Recovery Efficiencies of Nitrogen, Phosphorus and Potassium of the Garlic Crop

Luiz Paulo Dornelas dos Santos[1], Mário Lúcio Pereira Cunha[1], Junia Maria Clemente[2], Thaísa Fernanda Oliveira[1], Priscila Maria de Aquino[1], Natália Silva Assunção[1], Leonardo Angelo de Aquino[1]

[1] Federal University of Viçosa, Crop Production Department - Campus Rio Paranaíba

[2] Federal University of Viçosa, Crop Production Department - Campus Rio Paranaíba, Rodovia MG-230, Km 07, CEP 38810-000,

Address Correspondence to Junia Maria Clemente: junia.clemente@gmail.com

ABSTRACT

Garlic plants demand high quantities of nutrients, and fertilizers recommendations are necessarily evaluated for the availability of attributes such as recovery efficiency. The objective of this study was to evaluate the recovery efficiencies of nitrogen (N), phosphorus (P) and potassium (K) by micropopagated and conventionally propagated garlic plants. Two experiments were conducted in a greenhouse containing a sample of a Red Yellow Latosol, arranged in randomized blocks with five replications. Treatments consisted of four combinations of nutrients (kg per hectare): complete NPK (240-1200-550), without N (0-1200-550), without P (240-0-550) and without K (240-1200-0). Micropopagated plants maintained adequate contents of N, P, and

K, as well as good growth and development even without nutrients application; however, the depletion of N and K impaired the productivity of these plants. In both cultivations, recovery efficiencies of N, P and K were low and closely related to the garlic propagation.

Keywords: Allium sativum L., fertilization, extraction.

INTRODUCTION

Garlic (Allium sativum L.) is, among the vegetables, one of the most consumed by the Brazilian population. The monthly demand is around 22 million pounds and the production is below those quantities consumed by the domestic market, which supplies only 33% of the total market; the remaining is imported mainly from China and Argentina.

Fertilization has significant importance on productivity and along with good management, optimizes the productive income according to the varieties and techniques employed during the cultivation (Lipinski and Heras, 1997). The nutritional demand is influenced by the desired levels of productivity, cultivars, sources, supplying way and supplying time to the crops, which all simultaneously cause changes on the phenology of the plants (Resende et al., 1999; Fernandes et al., 2011a).

Nitrogen has great influence on raising the productivity and on the quality of garlic (Fernandes et al., 2010). However, imbalances in the levels of nitrogen (N) and inappropriate irrigation management may favor the occurrence of genetic and physiological abnormalities, such as pseudogrowing (Macêdo et al., 2009). Nitrogen and potassium are the nutrients most absorbed by the plants. In general, the decreasing order of the nutrients extraction is nitrogen>potassium>calcium>sulfur>phosphorus>magnesium (N>K>Ca>S>P>Mg) for garlic (Souza et al., 2011). Trani et al. (2008), observed an increasing productivity with N and K application, and the pseudogrowing decreased with the increase in the levels of K.

Phosphorus is the fifth nutrient most extracted by the crop, nevertheless, it is applied in high doses due to its natural deficiency in Brazilian soils and its strong interaction with iron (Fe)

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and aluminum (Al) oxyhydroxides that reduce the availability to plants (Vilar et al., 2010). Positive responses to P application are frequent as verified in several experiments in greenhouse (Lima et al., 2007; Büll et al., 2008; Villas Bôas et al., 2008), and, also, in field conditions (Macêdo et al., 2011).

With the advent of more productive cultivars and techniques such as the multiplication by tissue culture, it is essential to change the fertilizers recommendations since the nutritional demand differs from those plants conventionally propagated (Resende et al., 1999b). However, the nutritional requirement of micropropagated garlic is still little known. Silva et al. (2010) reported the higher productivity of cultivars derived from tissue culture than the conventional multiplication in nine consecutive crops. Plants derived from tissue culture accumulated higher quantities of nutrients than those derived from conventional propagation in studies performed by Resende et al. (1999a), besides the increase in height and production of dry matter in the shoot and roots (Resende et al., 1999b).

