



Nitrogen and potassium fertilization on cabbage biometrics and foliar nutritional levels

Fertilização nitrogenada e potássica na biometria e níveis nutricionais foliares do repolho

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Among the most absorbed nutrients by cabbage, nitrogen (N) and potassium (K) are the most extracted; thus, the objective of this study was to evaluate the responses of N and K fertilization on the cabbage biometrics and foliar levels of macro and micronutrients. Four N doses (0, 75, 150, 300 kg ha⁻¹ of N) and four K doses (0, 75, 150, 300 kg ha⁻¹ of K₂O). Biometrics of cabbage head (height, circumference and diameter) and productivity were evaluated. The cabbage levels of macro and micronutrients were also evaluated in leaves of plants at the phenological stage of head-formation. Nitrogen fertilization did not significantly affect the variables evaluated mostly due to the great natural fertility of the experimental soil area. This lack of response highlights the importance of constant monitoring of the nutritional status of the productive area to avoid non-necessary N fertilization. The lowest Mg leaf content was observed at 88 kg ha⁻¹ of K₂O, after which the Mg leaf content increased. The foliar Zn was reduced in doses after 133 kg ha⁻¹ of K₂O. The cabbage head diameter and circumference decreased with the increase of the K₂O doses. The cabbage head height increased up to 128 kg ha⁻¹ of K₂O. The decreasing sequence of the macro and micronutrient levels in cabbage leaves followed the sequence K>Ca>N>S>Mg>P and Mn>Fe>B>Zn>Cu regardless of the level of the factors applied.

Keywords: *Brassica oleracea* var. *capitata*, crop yield, plant mineral nutrition

Entre os nutrientes mais absorvidos pela cultura do repolho, o nitrogênio (N) e o potássio (K) são os mais extraídos. Assim, o objetivo deste estudo foi avaliar as respostas da fertilização de N e K sobre a biometria de repolho e os níveis foliares de macro e micronutrientes. Quatro doses de N (0, 75, 150, 300 kg ha⁻¹ de N) e quatro doses de K (0, 75, 150, 300 kg ha⁻¹ de K₂O). Foram avaliadas a biometria da cabeça de repolho (altura, circunferência e diâmetro) e produtividade. Os níveis de macro e micronutrientes nas folhas de repolho também foram avaliados na fase fenológica da formação da cabeça. A fertilização nitrogenada não afetou significativamente as variáveis avaliadas principalmente devido à grande fertilidade natural da área experimental do solo. A falta de resposta destaca a importância do monitoramento constante do estado nutricional da área produtiva para evitar fertilizações nitrogenadas desnecessárias. O menor teor foliar de Mg foi com a aplicação de 88 kg ha⁻¹ de K₂O, após esta dose o teor foliar de Mg aumentou. O Zn foliar foi reduzido em doses superiores a 133 kg ha⁻¹ de K₂O. O diâmetro da cabeça de repolho e a circunferência diminuíram com o aumento das doses de K₂O. A altura da cabeça de repolho aumentou com a aplicação de até 128 kg ha⁻¹ de K₂O. A sequência decrescente dos níveis de macro e micronutrientes nas folhas de repolho seguiu a sequência K>Ca>N>S>Mg>P e Mn>Fe>B>Zn>Cu independentemente do nível dos fatores aplicados.

Palavras-chave: *Brassica oleracea* var. *capitata*, produção agrícola, nutrição mineral de plantas

1. INTRODUCTION

Cabbage (*Brassica oleracea* var. *capitata*) is the one of the most cultivated crops of the Brassicaceae plant family and genetic breeding improvements has generated cabbage cultivars able to be cultivated during the whole year [1]. This horticultural crop is of a short cycle, shallow root system, and, therefore, needs high quantities of nutrients to express its productive potential and

quality [2]. The cabbage crop extracts and exports high quantities of nutrients. The nitrogen (N) and potassium (K) are the most extracted nutrients [3; 4].

According to Wang et al. (2013) [4], K is essential to the formation and translocation of carbohydrates, it improves the efficiency of water uses and increases the commercial quality of the final product (cabbage head). Domingues Neto et al. (2016) [5] reported that to obtain high yields the cabbage cannot undergo nutritional deficiencies, being the N essential to the production of compact cabbage head (great firmness) desired by the market.

