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Scientific Article

Modeling the requirement of nutrients by table beet crop

Modelagem da demanda de nutrientes pela cultura da beterraba de mesa

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ABSTRACT - The nutritional balance system may be more accurate in estimating the fertilization of crops compared to fertilizer recommendation tables. For its efficiency, the construction of the model needs information related to the requirement of nutrients by the crop and yield. The objective of this study was to generate models that best correlate the requirement of each nutrient by beet crop (*Beta vulgaris* L. var. *vulgaris*) and dry matter harvest index with root yield, in addition to determining the order of total nutrient accumulation and nutrient export index. The study was conducted in the Alto Paranaíba region, MG, Brazil, during the 2017 season. Forty -seven commercial areas of beet, with 'Boro' and 'Betty' hybrids, were sampled. The average yield of beet roots was 68.9 Mg ha^{-1}, ranging from 38.4 to 98.6 Mg ha^{-1}. The linear model was the most appropriate to express the relationship between yield and dry matter harvest index, as well as the relationship between yield and nutrient accumulations, except for the total accumulations (root + shoot) of Mn and Zn, which were described by the model of decreasing increments. The order of total nutrient accumulation in beet crop was: K > N > Ca > Mg > P > S > Fe > Zn > Mn > B > Cu. Beet export index follows the order: Zn > P > Cu > N > Mg > K > S > B > Ca > Fe > Mn.

Keywords: *Beta vulgaris* L.. Harvest index. Nutrient export. Nutritional requirement. Table beet.

RESUMO - O balanço nutricional pode apresentar maior exatidão na estimativa das fertilizações dos cultivos em comparação às tabelas de recomendação de fertilização. Para sua eficiência, a construção do modelo necessita de informações relativas à demanda de nutrientes pela cultura e de produtividade. Objetivou-se, então, gerar modelos que melhor relacionem a demanda de cada nutriente pela cultura da beterraba e o índice de colheita de matéria seca com a produtividade de raízes, além de determinar a ordem de acúmulo total e do índice de exportação de nutrientes. O trabalho foi conduzido na região do Alto Paranaíba, MG, Brasil, durante a safra de 2017. Foram amostradas 47 áreas comerciais de beterraba, híbridos Boro e Betty. A produtividade média de raízes de beterraba foi de 68,9 Mg ha^{-1}, com variação de 38,4 a 98,6 Mg ha^{-1}. O modelo linear foi o mais adequado para expressar a relação entre a produtividade e o índice de colheita de matéria seca, e também a relação entre a produtividade e os acúmulos de nutrientes, exceto para o acúmulo total (raiz + parte aérea) de Mn e Zn, que se ajustaram ao modelo de incrementos decrescentes. A ordem de acúmulo total de nutrientes na cultura da beterraba foi: K > N > Ca > Mg > P > S > Fe > Zn > Mn > B > Cu. O índice de exportação da beterraba segue a ordem: Zn > P > Cu > N > Mg > K > S > B > Ca > Fe > Mn.

Palavras-chave: *Beta vulgaris* L.. Índice de colheita. Exportação de nutrientes. Demanda nutricional. Beterraba de mesa.

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INTRODUCTION

The main fertilizer recommendation tables used for beet crop in the Southeast region of Brazil are in the official publications of Casali (1999) and Trani et al. (2018). In the latter, more recent, the fertilizer recommendation for beet is based on an expected yield of 30 to 50 t ha^{-1}, far below the yield currently obtained by producers with high technological level in the Alto Paranaíba region, which is the main beet producing region in Brazil.

An alternative to the use of tables is the nutritional balance system (DEUS et al., 2015; DEZORDI et al., 2015a). This system has been shown to be more appropriate than the recommendation table because it considers variations in yield estimates and in soil attributes (such as available nutrient contents and crop residues) in a continuous way and not in intervals of soil fertility classes (low, medium and high). For this, the system considers the relationship between the requirement of nutrients by plants, the supply of nutrients through the soil and the expected yield. However, as in any type of modeling, it is necessary to obtain information inherent to the model, especially in the producing region, since yield, fertilization efficiency and the requirement of nutrients are affected by environmental conditions and technological package.

Studies with nutritional requirement are fundamental for the management of fertilization of a crop, as they help in the definition of fertilizer doses that should be applied (OLIVEIRA et al., 2010). In beet crop, Grangeiro et al. (2007), Sediyama et al. (2011) and Cardoso et al. (2017) determined the accumulation of nutrients. However, these studies were carried out under specific experimental conditions that do not resemble those of the production system adopted in the largest beet producing region in Brazil, making it difficult to use the results.

