res) was estimated by the model proposed by Wieder and Lang (1982), who describe variation in the nutrient content or dry matter weight (wDM) in the material in decomposition as a function of the time which has passed or the crop cycle.

$$frNu_i = contNu_i\_Res \times e^{-k0x\ t}$$

$$supNu_i\_Res = contNu_i\_Res - frNu_i$$

in which: $frNu_i$: fraction remaining of the nutrient in the material in decomposition after passage of time t (kg ha^{-1}); $contNu_i$_Res: nutrient content in the crop residues (kg ha^{-1}); k0x: nutrient decomposition constant (Table 3); t: crop cycle (d); and $supNu_i$_Res: supply of nutrient x by crop residues (kg ha^{-1}).

The nutrient content in the crop residues at the time of establishing the crop ($contNu_i$_Res) was estimated as the product of the dry matter volume of crop residues in the area and the nutrient concentration in these residues.

Recommendation of nutrients for the carrot crop

Recommendation of macronutrients was generated according to the philosophy of nutrient balance. Thus, the recommendation consisted of the difference between the nutritional requirement of the crop ($reqNu_i$) and the supply of nutrients from the soil ($supNu_i$). However, the recommendation was generated in such a way that the rate of macronutrients applied was not less than the amount exported by the crop, corrected by the recovery efficiency of the plant. That way, the soil would not become impoverished over successive crop periods.

The recommendation of B aimed at raising the content of this element to the critical level in the soil [0.55 mg dm^{-3} – established by Mesquita Filho et al. (2005)] and meet crop demand. Thus, the recovery efficiency of B by the plant was not considered in recommending the application rate of this nutrient. For the other micronutrients, the system presented only the export and the demand of the crop, without recommending the rate to be applied. Thus, the amounts of Cu, Fe, Mn, and Zn applied will have to be estimated by responsible technicians in accordance with export and demand of the crop. This position was adopted because of not knowing the true recovery efficiency of these elements by carrot and, thus, the impossibility of determining the requirement for these nutrients by the crop.

Analysis of sensitivity

Iterative simulations of application of the model were carried out considering different scenarios for

Table 2. Recovery efficiency of the nutrient from the soil by the extractant as a function, or not, of remaining phosphorus (P-rem)

Nutrient	Extractant[1]	Equation	R^2
P	Mehlich-1	$TR_P = 0.0672821 + 0.012165^{**}$ P-rem	0.681
P	Resin	$TR_P = 0.419^{***}$ P-rem$^{0.128099}$	0.694
K	Mehlich-1	$TR_K = 0.8020$	-
K	Resin	$TR_K = 0.7559$	-
Ca	KCl and Resin	$TR_{Ca} = 0.7661$	-
Mg	KCl and Resin	$TR_{Mg} = 0.7989$	-
S	$Ca(H_2PO_4)_2$ + HOAc	$TR_S = 0.04 + 0.057^{**}$ P-rem	0.955

[1] mg dm^{-3} / mg dm^{-3}. *** and **: significant by the t test, respectively, at 0.1 and 1 %. Adapted from Morais (1999), Souza (1999), and Melo (2000). P-rem: remaining phosphorus (mg L^{-1}).

Table 3. Decomposition constant (k_{0X}) of dry matter (DM) and of macronutrients of the main crops that preceded this crop

Crop	k_{0X}						
	DM	N	P	K	Ca	Mg	S
Brachiaria	0.006	0.005	0.003	0.050	0.005	0.005	0.015
Crotalaria spectabilis[1]	0.004	0.020	0.015	0.030	0.010	0.015	0.010
Oilseed radish[1]	0.008	0.015	0.015	0.030	0.015	0.020	0.020
Pearl millet[1]	0.006	0.010	0.020	0.050	0.010	0.015	0.015
Maize and sorghum[2]	0.005	0.010	0.010	0.030	0.010	0.020	0.010
Soybean[2]	0.015	0.027	0.027	0.063	0.018	0.027	0.015
Fabaceae	0.010	0.025	0.020	0.045	0.015	0.020	0.010
Poaceae	0.006	0.010	0.010	0.040	0.010	0.010	0.010
Overall	0.008	0.015	0.015	0.040	0.010	0.015	0.015

[1] Constants obtained from management carried out during flowering of the crop. [2] Constants obtained from plant residues after grain harvest. Adapted from Padovan et al. (2006), Gama-Rodrigues et al. (2007), and Marcelo et al. (2012b).

comparing the recommendations of FERTICALC Carrot with those in the literature. To compare the recommendations of macronutrients and B, simulations were generated with the intention of producing 60, 80, 100, and 120 Mg ha^{-1} of roots in the winter crop; and 40, 60, and 80 Mg ha^1 in the summer crop. The simulations were made considering the mean values obtained in the region during sampling of the stands as the chemical properties of the soil (Table 4).