Despite the importance of cabbage nutritional management and cabbage economic and social impact, there are few studies on the appropriate management of the crop fertilization. Duarte et al. (2019) [6] report that there is a disagreement between the applications of fertilizers as recommended in literature and the effectively applied fertilizers by farmers, who generally use higher doses of nutrients. According to Zhang et al. (2010) [7], the current management of N does not provide nutrients in balance with the crop needs, thus resulting in wasted fertilizers and low efficiency of nutrient recovery.

Therefore, the best relation of nutrients applied contributes to high productivity, reduced production costs, and low environmental impacts. Given this, the objective of this study was to evaluate the effect of doses of N and K in the biometrics and foliar levels of macro and micronutrients.

2. MATERIAL AND METHODS

This study was conducted in an experimental area of the horticulture sector of the Federal Institute of Education, Science and Technology of the Triângulo Mineiro (IFTM), campus Uberaba, Brazil. The area is located at the coordinates 19°39'19" S and 47°57'27" W, 800 m above sea level. The climate, based on the international classification of Köppen, is Aw (tropical, hot and humid summer, with cold, dry winter) [8]. During the experiment, the accumulated precipitation and temperature averaged 672.68 mm and 23.8 °C, respectively.

The soil of the experimental area is a Dystrophic Red Latosol with medium texture (21% clay) [9]. The experimental area was destined for vegetable production for many years using organic and mineral fertilization. Previously to the cultivation of cabbage for the present study, the area was cultivated with green corn. Soil samples were collected before experiment installation at 0-0.2 m soil layer, and the soil chemical characteristics were analyzed according to the methodology described by Raij et al. (2001) [10]. The soil chemical results are presented in Table 1.

Table 1. Soil chemical characterization at 0-0.2 m soil layer.

pH	Ca	Mg	Al	H+Al	BS	CEC	V	K	P	S
CaCl	----- (cmol _c dm ⁻³) -----						(%)	----- (mg dm ⁻³) -----		
4.66	0.90	0.22	0.39	3.37	1.48	4.84	30	138	48	10
S.O.M	B	Cu		Fe		Mn		Zn		
g.kg ⁻¹	----- (mg dm ⁻³) -----									
36.33	0.18	4.55		26		28		3.29		

Ca, Mg, Al = KCl solution (1 mol L⁻¹); H + Al = SMP buffer solution (pH 7.5); BS = base sum (cmol_c dm⁻³); CEC = cation exchange capacity at pH 7; V = saturation of bases; K = 0.05 mol L⁻¹ HCl + H₂SO₄ 0.0125 mol L⁻¹; P = resin; S = calcium phosphate; S.O.M. = soil organic matter (colorimetric method). B, Cu, Fe, Mn, Zn = DTPA acid. Methodologies source: [10].

According to the soil chemical analysis, lime was applied to raise the soil base saturation to 70% as recommended by the Committee of Soil Fertility of the Minas Gerais State (Comissão de Fertilidade do Solo do Estado de Minas Gerais) [11] for cabbage. The lime was calcined limestone (RPTN = 120), distributed in a single dose (1,600 kg ha⁻¹), and subsequently incorporated into the soil with plowing and harrowing to the 0-0.2 m soil depth.

The experimental design used was randomized blocks with four replications in a 4×4 factorial scheme, being four doses of N (0, 75, 150 and 300 kg ha⁻¹ N) and four doses of K (0, 75, 150 and 300 kg ha⁻¹ of K₂O). The sources of N and K were urea (45% N) and potassium chloride (56% of K₂O), respectively.

The basic soil fertilization occurred two days before seedling transplant, and 300 kg ha⁻¹ of P₂O₅ and 20% of the N and K doses were applied. The remaining N and K doses for each treatment was applied in three moments: 20% of the dose applied to the 15 days after seedling transplant, 30% applied 15 days after the first application, and 30% applied 15 days after the second application. During the experiment, three fertilizations with boron (B, 1 g L⁻¹ of boric acid) and molybdenum (Mo, 0.5 g L⁻¹ of ammonium molybdate) occurred via foliar applications. The B and Mo fertilizations were 20 days after emergence and 15 and 30 days after the seedling transplant.