Quantifying nutrient accumulation and export by crops in commercial areas of high yield is necessary to model nutrient requirement and to cover a greater sampling variability (CUNHA et al., 2015). Considering these precepts, models have been published for rice (BURESH; PAMPOLINO; WITT, 2010; XU et al., 2015), maize (ZHANG et al., 2012; XU et al., 2013; JIANG et al., 2017), soybean (YANG et al., 2017) and wheat (CHUAN et al., 2013). Recently, studies with vegetables such as garlic (CUNHA et al., 2015), sweet potato (KUMAR et al., 2016), carrot (DEZORDI et al., 2015b) and cassava (BYJU et al., 2012; SANTOS et al., 2014; EZUI et al., 2017) have also been published. However, for table beet there is no modeling to express the amounts of nutrients accumulated and/or exported, because of the variation in yield, to allow the development of the nutritional balance system for the crop.

Thus, the objective was to generate models that best correlate the requirement of each nutrient by beet crop and the harvest index with root yield, besides determining the order of total nutrient accumulation and nutrient export index.

MATERIAL AND METHODS

To conduct the study, commercial areas of beet production in the municipalities of Ibiá, Campos Altos, Rio Paranaíba and São Gotardo, in the microregion of Alto Paranaíba, State of Minas Gerais, Brazil, were monitored in 2017. The crops were at an altitude of 980 to 1200 m, with predominance of Cwa climate, according to the Köppen-Geiger classification. This climate is characterized by a dry season and a well-defined rainy season between October and March. The climatic data were obtained from a weather station located at the Federal University of Viçosa, Rio Paranaíba Campus, recorded during the experimental period and are presented in Table 1. The predominant soil types were *Latossolo Vermelho and Latossolo Vermelho-Amarelo* (Oxisols), with very clayey texture.

Table 1. Minimum and maximum temperatures and rainfall during the experimental period.

Climate parameters	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min. temp. (°C)	19.1	18.2	18.2	18.2	16.4	14.7	12.2	15.2	15.4	18.2	17.9	18.9
Max. temp (°C)	28.8	28.6	29.3	27.6	25.6	25.0	23.0	27.9	27.9	30.2	26.5	27.3
Rainfall (mm)	337	151	95	24	108	11	0	0	29	94	260	274

The database consisted of samples from 47 commercial areas, 31 areas with Boro hybrid and 16 with Betty hybrid. The main crops grown prior to beet cultivation were garlic, carrot, maize and millet. No-tillage was performed in all areas, with thinning around 35 days after sowing and maintenance of 500 to 550,000 plants per hectare. The sowing of the crops extended between January and August 2017. Fertilization ranged from 99 to 280 kg ha^{-1} of N, 432 to 1254 kg ha^{-1} of P_2O_5 and 138 to 470 kg ha^{-1} of K_2O. The producers applied boron, manganese and zinc, which differed between them in terms of the form of application (foliar and/or fertigation), fertilizers and doses used. Copper was also used for phytosanitary reasons. Irrigation was performed by a center pivot system.

At the end of the beet cycle, which ranged from 88 to 124 days, each area was sampled in four plots of 3 m^2 to evaluate root yield. Roots and shoots of plants from these plots were separated, washed (in 0.1% detergent solution and running water with the aid of a sponge) and dried in an oven with forced air circulation at 70 ºC, for 72 h, to quantify root dry matter and shoot dry matter. Then, the samples were crushed in a Wiley mill, equipped with a 1.27-mm-mesh sieve, and prepared to determine the contents of nutrients (N, P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn) in the roots and shoots, according to methods described by Miyazawa et al. (2009).

The accumulation of each nutrient in shoots and roots was obtained by the product between the amount of dry matter and the nutrient content in each part of the plant (roots or shoots). Total accumulation in the plant was obtained by summing the accumulations of each nutrient in shoots and roots. The harvest index (HI) was calculated by the ratio between root dry matter accumulation and total accumulation in the plant, expressed as a percentage. The nutrient export index (EI), expressed as percentage, was obtained by the ratio between the accumulation of each nutrient in the root and its total accumulation in the plant.

The data were subjected to the analysis of outliers, with their exclusion. After exclusion, descriptive analysis of the variables was performed, using the mean, standard deviation, minimum value and maximum value. In addition, mathematical models were constructed from the relationship of the variables nutrient accumulation in the root, total nutrient accumulation (roots and shoots) and HI with root yield.

