

GYPSUM AND POTASSIUM DOSES ON CAULIFLOWER NUTRITIONAL STATUS AND PRODUCTION¹

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ABSTRACT - Gypsum is widely used in agriculture to supply nutrients to the soil-plant system. However, the excessive use of gypsum may lead to a reduction of cationic soil nutrients such as potassium in the most superficial soil layer. Thus, the objective of this study was to evaluate the feasibility of using gypsum and potassium for cauliflower crop nutritional status and commercial production. The experiment was conducted in 5x5 factorial scheme, corresponding to five K doses (0, 100, 180, 240, 360 kg ha⁻¹ of K₂O) and five gypsum doses (0, 500, 1000, 2000, 4000 kg ha⁻¹) in dystrophic Red Latosol. Leaf N, P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn contents, commercial head mass, diameter and height and peduncle diameter were evaluated. The application of 360 kg ha⁻¹ of K₂O resulted in 29.69% more K in cauliflower leaf and 18.94% more commercial head mass compared to the non-application of K. The application of 4000 kg ha⁻¹ of gypsum resulted in reductions of leaf S and Mn and increase in leaf Cu. Based on the results observed, 4000 kg ha⁻¹ of gypsum and 360 kg ha⁻¹ K₂O could be required for high cauliflower production.

Keywords: *Brassica oleracea* var. *botrytis*. Calcium sulfate dihydrate. Potassium chloride. Plant nutrition.

DOSES DE GESSO E POTÁSSIO NO ESTADO NUTRICIONAL E PRODUÇÃO DE COUVE-FLOR

RESUMO - O gesso é utilizado na agricultura para o fornecimento de nutrientes ao sistema solo-planta, aumento da profundidade do sistema radicular das culturas e, também, para mitigar os efeitos do estresse hídrico nas plantas. No entanto, seu uso indiscriminado pode levar à redução do conteúdo de nutrientes catiônicos da superfície do solo, principalmente o potássio. Assim, o objetivo deste estudo foi avaliar a viabilidade da utilização de gesso, associado à aplicação de potássio, no cultivo de couve-flor, cultivar Sharon. O experimento foi conduzido em esquema fatorial 5x5, sendo avaliadas cinco doses de K (0, 100, 180, 240 e 360 kg ha⁻¹ de K₂O) e cinco doses de gesso (0, 500, 1.000, 2.000 e 4.000 kg ha⁻¹) no delineamento em blocos completos casualizados, com três repetições. Foram determinados os teores foliares de N, P, K, Ca, S, Mg, B, Cu, Fe, Mn e Zn e a massa comercial da cabeça, o diâmetro da cabeça, o diâmetro do pedúnculo e a altura da cabeça. A aplicação de 360 kg ha⁻¹ de K₂O resultou no aumento de 29,69% no teor foliar de K e 18,94% na massa comercial da cabeça, em relação à dose de 0 kg ha⁻¹ de K₂O. A aplicação da dose máxima de gesso, resultou na redução dos teores foliares de enxofre (14,71%) e manganês (25,11%) e, aumento dos teores foliares de cobre (16,97%). Com base nos resultados observados, conclui-se que para a cultura da couve-flor, as doses de gesso e K₂O recomendadas são de, respectivamente, 4.000 e 360 kg ha⁻¹.

Palavras-chave: *Brassica oleracea* var. *botrytis*. Sulfato de cálcio di-hidratado. Cloreto de potássio. Nutrição de plantas.

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INTRODUCTION

Among the vegetable species of the Brassicaceae family, cauliflower is one of the most cultivated and consumed in Brazil (OLIVEIRA et al., 2019). However, to reach high cauliflower productivities, several crop production factors must be observed. Among them, there are the fertility and correction of the soil conditions and the nutritional requirements of the cauliflower crop (SHREE; SINGH; KUMAR, 2014; BIANCO; CECÍLIO FILHO; CARVALHO, 2015; SANTOS et al., 2020).

Soil acidity correction and the levels of nutrients are of great importance to cauliflower production (BHERING et al., 2017). Limestone is the most used input for the correction of soil acidity and supply of calcium (Ca) and magnesium (Mg). However, the effects of limestone are restricted to the soil layer where it is incorporated, usually 0-0.2 m, with little to no effects reaching deep soil layers.