Each experimental plot had 3.5 m length and two planting lines with seven plants each (14 plants per plot). The spacing between planting rows and between plants were 0.8 and 0.5 m, respectively. The cultivar studied was the Fênix (Sakata®), a cultivar with medium head size, semi-flat format, moderate resistance to *Xanthomonas campestris* pv. *campestris*, average weight of 3 kg, 110 days cycle, and high resistance to cracking. The sowing was performed in March 2016, in polystyrene trays with 128 cells, filled with commercial substrate recommended for the production of vegetable seedlings. The trays were placed in a protected environment, and at 35 days after sowing the seedling transplantation to the experimental area.

The phytosanitary control was performed whenever necessary after daily inspection to verify the need for weed, insect pests, and disease control. Plant weeds were removed manually. The irrigation occurred through a spray system and performed whenever it was necessary for the maintenance of the soil field capacity.

At the beginning of the head formation, newly mature cabbage leaves were collected from each plot to determine plant nutritional status based on the cabbage nutritional status proposed by Trani and Raij (1997) [12]. The leaves were gently washed and dried for the determination of foliar nutrient levels (N, P, K, Ca, S, Mg, B, Cu, Fe, Mn, Zn). The preparation and foliar analyses were performed according to the methodology proposed by Carmo et al. (2000) [13].

The harvest was started in July 2016, at 83 days after the transplant, when the cabbage heads were compact and fully developed, presenting excellent market characteristics. In each plot, the central eight plants were harvested and weighed to obtain the fresh mass of the cabbage head with adjacent leaves (CML) and fresh mass of the commercial cabbage head (without adjacent leaves) (CCH). The height, circumference and diameter of the cabbage head were measured with the aid of a ruler and a metric tape.

The data of the evaluated variables were submitted to ANOVA and regression analysis ($p < 0.05$), using the package ExpDes of the R statistical program. The model that better fits the data and significantly described the relationship between the two variables was selected and presented in graphs.

3. RESULTS AND DISCUSSION

There was no interaction between the factors (N and K fertilization) for any of the variables evaluated in the present study. The assessment of the nutritional status of the cabbage leaves indicated that the factors did not affect the levels of nutrients. Except for the Mg and Zn and only with the K fertilization (Table 2).

The Mg and Zn responses adequate to the quadratic polynomial model of response to doses of K₂O (Figure 1). The lowest content of Mg observed in the cabbage leaves was with a dose of 88 kg ha⁻¹ of K₂O, from which the Mg leaf content increases. The K application is recognized by competitively inhibiting the absorption of Mg [14]. This was not observed for the present study, where only an initial decrease in the Mg level was observed. However, the level foliar Zn reduces after a certain dose of K₂O; Zn is absorbed by plants as Zn²⁺, and in the case of this cationic micronutrient, doses above 132,8 kg ha⁻¹ sharply reduces Zn foliar levels in cabbage.

Table 2. Cabbage foliar averages and analysis of variance of the nutrients evaluated as a function of nitrogen and potassium fertilization.

