Australian Journal of Crop Science
AJCS

AJCS 9(12):1205-1213 (2015) ISSN:1835-2707

Modeling of nutrients demands in garlic crop

Mário Lúcio Pereira Cunha, Thaísa Fernanda Oliveira, Junia Maria Clemente, Talita Gabriela Gentil, Leonardo Angelo de Aquino

Departamento de Produção Vegetal, Universidade Federal de Viçosa, Campus Rio Paranaíba, MG, Brasil

Corresponding author: junia.clemente@gmail.com

Abstract

There is lack of information on calculation of nutrient and fertilizers supply in crop plants, especially regarding to the nutrient demands of most crops. The aim of this study was to find out models on nutrient demands of the garlic crop to produce the bulb yield. Garlic samples were taken from 142 commercial garlic fields in the Alto Paranaíba region, Brazil. The yields of the crop samples ranged from 9.1 to 24.2 t ha^{-1}, with an average of 17.3 t ha^{-1}. The harvest index and the mean moisture content were 72.1% and 38.2%, respectively. Only linear models or models of diminishing returns were fitted for all the correlations between the bulb yield and total nutrient accumulation or accumulation of nutrients in the bulbs. The linear models explained the behavior of nutrients in the deficiency range, whereas the second type explained the behavior of those found in the transition between the deficiency range and the sufficiency range. The mean accumulation of nutrients by the crop was 206.5 kg ha^{-1} of N, 29.4 of P, 123.0 of K, 59.8 of Ca, 10.4 of Mg, and 45.4 of S, as well as 179.4 g ha^{-1} of B, 134.7 of Cu, 1442.1 of Fe, 118.7 of Mn, and 308.5 of Zn. The mean harvest indices for the accumulated nutrients followed the order P (75.9%) > S (72.0%) > N (71.4%) > Zn (69.0%) > K (56.0%) > B (47.5%) > Ca (44.4%) > Fe (43.1%) > Mn (41.9%) > Mg (41.4%) > Cu (26.1%).

Keywords: bulb yield; fertilizer recommendation; nutrients uptake.

Abbreviations: R^2_coefficient of determination, QUEFTS_Quantitative Evaluation of the Fertility of Tropical Soils

Introduction

Currently, the main instruments being used in fertilizer management and farming systems are the recommendation tables. These tools may be highly inaccurate because they are developed based on political borders and not on regional edaphic and climatic conditions. In addition, information from recommendation tables does not allow professionals to incorporate new knowledge and adaptations arising from research or field experiments (Tomé Júnior, 2004).

The official tables used for the garlic crop in the Cerrado (Brazilian tropical savanna) region are those published by Souza et al. (1999) in recommendations for the use of soil amendments and fertilizers in Minas Gerais – 5th Estimate and by Trani et al. (1997) in Technical bulletin 100 – recommendations for fertilization and liming for the state of São Paulo). It may be seen that, in addition to the problems inherent to the use of tables, these publications are quite old, and may not be in line with current cropping conditions.

Studies that used increasing application rates of N (Resende et al., 2000; Backes et al., 2008; Macedo et al., 2009; Fernandes et al., 2010; Fernandes et al., 2011), P (Büll et al., 2004; Büll et al., 2008), and K (Büll et al., 2001; Trani et al., 2008) showed significant increases in garlic yield. In these studies, the rates found for maximum yield response are greater than those recommended by the official tables. Thus, the official recommendations of the fertilization tables might be out of date. Therefore, new instruments for fertilizer recommendation for the garlic crop are necessary to increase yields and incorporate new knowledge generated from research and from farmers.

Santos et al. (2008) suggested substitution of recommendation tables by systems of calculation with a greater scientific foundation. In this regard, the nutritional balance systems stand out, in which modeling of fertilizer recommendation is made in accordance with nutrient demand by the plants and the supply of nutrients by the soil. These systems go beyond the recommendation tables by considering variations in yield estimates and in soil properties in a continuous manner and not as classes. One of the main obstacles in creating these models is the lack of information on nutrient demands by plants. For the garlic crop, some studies, like those developed by Resende et al. (1999), Andrioli et al. (2008), and Souza et al. (2011) determined the amount of nutrients uptaken from soil by the crop species. Nevertheless, as emphasized by Setiyono et al. (2010), studies of this kind are fitted to specific experimental conditions, greatly limiting their applicability to broader environmental and management conditions. In addition, these studies consider yields much lower than those obtained by most producers, leading to questions in regard to their suitability for current conditions.

In this respect, researchers have chosen to undertake this type of study in areas with a commercial growing standard, seeking to obtain samples with yield levels equal to those achieved by producers and with a view toward considering maximum possible variability. Based on these principles, Witt et al. (1999) for rice, Liu et al. (2006) for wheat and maize, and Setiyono et al. (2010) for maize, successfully created more robust and comprehensive models that explain the nutrient demand by these crops for different yield levels.

Therefore, we aimed to create models that correlate the nutrient demand by the garlic crop with bulb yield, with a view toward promoting the creation of systems for calculation of fertilizer and soil amendment recommendations using a greater scientific foundation.

Results and Discussion

Productivity and nutritional status

The garlic bulb yield ranged from 9.1 to 24.2 t ha^{-1}, with a mean of 17.3 t ha^{-1} (Table 1). Mean yield of garlic in Brazil was 10.6 t ha^{-1} in 2012 (FAO, 2014), though the Alto Paranaíba region of Minas Gerais has shown an average yield above the other producer regions in Brazil. In this region, garlic growing is carried out by large and medium-sized producers with broad access to technology, which explains the greater mean yield (ANAPA, 2014). No correlation was observed between the harvest index and bulb yield (Fig. 1). Analyzing each of the variables separately, it was observed that there is a strong tendency toward normal distribution of the data. Thus, based on the principle that the first moment of a normal distribution is the arithmetic mean (Montgomery and Runger, 2012), it was assumed that for the mean yield of the study (17.3 t ha^{-1}), the harvest index was 72.1%. The harvest index allows estimation of the shoot dry matter from bulb yield. This estimate is important for calculation of the amount of nutrients allocated to the shoots.