In the modern agriculture, strategies to increase the productivity are required and in this sense, for the garlic crop, the knowledge on the capacity of the plants to recover the nutrients supplied stands out. Thus, fertilizations become efficient and economically profitable for adding enough quantities to the soil.

The recovery efficiency is the amount of the nutrient applied as fertilizers absorbed by plants. It is calculated by the ratio between the difference of the content of a nutrient from a fertilized and unfertilized plant and the amount applied as fertilizers (Fageria, 1998). Therefore, this index indicates the percentage of the nutrient absorbed from the amount applied.

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According to the nutritional demand, the recovery efficiency of nutrients by plants interferes on the adjustments of fertilizers recommendations for garlic crop. Thus, the objective of this study was to evaluate the nutritional status, growth, yield and recovery efficiencies of N, P and K by micropropagated and conventionally propagated garlic plants.

MATERIAL AND METHODS

The experiments were conducted in 132-dm^3 pots, from April to September of 2013, in an experimental area of the Federal University of Viçosa, Campus Rio Paranaíba, Brazil. The experimental field is located at 19º13’09” South and 46º13’17’’West, at 1143 m above the sea level. Plants were cultivated in a sample of Red-Yellow Latosol, frequently cultivated with vegetables. Table 1 shows the chemical soil characteristics at the beginning of both experiments.

In both experiments, the treatments consisted of four combinations of N-phosphorus pentoxide (P_2O_5)-potassium oxide (K_2O) (kg ha^{-1}): fertilization without N (0-1200-550), without P (240-0-550), without K (240-1200-0) and complete NPK (control - 240-1200-550). The experiment was designed as randomized blocks with five replications.

At planting, the total dose of P, half of the dose of K and one-third of the dose of N was incorporated to the soil, using ammonium sulphate as N source, single and triple superphosphate as P source and potassium chloride as K source.

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Two N and K topdressing fertilizations were carried out on 20 and 60 days after the emergency, where one third of the N dose and 25 % of K dose were used in each topdressing; in these occasions, the N source applied was ammonium nitrate and the K source was potassium chloride.

The first experiment was conducted using bulbs from conventional propagation of a previous crop. The second experiment was performed using micropropagated bulbs by tissue culture, which is a strategy of plant multiplication from cells or tissues taken from parts of a plant supposedly pathogen free (Souza and Mâcedo, 2009). Twelve plants of the cultivar "Ito" were cultivated per pot (33-dm^2 circular section), in equidistant manner, with a population corresponding to 3.6×10^5 plants per hectare. Bulbs weighed around 4 grams.

The water was daily replaced according to the evapotranspiration. Pests and diseases management were performed according to the assessment of plants and recommendations for the crop. During bulbs differentiation, the plants were submitted to a slight water stress in order to avoid pseudogrowing (Macêdo et al., 2006).

At harvest, the soil was washed with water and all parts of the plants were collected, and then separated in roots, bulbs, leaves and flower stems in order to reduce the flow of photoassimilates and nutrients to the bulbs (Lucini, 2004). After collection, the dry matter was measured by weighing roots, bulbs, leaves and flower stems after a drying process in an oven with forced air circulation at 70°C for 72 h. Before this step, the bulbs were submitted to drying process at room temperature for 30 days (curing), in order to determine the productivity.

Subsequently, the samples were ground in a Willey type grinder and the concentrations of N, P and K determined in roots, bulbs, leaves and flower stems according to the method

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described by Malavolta et al. (1997). The contents were the product of the dry mass times their concentrations in the roots, bulbs, leaves and flower stems. The recovery efficiencies of N, P and K were determined only for plants that received the complete NPK fertilization.

The data were submitted to analysis of variance and the means compared by Dunnett`s test at 5%, with the complete NPK fertilization as the control.

RESULTS AND DISCUSSION

For both experiments, the soil presented high fertility. Because garlic crops presents high demand for nutrients, this kind of soil is the most indicated, which also, justifies the assessment of recovery efficiency in this soil.

Growth and Production

In plants conventionally propagated with N depletion, the dry matter of roots and flower stem were significant higher than the control treatment. However, bulbs, leaves and total dry matter were significant lower in the same condition (Table 2). Adequate supplying of N increased the leaf expansion and the intake of dry matter to the drains with economic interest, such as bulbs (Fernandes et al., 2011a).