N (kg ha ⁻¹)	N	P	K				Ca					
			(g kg ⁻¹)				(mg kg ⁻¹)					
0	16.11	2.66	33.28	20.46	3.15	7.69	5.25	4.06	106.31	191.81	45.94	
75	17.06	2.66	34.28	20.45	3.29	7.85	6.69	4.19	103.81	166.38	43.44	
150	13.66	2.63	35.16	21.49	3.37	11.69	6.31	4.00	91.50	244.69	42.50	
300	16.13	2.63	34.69	22.28	3.49	10.39	6.69	3.94	107.63	186.00	43.75	
K ₂ O												
(kg ha ⁻¹)												
0	17.98	2.59	33.97	21.34	3.24	8.89	4.56	3.94	108.75	196.19	39.81	
75	16.51	2.68	34.84	20.64	3.24	7.46	6.56	4.13	97.00	177.25	51.81	
150	16.04	2.77	33.84	21.11	3.05	11.70	6.50	4.06	101.88	193.75	47.25	
300	12.44	2.53	34.75	21.59	3.76	9.56	7.31	4.06	101.63	221.69	36.75	
F _N	0.91 ^{ns}	0.09 ^{ns}	1.84 ^{ns}	1.38 ^{ns}	1.57 ^{ns}	0.66 ^{ns}	0.84 ^{ns}	0.64 ^{ns}	0.77 ^{ns}	0.88 ^{ns}	0.23 ^{ns}	
F _K	2.39 ^{ns}	2.64 ^{ns}	0.77 ^{ns}	0.29 ^{ns}	7.15 ^{**}	0.54 ^{ns}	2.49 ^{ns}	0.35 ^{ns}	0.33 ^{ns}	0.26 ^{ns}	5.05 ^{**}	
F _{NxK}	1.09 ^{ns}	0.46 ^{ns}	0.94 ^{ns}	2.04 ^{ns}	1.51 ^{ns}	0.94 ^{ns}	1.16 ^{ns}	0.49 ^{ns}	0.34 ^{ns}	0.58 ^{ns}	0.66 ^{ns}	
C.V. (%)	38.68	9.87	6.85	14.19	13.62	102.16	47.71	13.19	32.88	72.34	27.85	

N = nitrogen dose; K₂O = potassium oxide dose; ns = non-significant; “**” = significant at 1% probability by the *F* test; F_N: *F* test value for the factor N doses; F_K: *F* test value for the factor K doses; F_{NxK}: *F* test value for the interaction between the N and K factors; C.V. (%) = coefficient of variation.

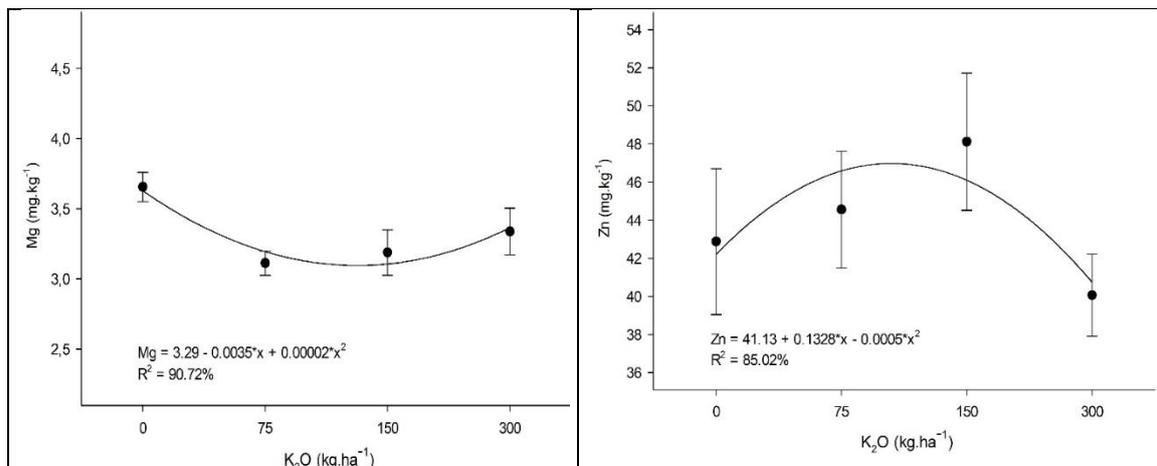


Figure 1. Cabbage foliar levels of magnesium (left graph) and zinc (right graph) as a function of potassium fertilizer. Each point in both graphs is an average of 16 observations. Bars represent standard error.

The decreasing sequence of the macronutrient levels in cabbage leaves followed the sequence K>Ca>N>S>Mg>P, regardless of the level of the factors (N and K fertilization) applied. Among the micronutrients, the sequence was Mn>Fe>B>Zn>Cu. The macronutrient levels observed at this cabbage phenological stage differed from [15], who reported superior foliar K levels compared to the N levels. However, current cabbage hybrids have shown Ca leaf concentration greater than those of N, as reported by [3], corroborating the results found in the present study.