The mean moisture content in the bulbs was 38.2%, with a coefficient of variation of 3.9% (Table 1). Knowledge of this variable is highly relevant in nutritional management because it allows estimation of bulb dry matter based on estimated yield. In contrast, with most grain crops, sale of garlic is not carried out based on a standard moisture value of the product. Nevertheless, the low variability obtained in moisture content of the field samples confers high reliability in the use of this variable for the garlic crop.

The order of mean accumulation of nutrients, both total accumulation and accumulation only in the bulbs, was N > K > Ca > S > P > Mg > Fe > Zn > B > Cu > Mn (Table 1). Resende et al. (1999) and Andrioli et al. (2008) obtained quite similar sequences, except for nutrients with lower accumulations. The former found that Cu, and not Mn, is the nutrient least uptaken by garlic crop. The sequence of Andrioli et al. (2008) differed in regard to the three least accumulated nutrients, with the order of Mn > B > Cu. The uptake of these three micronutrients is strongly influenced by edaphic and climatic characteristics, for example, moisture content for B (Mattiello et al., 2009), organic matter for Cu (Abreu et al., 2007), and the redox reaction conditions for Mn (Souza, 2001). Thus, it is suggested that the variations observed among the three studies are mainly due to the differences in the growing environments.

The mean harvest index of the nutrients in decreasing order was P > S > N > Zn > K > B > Ca > Fe > Mn > Mg > Cu (Table 2). This is relevant for the management practices to restore nutrients exported by the crop. When the leaves are also removed from the crop area during garlic harvest, attention must be paid to restoring the elements with a low harvest index. In this regard, the elements B, Ca, Fe, Mn, Mg, and Cu stand out with more than 50% of their accumulation in the leaves.

Modeling for correlation between productivity and nutrient accumulation

The models fitted for the correlation between yield and the accumulation of nutrients did not exhibit high coefficients of determination (values from 0.22 to 0.60). Nevertheless, all of them, as well as their parameters, showed high significance ($p \leq 0.001$) (Fig. 3, 4, 5).

Only linear models or models of diminishing returns were fitted for all the correlations of the study (Fig. 3, 4, 5). The choice of these models, in addition to obtaining a suitable statistical fit, allowed a biological explanation of the data to be made. Crop yield (or plant growth) as a function of nutrient accumulation, initially showed a linear stage, followed by a hyperbolic stage that culminates in a plateau (Witt et al., 1999; Taiz and Zeiger, 2013). Thus, the use of the two types of models allows explanation of the correlations that fit within one of the two stages.

In the model presented by Taiz and Zeiger (2013), which explains the correlation between plant growth and the concentration of nutrients in the plant tissue, it is possible to distinguish three ranges. The first, known as the deficiency range, is characterized by a function, in which the increase of availability of nutrients is positively and linearly associated with the increase in yield. The second, which is the sufficiency range, the accumulation of nutrients in the tissues no longer increases the yield. There are only increases in the concentration of the elements. Finally, the toxic level consists of a stage, in which the accumulation of the nutrient is so high that reductions in plant growth are observed, due to phytotoxicity.

In the recent years, various studies have aimed at obtaining the functions that explain these correlations for various crops, such as Dezordi (2014) for carrot, Witt et al. (1999) for rice, Liu et al. (2006) for wheat and maize, and Setiyono et al. (2010) for maize. For that purpose, these researchers used the tool QUEFTS, initially developed by Janssen et al. (1990) and modified by Witt et al. (1999). It is important to emphasize that, in contrast with results presented by Taiz and Zeiger (2013), we found greater importance to the transitional region between the first and the second range of nutrient accumulation, which was not treated as just a short and quick zone of transition. It was thus established that, disregarding the zone of toxicity that occurs under very high nutrient contents, the plant growth model, as a function of nutrient accumulation, follows a linear-parabolic-plateau model (Witt et al., 1999). Thus, between the first and the second region, there is one element that behaves parabolically, i.e., diminishing returns are observed in plant growth with the increase in nutrient concentration.

Modeling for correlation between productivity and accumulation of N, P, K, Ca, Mg and S

For the N, P, and K nutrients, positive linear behavior was observed between crop yield and nutrient accumulation, both in total accumulation (bulbs+leaves) and accumulation in the bulbs (Fig. 2). This behavior indicates that the concentrations of these nutrients in the plant tissue are still within the deficiency range, i.e., the increase in the accumulation of these elements will directly increase bulb yield.

Table 1. Yield, total dry matter (TDM), harvest index, moisture content in the bulb, total accumulation and accumulation in the bulbs of N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn of the garlic crop.

Parameter	Unit	n	Mean	SD	Minimum	Maximum
Yield	t ha^{-1}	142	17.3	2.7	9.1	24.2
TDM	kg ha^{-1}	140	9125.5	1360.7	4524.3	11998.2
Harvest index	kg kg^{-1}	140	72.1	4.9	57.6	84.4
Moisture content in the bulb	%	125	38.2	1.5	35.1	41.8
N accumulation in the bulbs	kg ha^{-1}	136	148.4	32.3	76.8	239.7
P accumulation in the bulbs	kg ha^{-1}	137	22.4	3.6	11.3	30.7
K accumulation in the bulbs	kg ha^{-1}	136	66.7	14.4	37.3	113.1
Ca accumulation in the bulbs	kg ha^{-1}	137	26.2	6.8	14.5	46.2
Mg accumulation in the bulbs	kg ha^{-1}	131	4.2	0.8	2.2	6.8
S accumulation in the bulbs	kg ha^{-1}	134	32.9	7.2	13.5	57.9
B accumulation in the bulbs	g ha^{-1}	141	85.0	21.2	32.2	145.1
Cu accumulation in the bulbs	g ha^{-1}	129	32.4	13.0	3.3	65.2
Fe accumulation in the bulbs	g ha^{-1}	78	534.2	165.1	14.3	786.1
Mn accumulation in the bulbs	g ha^{-1}	118	46.9	13.9	16.0	86.2
Zn accumulation in the bulbs	g ha^{-1}	111	204.2	40.3	105.3	296.6
Total N accumulation	kg ha^{-1}	134	206.5	34.9	107.7	291.9
Total P accumulation	kg ha^{-1}	137	29.4	3.8	17.1	37.4
Total K accumulation	kg ha^{-1}	128	123.0	21.0	67.4	167.0
Total Ca accumulation	kg ha^{-1}	131	59.8	12.6	32.1	92.3
Total Mg accumulation	kg ha^{-1}	125	10.4	1.9	6.3	14.4
Total S accumulation	kg ha^{-1}	139	45.4	8.0	21.8	68.3
Total B accumulation	g ha^{-1}	138	179.4	34.0	103.9	254.6
Total Cu accumulation	g ha^{-1}	68	134.7	62.2	49.1	306.4
Total Fe accumulation	g ha^{-1}	83	1442.1	309.0	794.4	1995.9
Total Mn accumulation	g ha^{-1}	84	118.7	35.4	57.0	187.3
Total Zn accumulation	g ha^{-1}	111	308.5	79.5	137.8	534.4