On the other hand, agricultural gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is recommended for soil conditioning and to improve root development in deeper soil layers. Gypsum is a more soluble product than limestone and can displace Ca in deep soil layers, reducing the concentration of toxic aluminum (Al^{3+}). Gypsum is a low-cost industrial residue, available in large quantities and also an important source of sulfur (S) (MOREIRA et al., 2020), which is primarily required by the Brassicaceae family species (GRANT; MAHLI; KARAMANOS, 2012). Besides that, gypsum application on the cauliflower crop can significantly reduce the losses caused by clubroot disease (*Plasmodiophora brassicae*) and the negative impacts of these stresses on production (SANTOS et al., 2020).

Gypsum effects are well studied in the management of soil fertility for the cultivation of crops such as maize, oilseeds, sorghum, sugarcane, among others (ZOCA; PENN, 2017; TIECHER et al., 2018). However, due to the demands for crop production sustainability and crop yield, the interest in gypsum for vegetable production has increased. There are few studies about gypsum application to vegetable crops. Santos et al. (2020) evaluated the combined application of gypsum and limestone in the cauliflower crop. They reported that gypsum increased soil cation exchange capacity (CEC) at 0.2-0.4 m soil depth due to Ca mobilization to deeper soil layers.

Gypsum application can also increase the levels of potassium (K) and Mg and improve soil fertility in subsoil layers (ZOCA; PENN, 2017). This characteristic benefits crop productivity, since cauliflower, whose root system is relatively deep and

explores the soil way below the superficial layer (0-0.2 m), is one of the most K-demanding vegetable (SILVA et al., 2016); in fact, K is the second most absorbed nutrient by cauliflower (CASTOLDI et al., 2009). However, excessive doses of gypsum may decrease the levels of cations such as potassium (K^+) in the superficial soil layer (0-0.2 m) due to the rise of calcium (Ca^{2+}) concentration in soil solution, leading to the deficiency of this nutrient, especially in soils with low organic matter content and low cation retention capacity.

Gypsum is an important agricultural input in soil fertility management, and the hypothesis of this study was based on the idea that the combined application of gypsum and K may improve soil conditions without causing K depletion to subsoil layers, and consequently increases nutrient absorption and cauliflower crop productivity. Thus, this study aimed to evaluate the influence of gypsum and potassium on the nutritional status and production of cauliflower.

MATERIAL AND METHODS

The study was carried out in a dystrophic Red Latosol (EMBRAPA, 2013), with medium texture, in the experimental area of the horticulture sector, of the Federal Institute of Education, Science and Technology of Triângulo Mineiro (IFTM), Campus Uberaba, Minas Gerais State (19°39'19" S; 47°57'27" W), Brazil. The climate of the region, based on the international classification of Köppen, is Aw type, with hot, humid summer and cold, dry winter. From November 2014 to January 2015, the average rainfall and temperature were 672.68 mm and 23.82 °C, respectively.

The soil (0-0.2 m) chemical analysis before the application of the treatments showed: pH (CaCl_2) = 4.66; organic matter (O.M.) = 36 g dm^{-3} ; P (resin) = 47 g dm^{-3} ; H+Al = 33 mmolc dm^{-3} ; Al = 4 mmolc dm^{-3} ; Ca = 9 mmolc dm^{-3} ; K = 3 mmolc dm^{-3} ; Mg = 2 mmolc dm^{-3} ; S- SO_4 = 10 mg dm^{-3} ; base sum (BS) = 14 mmolc dm^{-3} ; cation exchange capacity (CEC) = 48 mmolc dm^{-3} ; V = 30.48% (EMBRAPA, 2009).

The chemical analysis of the 0.2-0.4 m soil layer showed: pH (CaCl_2) = 4.86; O.M. = 19.33 g dm^{-3} ; P (resin) = 32.33 g dm^{-3} ; H + Al = 26.67 mmolc dm^{-3} ; Al = 2.60 mmolc dm^{-3} ; Ca = 8.90 mmolc dm^{-3} ; K = 2.12 mmolc dm^{-3} ; Mg = 2.65 mmolc dm^{-3} ; S- SO_4 = 18.53 mg dm^{-3} ; BS = 18.65 mmolc dm^{-3} ; CEC = 45.32 mmolc dm^{-3} ; V = 40.78%.