On the other hand, in micropropagated plants, the lack of N decreased only the dry matter of root, flower stem and bulb when compared to the control treatment. In part, this result can be

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explained by the cultivation of stronger and more efficient plants, given the absence or the low concentration of virus in these plants (Table 2).

Resende et al. (1999a) found that micropropagated plants accumulated more dry matter than plants conventionally propagated whereas the plants conventionally propagated accumulated less dry matter when N, P and K were depleted.

Regarding the omission of P and K in plants derived from conventional propagation, the total dry matter and the dry matter of leaves and flower stem decreased significantly related to the NPK complete fertilization (Table 2).

In micropopagated plants, when P was depleted, the dry matter of bulbs and the total dry matter were higher than in plants that received the total NPK dose, suggesting that the amount of P in the soil was enough to the growth and development of these plants combined with the best conditions for the development due to the absence of virus (Table 2).

Moreover, only micropopagated plants with P depletion did not present lower productivity than the control (Table 2). The effect of frequent irrigations provided better conditions to P transportations in the soil and plant absorption (Novais et al., 2007). In micropropagated plants with K depletion, only the dry matter of roots and flower stem differ from the complete NPK fertilization.

Concentration and Content of N

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Based on the comparison with the control treatment, the lack of N impaired the concentrations of N in the root, bulb, leaf and floral stem for both experiments. Regarding the content, this same effect is not observed only for roots (Table 3).

The lack of P had effect on the content of N in bulbs, leaves and flower stem, in plants conventionally propagated. On the other hand, there was no effect on the concentrations, showing the dilution effect of the nutrient and the depletion effect of P fertilization on the growth of plants. In the same conditions for micropropagated plants, the N concentration only differ from the control treatment in bulbs, nevertheless, the content is statistically similar (Table 3).

Leaves and floral stem of micropropagated plants presented N concentrations similar to the control, and its content is significantly higher, suggesting the good translocation of the nutrient towards the shoot because of the virus absence. It is known that P is a mobile element inside the plant and in conditions of deficiency, symptoms are firstly observed in the lower parts of the plants (Marschner, 2011).

Regarding the lack of K, the concentration of N in leaves of plants derived from the conventional propagation was similar to the control treatment, the content was significantly lower, however. The total content of N was statistically similar to the control treatment for both experiments (Table 3).

Concentration and Content of Phosphorus

The P concentrations in roots, leaves and floral stem were not influenced by P depletion in plants derived from conventional propagation. However, in leaves and floral stem, P contents were

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lower than the control, showing the dilution effect of the nutrient, confirming the previous information that lack of P impaired plant growth. In bulbs, the concentration and content of P reduced without N and P fertilizations (Table 4).

For micropropagated plants (virus free), the concentrations of P in roots and bulbs are significantly lower and contents are similar to the control treatment, suggesting that no application of P did not influence the growth of roots and bulbs probably because there were sufficient levels in the soil or because of the virus absence in these plants. To enhance this idea, in leaves, the concentration and content did not differ from the control treatment (Table 4).

The concentration of P in the floral stem is significantly lower; however, the content was higher than the control treatment. The lack of N, P and K decreased the total content of P in plants derived from conventional propagation whereas in micropropagated plants, only the lack of N decreased the total content of P (Table 4).

Concentration and Content of Potassium

The depletion of K decreased the concentration and the content of K in all parts evaluated for both experiments as well as the total content of K, suggesting that garlic plants had a good response to fertilization with K in soil (Table 5).

For the conventional propagation, the depletion of N or P did not influence the concentrations of K, except in leaves, in which the absence of N decreased the concentration of K. Depletions of N, P and K decreased significantly the total content of K in plants derived from conventional propagation and in micropropagated plants (Table 5).

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Resende et al. (1999b) reported an accumulation of 206.4 mg/ plant (shoot + bulb at 130 days) of N in micropropagated plants, and in conventional propagation, an accumulation of 178 mg/ plant. These values are lower than those found in this study. The greater productive potential of the plants and the use of different cultivars may explain this result.