n = number of observations; SD = standard deviation.

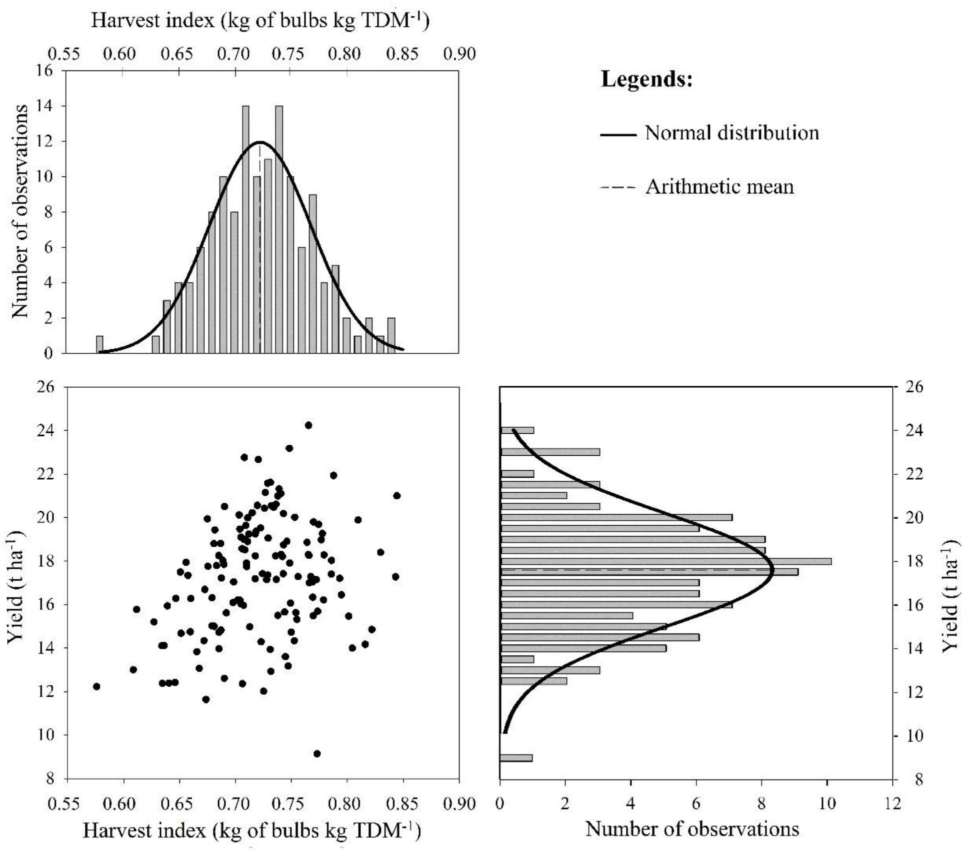


Fig 1. Correlation between yield and the harvest index of the garlic crop.

Table 2. Harvest index of N, P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn of the garlic crop.

Nutrient	n	Mean	S	Minimum	Maximum
		--------------------------------%--------------------------------			
N	132	71.4	8.3	54.0	94.1
P	133	75.9	6.8	58.8	92.1
K	123	56.0	8.3	38.3	85.5
Ca	131	44.4	8.3	26.4	66.5
Mg	117	41.4	6.5	26.9	54.5
S	133	72.0	9.6	45.8	94.2
B	138	47.5	8.7	24.4	67.9
Cu	58	26.1	10.7	11.6	56.1
Fe	57	43.1	11.3	21.8	73.6
Mn	83	41.9	14.7	14.8	74.2
Zn	111	69.0	14.8	22.5	93.8