Moreover, 8 Mg ha^{-1} of maize crop residues (plant dry matter – leaves and stalks) were considered in the crop area, containing 4.6, 0.2, 5.9, 1.8, 1.5, and 0.4 g kg^{-1} de N, P, K, Ca, Mg, and S in the dry matter, respectively (Marcelo et al., 2012a). For purposes of calculation, it was considered that carrot grown in the summer and winter had cycles of 100 and 125 days, respectively, and 0.20 m was adopted as the effective depth of the crop root system. For the other micronutrients (Cu, Fe, Mn, and Zn), the system generated only the amounts extracted and exported.

Table 4. Chemical properties of the soil used in simulations of fertilizer recommendation by FERTICALC Carrot

Property	Extractant/ Method	Mean
pH	H_2O	6.3
OM (dag kg^{-1})	$K_2Cr_2O_7$/Walkley-Black	3.4
P-rem (mg L^{-1})	-	10.6
P (mg dm^{-3})	Mehlich-1	28.0
K^+ ($mmol_c$ dm^{-3})	Mehlich-1	3.1
Ca^{2+} ($mmol_c$ dm^{-3})	KCl	33.9
Mg^{2+} ($mmol_c$ dm^{-3})	KCl	10.7
S-SO_4^{2-} (mg dm^{-3})	$Ca(H_2PO_4)_2.H_2O$ in AcOH	7.5
CEC (T) ($mmol_c$ dm^{-3})	-	82.3
V (%)	-	58.0
B (mg dm^{-3})	Hot water	0.52
Cu (mg dm^{-3})	Mehlich-1	2.5
Fe (mg dm^{-3})	Mehlich-1	38.0
Mn (mg dm^{-3})	Mehlich-1	3.2
Zn (mg dm^{-3})	Mehlich-1	6.8
Saturation by Ca (%)	-	41.2
Saturation by Mg (%)	-	13.0
Saturation by K (%)	-	3.8

OM: organic matter; P-rem: remaining phosphorus; CEC: cation exchange capacity; V: base saturation.

Simulations were also made to evaluate the recommendations for N, P_2O_5, and K_2O by FERTICALC Carrot and by the literature as a function of the variation in chemical properties of the soil (organic matter content - MO; P content - Mehlich-1, and K content - Mehlich-1) and of the intended yield of roots for the winter and summer crops. These simulations also considered the presence of maize crop residues in the area, the 100 days (summer) and 125 days (winter) cycle, and a 0.20 m depth of the effective root system of the crop.

RESULTS AND DISCUSSION

In the simulations generated by FERTICALC Carrot, the supply (SUP) of Ca and Mg via liming and the SUP of Ca and S via gypsum application were not considered since application of these soil amendments was not necessary, based on the results of chemical analysis used in the simulation (Table 4). The pH (6.3) of the soil considered in the simulations can be considered high, and the Ca, Mg, and S contents are all considered adequate according to the CFSEMG (1999).

The recommendations of macronutrients and B generated by the system were constant as a function of yield for all the conditions proposed (intended yield and crop season) (Table 5). This fact occurred due to the simulations being made considering the mean chemical properties of the soils of the Alto Paranaiba region (Table 4), which are characterized as having high fertility. Thus, the recommendations generated in these simulations consisted of the ratio between the crop export and the recovery efficiency of the plant for the nutrient applied (except for B), and not of the difference between the crop requirement (REQ) and the soil supply (SUP).

Table 5. Recommendations of application rates of N, P_2O_5, K_2O, Ca, Mg, S, and B generated by FERTICALC Carrot and by the literature for different intended yields of roots in the winter and summer crops

Nutrient	Summer			Winter				Trani et al. (1999)
	40 Mg ha^{-1}	60 Mg ha^{-1}	80 Mg ha^{-1}	60 Mg ha^{-1}	80 Mg ha^{-1}	100 Mg ha^{-1}	120 Mg ha^{-1}	40 Mg ha^{-1}
	kg ha^{-1}							
N	74.4	111.7	148.9	85.8	114.4	142.9	171.5	120.0
P_2O_5	431.6	647.4	863.2	475.2	633.6	792.0	950.4	160.0
K_2O	311.4	467.2	622.9	363.8	485.1	606.4	727.7	80.0
Ca	14.6	22.0	29.3	30.6	40.8	51.1	61.3	-
Mg	7.4	11.2	14.9	13.9	18.5	23.1	27.7	-
S	5.0	7.5	10.1	6.4	8.6	10.7	12.9	-
B	0.283	0.394	0.506	0.361	0.461	0.560	0.660	1.0 to 2.0

Under high fertility conditions, the supply of nutrients by the soil is high, and may be greater than that required by the crop. Therefore, under these conditions, the recommendation of nutrients should be generated so as to avoid impoverishment of the soil over successive croppings. Thus, FERTICALC Carrot recommends the application of at least the amount of nutrients exported by the crop, corrected by recovery efficiency of the plant. Recommendations of B were also constant in relation to the intended yield. However, these recommendations were generated in the system to supply the demand of the crop and raise the soil content to the critical level, that is, 0.55 mg dm^{-3} (Mesquita Filho et al., 2005).