The criteria for fitting models between yield and nutrient accumulation in the roots and total (roots and shoots) were as follows, in decreasing order of priority: i) biological explanation of the data, ii) significance of the models, iii) significance of the model parameters, and iv) coefficient of determination (CUNHA et al., 2015). According to these criteria, only two types of models were fitted to the data: linear ($\hat{y} = a + bx$) and decreasing increments ($\hat{y} = a\,(1-e^{(-bxi)})$). SigmaPlot 10.0 (Inpixon®) was used.

RESULTS AND DISCUSSION

Beet yield showed an average of 68.9 Mg ha^{-1}, ranging from 38.4 to 98.6 Mg ha^{-1} (Table 2), mainly due to the sowing season, which brings changes mainly in temperature. Corrêa et al. (2014), Magro et al. (2015) and Silva, Lanna and Cardoso (2016) reported beet crop yields ranging between 25.4 and 44.7 Mg ha^{-1}.

Considering the average yield obtained, the total accumulation of macronutrients was 294.1, 33.6, 359.6, 93.4, 37.0 and 24.3 kg ha^{-1} for N, P, K, Ca, Mg and S, respectively, and total accumulation of micronutrients was 260.2, 70.7, 1687.1, 323.3 and 411.1 g ha^{-1} for B, Cu, Fe, Mn and Zn, respectively (Table 2).

There was a difference in the order of average accumulation of nutrients in roots + shoots (total) and in the roots (Table 2). The order of average accumulation in roots + shoots (total) was K > N > Ca > Mg > P > S > Fe > Zn > Mn > B > Cu, while the order of average accumulation in the roots was N > K > Ca > P > Mg > S > Fe > Zn > B > Mn > Cu. The sequence obtained for the average total accumulation of macronutrients was equal to that reported by Sediyama et al. (2011) and similar to that reported by Cardoso et al. (2017), with reversed positions of Ca and Mg (K > N > Mg > Ca > P > S). For micronutrients, Sediyama et al. (2011) obtained a similar sequence, with a difference in position only for Zn and Mn (Fe > Mn > Zn > B > Cu). This may be due to the difference in the redox conditions of Mn in the cultivation environments, given that Sediyama et al. (2011) applied organic residues. These residues intensify microbial activity, which increases the reduction of Mn and its release to the soil solution (SCHMIDT et al., 2009).

Table 2. Yield, total dry matter, harvest index and nutrients accumulation in the beet roots and total plant (roots and shoots).

Variable	Unit	n	Average	s	Minimum	Maximum
Yield	Mg ha^{-1}	47	68.9	15.0	38.4	98.6
Total dry matter	Mg ha^{-1}	47	13.8	2.1	9.6	17.4
Harvest index	%	47	67.6	6.1	56.8	83.0
	Accumulation in the roots					
N	kg ha^{-1}	40	177	39	100	246
P	kg ha^{-1}	45	21	5	12	29
K	kg ha^{-1}	46	167	42	71	240
Ca	kg ha^{-1}	40	29	5	21	38
Mg	kg ha^{-1}	47	18	4	11	29
S	kg ha^{-1}	43	9	2	4	13
B	g ha^{-1}	45	95	16	62	130
Cu	g ha^{-1}	41	46	15	15	80
Fe	g ha^{-1}	35	499	99	343	715
Mn	g ha^{-1}	38	83	24	49	138
Zn	g ha^{-1}	40	253	51	158	372
	Accumulation in total plant					
N	kg ha^{-1}	39	294	52	186	394
P	kg ha^{-1}	47	34	6	22	44
K	kg ha^{-1}	46	360	93	149	501
Ca	kg ha^{-1}	41	93	17	66	127
Mg	kg ha^{-1}	46	37	6	26	50
S	kg ha^{-1}	41	24	5	16	32
B	g ha^{-1}	40	260	43	188	352
Cu	g ha^{-1}	15	71	22	34	114
Fe	g ha^{-1}	40	1687	395	1075	2346
Mn	g ha^{-1}	38	323	114	177	577
Zn	g ha^{-1}	41	411	99	244	695

n: number of observations; s: standard deviation.