Recovery Efficiencies of N, P and K

In plants conventionally propagated, the recovery efficiencies for N, P and K was 53.6, 1.30 and 22.1%, respectively, and for micropropagated plants, they were 48.6, 0.61 and 18.7%, respectively (Table 6). In both experiments, these values are low, which corroborate with Fageria, (1998), who reports very low recovery efficiencies for most crops.

Several factors affect the recovery efficiency including precipitation, temperature and solar radiation, pH of soil, concentration of organic matter, salinity, Al toxicity, P deficiency, genetic variability, root growth, mycorrhizae, allelopathy, diseases, pests and invasive plants, and they are observed on the productivity (Fageria, 1998).

The characteristics of cultivars related to the absorption variables such as Michaelis-Menten (K_m) constant and the minimum concentration (C_{min}) may alter the uptake efficiency of plants. According to Fernandes (2011b) for the potato crop, differences among cultivars related to absorption variables alter the P absorption.

The recovery efficiencies 1.30 and 0.61 %, of P for conventionally and micropropagated plants, respectively, are low in comparison to N and K. Besides being absorbed in smaller quantities, in tropical soils conditions, P is submitted to fixation with Fe and Al oxyhydroxides because of the reduced availability (and recovery) for plants (Vilar et al., 2010).

Natural fertility of soil influenced the values of efficiency obtained in this study due to the high availability of P. Thus, the supplying by the soil provided or would provide most of the plant demand, reducing the absorption from fertilizers. The low recovery efficiency of P may indicate that the focus on the management of nutrients regarding the applied dose may not be correct. Strategies such as the use of granulated fertilizers applied as localized associated to high frequency of water supplying may be more effective for providing the nutrient to the plants (Novais et al., 2007).

In general, the estimates of fertilizer efficiency are lower than 50% for N and lower than 10% for P and around 40% for K (Baligar et al. 2001). An upland rice crop in a Brazilian Cerrado soil presented recovery efficiency of 66% for K (Fageria, 2000c) whereas for N and P, it was approximately 15% and 45%, respectively (Fageria, 1997).

Baligar and Bennet (1986) reported the average recovery efficiency of 50 % for N. According to Rambo et al. (2007), the worldwide estimated N efficiency is only 33%, and therefore alternatives that aim to increase this efficiency such as the use of adequate doses and times of application are often discussed.

CONCLUSIONS

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Plants derived from conventional propagation had very low contents and concentrations of N, P and K as well as low growth and productivity. On the other hand, micropropagated plants reached higher contents and concentrations of N, P and K as well as better growth and development even with N, P or K depletions.

The recovery efficiencies of N, P and K are low and depend on the propagation modes.

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Table 1 - Chemical characterization of the soil used for both experiments

pH		P-Melich	$S\text{-}SO_4^{2-}$	P-rem	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	H+Al	O.M.
H_2O	$CaCl_2$	------mg dm^{-3}------		mg L^{-1}	--------------mmol$_c$ dm^{-3}----------					g dm^{-3}
6.1	5.3	13.6	9.0	3.3	2.4	27.0	11.0	0.0	42.1	28.0

SB	t	T	V	m	B	Cu	Fe	Mn	Zn
----------mmol$_c$ dm^{-3}----------			----%---		-----------------mg dm^{-3}-------------------				
40.4	40.4	82.5	49	0.0	0.15	1.9	41	1.5	6.7

P, K, Na = (Hydrochloric acid at 0,05 mol L^{-1} + H_2SO_4 0,0125 mol L^{-1}); $S\text{-}SO_4^{2-}$ (Monobasic calcium phosphate 0,01 mol L^{-1}); Ca^{2+}, Mg^{2+}, Al^{3+} = (KCl 1 mol L^{-1}); H + Al = (SMP Buffer solution at pH 7,5); O. M. = Walkley-Black method; Cu, Fe, Mn, Zn = DTPA pH 7,3; B = hot water.