The experiment was conducted in 5x5 factorial scheme, corresponding to five K doses (0,

100, 180, 240, 360 kg ha⁻¹ of K₂O) and five gypsum doses (0, 500, 1000, 2000, 4000 kg ha⁻¹) in a randomized complete block design with three replicates. Each experimental unit consisted of 12 plants arranged in rows with planting lines spaced by 0.8 m and plants by 0.5 m in planting beds of 1.10 m width by 0.2 m height. The usable area consisted of the eight central plants in each plot.

Forty days before seedling transplanting, lime was applied to the experimental area, aiming to elevate base saturation to 70% (FONTES, 1999), with the application of 1600 kg ha⁻¹ of calcined limestone (relative total neutralization power = 120), with subsequent incorporation (0-0.2 m) by soil plowing. During this period (40 days), the area was irrigated to improve the limestone reaction. After 35 days, the area was prepared with a disk harrow followed by a light leveling harrow before bed preparing. After the soil bed raising, all gypsum was applied manually to each plot according to its respective treatment, without incorporation. According to the technical report provided by the company Agronelli Indústria e Comércio de Insumos Agropecuários Ltda., the gypsum (CaSO₄) applied in this experiment had the following chemical composition: Ca = 18%, S = 15%. The fertilizers (N, P, K) were added to each bed in two furrow lines with subsequent incorporation in the furrow (0.1 m depth).

According to the results of soil chemical analysis, the fertilizers applied at planting were: 50 kg ha⁻¹ of P₂O₅ as single superphosphate (18% of P₂O₅ and 20% of Ca); 20% of each K doses and 20% of the N dose (30 kg ha⁻¹ of N) (FONTES, 1999), using, as a source, potassium chloride (56% of KCl) and urea (44% of N), respectively. The side-dressing fertilization was performed by applying the N and K doses in the following way: 20% in the first application, 15 days after the transplant (DAT), 30% in the second application at 30 DAT, and 30% in the third application at 45 DAT.

The cauliflower seedlings ("Sharon" cultivar) were produced in trays filled with a commercial substrate (Bioplant®) and grown under greenhouse conditions. At 34 days after sowing, when they had four to five leaves, the seedlings were transplanted to the experimental plots.

Three foliar fertilization with boron (B) and molybdenum (Mo) were done at 20 days after sowing (seedling stage), and at 15 and 30 days after seedling transplant, using 1 g L⁻¹ of B (boric acid) and 0.5 g L⁻¹ of Mo (ammonium molybdate) (RAIJ et al., 1997). Due to the thick wax layer covering the cauliflower leaves, an adhesive-spreader adjuvant was added to each spray solution at the dosage

recommended by the manufacturer.

The control of insect pests and diseases was performed with insecticides and fungicides at the recommended dose for cauliflower crop. Weed control in the area during the cauliflower cycle was done manually. Irrigation (sprinklers) was used throughout the crop cycle to maintain the soil close to field capacity.

The analysis of the nutritional status of the cauliflower plants was done on composite samples from ten newly mature leaves of each treatment at the beginning of the inflorescences (RAIJ et al., 1997). The collected material was washed with deionized water, placed to dry in an oven at 65 °C with forced air circulation until constant weight and, subsequently, ground. The determination of foliar N, P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn levels was done according to the methodology described by Embrapa (2009).

The cauliflower harvest began at 66 days after seedling transplant for all treatments - when the inflorescences were fully developed, with compact and firm heads. Once started, the harvest period was 10 days. The main stem was cut, and some leaves were left to protect the head during transport to the laboratory; these extra leaves were removed before weighing. The commercial head mass (CHM) was assessed with the aid of a precision digital scale - the values were expressed in kilograms (kg). Head diameter (HD), peduncle diameter (PD) and head height (HH) were assessed with the aid of a millimeter ruler; the values were expressed in centimeters (cm).

The data analysis of the factors included the analysis of variance (*F* test). When significant effects were identified, multiple regression analyses were performed. Each of the evaluated characteristics was considered as *response variables*, and as *explanatory variables* or predictors, the linear effects, quadratic effects and the effect of interaction (G, K, G², K², GK) of the gypsum (G) and potassium (K) doses.