The average EI followed the order: Zn > P > Cu > N > Mg > K > S > B > Ca > Fe > Mn (Table 3). Therefore, special attention should be given to the nutrients P, N and K in replacement fertilization, as they have relatively high EI and are required in larger quantities (Table 2). Consequently, soil may be impoverished by successive harvests if the fertilizations are lower than the quantities exported (CUNHA et al., 2015). Impoverishment can be even greater in areas of high-yield production, given the linear increase in HI as a function of yield (Figure 1). In some markets, beet is commercialized in bunches of roots with leaves (TIVELLI et al., 2011). In this case, nutrients with low EI stand out, such as S, B, Ca, Fe and Mn, as more than 60% of their accumulations are in the leaves.

The models fitted to the relationship between yield and nutrient accumulation did not have high coefficients of determination (R^2) (values between 0.11 and 0.84). However, all models and their respective parameters were significant ($p \leq 0.001$), except for Cu and Mn (Figures 2 and 3).

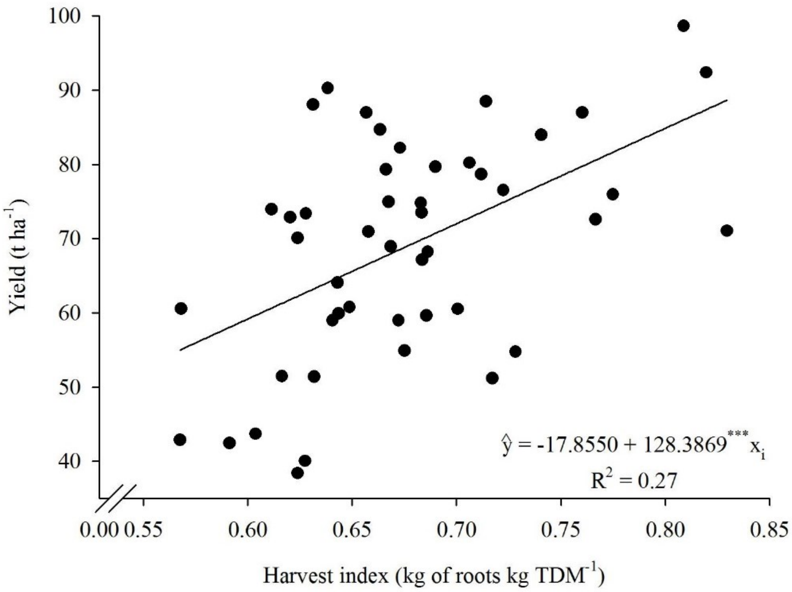

Figure 1. Relationship between yield and harvest index of beet crop. *** significant at 0.001 level. TDM = Total dry matter.

Table 3. Average export index of N, P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn in beet crop.

Nutrient	n	Average	s	Minimum	Maximum
		%			
N	41	59.9	4.9	51.2	69.2
P	40	62.5	6.5	48.6	72.0
K	42	47.3	7.8	34.0	62.8
Ca	45	32.1	5.9	21.4	41.9
Mg	43	49.5	5.0	42.0	60.0
S	40	35.9	5.6	28.1	49.8
B	40	34.7	4.9	26.4	47.6
Cu	15	60.8	9.8	42.4	74.1
Fe	39	31.5	5.2	22.6	42.0
Mn	43	22.8	4.1	14.9	28.9
Zn	40	64.4	8.4	51.4	80.0

n: number of observations; s: standard deviation.

The increasing linear model was the one that best expressed the relationship between crop yield and nutrient accumulation in the roots and roots + shoots (total), except for Ca accumulation in the roots (Figure 2). This result can be attributed to the low mobility of Ca in the plant (PRADO, 2008), which caused low accumulation of this nutrient in the root, a reserve organ. For the other nutrients, the increasing linear trend, for not having reached maximum accumulation, suggests that the plant, and consequently root yield, still responds to the nutrient supply.

Within the range of each function, the fitted models suggested that to increase crop yield by 1 Mg ha^{-1}, the beet crop will accumulate 4.41 kg ha^{-1} of N, 0.45 kg ha^{-1} of P, 8.67 kg ha^{-1} of K, 2.19 kg ha^{-1} of Ca, 0.66 kg ha^{-1} of Mg and 0.48 kg ha^{-1} of S. For roots, the models indicated average increments of 3.00 kg ha^{-1} of N, 0.39 kg ha^{-1} of P, 2.99 kg ha^{-1} of K, 0.37 kg ha^{-1} of Mg and 0.24 kg ha^{-1} of S. Still according to the models, the accumulation required to achieve the average yield of the study (68.9 Mg ha^{-1}) is 306 kg ha^{-1} of N, 34 kg ha^{-1} of P, 354 kg ha^{-1} of K, 97 kg ha^{-1} of Ca, 37 kg ha^{-1} of Mg and 25 kg ha^{-1} of S.