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Table 2. Dry matter of roots (DMR - g/ pot), dry matter of bulbs (DMB - g/ pot), dry matter of leaves (DML - g/ pot), dry matter of flower stems (DMFS - g/ pot), total dry matter (TDM - g/ pot) and production (PROD - g/ pot) in response to the tested fertilizations in garlic plants

Treatments	DMR	DMB	DML	DMFS	TDM	PROD
	Conventional propagation					
0-1200-550	56.0 *	141.0 *	64.3 *	19.1 *	280.5 *	366.6 *
240-0-550	41.6	189.1	65.5 *	7.4 *	309.8 *	537.3 *
240-1200-0	36.6	194.9	61.1 *	7.8 *	303.1 *	529.9 *
240-1200-550	39.7	206.9	79.2	11.9	337.6	593.1
Average	43.5	182.9	67.5	11.6	307.7	506.7
CV (%)	10.6	6.7	7.9	11.9	4.52	6.22
	Micropropagation					
0-1200-550	60.8 *	145.0 *	80.6	26.6 *	321.0	354.3 *
240-0-550	49.5	239.0 *	90.3 *	14.1 *	390.1 *	646.0
240-1200-0	35.3 *	211.5	80.0	12.9 *	350.4	596.7 *
240-1200-550	44.3	207.9	81.0	5.5	329.2	634.5
Average	47.5	200.8	83.0	14.8	347.7	557.9
CV (%)	11.0	4.0	4.8	12.2	7.0	3.5

Means followed by * differ significantly from the control treatment (complete fertilization - 240:1200:550 kg ha^{-1} de N: P_2O_5: K_2O) according to Dunnett test at 5 %.

Table 3 - Concentrations of N in roots (CoNR - g kg^{-1}), bulbs (CoNB - g kg^{-1}), leaves (CoNL - g kg^{-1}), floral stems (CoNFS - g kg^{-1}), and content of N in roots (CNR - g/ pot), bulbs (CNB - g/ pot), leaves (CNL - g/ pot), floral stems (CNFS - g/ pot) and total content of N (TCN - g/ pot) in response to NPK fertilizations in garlic plants

Treatments	CoNR	CNR	CoNB	CNB	CoNL	CNL	CoNFS	CNFS	CTN
	Conventional propagation								
0-1200-550	8.6 *	0.47	12.1 *	1.70 *	12.9 *	0.84 *	12.8 *	0.25	3.26 *
240-0-550	13.4	0.56	23.2	4.40 *	21.9	1.44 *	22.3	0.16 *	6.56 *
240-1200-0	15.4	0.57	25.9	5.10	21.7	1.32 *	23.1 *	0.18 *	7.17
240-1200-550	13.1	0.52	25.4	5.26	21.7	1.72	21.6	0.26	7.16
Average	12.6	0.53	21.7	4.1	19.5	1.33	20.0	0.21	6.17
CV (%)	12.8	16.6	8.2	11.5	5.9	11.5	2.8	13.4	9.2
	Micropropagation								
0-1200-550	6.7 *	0.41	11.7 *	1.70 *	9.5 *	0.76 *	11.1 *	0.29 *	3.16 *
240-0-550	11.5	0.56 *	21.9 *	5.22	15.5	1.40 *	18.7	0.26 *	7.45 *
240-1200-0	12.4	0.44	24.2	5.12	12.7	1.02	19.3	0.25 *	6.82
240-1200-550	10.2	0.45	25.1	5.21	14.1	1.14	20.0	0.11	6.91
Average	10.2	0.46	20.7	4.3	12.9	1.08	17.3	0.23	6.09
CV (%)	14.3	13.9	7.4	6.6	9.9	11.7	7.1	13.2	4.2

Means followed by * differ significantly from the control treatment (complete fertilization - 240:1200:550 kg ha^{-1} de N: P_2O_5: K_2O) according to Dunnett test at 5 %.

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Table 4 - Concentration of P in roots (CoPR- g kg^{-1}), bulbs (CoPB- g kg^{-1}), leaves (CoPL- g kg^{-1}), floral stems (CoPFS - g kg^{-1}), content of N in roots (CPR - g/ pot), bulbs (CPB - g/ pot), leaves (CPL - g/ pot), floral stems (CPFS - g/ pot) and total content of P (CTP - g/ pot) in response to NPK fertilizations in garlic plants