The best models for each of the possible model sizes (1, 2, 3, 4 and 5) were selected according to the *backward stepwise selection* method (JAMES et al., 2013). After selecting the best model in each size, the *t*-test was applied to the coefficients of the models to verify if these were significant. In addition, the Bayesian information criterion (BIC) was obtained for each of the models for each one of the response variables. The best models were those with low BIC values. All analyses were performed using the probability level of 5% and with the aid of R software (R CORE TEAM, 2014) using the packages MASS, leaps, ExpDes.

RESULTS AND DISCUSSION

Increasing doses of soil-applied K tended to result in increased leaf K content (Table 1, Figure 1A). Any K₂O dose applied, except for the control (0 kg ha⁻¹ K₂O), led to leaf K content above 25 g kg⁻¹. The application of the highest K₂O dose (360 kg ha⁻¹) resulted in 30.35 g kg⁻¹ of K in the cauliflower leaf. The leaf K levels observed are considered appropriate (25 to 50 g kg⁻¹) according to the nutritional requirements of the cauliflower crop (BATAGLIA et al., 1983).

Increasing doses of gypsum and K₂O did not affect the level of N in cauliflower leaves

(Table 1), which had 34.52 g kg⁻¹ of leaf N, on average. In the same way, the leaf P level in cauliflower was not influenced by the application of gypsum and potassium (Table 1). The average content of 2.79 g kg⁻¹ of leaf P was observed and also considered below the adequate levels for cauliflower crop, which is between 4 and 8 g kg⁻¹ (BATAGLIA et al., 1983).

Leaf Ca and Mg levels were also not influenced by the doses of gypsum and K₂O. The average leaf levels of Ca and Mg were 7.13 and 1.21 g kg⁻¹, respectively (Table 1). The Ca and Mg

levels were below the adequate levels for cauliflower crop (BATAGLIA et al., 1983), which are 20-35 g kg⁻¹ and 2.5-5.0 g kg⁻¹ for Ca and Mg, respectively.

The increase in K₂O doses decreased the foliar S levels from 2.65 to 2.22 g kg⁻¹ (Table 1, Figure 1B). The minimum foliar S level was verified with the dose of 360 kg ha⁻¹ of K₂O (Figure 1B); however, this difference is relatively small, and both levels are classified in the same status of nutritional sufficiency (BATAGLIA et al., 1983; TRANI; RAIJ, 1997).

Foliar B was not influenced by the levels of the factors evaluated (Table 2), showing an average of 18.53 mg kg⁻¹ of B. Leaf Fe and Zn contents (Table 2) were not affected by the factors evaluated (gypsum and K₂O), and averaged 92.63 and 33.2 mg kg⁻¹ of Fe and Zn in cauliflower leaves, respectively.

Levels of these nutrients considered adequate for cauliflower are 30 to 200 and 20 to 250 mg kg⁻¹ of foliar Fe and Zn, respectively (BATAGLIA et al., 1983). These results indicate that increasing doses of gypsum (up to 4000 kg ha⁻¹) in the cultivation of cauliflower might not affect the absorption of cationic micronutrients.

Table 1. Averages of foliar macronutrients in cauliflower as function of gypsum and K₂O doses.

G (kg ha ⁻¹)	N	P	K	Ca	Mg	S
	----- g kg ⁻¹ -----					
0	34.45	2.68	26.83	6.84	1.34	2.45
500	34.88	2.69	27.07	6.8	1.23	2.65
1000	35.10	2.86	27.28	7.01	1.21	2.79
2000	34.08	2.74	26.06	7.35	1.12	2.42
4000	34.09	2.97	27.36	7.64	1.17	2.22
K ₂ O (kg ha ⁻¹)						
0	35.18	2.56	22.77	7.52	1.21	2.65
100	34.55	2.85	25.53	7.45	1.27	2.44
180	34.33	2.94	27.21	7.21	1.23	2.52
240	33.97	2.84	29.46	7.02	1.22	2.36
360	34.58	2.74	29.62	6.43	1.14	2.57
Average	34.52	2.79	26.92	7.13	1.21	2.51
FG	0.85 ^{ns}	1.84 ^{ns}	0.21 ^{ns}	1.48 ^{ns}	6.48 ^{ns}	2.95 ^{***}
FK	0.76 ^{ns}	2.52 ^{ns}	7.26 ^{***}	2.18 ^{ns}	2.36 ^{ns}	0.82 ^{ns}
FGxK	1.06 ^{ns}	1.01 ^{ns}	0.86 ^{ns}	1.29 ^{ns}	1.61 ^{ns}	1.07 ^{ns}
C.V. (%)	5.62	12.73	14.69	16.05	10.17	19.68

G = gypsum doses; ns = non-significant; “*” = significant at p < 0.05; “**” = significant at p < 0.01; “***” = significant at p < 0.001 by the F test; C.V. = coefficient of variation.