n = number of observations

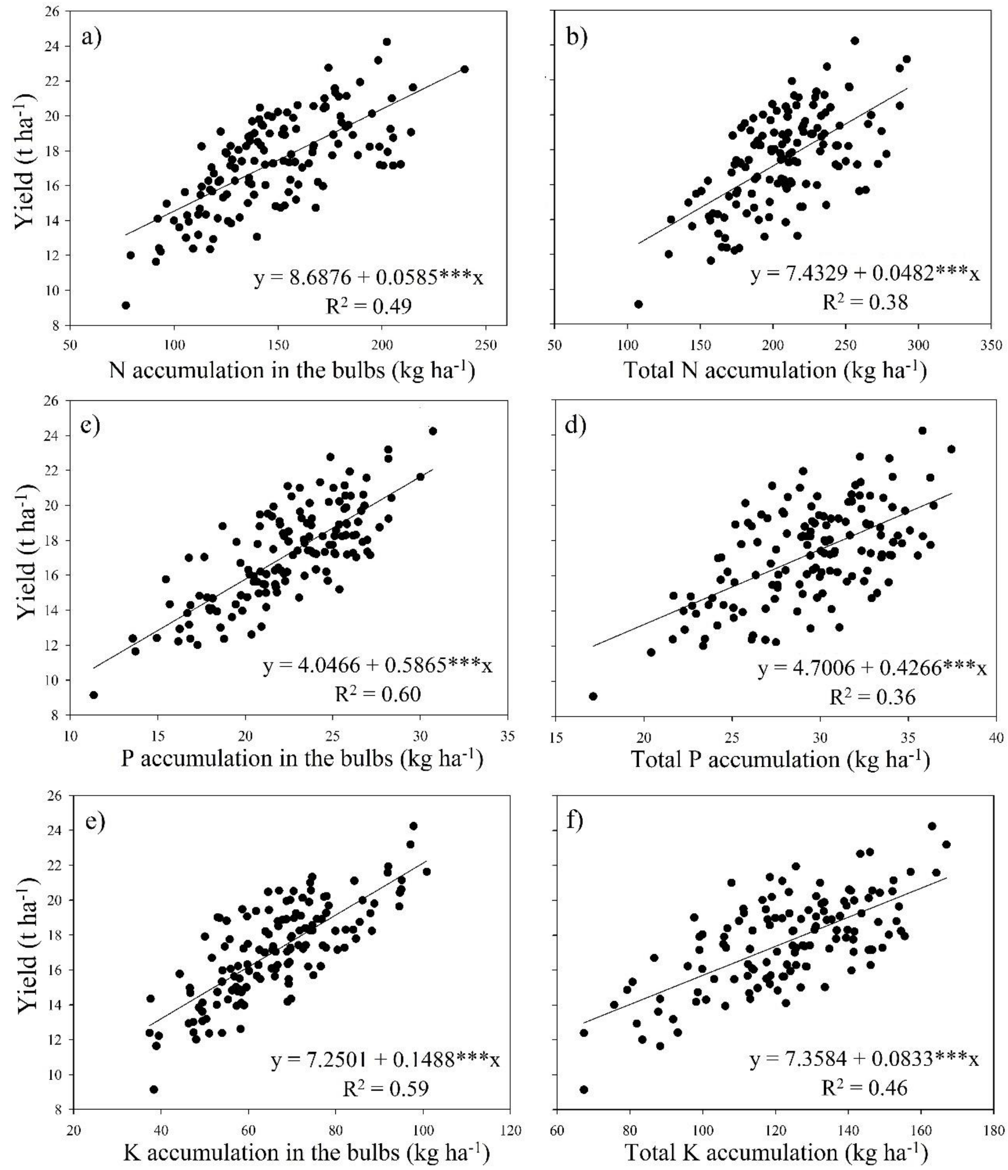
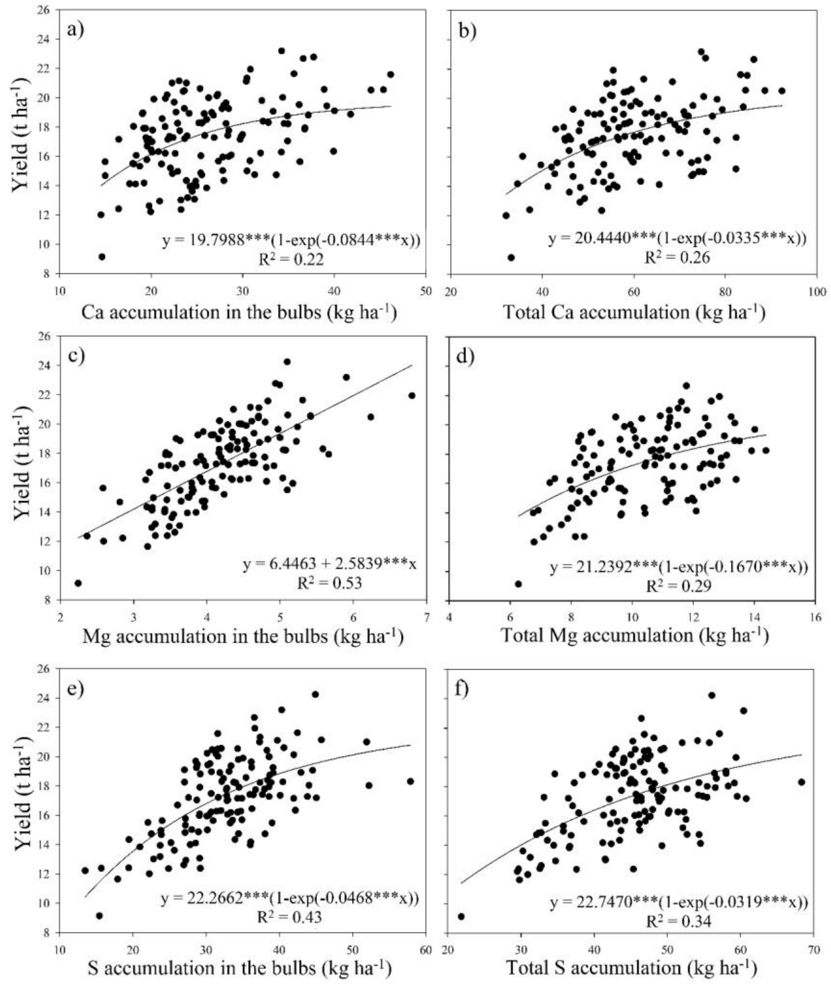


Fig 2. Correlation between yield and total accumulation and accumulation in the bulbs of N (a, b), P (c, d), and K (e, f). *** significant at the level of 0.001.



*** significant at the level of 0.001

Fig 3. Correlation between yield and total accumulation and accumulation in the bulbs of Ca (a, b), Mg (c, d), and S (e, f).