Comparing the recommendations generated by FERTICALC Carrot for the yield of 60 Mg ha^{-1} in the summer and winter crops, a lower recommended application rate for N, P_2O_5, and K_2O is observed in the winter (Table 5). This shows the importance of modeling in recommendation of nutrients. In this case, modeling allowed differentiated recommendation since variables related to the nutritional requirement (DM content in the roots, CBU of the nutrients in the root system, and HI) as a function of the crop season had been distinguished in the method.

The application rates of nutrients recommended by the literature were different from those generated by FERTICALC Carrot. In relation to N, the rate recommended by Trani et al. (1999) for a yield of 40 Mg ha^{-1} of roots was similar to that indicated by the model proposed for the yields of 60 and 80 Mg ha^{-1} in the winter and summer crops (Table 5). As for the recommendations for P_2O_5 and K_2O, the application rates recommended by Trani et al. (1999) were much lower than those generated by FERTICALC Carrot, regardless of the intended yield. It should be noted that the recommendation in the literature indicated in table 5 is considering only the chemical fertilization. The application of chicken manure (10 Mg ha^{-1}) or cattle manure (30 Mg ha^{-1}) were recommended by Trani et al. (1999); however, this is not a common practice in the carrot growing areas of Alto Paranaíba, due to their extensiveness.

The cationic micronutrients (Cu, Fe, Mn, and Zn), the model exhibited only export (amount accumulated in the roots) and demand (amount accumulated in the roots and shoots) of the crop in the simulations carried out (Table 6). Since the recovery efficiency of the crop for these micronutrients was not known, it was not possible to estimate the nutritional requirement and, in such a way, generate the recommendation for micronutrients.

The simulations generated to evaluate the recommendations of FERTICALC Carrot as a function of variations in the soil properties and the intended yields (sensitivity analysis), two distinct responses of the model were observed, depending on the condition simulated (Figure 1). In the graph regions represented by high supply of N, P, and K (high contents of OM, P - Mehlich-1, and K - Mehlich-1), the recommendation of fertilization of FERTICALC Carrot is constant for the different yields. In this situation, the difference between the crop requirement and the soil supply is less than the crop export, and thus, the model recommends using the amount exported, corrected by recovery efficiency.

In contrast, in the chart regions represented by high yields and low nutrient supply from the soil, the recommendation of the model arises from the difference between the nutritional requirement and the soil supply. Thus, the recommendation of FERTICALC Carrot, under these conditions, is greater than the amount exported by the crop corrected by recovery efficiency, a fact that can be observed in the charts by the curve of the lines of best fit generated for each yield (Figure 1).

The divergence between the recommendations generated by FERTICALC Carrot and the literature in effect (Trani et al., 1999) (Table 5, Figure 1). Among the reasons that tend to generate these

Table 6. Export of and demand for cationic micronutrients generated by FERTICALC Carrot as a function of the intended yield of roots and the growing season (winter or summer)

Nutrient	Summer			Winter			
	40 Mg ha^{-1}	60 Mg ha^{-1}	80 Mg ha^{-1}	60 Mg ha^{-1}	80 Mg ha^{-1}	100 Mg ha^{-1}	120 Mg ha^{-1}
			Export (g ha^{-1})				
Cu	8	12	16	19	26	32	39
Fe	662	993	1,322	659	878	1,098	1,317
Mn	16	24	32	43	57	72	86
Zn	35	53	70	47	63	78	94
			Demand (g ha^{-1})				
Cu	44	66	88	89	119	148	178
Fe	2,626	3,939	5,253	1,564	2,086	2,607	3,128
Mn	55	82	110	140	187	234	281
Zn	89	133	177	93	124	155	186