Treatments	CoPR	CPR	CoPB	CPB	CoPL	CPL	CoPFS	CPFS	CTP
	Conventional propagation								
0-1200-550	1.08	0.06 *	3.3 *	0.45 *	0.30	0.019 *	2.30	0.05 *	0.58 *
240-0-550	0.93	0.03	3.5 *	0.66 *	0.29	0.019 *	2.40	0.02 *	0.74 *
240-1200-0	1.15	0.04	4.1	0.79 *	0.30	0.018 *	2.50	0.02 *	0.87 *
240-1200-550	1.05	0.04	4.5	0.93	0.29	0.023	2.40	0.03	1.02
Average	1.1	0.04	3.8	0.71	0.30	0.02	2.40	0.03	0.80
CV (%)	8.5	11.6	6.6	10.6	2.3	7.65	4.8	13.1	9.2
					Micropropagation				
0-1200-550	1.13	0.07 *	3.36 *	0.48 *	1.35	0.11	1.58	0.04 *	0.71 *
240-0-550	0.97 *	0.04	3.71 *	0.88	1.31	0.12	1.47 *	0.02 *	1.07
240-1200-0	1.08	0.04 *	4.11	0.86	1.74 *	0.14 *	1.75	0.02 *	1.07
240-1200-550	1.21	0.05	4.42	0.92	1.23	0.10	1.83	0.01	1.08
Average	1.10	0.05	3.9	0.79	1.40	0.12	1.66	0.02	0.98
CV (%)	7.0	10.5	5.3	6.4	9.5	12.1	8.9	15.9	5.6

Means followed by * differ significantly from the control treatment (complete fertilization - 240:1200:550 kg ha^{-1} de N: P_2O_5: K_2O) according to Dunnett test at 5 %.

Table 5 - Concentration of K in roots (CoKR - g kg^{-1}), bulbs (CoKB - g kg^{-1}), leaves (CoKL - g kg^{-1}), floral stems (CoKFS - g kg^{-1}), content of N in roots (CKR - g/ pot), bulbs (CKB - g/ pot), leaves (CKL - g/ pot), floral stems (CKFS - g/ pot) and total content of K (CTK - g/ pot) in response to NPK fertilizations in garlic plants

Treatments	CoKR	CKR	CoKB	CKB	CoKL	CKL	CoKFS	CKFS	CTK
	Conventional propagation								
0-1200-550	18,9	1,05 *	17,5	2,46 *	26,6 *	1,71 *	15,8	0,30 *	5,53 *
240-0-550	20,0	0,83	17,5	3,31 *	32,4	2,12 *	17,4	0,12 *	6,39 *
240-1200-0	14,2 *	0,52 *	12,1 *	2,35 *	14,9 *	0,90 *	11,3 *	0,08 *	3,86 *
240-1200-550	20,9	0,83	19,8	4,11	31,5	2,49	16,2	0,19	7,62
Average	18,5	0,81	16,7	3,06	26,3	1,81	15,2	0,18	5,85
CV (%)	9,7	12,6	8,7	13,6	6,0	8,6	7,2	10,5	8,8
	Micropropagaion								
0-1200-550	20,2	1,22 *	16,1 *	2,33 *	16,6 *	1,34 *	12,2	0,32 *	5,21 *
240-0-550	29,7 *	1,47 *	17,5	4,19 *	22,6	2,04	11,1	0,16 *	7,85 *
240-1200-0	12,5 *	0,44 *	10,7 *	2,27 *	6,0 *	0,48 *	7,6 *	0,10	3,30 *
240-1200-550	21,5	0,95	18,3	3,81	23,4	1,89	12,6	0,07	6,72
Average	21,0	1,02	15,7	3,15	17,2	1,44	10,9	0,16	5,77
CV (%)	10,6	12,1	4,9	5,2	9,9	11,3	10,7	19,1	4,2

Means followed by * differ significantly from the control treatment (complete fertilization - 240:1200:550 kg ha^{-1} de N: P_2O_5: K_2O) according to Dunnett test at 5 %.

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Table 6 - Recovery efficiencies of N, P and K regarding the complete NPK fertilization (240:1200:550 kg ha^{-1} de N: P_2O_5: K_2O) by garlic crop

	N	P	K
Conventional propagation	53. (± 4,084)	1.30 (± 0,412)	22.1 (± 2,491)
Micropropagation	48.6 (± 1,863)	0.61 (± 0,176)	18.7 (± 1,979)

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