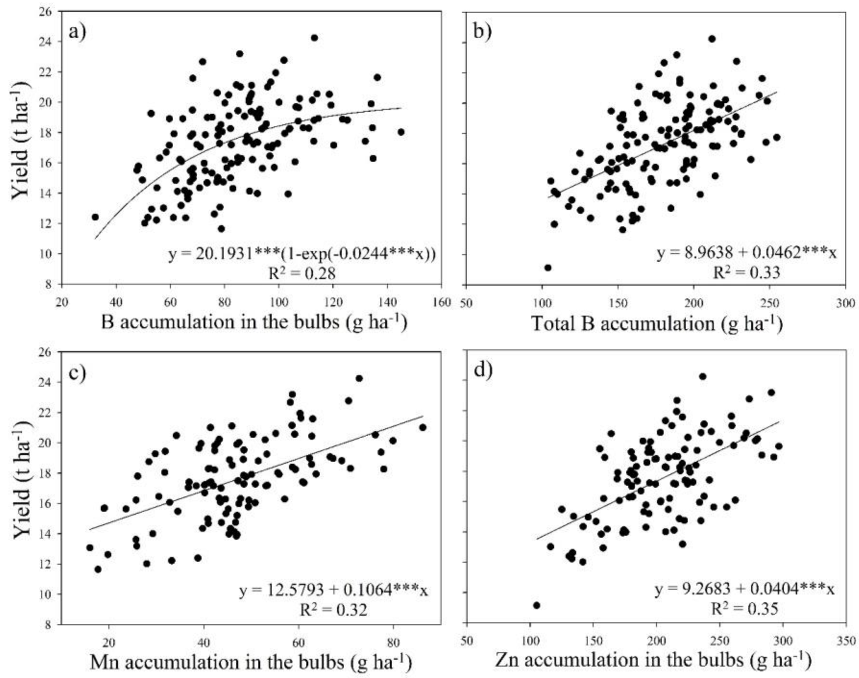


Fig 4. Correlation between yield and total B accumulation (a) and accumulation in the bulbs of B (b), Mn (c), and Zn (d). *** significant at the level of 0.001.

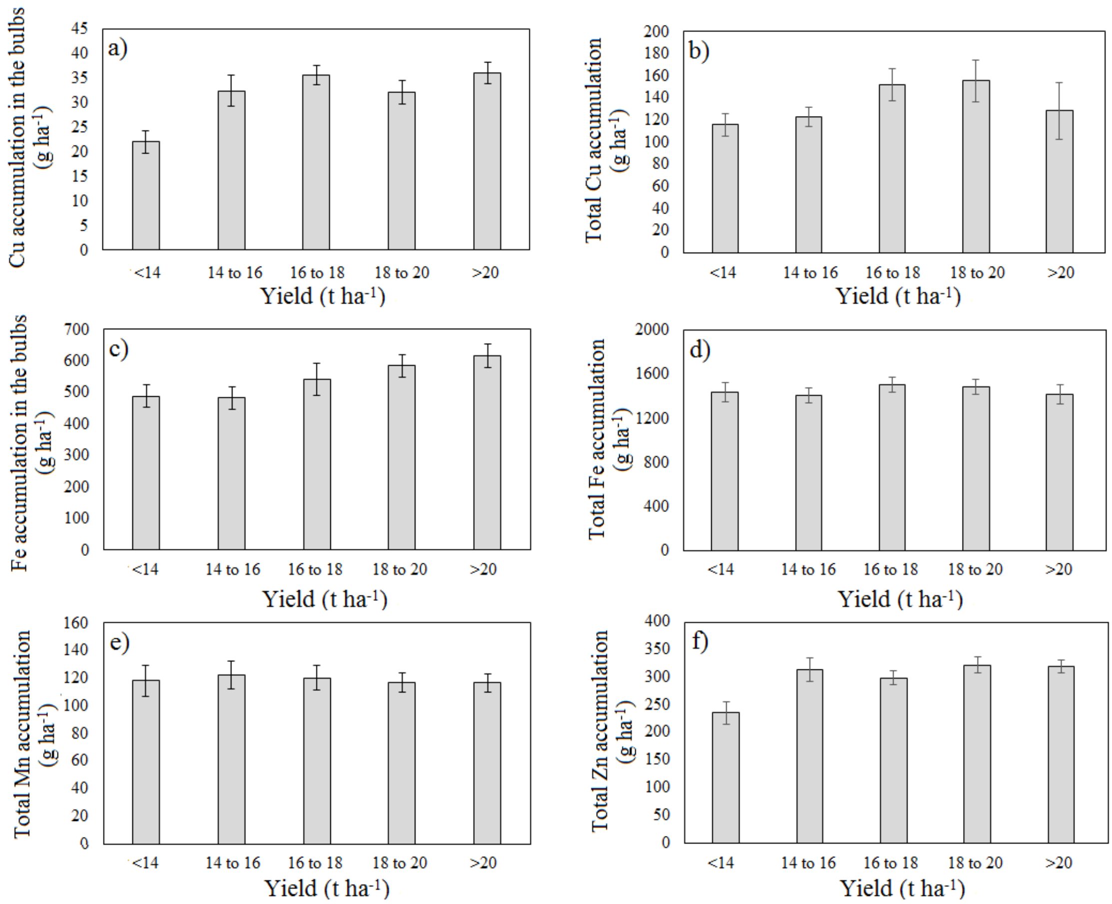


Fig 5. Mean and standard error of the mean of Cu (a) and Fe (c) accumulation in the bulbs, and total Cu (b), Fe (d), Mn (e), and Zn (f) accumulation as a function of five yield classes of garlic.

The fitted models indicated that to increase crop yield by 1 t ha^{-1}, within the interval of each function, the garlic will accumulate an additional 20.7 kg ha^{-1} of N, 2.3 kg ha^{-1} of P, and 12.0 kg ha^{-1} of K. For the bulbs, there will be mean increases of 17.1 kg ha^{-1} of N, 1.7 kg ha^{-1} of P , and 6.7 kg ha^{-1} of K. From the models fitted, it is calculated that 205 kg ha^{-1} of N, 30 of P, and 120 of K are the amounts of these elements necessary to achieve the mean yield obtained in the study (17.3 t ha^{-1}).