For micronutrients, there was an increasing linear trend between beet crop yield and nutrient accumulation in the roots (Figure 3). Regarding the total accumulation, the means for B, Cu and Fe were better described by the positive linear model, while for Mn and Zn the means were described by the model of decreasing increments. This model is represented by the region of parabolic behavior between the deficiency zone and the appropriate zone of the model that explains the relationship between plant growth (or crop yield) and the content of a nutrient in plant tissue (WITT et al., 1999). Thus, Mn and Zn accumulations may have exceeded the limits of the deficiency zone and small increments in yield are expected with the supply of these nutrients.

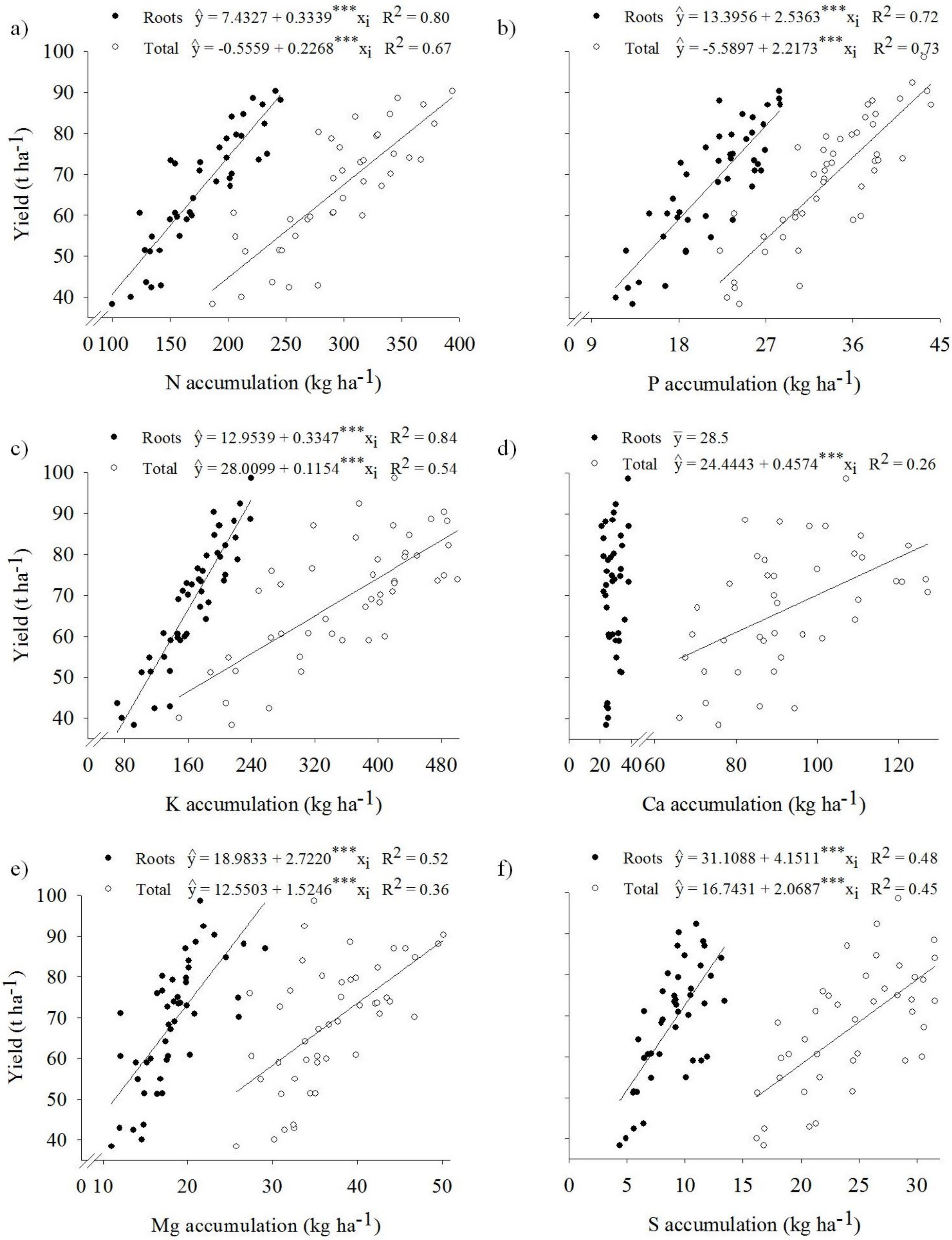

Figure 2. Relationship between yield and accumulation in the roots and roots + shoots (total) of N (a), P (b), K (c), Ca (d), Mg (e) and S (f). *** significant at 0.001 level.