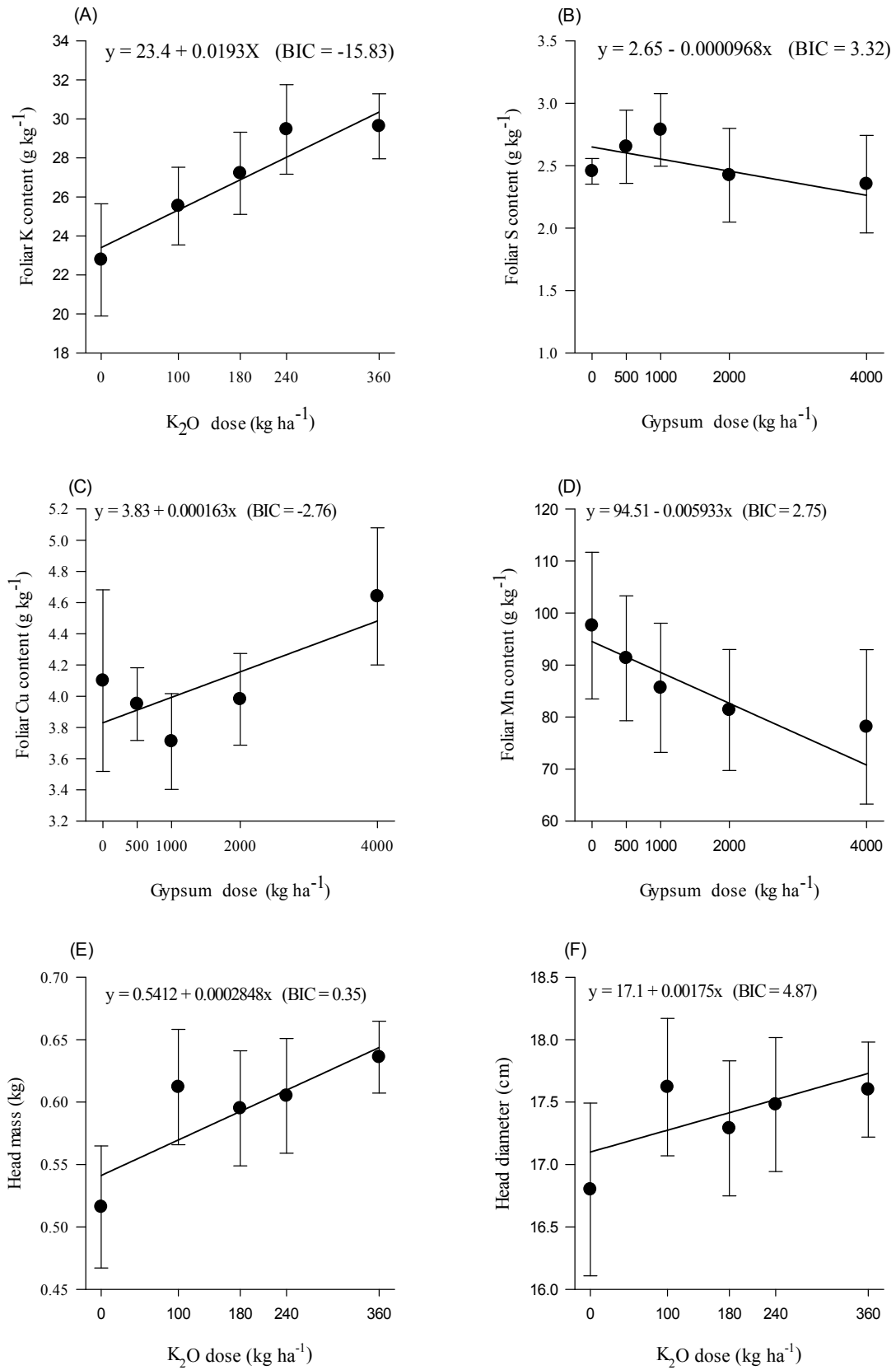


Figure 1. Foliar potassium (K) as function of K₂O doses; foliar sulfur (S), copper (Cu) and manganese (Mn) as function of gypsum doses; head diameter and mass as function of K₂O doses in cauliflower crop. Bayesian information criterion (BIC). Bars indicate the standard error of the mean.