The behavior observed for Ca, Mg, and S differed with those recorded for N, P, and K. Except for the accumulation of Mg in the bulbs, it was noted that the parabolic behavior was assumed by the models for the best fit (Fig. 3). These results indicate that the total concentrations of Ca, Mg, and S and the concentrations of Ca and S in the bulbs exceeded the limit contents of the deficiency range. Thus, diminishing returns are expected in yield for the increase in the supply of these elements. The total accumulation of Ca and of Mg above the deficiency range is probably due to the high application rates of limestone used in the region. Most of the planting fields had their base saturation raised to 80% or 85% (data not shown). It is believed that the amount of these elements in the soils were more than sufficient for the needs of the garlic. Therefore, it is expected that, in fact, the models for Ca and Mg draw nearer the sufficient range than the deficient range. The supply of S to the planting fields was through application of simple superphosphate (12% S). The mean application rate of simple superphosphate used in the planting fields was 1250 kg ha^{-1}, with a mean content of 150 kg ha^{-1} of S (data not presented). According to the model fitted to total accumulation of the nutrient (Fig. 3e), the garlic can extract 44.8 kg ha^{-1} of S for the mean yield of the study (17.3 t ha^{-1}). Thus, the mean supply of S through fertilizer was more than three times the mean needs of the crop.

In studies on fertilization with S, values obtained for the recovery rates of the nutrient supplied through fertilization were 0.40 for sugarcane (Freire, 2001), 0.45 for banana (Oliveira et al., 2005), 0.50 for cotton (Possamai, 2003), 0.50 for soybean (Santos et al., 2008), and 0.59 for pineapple (Silva et al., 2009). Based on these values, it may be calculated that for the mean quantity of S applied, at least 60 kg ha^{-1} would be taken up by the garlic plants. Thus, the availability of S for garlic exceeded the mean needs of the crop (44.8 kg ha^{-1}).

Modeling for correlation between productivity and accumulation of B, Cu, Zn, Fe and Mn

It was not possible to fit significant models to the correlation between yield and the accumulation of most of the micronutrients. Success in fitting these models was only obtained for total accumulation of B, Mn, and Zn, and for the accumulation of B in the bulbs (Fig. 4). The ratio between the accumulation of B in the bulbs and the crop yield assumed a parabolic tendency. In contrast, the total accumulation of the nutrient was related in a positive linear manner to crop yield, with increases of 21.6 g ha^{-1} per ton produced (within the interval of the model). These results indicate that for high yields, the B needs of garlic are greater for bulb formation than for leaf formation. For the micronutrients Mn and Zn, an the bulb accumulation of 9.4 g ha^{-1} and 24.8 g ha^{-}1, respectively, were obtained for the increase of 1 t ha^{-1} in yield within the interval of the function. Thus, for the mean yield of the study (17.3 t ha^{-1}), the accumulation in the bulbs of 44 g ha^{-1} of Mn and 199 g ha^{-1} of Zn are necessary.

For the micronutrients, in which it was not possible to fit models, the mean accumulation and the standard error of the mean were analyzed in five yield classes (<14, 14 to 16, 16 to 18, 18 to 20, and >20 t ha^{-1}). The classes were compared through overlapping of the error bars, and those in which the intervals of accumulation of nutrients delimited by the standard error of the mean did not overlap were considered distinct (Fig. 5).

Analysis of Cu accumulation in the bulbs allowed determination of two distinct groups. All the classes with a yield greater than 14 t ha^{-1} were considered similar according to the criteria of overlapping of the error bars. Thus, for the yields less than 14 t ha^{-1}, the mean value of Cu accumulation in the bulbs was 22 g ha^{-1}, whereas for yields greater than 14 t ha^{-1}, the accumulation was 34 g ha^{-1}.

For the total accumulated Cu, it was observed that the first two yield classes were distinct from the third and fourth classes, which were very similar. The last class (> 20 t ha^{-1}) did not differ from any other classes. Thus, we chose to separate the five classes in three distinct groups. In the first class, with the yields less than 16 t ha^{-1}, the mean accumulation was 119 g ha^{-1}; for the second, with yield from 16 to 20 t ha^{-1}, the mean accumulation was 153 g ha^{-1}; and for the last group, with yields greater than 20 t ha^{-1}, the mean accumulation was 128 g ha^{-1}.

The Fe accumulation in the bulbs exhibited distinction among the yield classes less than 16 t ha^{-1}, and the classes with yield greater than 18 t ha^{-1}, observing a transition (without differences for the other classes) in the class from 16 to 18 t ha^{-1}. Thus, these three groups were used as criteria of separation for Fe accumulation in the bulbs. The first group (yield less than 16 t ha^{-1}) accumulated an average of 485 g ha^{-1}; the second (yield from 16 to 18 t ha^{-1}), 542 g ha^{-1}; and the last (yield greater than 18 t ha^{-1}), 600 g ha^{-1}.

Both for total Fe accumulation and for total Mn accumulation, distinctions were not observed among the yield classes. Thus, it was assumed that the mean total extractions, regardless of yield, were 1452 g ha^{-1} of Fe and 119 g ha^{-1} of Mn. Analysis of classes for total Zn accumulation allowed two distinct groups to be distinguished. In the first group, with yield less than 14 t ha^{-1}, mean Zn accumulation was 237 g ha^{-1}. In the second, with yield greater than 14 t ha^{-1}, the mean accumulation was 315 g ha^{-1} of Zn.

Materials and Methods

Location, climate and soil classification

This study was carried out in the Alto Paranaíba region of Minas Gerais, Brazil in the 2012 and 2013 crops seasons. The regional climate was classified as Cwa, following the Köppen-Geiger system. The altitude of the areas ranged from 900 to 1200 m. The vast majority of the garlic fields under study have soils classified as Latossolo Vermelho-Amarelo (Oxisol), and a smaller number as Latossolo Vermelho and Latossolo Amarelo (Embrapa, 2013).