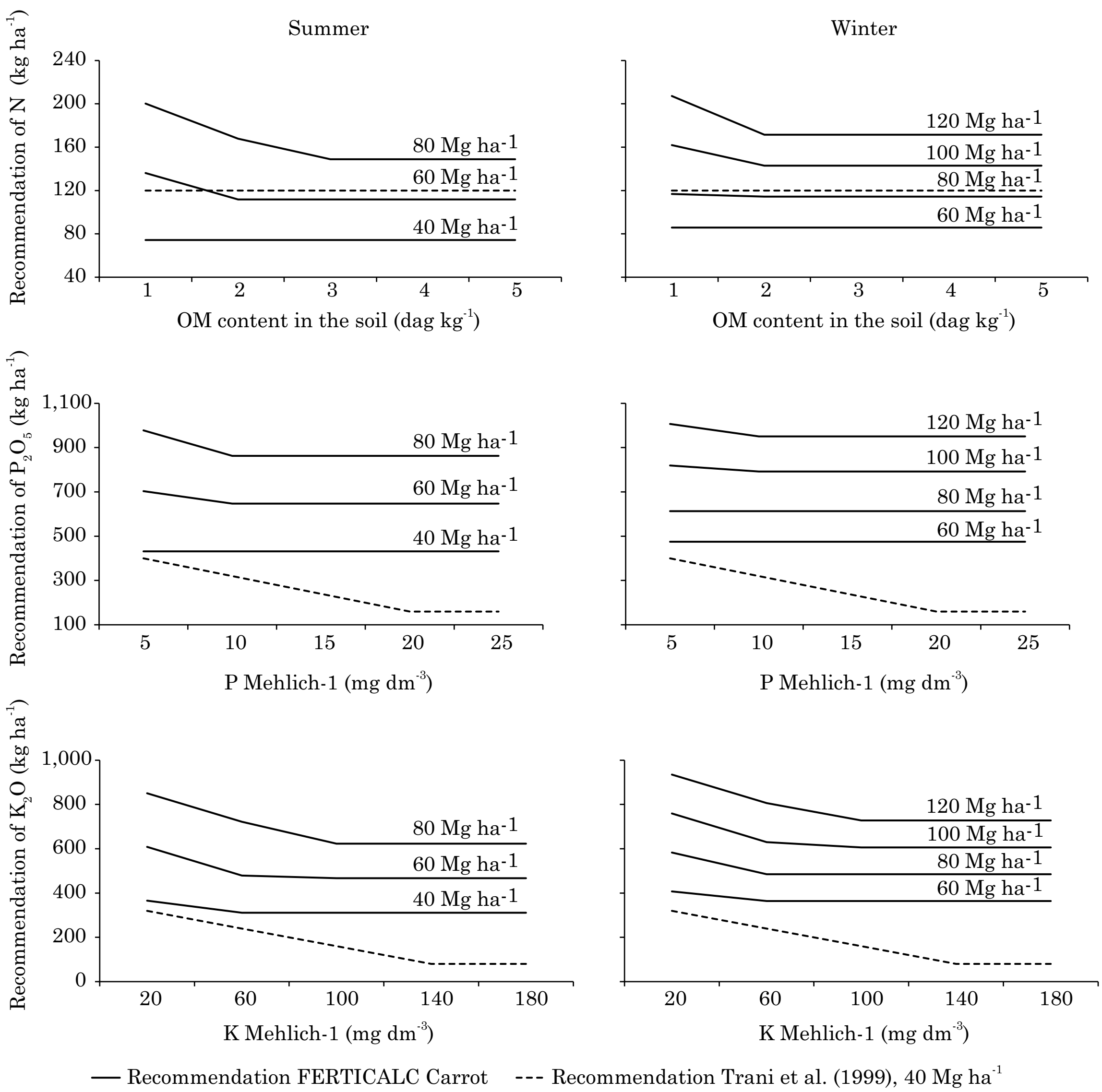

Figure 1. Analysis of sensitivity of FERTICALC Carrot for recommendation of N, P_2O_5, and K_2O as a function of properties of soil chemical analysis, yield expectation, and crop season (winter or summer).

discrepancies is the lack of constant updating of the recommendation tables of the literature in relation to new cultivars and techniques that are adopted in more advanced cropping systems (Oliveira et al., 2007; Santos et al., 2008; Silva et al., 2009).

The nutrient recommendation model proposed (FERTICALC Carrot) can be improved with new research results, especially in regard to the recovery efficiency by the plant of the nutrients applied to the soil.

CONCLUSIONS

FERTICALC Carrot proved to be efficient for recommending nutrients for the crop.

Recommendation with continuous variation of the application rates as a function of the soil chemical properties and the intended yield of roots is the main advantage of this model.

ACKNOWLEDGMENTS

Our thanks to the Coordenação de Aperfeiçoamento Pessoal de Nível Superior (CAPES) for granting a master's scholarship to the first author; to the Fundação Arthur Bernardes (Funarbe) for the research productivity and excellence scholarship granted to the second author; to the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the research productivity and excellence scholarship granted to the thirth author and CNPq and to the Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG) for financial assistance; to the Cooperativa Agropecuária do Alto Paranaíba (COOPADAP); and to Agrichem do Brasil for financial assistance.

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