Table 2. Averages of foliar micronutrients in cauliflower as function of gypsum and K₂O doses.

G (kg ha ⁻¹)	B	Cu	Fe	Mn	Zn
	----- mg kg ⁻¹ -----				
0	17.99	4.10	80.13	97.59	35.21
500	19.18	3.95	92.40	91.30	34.37
1000	20.52	3.71	92.88	85.62	33.09
2000	16.70	3.98	112.27	81.35	31.66
4000	18.24	4.64	85.48	78.10	31.66
K₂O					
(kg ha ⁻¹)					
0	16.12	4.23	93.77	99.76	33.60
100	19.07	3.91	87.56	77.79	31.50
180	18.91	3.95	92.08	79.98	33.78
240	19.71	4.05	84.97	91.4	32.87
360	18.82	4.24	104.78	85.02	34.24
Average	18.53	4.08	92.63	86.79	33.2
FG	0.78 ^{ns}	3.19 ^{***}	1.17 ^{ns}	3.31 ^{***}	0.93 ^{ns}
FK	0.75 ^{ns}	0.63 ^{ns}	0.46 ^{ns}	2.74 ^{ns}	0.43 ^{ns}
FGxK	1.12 ^{ns}	0.45 ^{ns}	1.25 ^{ns}	0.57 ^{ns}	1.06 ^{ns}
C.V. (%)	33.55	18.31	47.16	25.59	19.20

G = gypsum doses; ns = non-significant; “*” = significant at $p < 0.05$; “**” = significant at $p < 0.01$; “***” = significant at $p < 0.001$ by the F test; C.V. = coefficient of variation.

Leaf Cu content (Table 2, Figure 1C) increased linearly with the application of gypsum, with increments of 0.000163 mg g⁻¹ in leaf content of this micronutrient for each kilogram of gypsum applied to the soil, which resulted in the maximum leaf Cu content of 4.48 mg kg⁻¹.

Leaf Mn content (Table 2, Figure 1D) decreased linearly with the application of gypsum. The application of 0 and 4000 kg ha⁻¹ of gypsum resulted in 94.51 and 70.78 mg kg⁻¹ of Mn in cauliflower leaf; leaf Mn contents considered appropriate for cauliflower ranged from 25 to 250 mg kg⁻¹ according to Bataglia et al. (1983).

The doses of K₂O linearly increased cauliflower head diameter. The maximum head diameter (17.73 cm) was verified with the dose of 360 kg ha⁻¹ of K₂O (Figure 1E), a value close to the values reported by Oliveira et al. (2019) for ‘Barcelona CMS’ and Santos et al. (2020) for the cultivars Sharon and Piracicaba Precoce.

Commercial head mass (CHM) increased linearly with the application of K₂O (Table 3, Figure 1F), reaching 0.644 kg per cauliflower head with 360 kg ha⁻¹ of K₂O. Silva et al. (2016) observed the increase of ‘Verona’ cauliflower head mass with increasing doses of K₂O (up to 200 kg ha⁻¹), corroborating the effects observed in the present

study.

It should be emphasized that the present study was conducted in the summer - a season of high market price of cauliflower but difficult to cultivate it due to the heat and humidity of the season. Thus, K doses above 210 kg ha⁻¹ resulted in cauliflower heads with more than 0.6 kg weight (Figure 1F), which can be considered adequate for cauliflower cultivation.

Concerning peduncle diameter (PD), we found significant interaction between gypsum and K₂O doses (Table 3). Based on the response curve of the peduncle diameter to the gypsum and K₂O doses (Figure 2A), the maximum peduncle diameter (2.89 cm) was observed with 4000 and 297.42 kg ha⁻¹ of gypsum and K₂O, respectively. The peduncle is an important characteristic in crops where the inflorescence is the commercial part since the peduncle is the base of support. Thus, resistant and large peduncles generate productivity gains and reduce the losses by breaking during handling and transport.