Berça, Mendonça and Souza (2019) [16] evaluated the levels of macro and micronutrients in cabbage leaves at harvest. They also observed that the macronutrient content followed the sequence N>K>Ca>S>Mg>P, and micronutrients followed the sequence Fe>Mn>Cu>Zn>B. Differences in the crop management (e.g., nutrition, irrigation, genotype), as well as soil differences, can affect the results of the experiments; however, the differences between the results observed by Berça, Mendonça and Souza (2019) [16] and the results of the present study are probably due to the time

of evaluation of the cabbage leaves. In both experiments, the macronutrients N, Ca and K, and the micronutrients Fe and Mn were the most accumulated by cabbage leaves.

The cabbage biometric evaluations (height, diameter, weight and masses) indicated that the N fertilization did not affect these variables for the edaphic conditions of this study. Very likely, the N for the full crop development was supplied by the soil organic matter [17], which in this study was 36.33 g dm^{-3} , masking the effect of the N fertilization. However, these variables were affected by the factor: K fertilization ($p < 0.05$) (Table 3).

Table 3. Cabbage biometric averages and analysis of variance of the nutrients evaluated as a function of nitrogen and potassium fertilization.

N (kg ha^{-1})	Head height (cm)	Diameter (cm)	Circumference (cm)	CML (kg planta^{-1})	CCH (kg planta^{-1})
0	10.87	13.97	47.40	1.16	0.96
75	11.02	14.10	46.88	1.04	0.94
150	11.52	14.48	47.81	1.25	1.09
300	11.32	14.77	49.04	1.42	1.23
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K_2O (kg ha^{-1})					
0	11.00	14.65	49.20	1.13	1.01
75	11.55	14.64	48.39	1.47	1.25
150	11.50	14.50	47.76	1.34	1.17
300	10.68	13.54	45.79	0.94	0.79
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F_N	2.42 ^{ns}	1.70 ^{ns}	2.46 ^{ns}	2.26 ^{ns}	2.17 ^{ns}
F_K	4.90 ^{**}	3.63 [*]	6.17 ^{**}	5.00 ^{**}	4.86 ^{**}
$F_{N \times K}$	0.69 ^{ns}	0.62 ^{ns}	1.53 ^{ns}	1.78 ^{ns}	1.92 ^{ns}
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C.V. (%)	6.76	7.84	4.91	34.72	34.87

N = nitrogen dose; K_2O = potassium oxide dose; ns = non-significant; “*” and “**” = significant at 5 and 1% probability by the *F* test, respectively; F_N : *F* test value for the factor N doses; F_K : *F* test value for the factor K doses; $F_{N \times K}$: *F* test value for the interaction between the N and K factors; C.V. (%) = coefficient of variation. CML = cabbage head fresh mass with all leaves; CCH = cabbage head fresh mass without all leaves (commercial cabbage head).

The height of the cabbage head was influenced by the K doses according to a quadratic model response (Figure 2). The maximum height of the cabbage head (11.56 cm) was observed with a dose of 128 kg ha^{-1} of K_2O . The diameter and the circumference of the cabbage head were influenced by the doses of K_2O following. Linear models of response. The initial diameter (0 kg ha^{-1} of K) was 14.84 cm and decreased approximately 0.0039 cm for each kilogram of K_2O applied per hectare. The initial cabbage head circumference was 49.26 cm and decreased approximately 0.0113 cm for each kilogram of K_2O applied per hectare.

There is a maximum dose of K_2O (128 kg ha^{-1}) to the cabbage head height (11.56 cm); however, there is a trend of negative response to the increasing doses of K_2O for the other variables evaluated. This negative effect may be directly related to the saline effect of the K source used (KCl) [18], or even by the competition among the cationic nutrients.