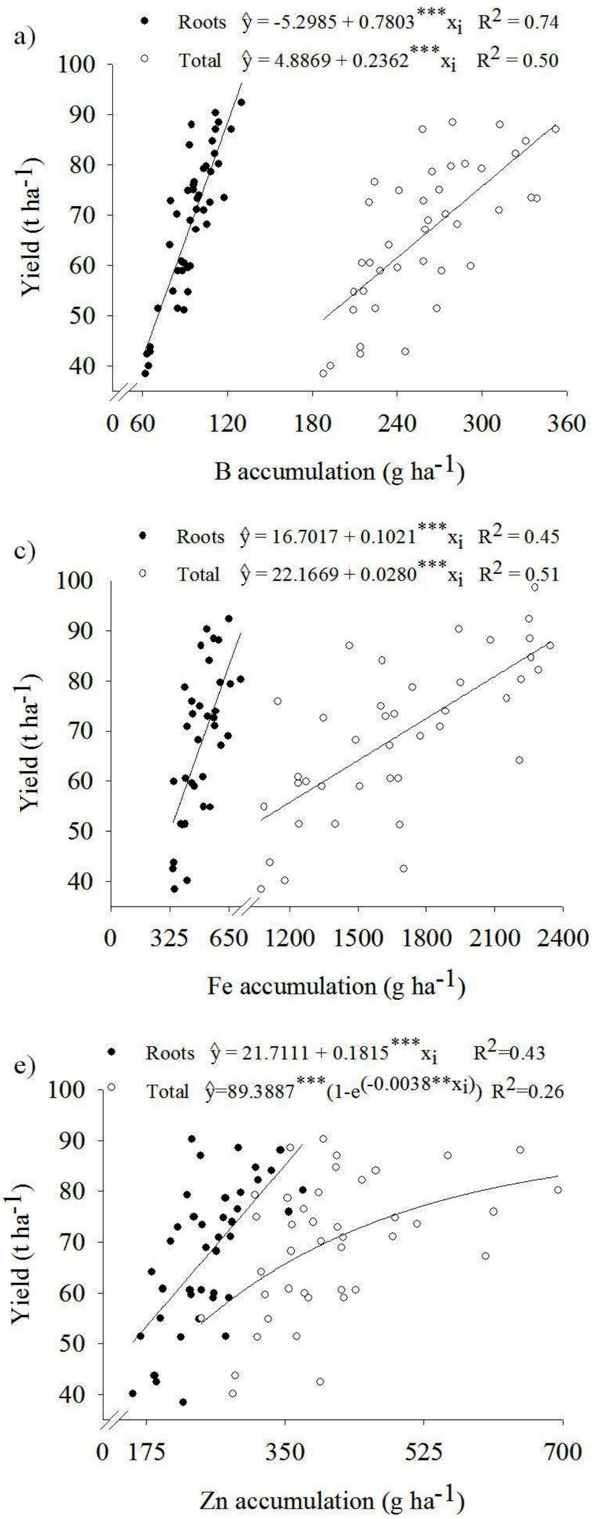

Figure 3. Relationship between yield and accumulation in the roots and roots + shoots (total) of B (a), Cu (b), Fe (c), Mn (d) and Zn (e). ** and *** significant at 0.01 and 0.001 level, respectively.

The models indicated that in order to increase yield by 1 Mg ha^{-1}, within the function range, the beet crop will accumulate in the roots 1.28 g ha^{-1} of B, 1.34 g ha^{-1} of Cu, 9.79 g ha^{-1} of Fe, 3.41 g ha^{-1} of Mn and 5.51 g ha^{-1} of Zn. For the average yield of the study (68.9 Mg ha^{-1}), the total accumulation required is 271 g ha^{-1} of B, 65 g ha^{-1} of Cu, 1,669 g ha^{-1} of Fe, 263 g ha^{-1} of Mn and 388 g ha^{-1} of Zn.

CONCLUSION

The linear model allows better estimating the accumulation of nutrients by beet crop from root yield, except for manganese and zinc.

The order of total accumulation of nutrients in beet crop is: K > N > Ca > Mg > P > S > Fe > Zn > Mn > B > Cu.

Beet export index follows the order: Zn > P > Cu > N > Mg > K > S > B > Ca > Fe > Mn.

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