For head height, there was also a significant interaction between gypsum and K₂O doses (Table 2). The highest head height (13.06 cm) (Figure 2) was observed with 4000 and 222.50 kg ha⁻¹ doses of gypsum and K₂O, respectively.

Table 3. Averages of cauliflower biometric variables as function of gypsum and K₂O doses.

G (kg ha ⁻¹)	CHM	HD	PD	HH
	kg	----- cm -----	----- cm -----	----- cm -----
0	0.580	17.10	2.67	12.40
500	0.575	17.21	2.68	12.10
1000	0.604	17.46	2.70	12.25
2000	0.595	17.47	2.75	12.61
4000	0.609	17.54	2.79	12.78
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K ₂ O (kg ha ⁻¹)				
0	0.516	16.80	2.52	11.79
100	0.612	17.62	2.75	12.93
180	0.595	17.29	2.74	12.54
240	0.605	17.48	2.78	12.35
360	0.636	17.60	2.81	12.53
Average	0.593	17.36	2.72	12.43
FG	0.50 ^{ns}	0.48 ^{ns}	1.88 ^{ns}	1.52 ^{ns}
FK	4.65 ^{**}	1.58 ^{**}	0.58 ^{ns}	0.72 ^{ns}
FGxK	0.63 ^{ns}	0.47 ^{ns}	10.35 ^{**}	3.60 ^{**}
C.V. (%)	13.79	5.99	5.19	6.86

G = gypsum doses; ns = non-significant; “**” = significant at p < 0.01 by the F test; C.V. = coefficient of variation; CHM = commercial head mass; HD = head diameter; PD = peduncle diameter; HH = head height.

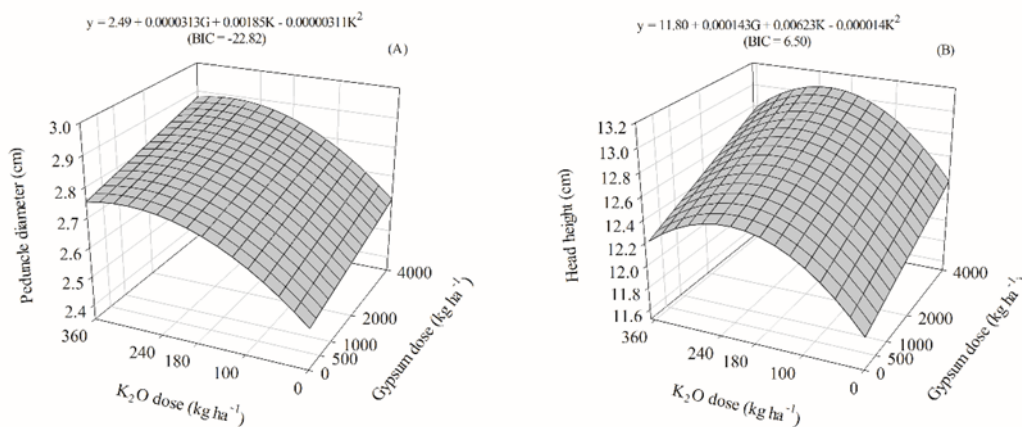


Figure 2. Cauliflower peduncle diameter and head height as function gypsum and K₂O doses. Bayesian information criterion (BIC).

The results observed in this study indicates that gypsum and K₂O affect the nutritional status and production of cauliflower. The increase of K levels in cauliflower leaves as a function of the increasing K₂O doses was also observed by Silva et al. (2016), who reported a maximum level of 35.44 g kg⁻¹ of K

with the foliar application of 200 kg ha⁻¹ of K₂O. This increase of leaf K concentration is related to the high availability of K in the soil solution after its application at great doses, thus resulting in high K absorption by the cauliflower plants.

Under the conditions of the present study, that

is, the use of modern hybrid cultivar, medium-textured soil and K contents close to 3 mmolc dm^{-3} (0-0.20 m soil layer) gypsum and K_2O did not affect the level of N in cauliflower leaves (Table 1), which had 34.52 g kg^{-1} of leaf N, on average. Bataglia et al. (1983) and Trani and Raij (1997) indicated as adequate for cauliflower the leaf N level between 40 and 60 g kg^{-1} ; thus, the content of leaf N observed in the present study was below the appropriate for this crop. However, Martinez, Carvalho and Souza (1999) found that leaf N level of 25 g kg^{-1} was able to sustain the plant development at adequate levels without compromising its metabolism. Although the values of leaf N level found in the present study were below that indicated as adequate by Bataglia et al. (1983) and Trani and Raij (1997), the development of the plants was normal and apparently without any damage to metabolism, as indicated by Martinez, Carvalho and Souza (1999) under conditions of lower N levels.