Fields characterization and measurements

The database of this study was made up of 142 commercial planting fields, where samples were taken at the end of the garlic crop cycle. Fifteen sequential plants from four distinct points were taken in each planting field, resulting in a compound sample made up of 60 plants. In each one of these samples, yield, bulb and leaf dry matter, and nutrient content in bulbs and leaves were evaluated. In addition, the harvest index, the moisture content in the bulbs, and the accumulation of nutrients in the bulbs and leaves were calculated. The garlic variety “Ito” belonging to the noble group with a late cycle and purple coloring was planted in all planting fields. The cloves went through the process of vernalization before planting, with temperatures from 2°C to 5ºC for a period of 45 to 60 days. All the areas were under center pivot irrigation, except for two planting fields that were irrigated by conventional sprinkling. The mean values and the standard deviations of the fertilizations were 222 ± 30 kg ha^{-1} of N; 371 ± 39 of P, and 417 ± 62 of K. For liming recommendation, the base saturation method predominated, using 80% or 85% for the expected saturation values.

Chemical analysis

To determine the yield of each planting field, 60 collected bulbs were weighed, after natural drying for 30 days, extrapolating the value obtained to one hectare. The bulb and leaf dry matter was evaluated by drying the collected material in an air circulation laboratory oven at 70°C for 72 h, followed by weighing. The dry samples were ground in a Wiley type mill and sent for chemical analysis for determination of the nutritional contents of the bulbs and leaves in the Mineral Nutrition lab from the Federal University of Viçosa - Campus Rio Paranaíba.

The harvest index was calculated by the ratio between the dry matter of the bulbs and the total dry matter (bulbs + leaves). Moisture content in the bulbs was calculated by the quotient between the bulb weight after air drying and after drying in the laboratory oven. The accumulation of nutrients in the bulbs and leaves was obtained by the product between the nutrient content and the accumulation of dry matter in the respective organs.

Chemical analyses of the plant tissues were carried out according to the methods described by Silva (2009). For determination of N, sulfuric digestion was carried out, followed by Kjeldahl distillation. The other nutrients were subjected to nitro-perchloric digestion and analyzed by spectrophotometry (P and B), flame photometry (K), turbidimetry (S), and atomic absorption spectrophotometry (Ca, Mg, Cu, Fe, Mn, and Zn).

Statistical analysis

All the data were subjected to analysis of outliers, directed by the standardized residual method. The results with discrepant values associated with unexplainable factors were eliminated. After elimination, descriptive analysis of the variables was carried out through the mean, standard deviation, maximum value, and minimum value. In addition, based on correlation with yield, mathematical models were constructed of the accumulation of nutrients in the leaves and bulbs and harvest index variables. It was not possible to fit a significant model for the correlation between yield and the harvest index.

Thus, we chose to analyze the data distribution of each one of the variables in a separate manner so as to obtain the value expected from each one, thus estimating the harvest index for the mean yield of the region.

The criteria for fitting the models to correlations between yield and nutrient accumulation in the leaves or bulbs followed the criteria with decreasing order of priority as: the biological explanation of the data, the significance of the models, the significance of the parameters of the model, and the coefficient of determination. Through these criteria, only two distinct types of models were fitted to the data: linear model (1) and model of diminishing returns (2).

$$y = a + bx \quad (1)$$

$$y = 1 + e^{-bx} \quad (2)$$

For the elements that were not possible to fit with the significant models of correlation between accumulation and yield, the mean value and the standard error of the mean value were analyzed in five yield classes (<14, 14 to 16, 16 to 18, 18 to 20, and >20 t ha^{-1}). The classes were compared through overlapping of the error bars. Those in which the intervals of nutrient accumulation, delimited by the standard error of the mean, did not overlap were considered distinct.

Conclusions

The models allow estimation of nutrient uptake by the garlic crop according to bulb yield and this is an important way for recommending fertilizers. The most extracted nutrients by garlic crop follow the order N (206.5 kg ha^{-1}) > K (123 kg ha^{-1}) > Ca (59.8 kg ha^{-1}) > S (45.4 kg ha^{-1}) > P (29.4 kg ha^{-1}) > Mg (10.4 kg ha^{-1}) > Fe (1442.1 g ha^{-1}) > Zn (308.5 g ha^{-1}) > B (179.4 g ha^{-1}) > Cu (134.7 g ha^{-1}) > Mn (118.7 g ha^{-1}). The harvest index of nutrients of the garlic crop follows the order of: P > S > N > Zn > K > B > Ca > Fe > Mn > Mg > Cu.

Acknowledgements

The authors are grateful to Coordination for the Improvement of Higher Education Personnel - (CAPES), Arthur Bernardes Foundation - (Funarbe), National Counsel of Technological and Scientific Development - (CNPq) and Foundation for Supporting Research in the states of Minas Gerais - (FAPEMIG).The authors thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - (CAPES) by granting the Master's scholarship to the first author, the Fundação de Amparo à Pesquisa do Estado de Minas Gerais - (FAPEMIG) by granting the scholarship to the second author. The authors also thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico - (CNPq) and Fundação Arthur Bernardes - (Funarbe).

References

Abreu CA, Lopes AS, Santos GCG (2007) Micronutrientes. In: Novais RF, Alvarez VVH, Barros NF, Fontes RL, Cantarutti RB, Neves JCL (ed) Fertilidade do solo, 1ed. Sociedade Brasileira de Ciência do Solo, Viçosa.

Anapa (2014) Brazilian garlic. Available at: <http://www.anapa.com.br/simples/?page_id=5 > Access: March 13th, 2014.

Andrioli FF, Prado RM, Andrioli I, Saes LP (2008) Curve of growth and uptake for the garlic crop under field conditions. Sci Agric. 9:385-393.

Backes C, Lima CP, Godoy LJG, Bôas RLV, Imaizumi I (2008) Green hue in vernalized garlic leaves in response to nitrogen fertilization. Bragantia. 67:491-498.

Büll LT, Bôas RLV, Fernandes DM, Bertani RMA (2001) Potassic fertilization for the vernalized garlic crop. Sci Agric. 58:157-163.