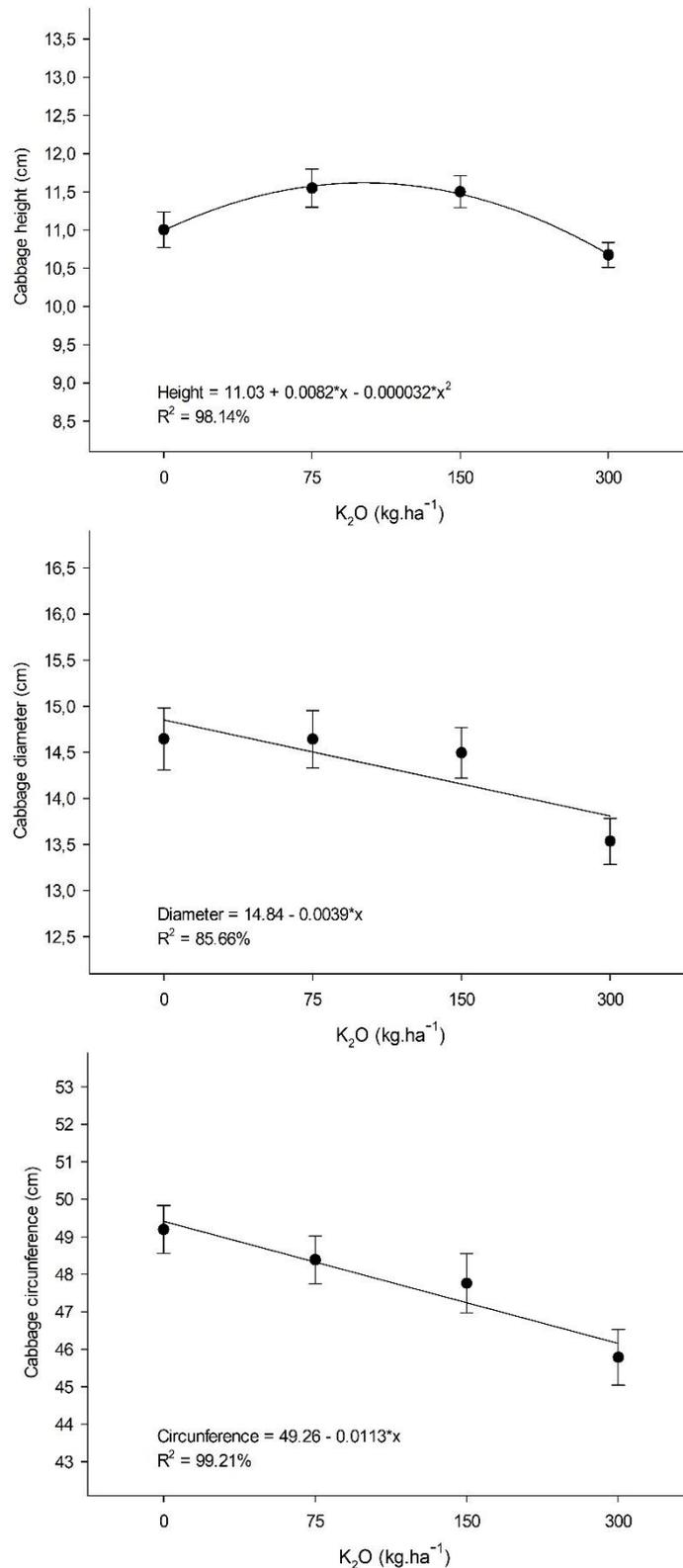


Figure 2. Cabbage height, diameter and circumference as a function of potassium fertilizer. Each dot is an average of 16 observations. Bars represent standard error.

The biomass production of cabbage heads with adjacent leaves or commercial (without adjacent leaves) were affected by the doses of K according to a quadratic model of response (Figure 3). The largest mass of cabbage head with adjacent sheets (1.42 kg) and the largest commercial head (1.23 kg) were obtained with a dose of 128 and 123 kg ha⁻¹ of K₂O.