It is important to emphasize that the leaf levels of nutrients in cauliflower can vary according to the cultivar, the soil chemical characteristics, the fertilization applied at planting and side-dressing, and the season of the year. Modern cultivars have excellent efficiency of nutrient use compared to the cultivars used in studies of nutrient sufficiency decades ago. In the case of this study, despite the low contents of foliar N, P, Ca, and Mg established by other authors, the cauliflower plants developed without any symptoms of deficiency of those nutrients, indicating that new parameters of nutrient sufficiency need to be established.

Bataglia et al. (1983) and Trani and Raij (1997) indicated foliar B contents from 30 to 80 and from 25 to 75 mg kg^{-1} as appropriate, respectively. Thus, the average content of B in cauliflower leaf found in the present study was below the ideal for cauliflower crop. The B deficiency symptoms in cauliflower are identified by the occurrence of dark spots on the inflorescence and by the development of a cavity in the main stem. However, no visual symptoms of B deficiency were observed in the present study.

The increase in leaf Cu content in response to gypsum doses can be attributed to a better distribution of the cauliflower root system in the soil volume, allowing great absorption of this nutrient. For Bataglia et al. (1983), leaf Cu contents between 4 and 15 mg kg^{-1} are considered appropriate for cauliflower crop production.

The reduction in foliar Mn levels as a function of the gypsum doses was expected. Charlo et al. (2020) studied the soil chemical changes with the combined application of gypsum and K in maize

and found that higher doses of gypsum decreased the availability of Mn in the 0-0.2 m soil layer. The authors reported that gypsum increases the percolation of Mn to deeper soil layers after the formation of sulfate (SO_4^-) complexes.

Gypsum has a direct effect on plant biometrics since the largest peduncle diameter and head height were observed with the maximum dose of gypsum (4000 kg ha^{-1}). Thus, it can be inferred that gypsum also stimulated the growth and development of cauliflower leaves (although it has not been directly evaluated), which had the effect of dilution of the nutrients due to the further development of the plant. This effect becomes even clearer when the S content in plants decreased with increased gypsum doses, although gypsum is a source of S. This observation indicates that gypsum application had an indirect positive effect on cauliflower biometrics and yield. The gypsum component (Figures 2A and 2B) led to a linear positive response in peduncle diameter and head height as its dose increased. However, a great plant development as a function of the gypsum doses resulted in increased K demand, a situation that was detected by the largest diameter and head mass observed at the highest K_2O dose (Figures 1E and 1F).

Several studies have reported the effects of nutrient dilution, i.e., low leaf levels in well-developed plants (LI et al., 2020; PENUELAS et al., 2020; VIÇOSI et al., 2020). Since gypsum has increased cauliflower biometric parameters (stem diameter and head height), it is also believed that there was a “diluting effect” of the nutrients as a consequence of further leaf development. This “diluting effect” could be observed for the N, P, Ca, Mg, S and B contents that were below the appropriate levels indicated by Bataglia et al. (1983), Trani and Raij (1997) and by Martinez, Carvalho and Souza (1999). However, visual symptoms of deficiency of these elements and reduced production were not observed for cauliflower cropping in summer.

Moreover, in many crops, studies have shown great efficiency of new cultivars in the use of nutrients for the production at low levels of foliar nutrients (JU et al., 2015; SOBOLEWSKA et al., 2020). Therefore, under similar conditions to those of the present study, that is, the use of modern hybrid cultivars, medium-textured soil and K contents close to 3 mmolc dm^{-3} (0-0.20 soil layer), the foliar content of nutrients is expected to be lower than that reported in the main reference books and journals, further reinforcing the need for readjustment of the levels proposed as adequate for the cauliflower cultivation.

CONCLUSIONS

Based on the results observed, the recommended doses for adequate nutritional status and high yield of cauliflower are 4000 kg ha⁻¹ of gypsum and 360 kg ha⁻¹ of K₂O.

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