Büll LT, Costa MCG, Fernandes, DM, Bôas RLV (2004) Doses and forms of application of phosphorus in vernalized garlic. Sci Agric. 61:516-521.

Büll LT, Novello A, Corrêa JC, Bôas RLV (2008) Doses of phosphorus and zinc on garlic crop in greenhouse. Bragantia. 67:941-949.

Dezordi LR (2014) Modelagem da demanda nutricional e índices diagnósticos foliares para a cultura da cenoura. 72 f. Dissertation (Master in Plant Science), Universidade Federal de Viçosa, Viçosa.

Embrapa - Empresa Brasileira de Pesquisa Agropecuária (2013) Sistema brasileiro de classificação de solos. 3.ed. Brasília, Embrapa. p 353.

FAO (2014) Value of Agricultural Production. Available at: <http://faostat.fao.org/site/567/DesktopDefault.aspx?> Access: March 13th, 2014.

Fernandes LJC, Büll LT, Corrêa JC, Pavan MA, Imaizumi I (2010) Nitrogen fertilization in garlic free of virus cultivated in protected environment. Hortic Bras. 28:97-101.

Fernandes LJC, Bôas RLV, Backes C, Lima CP, Büll LT (2011) Contribution of nitrogen concentrations in garlic cloves treated with doses of N in side dressing. Hortic Bras. 29:26-31.

Freire JF (2001) Sistema para cálculo do balanço nutricional e recomendação de corretivos e fertilizantes para cana-de-açúcar. 156 f. Thesis (Doctorate in Soil Science), Universidade Federal de Viçosa, Viçosa.

Janssen BH, Guiking FCT, Van der Eijk D, Smaling EMA, Wolf J, Van Reuler H (1990) ‘A system for quantitative evaluation of the fertility of tropical soils QUEFTS.’ Geoderma. 46:299-318.

Liu M, Yu Z, Liu Y, Konjin NT (2006) Fertilizer requirements for wheat and maize in China: the QUEFTS approach. Nutr Cycl Agroecosys. 74:245-258.

Macedo FS, Souza RJ, Carvalho JG, Santos BR, Leite LVR (2009) Productivity of vernalized garlic in function of nitrogen and molybdenum doses. Bragantia. 68:657-663.

Mattiello EM, Ruiz HA, Silva IR, Barros NF, Neves JCL, Behling M (2009) Transport of boron in soil and its uptake by eucalypt. R Bras Ci Solo. 33:1281-1290.

Montgomery DC, Runger GC (2012) Estatística aplicada e probabilidade para engenheiros, 5th edn. LTC, Rio de Janeiro.

Oliveira FHT, Novais RF, Alvarez VVH, Cantarutti RB (2005) Development of a fertilization recommendation system for banana plantations. R Bras Ci Solo. 29:131-143.

Possamai JM (2003) Sistema de recomendação de corretivos e fertilizantes para a cultura do algodoeiro. 91 f. Dissertation (Master in Soil and Science), Universidade Federal de Viçosa, Viçosa.

Resende FV, Faquin V, Souza RJ, Silva VS (1999) Dry matter accumulation and nutritional requirements of garlic planted with cloves obtained by tissue culture or produced directly on the field. Hortic Bras. 17:220 - 226.

Resende FV, Oliveira PSR, Souza RJ (2000) Growth, yield and nitrogen uptake in garlic obtained by tissue culture, cultivated under high nitrogen levels. Hortic Bras. 18:31-36.

Santos FC, Neves JCL, Novais RF, Alvarez VVH, Sediyama CS (2008) Modeling lime and fertilizer recommendations for soybean. R Bras Ci Solo. 32:1661-1674.

Setiyono TD, Walters DT, Cassman KG, Witt C, Dobermann A (2010) Estimating maize nutrient uptake requirements. Field Crop Res. 118:158-168.

Silva AP, Alvarez VVH, Souza AP, Neves JCL, Novais RF, Dantas JP (2009) Fertilizer and lime recommendation system for pineapple - fertcalc-abacaxi. R Bras Ci Solo. 33:1269-1280.

Silva FC (2009) Manual de análises químicas de solos, plantas e fertilizantes, 2nd ed. Embrapa, Brasília.

Souza RJ, Paula MB, Filho ABC (1999) Alho. In: Ribeiro AC, Guimarães PTG, Alvares VV H (eds) Recomendações para o uso de corretivos e fertilizantes em Minas Gerais - 5ª aproximação, UFV, Viçosa.

Souza RJ, Macêdo FS, Carvalho JG, Santos BR, Leite LVR (2011) Absorption march of nutrients in vernalized garlic originated from tissue culture cultivated under nitrogen doses. Hortic Bras. 29:498-503.

Souza RO (2001) Oxirredução em solos alagados afetada por resíduos vegetais. 164 f. Thesis (Doctorate in Soil Science), Universidade Federal do Rio Grande do Sul, Porto Alegre.

Taiz L, Zeiger E (2013) Fisiologia Vegetal, 5th ed. Artmed, Porto Alegre.

Tomé Junior JB (2004) Uma nova abordagem nas recomendações de adubação. 141 f. (Doctorate in Soil Science), Universidade Federal de Viçosa, Viçosa.

Trani PE, Tavares PET, Siqueira WJ (1997) Hortaliças - Alho. In: Raij B, Cantarella H, Quaggio JA, Furlani AMC Recomendação de adubação e calagem para o Estado de São Paulo. 2 ed. Campinas: IAC. 279 p. Boletim n. 100.

Trani PE, Camargo MS, Foltran DE, Hiroce R, Arruda FB, Sawazaki HE (2008) Yield and lateral shoot growing of garlic influenced by nitrogen, potassium and mulching. Hortic Bras. 26:330-334.

Witt C, Dobermann A, Abdulrachman S, Gines HC, Guanghuo W, Nagarajan R, Satawatananont S, Son TT, Tan PS, Tiem LV, Simbahan GC, Olk DC (1999) Internal nutrient efficiencies of irrigated lowland rice in tropical and subtropical Asia. Field Crop Res. 63:113-138.