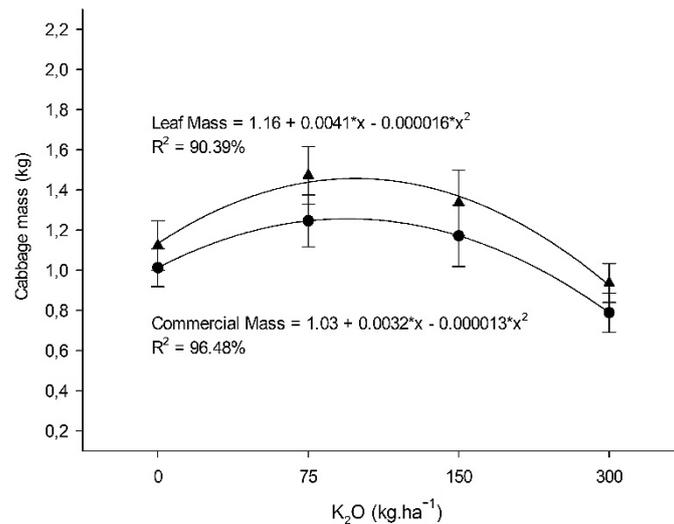


Figure 3. Mass of cabbage head with adjacent leaves and commercial (head without adjacent leaves) as a function of potassium fertilizer.

The response of cabbage to N is variable and depends on factors like the growing season [19] and the genotype cultivated [5]. Moreira and Vidigal (2011) [20] observed an increase of the cabbage mass with the elevation of the N doses of nitrogen fertilizer; however, these authors utilized N doses exceeding 300 kg ha⁻¹, differing from the present study. These authors also observed that the greatest mass of commercial head was 1.13 kg at a dose of 277.8 kg ha⁻¹ of N, which is close to the maximum value obtained in the present study, where the dose of 150 kg ha⁻¹ of N produced a mass of commercial head of 1.09 kg (Table 3).

The N doses applied did not affect the variables evaluated in the present study. However, Aquino et al. (2005) [1] observed that the higher average weight of cabbage heads was at the highest dose of N evaluated (300 kg ha⁻¹) and planting spacing of 0.8 × 0.3 m. The high soil fertilization can justify this situation in the area, a condition regularly found in areas of cultivation of vegetables. Fontanétti et al. (2006) [21] pointed out that the cultivation of cabbage may be benefited if preceded by the cultivation of sunn hemp supplemented with 20 ton ha⁻¹ of wet organic compost, indicating that the N of organic origin is important for this crop.

Cabbage showed to be responsive to K and with high efficiency of K recovery from the soil due to the high leaf content. The results indicate that increasing K doses significantly increase the commercial cabbage yield up to 123 kg ha⁻¹ of K₂O dose. However, the study conducted by Ribas et al. (2015) [22] in a condition of considerable K availability in the soil (K = 129 mg.dm⁻³), similar to that found in the present study (K = 138 mg.dm⁻³, Table 1), did not identify differences (p>0.05) in cabbage head diameter or yield, even applying 360 kg ha⁻¹ of K₂O. The conflicting results found by Ribas et al. (2015) [22] and in the present study demonstrates how important is to monitor and manage the soil nutrients, especially K for cabbage cultivation.

The excessive fertilization with K, beyond the limit of positive, productive responses, can increase the soil salinity (especially with KCl as the source of K) and reduce the absorption of other cations (mainly calcium and magnesium), consequently causing nutrient losses by leaching and reductions in crop yield.

The lack of significant differences among the results from N doses observed in this study indicates that an area managed during many seasons with vegetables can supply the cabbage N needs. In the case of the K, the applied doses were able to influence the responses of the studied variables (p<0.05), indicating the importance of careful monitoring of the levels of K in the soil and the amount of K fertilizer applied. This monitoring between harvests prevents the occurrence of deficiencies of this nutrient in future seasons, especially after cabbage crops (high K consumption).

4. CONCLUSIONS

Nitrogen fertilization does not significantly affect any of the variables evaluated for cabbage, indicating that for conditions similar to this study the application of N might not present significant increments for cabbage production.

The foliar Mg content decrease until the dose of 88 kg ha⁻¹ of K₂O, from which the foliar Mg content increases, and the level of foliar Zn reduces after 133 kg ha⁻¹ of K₂O. The application of K₂O between 88 and 133 kg ha⁻¹ would generate bigger Mg and Zn levels in the cabbage leaves.

The largest biomass of cabbage head with adjacent sheets (1.42 kg) and the commercial head (1.23 kg) was obtained with 128 and 123 kg ha⁻¹ of K₂O, respectively. Thus, the application of 123-128 kg ha⁻¹ of K₂O would generate good Mg and Zn levels and high cabbage production.

5. ACKNOWLEDGMENTS

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